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INSTABILITY IN INDIAN FOODGRAIN PRODUCTION

Peter B. R. Hazell

May 1982

INTERNATIONAL FOOD POLICY RESEARCH INSTITUTE

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FOREWORD

In this research report by Peter Hazell, the International Food Policy Research Institute continues its research on sources of instability in food production and means of reducing its harmful effects.

This work is an extension of an earlier effort by Shakuntla Mehra reported in IFPRI Research Report 25. In that study she provides a detailed analysis of differences in the year-to-year variability among individual crops and regions, both within and between two time periods. She draws particular attention to how irrigation affects yield stability and the implications this has for irrigation policy. In this respect her research complements IFPRI's work on irrigation and multiple cropping. She also found a significant correlation between new, high-yielding crop varieties and increases in the absolute and relative variations in production. This correlation is important. For, although the new agricultural production technologies bring major benefits to low-income people by enlarging food supplies, if they increase fluctuations, they must be supplemented by other policies if a stabilized increase in consumption is to occur. Thus it was logical to undertake a follow-up study to define this relationship more precisely.

Peter Hazell's work confirms the basic findings of Mehra but in addition reveals the substantial increase in yield correlations between crops and regions. It also underlines the part played by changes in area sown in increased fluctuations. He concludes that it would be difficult to devise production policies and crop varieties to substantially mitigate production instability because these approaches do not confront the basic problem of increased yield correlations. Attention must turn instead to other research designed to develop policies for stabilizing consumption.

Earlier IFPRI research has shown how much of the burden of fluctuations in food supplies is carried by low-income people with already inadequate diets. This is because shortages in supplies raise prices and thus sharply reduce the purchasing power of people who spend most of their income on food. The new agricultural technologies have, of course, been a boon to the poor. They have not only increased total supplies of food, they have also either reduced food prices or relieved the upward pressure on prices of rising population and income. In this context, financing interregional grain movements could potentially add to the benefits from high-yielding crop varieties. IFPRI's research findings have emphasized the advantages of an international food financial facility. Now that there is such a system, research is turning more to food aid and domestic programs to ensure purchasing power to the poor in times of special stress on income and food supplies.

John W. Mellor

Washington, D.C.
May 1982

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1

SUMMARY

The last three decades have seen India's total cereal production grow significantly, by, on average, about 2.7 percent per year. Average production increased by 44 percent (or 29.4 million tons) between the periods 1954/55-1964/65 and 1967/68-1977/78. Almost half of this was due to a remarkable increase of 142 percent in wheat production (14.4 million tons), and one third was due to a 32 percent increase in rice production (10.3 million tons). Increases in mean yields account for about half of these production increases. These are a direct consequence of improved seed varieties and the increased use of fertilizers and irrigation.

These increases in average production have been accompanied by increased production instability. The coefficient of variation of total cereal production increased by one half between the two periods when measured around the trend. It was 5.9 percent compared with 4.03 percent in the first period. Although this variability is not large in comparison with that of many countries, two thirds of Indian production goes to feed farm families and the marketed surplus has to bear the burden of output variations. Even modest variations in production can cause prices to fluctuate significantly. Unless stabilization policies are adopted, farm incomes could be unstable and the poor could suffer from food shortages.

In this study, available state and crop data on the production and areas sown with different cereals are used to examine the sources of this increased instability in total cereal production. The study builds on work by Shakuntla Mehra (*Instability in Indian Agriculture in the Context of the New Technology*: IFPRI Research Report 25, July 1981) and attempts to show more precisely how the improved seed/fertilizer-based technologies have contributed to the increase in production instability. Proper understanding of the sources of the increase in instability is necessary if appropriate strategies are to be derived for reducing it.

The analysis is confined to rice, wheat, bajra, barley, jowar, maize, ragi, small millets, and total cereal production, where the latter is defined as the unweighted sum of the production of individual crops. Instability is measured as the variance of total cereal production for all India, which is equal to the sum of the production variances of individual crops within states and the sum of all intercrop and interstate production covariances. The latter measures patterns of association in production variations that exist between crops and states. The production variances and covariances are decomposed through statistical identities to isolate their sources of change between two periods: 1954/55-1964/65 and 1967/68-1977/78.

The variance of total cereal production for all India increased by 342 percent between the two periods. Of this increase, only about 6 percent can be attributed directly to increases in the variances of individual crop yields measured at the state level. The lion's share of the increase (82 percent) can be attributed to increases in the covariances of production between crops grown in the same and in different states. Furthermore, increases in intercrop and interstate yield covariances were the dominant source of the increases in these production covariances.

Surprisingly, increases in yield variances only account for a small part of the increase in the yield covariances. Nearly 90 percent of the increase in these yield covariances would not have occurred if there had not been a simultaneous shift toward more positive correlations between the yields of crops grown in the same and in different states. It is difficult to see how the improved technologies can be blamed for these increased yield correlations; at most they are accountable for increases in yield variances. More likely causes are changes in weather patterns and the more widespread use of irrigation and fertilizers at a time when the supplies of fertilizers and electric power for irrigation pumps became less reliable.

Another important source of the increase in the variance of total cereal production has been a simultaneous increase in the year-to-year variability of the areas sown with individual crops, as well as an increase in covariances between the areas sown and the yields obtained. About 37 percent of the increase in the variance of total cereal

production can be attributed to these sources, and about 85 percent of this can be attributed to increases in intercrop and interstate covariances between areas sown and between areas sown and yields.

The results from this analysis suggest that attempts to reduce the instability of total cereal production by breeding less risky varieties would not be very effective for all India. This is because reducing yield variability at the micro level fails to confront the more basic problems of reducing the large increases in yield and area-yield correlations that have occurred between crops in the same and in different states. Policies to stabilize the supplies of fertilizers and electric power for irrigation pumps might be more effective in this respect.

Some gain in aggregate production stability might be obtained through policies that stabilize year-to-year fluctuations in the areas sown with individual cereal crops, but again the overwhelming importance of intercrop and interstate correlations reduces the effectiveness of this approach for the whole country. This approach is likely to be less effective than attempts to reduce yield variability.

As most of the increased instability in India's total cereal production must be attributed to increases in intercrop and interstate production covariances, another approach to reducing instability is to take advantage of these covariances and distribute production among crops and states in a more risk-efficient way. This possibility is examined with the aid of a linear programming model, which is used to derive production patterns that have the minimum possible variance for given levels of average production. There are some potential gains to be had from this approach, but they may require policy changes that could be inconsistent with other public objectives.

The primary conclusion from this study is that aggregate production instability is an inevitable consequence of rapid agricultural growth, and there is little that can effectively be done about it. From this perspective, policies that attempt to stabilize consumption, such as storage and trade policies, appear to be more promising.

2

INTRODUCTION

The last three decades have seen significant growth in total cereal production in India. A log-trend regression fitted to the data in Figure 1 (but omitting the drought years 1965/66 and 1966/67) yields an annual growth rate of 2.7 percent for the years 1952/53-1977/78. This is marginally higher than a similarly estimated growth rate for human food consumption of 2.5 percent. Although growth in production has successfully kept pace with the growth in human food consumption, it has been accompanied by a more than proportional increase in both the standard deviation and the coefficient of variation of production. The coefficient of variation of production around the trend in the data used for Figure 1 was about 4 percent before the drought years 1965/66 and 1966/67. It increased to nearly 6 percent in the postdrought years.

Coefficients of variation of these sizes are modest by international standards and at first appearance would not seem to warrant much concern. But two aspects are worrying. First is the continued possibility of severe drought years. Declines in production in the future of similar proportions to those of 1965/66 and 1966/67 could mean much larger shortfalls in the amounts of cereals needed, thereby requiring larger emergency stocks to be carried.

Second, as only about one third of India's cereal production is actually marketed (the rest is retained by farm households for their own consumption), year-to-year fluctuations in production tend to be transmitted to relatively thin markets. In the absence of stabilization policies, they may, therefore, cause prices to fluctuate widely. Fluctuations in food prices inevitably bear heavily on the poor and may destabilize farm incomes. Clearly, these outcomes are of some concern to policymakers.

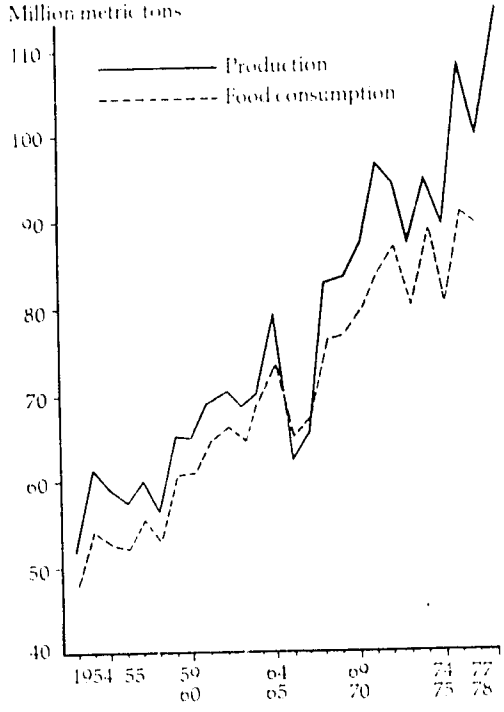
Shakuntla Mehra argues in a recent paper that much of this increased instability in total foodgrain production can be attributed to the widespread adoption of the improved seed/fertilizer-intensive technologies since the mid-1960s.[1] Similar arguments are made by Rao and by Barker, Gabler, and Winkelmann.[2] The yields of crops grown with the new technologies not only appear to be more sensitive to weather and disease but, because they require greater use of modern inputs, it is argued that their yields are also sensitive to year-to-year variations in input use, such as might arise from frequent price changes or from restrictions in supplies.

Proper tests of the possible risk-increasing characteristics of the new technologies should be based on individual farm data. But suitable time-series data rarely exist, and they are not available on the representative farm basis that would be required to analyze changes in the standard deviation of national foodgrain production. For these reasons, much of Mehra's analysis is based on a direct examination of time-series data on aggregate foodgrain production. A problem with this approach is that changes in the standard deviation of production at an aggregate level are almost certainly attributable to factors other than increases in yield variability. Indeed, as Mehra points out, the increase in the standard deviation of national foodgrain production may be due to "an increase in the variance of individual crops; increased weight of more variable crops and/or more regions with erratic weather in crop output or area; and reduction in the mutually offsetting variations in yield and

[1] Shakuntla Mehra, *Instability in Indian Agriculture in the Context of the New Technology*, Research Report 25 (Washington, D.C.: International Food Policy Research Institute, 1981).

[2] C. H. H. Rao, *Technological Change and Distribution of Gains in Indian Agriculture* (Delhi: Macmillan Co. of India, Ltd. 1975). Randolph Barker, Eric C. Gabler, and Donald Winkelmann, "Long-Term Consequences of Technological Change on Crop Yield Stability: The Case for Cereal Grain," in *Food Security for Developing Countries*, ed. Alberto Valdés (Boulder, Colo.: Westview Press, 1981), pp. 53-78.

Figure 1—Production and food consumption of total cereals, 1952/53-1977/78



Source: J. S. Sarma, "India—A Drive Towards Self-Sufficiency in Food Grains," *American Journal of Agricultural Economics* 60 (December 1978): 861, and calculations from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.

area of crops."[3]

The purpose of this paper is to provide a systematic study of the components of change in the variability of India's foodgrain production. Statistical identities are used to provide an exact decomposition of the components of change in the mean and variance of total cereal production. This method of analysis does not impose any behavioral assumptions on the data, but it is able to reveal the importance of the different components of increased instability, including the kinds of intercrop and interstate covariance relations suspected by Mehra.

The approach is quite different from the usual econometric approach. Mukhopadhyay, for example, applies production function analysis to pooled time-series and cross-sectional data to explain interregional and intertemporal differences in factor productivity.[4] His analysis sheds some light on the sources of production variability within regions, but it is not a suitable approach for analyzing production variability at the national level. Among other assumptions, Mukhopadhyay has to aggregate crop outputs and then assume that all interregional production covariances are zero. Although the analysis in this paper fails to provide the sort of explanatory detail that Mukhopadhyay's approach offers, it is able to determine that changes in production covariances between crops and states account for more than 80 percent of recent increases in the variance of India's total cereal production, and consequently they cannot just be assumed away. The point to be emphasized is that this paper uses a methodology which, without any assumption about how the real world works, is able to identify the important components of increased foodgrain instability. Once these components are identified, analytical work can tackle the problem of understanding how these components come about and how they may be changed through policy intervention.

Scope of the Study

This study is limited to an analysis of cereal production, and more specifically to changes in rice, wheat, bajra, barley, jowar, maize, ragi, and small millet production, as well as to changes in total cereal production (defined as the unweighted sum of these crops). The analysis is undertaken at the state and national (all-India) levels, and no attempt is made to disaggregate results to districts. The methodology easily permits such disaggregation, but a comprehensive set of district data is not readily available.

[3] Mehra, *Instability in Indian Agriculture*, p. 12.

[4] S. K. Mukhopadhyay, *Sources of Variation in Agricultural Productivity: A Cross Section Time Series Study in India* (Delhi: Macmillan Co. of India, Ltd., 1976).

As in Mehra's study, production variability is measured in two time periods, one preceding the introduction of the improved seed/fertilizer technologies in the mid-1960s and one following its adoption. The first period is defined here as the 11-year period 1954/55-1964/65; the second period is the 11-year period 1967/68-1977/78. Omission of the two drought years, 1965/66 and 1966/67, is deliberate. Catastrophes of this kind are sufficiently rare and severe (as shown in Figure 1) that they can be considered as separate phenomena from the more usual year-to-year fluctuations in cereal production. Such a distinction is particularly useful in developing policy (see Chapter 7).

The data used in this report were compiled by Mehra from various published and unpublished sources in India, particularly the Directorate of Economics and Statistics of the Ministry of Agriculture and Irrigation. The basic data comprise time-series information on annual production and the area sown by crop in each state.[5] In this analysis, yields are estimated for each crop, state, and year by dividing the relevant production figure by the area sown. For each crop only the states producing 1 percent or more of average national production in the second period are retained separately for the analysis (see Table 1). All other states are aggregated into a residual group of states for that crop.

The area and yield data for each crop and state are detrended using linear relations of the form

$$Z_t = a + bt + e_t, \qquad (1)$$

Table 1 — Distribution by state and crop of average cereal production, 1967/68-1977/78

State	Rice	Wheat	Bajra	Barley	Jowar	Maize	Ragi	Small Millets	Total Cereals
				(1,000 metric tons)					
Andhra Pradesh	5,032.7	...	...	...	1,237.2	352.5	282.1	266.6	7,170.5
Assam	2,065.7	...	...	...	...	...	...	...	2,065.7
Bihar	4,695.9	1,897.1	...	140.3	...	858.8	92.6	...	7,685.2
Gujarat	444.3	844.8	1,181.7	...	...	279.8	41.8	59.0	2,891.7
Haryana	505.4	2,730.8	504.3	159.2	...	453.7	...	...	4,353.2
Karnataka	2,003.0	...	...	...	1,680.7	308.5	851.3	140.1	4,983.7
Kerala	1,294.8	...	...	...	...	...	...	...	1,294.8
Madhya Pradesh	3,362.5	2,457.2	...	167.0	1,530.1	558.6	...	375.1	8,452.5
Maharashtra	1,596.0	611.9	622.7	...	3,145.4	...	169.2	93.0	6,239
Orissa	4,032.4	...	...	...	...	...	148.5	77.5	4,258.7
Punjab	1,046.1	5,243.3	...	98.4	...	801.1	...	...	7,188.6
Rajasthan	...	1,813.9	1,228.9	682.6	...	653.9	...	...	4,379.4
Tamil Nadu	4,853.1	...	...	...	...	...	350.5	314.8	5,518.2
Uttar Pradesh	3,772.8	7,339.9	673.3	1,333.9	...	1,144.5	200.5	298.4	14,762.6
West Bengal	6,254.1	704.5	...	...	...	...	...	...	6,958.5
Other states	1,601.2	886.5	1,309.5	138.5	1,885.0	706.8	38.4	246.0	6,812.5
All India	42,562.6	24,530.0	5,520.4	2,719.9	9,478.3	6,118.3	2,174.8	1,910.6	95,014.9
Share of crop in all-India cereal production (percent)	44.8	25.8	5.8	2.9	10.0	6.4	2.3	2.0	100.0

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.

[5] The data are available from the author on request.

where Z_t denotes the dependent variable (area or yield), t is time, and e_t is a random residual with zero mean and variance σ^2. Separate regressions are run for each of the two time periods to ensure that $\Sigma_t e_t = 0$ for each period. Mehra used log-linear equations, but linear relations are used here because they do not assume a deterministic part to any relation between the variance of Z and time t. The variance of Z in equation (1) is simply σ^2, and by estimating separate equations for the two periods, the estimated variances can take on any relation to each other. Also, unbiased and efficient estimates of the variances of Z, as well as the covariances between Zs for different crops or states, are easily obtained from the variance-covariance matrix of the residuals e_t. Specifically, $Cov(Z_i, Z_j) = Cov(e_i, e_j)$.

After detrending, the residuals are centered on the mean areas or yields for each period, $\bar{Z}$, resulting in detrended time-series data of the form

$$\hat{Z}_t = e_t + \bar{Z}. \qquad (2)$$

Time-series data on detrended production for each crop and state are then calculated as the product of the detrended areas and yields, and these are added for all states, including the residual group of states, to obtain estimates of detrended, all-India production.

Changes in Cereal Production

Total cereal production for all India increased on average by 29.4 million tons[6] between the two periods, or by 44.8 percent (see Table 2). About one half of this increase was due to a remarkable increase in average wheat production of 14.4 million tons and about one third to a 10.3-million-ton increase in rice production. There were also large percentage increases in the output of bajra and maize, but the quantities involved were quite modest. Only small millets experienced a decline in average output and this by only 0.22 million tons.

Table 2—Average production, area, and yield of cereal crops, 1954/55-1964/65 and 1967/68-1977/78

Crop	1954/55 1964/65	1967/68-1977/78	Change
	Average Production		
	(1,000 metric tons)		(percent)
Rice	32,302	42,560	31.8
Wheat	10,142	24,530	141.9
Bajra	3,658	5,520	50.9
Barley	2,672	2,720	1.8
Jowar	8,723	9,478	8.7
Maize	4,034	6,118	51.7
Ragi	1,931	2,175	12.6
Small millets	2,131	1,911	10.3
Total cereals	65,596	95,015	44.8
	Average Area		
	(1,000 hectares)		(percent)
Rice	33,693	37,935	12.6
Wheat	12,906	18,809	45.7
Bajra	11,262	12,299	9.2
Barley	3,191	2,630	-17.6
Jowar	17,782	17,025	-4.3
Maize	4,295	5,830	35.7
Ragi	2,450	2,467	0.7
Small millets	5,075	4,815	-5.1
Total cereals	90,655	101,810	12.3
	Average Yield		
	(metric tons/hectare)		(percent)
Rice	0.96	1.12	16.7
Wheat	0.79	1.30	64.6
Bajra	0.32	0.45	40.6
Barley	0.84	1.03	22.6
Jowar	0.49	0.56	14.3
Maize	0.94	1.05	11.7
Ragi	0.79	0.88	11.4
Small millets	0.42	0.4	-4.8
Total cereals	0.72	0.93	29.2

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.

The average area sown with total cereals increased by 12.3 percent between the two periods. Some land was also shifted away from barley, jowar, and small millets to other cereal crops (Table 2).

Changes in the areas sown account for only the smaller part of the changes in

[6] "Tons" refers to metric tons throughout this report.

production for most crops. Changes in average yields were of greater consequence. The average yield for total cereals increased by 29.2 percent, with outstanding increases of 64.6 percent for wheat and 40.6 percent for bajra (Table 2). The yield increases for barley and jowar were more than adequate to compensate for the loss in area of these crops; average production levels increased. Only small millets experienced a decline in average yields.

These average production increases were accompanied by more than proportionate increases in the standard deviation of production for most cereals (Table 3). Total cereal production increased by 44.8 percent between the two periods, but the standard deviation of production increased by 110.1 percent, so the consequent increase in the coefficient of variation was 45.2 percent. Similar trends emerged for all cereal crops except wheat and small millets. Average wheat production increased by 141.9 percent, and because this was matched by an almost identical increase in the standard deviation of production, the coefficient of variation increased by only 2.1 percent.

Table 3 also shows the enormous variability in production risks between crops and states. The coefficient of variation of total cereal production for all India was still quite modest in the second period, 5.9 percent. This was lower, often much lower, than the comparable coefficients of variation for any crop or state disaggregate, except for rice production in Assam. Bajra production was particularly risky for both individual states and all India. Its national coefficient of variation was 27.7 percent in the second period and was as high as 54.9 percent in Rajasthan. Of the individual states, cereal production was most risky in Gujarat, Maharashtra, and Rajasthan, which had coefficients of variation greater than 20 percent in the second period.

Table 3 also shows a variety of experiences in the way production risks have changed for both individual crops and states. The coefficient of variation of rice production, for example, decreased in Bihar, Haryana, Punjab, Uttar Pradesh, and West Bengal, but increased in all other states, as well as for all India.

Considering that the relative risk in production (as measured by the coefficient of variation) increased substantially for all cereals except wheat and small millets at the national level, how much of this increase must be attributed to increased variability in yields? Table 4 shows the changes in the coefficients of variation of yields for each cereal crop by state and for all India. For the nation, the relative risk in yields increased for all cereals except wheat and barley but not by as much as the corresponding increase in the relative risk of production (Table 3). Whereas the coefficient of variation of total cereal production increased by 45.2 percent for all India (Table 3), the coefficient of variation of yields increased by only 20.4 percent (Table 4). There are similar relationships for rice, bajra, jowar, maize, and ragi. Relative yield risks increased faster than production risks for small millets, but actually declined for wheat and barley. It is also noticeable in Tables 3 and 4 that the coefficients of variation of yields and production do not necessarily move in the same direction. For example, the coefficient of variation of wheat yields fell in most states, but the coefficient of variation of production increased. Clearly, changes in relative yield risks are important, but they are by no means the only variable explaining the changes in relative production risks.

In order to analyze the problem more completely, a formal decomposition procedure is now developed. This procedure can be used to separate the components of the changes in production variability.

Table 3—Coefficients of variation of production, by crop and state, 1954/55-1964/65 and 1967/68-1977/78

State/Period	Rice	Wheat	Bajra	Barley	Jowar	Maize	Ragi	Small Millets	Total Cereals
					(percent)				
Andhra Pradesh									
First period	4.44	...	...	...	9.60	19.17	10.90	5.64	3.72
Second period	10.06	...	...	...	14.72	17.37	11.87	17.47	8.65
Change	126.6	...	...	...	53.3	−9.4	8.9	209.8	132.5
Assam									
First period	4.49	...	...	...	...	...	...	...	4.49
Second period	5.05	...	...	...	...	...	...	...	5.05
Change	12.5	...	...	...	...	...	...	...	12.5
Bihar									
First period	13.83	21.95	...	18.20	...	17.56	14.46	...	11.12
Second period	10.07	27.88	...	13.28	...	32.84	33.74	...	8.77
Change	−27.2	27.0	...	−27.0	...	87.0	133.3	...	−21.1
Gujarat									
First period	21.49	15.81	27.78	...	...	28.79	12.61	21.38	15.50
Second period	37.84	18.23	29.08	...	...	44.89	26.42	24.46	25.25
Change	76.1	15.3	4.7	...	...	56.0	109.5	14.4	62.9
Haryana									
First period	20.12	6.64	27.47	40.87	...	11.19	...	...	6.52
Second period	17.76	12.85	36.57	44.55	...	12.00	...	...	11.06
Change	−11.7	93.5	33.1	9.0	...	7.2	...	...	69.6
Kerala									
First period	2.99	...	...	...	...	...	...	...	2.99
Second period	6.20	...	...	...	...	...	...	...	6.20
Change	107.3	...	...	...	...	...	...	...	107.4
Karnataka									
First period	5.74	...	...	...	13.74	13.18	10.13	11.12	4.65
Second period	12.53	...	...	...	17.58	25.10	21.95	38.68	13.43
Change	118.3	...	...	...	27.8	90.4	116.7	247.8	188.8
Madhya Pradesh									
First period	15.02	13.21	...	25.57	18.25	13.92	...	35.83	8.66
Second period	15.63	13.63	...	15.65	17.15	21.86	...	12.75	8.52
Change	4.1	3.2	...	−38.8	−6.0	57.0	...	−64.4	−1.6
Maharashtra									
First period	5.40	10.99	8.05	...	13.15	...	3.96	19.59	7.82
Second period	22.26	30.27	45.45	...	33.61	...	19.54	16.43	25.31
Change	312.2	175.4	465.3	...	155.6	...	393.4	−16.1	223.7
Orissa									
First period	8.98	...	...	...	...	...	11.84	12.49	8.88
Second period	12.69	...	...	...	...	...	13.94	8.15	12.41
Change	41.3	...	...	...	...	...	17.7	−34.7	39.8
Punjab									
First period	20.35	7.65	...	21.54	...	21.88	...	...	8.65
Second period	17.61	7.95	...	51.76	...	10.26	...	...	6.03
Change	−13.5	3.9	...	140.3	...	−53.1	...	...	−30.3
Rajasthan									
First period	...	14.60	17.45	12.21	...	15.56	...	...	9.20
Second period	...	10.98	54.94	22.21	...	27.12	...	...	21.86
Change	...	−24.8	214.8	81.9	...	74.4	...	...	137.6
Tamil Nadu									
First period	3.66	...	...	...	...	...	6.74	10.19	3.16
Second period	15.10	...	...	...	...	...	15.39	21.42	14.10
Change	312.5	...	...	...	...	...	128.3	110.2	345.8
Uttar Pradesh									
First period	9.06	13.89	19.79	12.78	...	19.25	6.79	18.18	7.60
Second period	8.89	9.87	19.23	9.89	...	21.14	21.22	17.91	7.52
Change	−1.9	−28.9	−2.8	−22.6	...	9.8	212.5	−1.5	−1.1
West Bengal									
First period	8.57	24.14	...	...	...	...	...	...	8.54
Second period	7.93	31.98	...	...	...	...	...	...	8.90
Change	−7.5	32.5	...	...	...	...	...	...	4.2
All India									
First period	5.25	8.45	8.53	11.16	9.91	4.32	4.12	9.28	4.03
Second period	7.16	8.63	27.74	13.60	14.11	11.59	12.07	9.33	5.85
Change	36.4	2.1	225.2	21.9	42.4	168.3	193.0	0.5	45.2

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.

Note: The first period is from 1954/55 to 1964/65; the second period is from 1967/68 to 1977/78.

Table 4—Coefficients of variation of yield, by crop and state, 1954/55-1964/65 and 1967/68-1977/78

State/Period	Rice	Wheat	Bajra	Barley	Jowar	Maize	Ragi	Small Millets	Total Cereals
					(percent)				
Andhra Pradesh									
First period	4.38	...	...	...	8.21	18.68	12.50	3.02	3.53
Second period	6.59	...	...	...	13.67	16.57	9.35	17.35	6.12
Change	50.5	...	...	...	66.5	-11.3	-25.2	474.5	73.4
Assam									
First period	5.20	...	...	...	...	...	...	...	5.20
Second period	4.28	...	...	...	...	...	...	...	4.28
Change	-17.7	...	...	...	...	...	...	...	-17.7
Bihar									
First period	12.54	21.01	...	14.82	...	12.94	8.70	...	9.35
Second period	9.04	17.73	...	7.75	...	31.06	23.88	...	7.35
Change	-27.9	-15.6	...	-47.8	...	140.0	174.5	...	-21.4
Gujarat									
First period	18.94	13.99	24.27	...	...	26.65	10.14	14.70	13.80
Second period	34.07	8.52	23.76	...	...	43.30	24.10	21.43	19.90
Change	79.9	-39.0	-2.1	...	...	62.5	137.7	45.8	44.2
Haryana									
First period	22.33	14.76	23.30	36.90	...	11.32	...	...	5.84
Second period	13.73	10.07	36.01	28.65	...	9.93	...	...	10.53
Change	-38.5	-31.8	54.5	-22.4	...	-12.3	...	...	80.3
Kerala									
First period	2.8	...	...	...	...	...	...	...	2.85
Second period	3.74	...	...	...	...	...	...	...	3.74
Change	33.5	...	...	...	...	...	...	...	31.2
Karnataka									
First period	5.87	...	...	...	15.09	20.31	10.07	8.83	4.70
Second period	9.84	...	...	...	12.82	20.78	18.06	33.98	8.95
Change	67.6	...	...	...	-15.0	2.3	79.3	284.8	90.43
Madhya Pradesh									
First period	14.97	10.75	...	17.88	16.87	14.18	...	18.36	8.88
Second period	15.63	8.00	...	11.63	14.12	22.17	...	1[illegible].97	8.23
Change	4.4	-25.6	...	-35.0	-16.3	56.3	...	-34.8	-7.4
Maharashtra									
First period	12.23	11.59	8.13	...	11.89	...	3.67	22.52	7.30
Second period	20.02	23.05	31.14	...	29.72	...	19.23	15.92	21.92
Change	63.6	98.9	283.0	...	150.0	...	423.9	-29.3	200.3
Orissa									
First period	9.35	...	...	...	...	...	18.38	3.43	9.07
Second period	12.30	...	...	...	...	...	12.72	6.99	11.84
Change	31.6	...	...	...	...	...	-30.8	103.8	30.7
Punjab									
First period	20.45	8.20	...	17.89	...	23.33	...	...	9.07
Second period	9.39	4.36	...	9.88	...	9.63	...	...	4.52
Change	-54.1	-46.8	...	-44.8	...	-58.7	...	...	-50.2
Rajasthan									
First period	...	7.92	17.42	5.81	...	12.30	...	...	7.82
Second period	...	7.73	48.70	10.79	...	30.74	...	...	19.51
Change	...	2.4	179.6	85.7	...	149.9	...	...	149.4
Tamil Nadu									
First period	2.51	...	...	...	...	...	5.32	2.76	2.08
Second period	9.60	...	...	...	...	...	9.75	15.62	9.72
Change	282.5	...	...	...	...	...	83.3	465.9	367.3
Uttar Pradesh									
First period	8.96	13.27	18.08	11.18	...	19.06	7.07	16.19	7.07
Second period	7.47	8.76	16.65	7.61	...	26.20	10.14	11.04	6.85
Change	-16.6	-34.0	-7.9	-31.9	...	6[illegible]	43.4	-31.8	-3.11
West Bengal									
First period	7.11	18.48	...	...	...	...	...	...	7.02
Second period	7.38	17.73	...	...	...	...	...	...	7.87
Change	3.8	-4.1	...	...	...	...	...	...	12.1
All India									
First period	5.26	8.31	7.91	8.36	8.92	6.37	4.04	6.95	3.70
Second period	5.85	5.41	23.62	6.41	11.77	10.87	9.08	7.47	4.46
Change	11.2	-35.0	198.6	-23.4	32.0	70.6	124.6	7.5	20.4

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.

Note: The first period is from 1954/55 to 1964/65; the second period is from 1967/68 to 1977/78.

3

METHOD OF ANALYSIS

Let Q denote production, A, the area sown, and y, yield. Then for each crop and state, $Q = Ay$.

As shown in Appendix 1, the variance of production, V(Q), can be expressed as

$$V(Q) = \bar{A}^2 V(y) + \bar{y}^2 V(A) + 2\bar{A}\bar{y}\,Cov(A, y) - Cov(A, y)^2 + R, \qquad (3)$$

where $\bar{A}$ and $\bar{y}$ denote the mean areas and yields and R is a residual term, which is expected to be small. It is apparent from this expression that V(Q) is not only a function of the variances of yields and areas sown, but also of the mean area and yield and of the covariance between areas and yields. Clearly, a change in any one of these components will lead to a change in V(Q) between two periods in time.

Similarly, average production, E(Q), can be expressed as

$$E(Q) = \bar{A}\bar{y} + Cov(A, y). \qquad (4)$$

It is affected by changes in the covariance between area and yield and by changes in mean area and mean yield.

The objective of the decomposition analysis is to partition the changes in V(Q) and E(Q) between the first and second periods into constituent parts, which can be attributed separately to changes in the means, variances, and covariances of areas and yields. The method is developed first for the decomposition of average production because this is the least cumbersome to present and yet adequately illustrates all the principles involved.

Using equation (4), average production in the first period is

$$E(Q_I) = \bar{A}_I \bar{y}_I + Cov(A_I, y_I); \qquad (5)$$

and in the second period it is

$$E(Q_{II}) = \bar{A}_{II} \bar{y}_{II} + Cov(A_{II}, y_{II}). \qquad (6)$$

Each variable in the second period can be expressed as its counterpart in the first plus the change in the variable between the two. For example,

$$\bar{A}_{II} = \bar{A}_I + \Delta\bar{A},$$

where $\Delta\bar{A} = \bar{A}_{II} - \bar{A}_I$. Equation (6) can therefore be rewritten as

$$E(Q_{II}) = (\bar{A}_I + \Delta\bar{A})(\bar{y}_I + \Delta\bar{y}) + Cov(A_I, y_I) + \Delta Cov(A, y). \qquad (7)$$

The change in average production, $\Delta E(Q)$, is then obtained by subtracting equation (5) from equation (7). This reduces to

$$\Delta E(Q) = E(Q_{II}) - E(Q_I) = \bar{A}_I \Delta\bar{y} + \bar{y}_I \Delta\bar{A} + \Delta\bar{A}\,\Delta\bar{y} + \Delta Cov(A, y), \qquad (8)$$

which can be arranged as shown under method I in Table 5.

There are four sources of change in $\Delta E(Q)$. Two parts, $\bar{A}_I \Delta\bar{y}$ and $\bar{y}_I \Delta\bar{A}$, arise from the changes in the mean yield and the mean area. These are "pure" effects; they arise even if there are no other sources of change. The term $\Delta\bar{A}\Delta\bar{y}$ is an interaction effect, which arises from the simultaneous occurrence of changes in mean yield and mean area. Obviously, this term will be zero if either the mean yield or the mean area remains unchanged. The last term, $\Delta Cov(A, y)$, arises from changes in the variability of area and yields. Since

$$Cov(A, y) = \rho[V(A)\,V(y)]^{1/2},$$

where ρ is the correlation coefficient, then it can be seen that $\Delta Cov(A, y)$ arises from changes in the variances of areas and yields and from changes in the correlation between areas and yields.

Figure 2 portrays the geometry of the analysis under the simplifying assumption that $Cov(A, y) = 0$. Average production is

Table 5—Components of change in average production

Source of Change		Components of Change	
Description	Symbols	Method I[a]	Method II[b]
Change in mean yield	$\Delta\bar{y}$	$\bar{A}_I\,\Delta\bar{y}$	$\bar{A}_{II}\,\Delta\bar{y}$
Change in mean area	$\Delta\bar{A}$	$\bar{y}_I\,\Delta\bar{A}$	$\bar{y}_{II}\,\Delta\bar{A}$
Interaction between changes in mean area and mean yield	$\Delta\bar{y}\,.\,\Delta\bar{A}$	$\Delta\bar{A}\,\Delta\bar{y}$	$-\Delta\bar{A}\,\Delta\bar{y}$
Change in area-yield covariance	$\Delta Cov(A,y)$	$\Delta Cov(A,y)$	$\Delta Cov(A,y)$

Note: A denotes area sown and y, yield.
[a] The years 1954/55-1964/65 are used as a base.
[b] The years 1967/68-1977/78 are used as a base.

initially $\bar{A}_I\bar{y}_I$, which is labeled as area A in Figure 2. The change in mean yield leads to an increase in mean production of $\bar{A}_I\Delta\bar{y}$, which is equivalent to area D. Similarly, the change in mean area leads to additional mean production of $\bar{y}_I\Delta\bar{A}$, or area B in Figure 2. The interaction term arising from the simultaneous occurrence of $\Delta\bar{A}$ and $\Delta\bar{y}$ is area C, and the total change in E(Q) is then B + C + D.

This method of analysis uses the first period as the base, but an alternative procedure can be developed, based on the second period. Returning to equation (5), each of the first-period variables can be expressed as their second-period values less the change between the two periods. For example,

$$\bar{A}_I = \bar{A}_{II} - \Delta\bar{A},$$

where $\Delta\bar{A}$ is again defined as $\bar{A}_{II} - \bar{A}_I$. Equation (5) can then be written as,

$$E(Q_I) = (\bar{A}_{II} - \Delta\bar{A})(\bar{y}_{II} - \Delta\bar{y}) + Cov(A_{II}, y_{II}) - \Delta Cov(A, y). \quad (9)$$

Subtracting equation (9) from equation (6) to get $\Delta E(Q)$, this is now

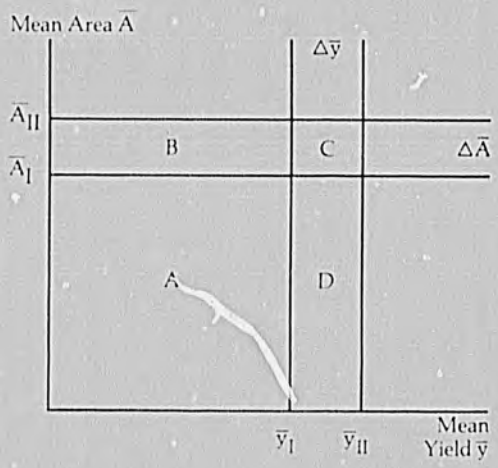
$$\Delta E(Q) = \bar{A}_{II}\,\Delta\bar{y} + \bar{y}_{II}\,\Delta\bar{A} - \Delta\bar{A}\,\Delta\bar{y} + \Delta Cov(A, y), \quad (10)$$

which can be arranged as shown under method II in Table 5.

Whereas this method leads to the same estimate of the change in average production, $\Delta E(Q)$, as in method I, it is clear from Table 5 that the attribution to sources is quite different. The fourth term remains unchanged; the third term is equal but of opposite sign; and the first and second terms contain second-period weights instead of first-period weights.

The differences in the decomposition methods can be illustrated graphically with the aid of Figure 2. Whereas the pure mean-yield effect under method I was equal to area D, under method II it becomes $\bar{A}_{II}\Delta\bar{y}$, or area D + C. Area C is included because the pure mean-yield effect is now evaluated

Figure 2—Geometric analysis of the components of change in mean production



assuming that the mean area has also increased to its second-period value, and therefore both the pure effect and the interaction effect are lumped together. Similarly, the pure mean-area effect increases from area B to area B + C under method II. Then, because C is now a part of both pure effects, the interaction term between changes in mean area and mean yield is $-\Delta\bar{y}\,\Delta\bar{A}$, or $-C$. This ensures that the total effects still add up to B + C + D.

Both methods are mathematically correct, but since method II combines pure and interaction effects, it has less to recommend it for this analysis.

The change in the variance of production, $\Delta V(Q)$, can be decomposed in an analogous way. Taking the variance of production for a single crop in a single state, then applying the results in Appendix I (with $i = j$) to equation (3) leads to the decomposition in Table 6. These results also measure the changes using the first period as the base.

Table 6 identifies 10 sources of change in a production variance. Four of these—changes in mean yield, changes in mean area, interaction between changes in mean area and mean yield, and changes in area-yield covariance—parallel the sources of change in average production in Table 5. But changes in the production variance also occur through changes in the variances of areas and yields and from changes in interaction terms between all these components.

So far, the analysis has dealt with the decomposition of change in the mean and variance of production of a single crop in a single state. As production aggregates for crops and states are of interest, the analysis is extended to total cereals for all India, recognizing that production aggregates of single crops or states are simply special cases.

Let subscripts i and j denote crops, and let subscripts h and k denote states. Then total cereal production for all India is

$$Q = \sum_h \sum_j A_{hj}\, y_{hj},$$

and average production is:

$$E(Q) = \sum_h \sum_j [\bar{A}_{hj}\, \bar{y}_{hj} + \mathrm{Cov}(A_{hj}, y_{hj})]. \quad (11)$$

Table 6—Components of change in the variance of production

Source of Change: Description	Source of Change: Symbol	Components of Change
Change in mean yield	$\Delta\bar{y}$	$2\bar{A}_i\,\Delta\bar{y}\,\mathrm{Cov}(y_i, A_i) + [2\bar{y}_i\,\Delta\bar{y} + (\Delta\bar{y})^2]\,V(A_i)$
Change in mean area	$\Delta\bar{A}$	$2\bar{y}_i\,\Delta\bar{A}\,\mathrm{Cov}(y_i, A_i) + [2\bar{A}_i\,\Delta\bar{A} + (\Delta\bar{A})^2]\,V(y_i)$
Change in yield variance	$\Delta V(y)$	$(\bar{A}_i)^2\,\Delta V(y)$
Change in area variance	$\Delta V(A)$	$(\bar{y}_i)^2\,\Delta V(A)$
Interaction between changes in mean yield and mean area	$\Delta\bar{y}, \Delta\bar{A}$	$2\Delta\bar{y}\,\Delta\bar{A}\,\mathrm{Cov}(y_i, A_i)$
Change in area-yield covariance	$\Delta\mathrm{Cov}(y, A)$	$[2\bar{A}_i\,\bar{y}_i - 2\,\mathrm{Cov}(y_i, A_i)]\,\Delta\mathrm{Cov}(y, A) - [\Delta\mathrm{Cov}(y, A)]^2$
Interaction between changes in mean area and yield variance	$\Delta\bar{A}, \Delta V(y)$	$[2\bar{A}_i\,\Delta\bar{A} + (\Delta\bar{A})^2]\,\Delta V(y)$
Interaction between changes in mean yield and area variance	$\Delta\bar{y}, \Delta V(A)$	$[2\bar{y}_i\,\Delta\bar{y} + (\Delta\bar{y})^2]\,\Delta V(A)$
Interactions between changes in mean area and yield and changes in area-yield covariance	$\Delta\bar{y}, \Delta\bar{A}, \Delta\mathrm{Cov}(y, A)$	$[2\bar{y}_i\,\Delta\bar{A} + 2\bar{A}_i\,\Delta\bar{y} + 2\Delta\bar{A}\,\Delta\bar{y}]\,\Delta\mathrm{Cov}(y, A)$
Change in residual	ΔR	$\Delta V(A\,y)$ − sum of the other components

Note: A denotes area sown, y, yield, and V, variance.

The change in mean production, $\Delta E(Q)$, can be decomposed by applying the results in Table 5 to each of the terms in equation (11) and summing the components over h and j.

Analysis of the change in the variance of total cereal production is more complicated:

$$V(Q) = \sum_{h} \sum_{k} \sum_{i} \sum_{j} Cov(A_{hi} y_{hi}, A_{kj} y_{kj}), \qquad (12)$$

and this can be partitioned as follows:

$$\begin{aligned} V(Q) = & \sum_{h} \sum_{i} V(A_{hi} y_{hi}) \\ & + \sum_{h} \sum_{i \neq j} \sum_{j} Cov(A_{hi} y_{hi}, A_{hj} y_{hj}) \\ & + \sum_{i} \sum_{h \neq k} \sum_{k} Cov(A_{hi} y_{hi}, A_{ki} y_{ki}) \\ & + \sum_{h \neq k} \sum_{k} \sum_{i \neq j} \sum_{j} Cov(A_{hi} y_{hi}, A_{kj} y_{kj}). \qquad (13) \end{aligned}$$

In words,

$$\begin{aligned} V(Q) = & \begin{bmatrix} \text{sum of individual crop} \\ \text{variances within states} \\ (h = k,\ i = j) \end{bmatrix} \\ + & \begin{bmatrix} \text{sum of intercrop co-} \\ \text{variances within states} \\ (k = h,\ i \neq j) \end{bmatrix} \\ + & \begin{bmatrix} \text{sum of interstate} \\ \text{covariances for each} \\ \text{crop } (i = j,\ k \neq h) \end{bmatrix} \\ + & \begin{bmatrix} \text{sum of all covariances} \\ \text{between both crops} \\ \text{and states } (h \neq k,\ i \neq j). \end{bmatrix} \end{aligned}$$

The variance of total cereal production therefore depends not only on the production variances of individual crops in each state, but on covariances between crop production within states, on covariances between state production for each crop, and on covariances between the production of different crops in different states.

When production of a single crop is aggregated for all states, then only terms in the first and third blocks of equation (13) are relevant. Similarly, aggregation of crops within a single state leads to terms in only the first and second blocks of equation (13).

The change in the variance of production, $\Delta V(Q)$, is decomposed by applying the decomposition results in Appendix I, Table 18, to each of the covariance terms in equation (12). The components of change can then be aggregated in relevant ways; for example, they can be grouped as in equation (13).

4

SOURCES OF INSTABILITY FOR ALL INDIA

Components of Change in Production Variability

Table 7 presents a summary of the components of change in the variance of production of individual cereal crops for all India.

Changes in the variance of yields account for large shares of the changes in the variance of production for all crops except wheat and barley. They account for 37 percent of the increase in the variance of total cereal production, for 40 percent of the increase in the variance of rice production, and for even larger shares of the changes in the variance of bajra, jowar, maize, ragi, and small millet production.

The small share of the increase in the variance of wheat production accounted for by changes in yield variability (about 1 percent) is consistent with a small increase of 7 percent in the standard deviation of wheat yields (Table 8). A slight decline of 6 percent in the standard deviation of barley yields (Table 8) also explains the negative effect of changes in yield variability on the variance of barley production. The negative entry for small millets is really a positive effect because the variance of small millet production actually declined by 19 percent between the two periods.

Changes in mean yields account for only small shares of the changes in the variance of production for most crops; they account for only about 1 percent of the increase in the variance of total cereal production. Changes in mean area are generally more important. They account for nearly 9 percent of the increase in the variance of total cereal production and for 16 percent of the increase in the variance of wheat production. Changes in mean area had little effect on the stability of rice production, but they acted to reduce the variability of bajra, barley, jowar, and small millet production.

Changes in the variances of areas sown had destabilizing effects on all crops except maize and small millets. They account for about 6 percent of the increase in the variance of rice, wheat, and total cereal production, but for three quarters of the increase in the variance of barley production and about half the reduction in the variance of small millet production.

Changes in the covariances between areas and yields account for a surprisingly large part of the changes in the variances of production for all crops. In fact, they are the second largest component of the change in the variance of production for all crops except wheat, barley, and maize. For several crops they are at least half as important as the effect of changes in the variance of yields. Changes in the area-yield covariance account for about 31 percent of the increase in the variance of total cereal production, 32 percent of the increase in the variance of rice production, and three quarters of the reduction in the variance of small millet production. The covariance effect was 10 times larger than the yield variance effect for wheat, but it had a stabilizing effect on barley production.

Since $Cov(A, y) = \rho [V(A)\ V(y)]^{1/2}$, where ρ is the correlation coefficient between area and yield, then changes in the covariance can arise through changes in ρ, V(A) or V(y). In fact,

$$\Delta Cov(A, y) = \rho_I [\sigma_{yI} \Delta\sigma_A + \sigma_{AI} \Delta\sigma_y + \Delta\sigma_A \Delta\sigma_y] + \Delta\rho [\sigma_{AI} \sigma_{yI} + \sigma_{yI} \Delta\sigma_A + \sigma_{AI} \Delta\sigma_y + \Delta\sigma_y \Delta\sigma_A], \qquad (14)$$

where σ_a and σ_y denote the standard deviations of area sown and yield, respectively.[7]

[7] Equation (14) is obtained by writing

$$Cov(A_{II}, y_{II}) = (\rho_I + \Delta\rho)(\sigma_{AI} + \Delta\sigma_A)(\sigma_{yI} + \Delta\sigma_y)$$

and then subtracting $Cov(A_I, y_I) = \rho_I \sigma_{AI} \sigma_{yI}$.

Table 7—Components of change in the variance of production of individual cereals, all India, 1954/55-1964/65 — 1967/68-1977/78

Source of Change: Description	Symbols	Rice	Wheat	Bajra	Barley	Jowar	Maize	Ragi	Small Millets	Total Cereals
					(percent)					
Change in mean yield	$\Delta\bar{y}$	−0.69	5.20	0.81	15.08	2.71	0.55	1.24	2.16	1.43
Change in mean area	$\Delta\bar{A}$	1.68	15.75	−0.15	−46.59	−3.81	3.92	2.34	17.78	8.75
Change in yield variance	$\Delta V(y)$	40.05	1.12	57.98	−7.88	56.79	48.17	58.66	−179.94	37.20
Change in area variance	$\Delta V(A)$	5.20	6.86	3.09	76.50	5.28	−7.08	20.44	45.26	5.97
Interaction between changes in mean yields and mean areas	$\Delta\bar{y}, \Delta\bar{A}$	1.23	−1.65	−0.15	−0.73	−0.19	−0.19	0.13	0.41	0.22
Change in area-yield covariance	$\Delta Cov(A,y)$	31.89	11.98	18.52	−8.27	36.12	19.13	24.32	75.57	31.04
Interaction between changes in mean area and yield variance	$\Delta\bar{A}, \Delta V(y)$	18.08	10.95	8.99	8.55	6.13	28.47	−9.14	73.43	7.34
Interaction between changes in mean yield and area variance	$\Delta\bar{y}, \Delta V(A)$	2.19	14.29	2.27	52.22	3.87	0.60	5.34	6.83	2.92
Interactions between changes in mean area and yield and changes in area-yield covariance	$\Delta\bar{y}, \Delta\bar{A}, \Delta Cov(y,A)$	13.17	31.63	8.43	2.22	8.02	7.56	0.67	−1.49	12.30
Change in residual	ΔR	−12.79	3.88	0.21	8.91	−14.91	−1.14	−3.99	59.99	−7.16
Change in the variance of production in all India		224.00	510.00	2,307.00	54.00	139.00	1,560.00	988.00	−19.00	342.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.
Note: A denotes area, y, yield, and V, variance.

Table 8—Changes in the standard deviations of yield and area sown, by crop, all India, 1954/55-1964/65 – 1967/68-1977/78

Crop	Standard Deviation of Yield ($\Delta\sigma_y$)	Standard Deviation of Area ($\Delta\sigma_A$)
	(percent)	
Rice	29.9	227.7
Wheat	7.0	45.7
Bajra	319.9	177.6
Barley	6.1	67.8
Jowar	30.9	51.7
Maize	90.6	42.4
Ragi	150.3	138.4
Small millets	2.4	55.7
Total cereals	55.6	171.8

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.

The area-yield correlations for both periods are reported in Table 9. Apart from barley, these correlations increased substantially for all crops at the all India level. Indeed, they all became positive in the second period, even for crops such as maize, where the correlations were large but negative in the first period.

A positive correlation between area and yield implies that the two tend to fluctuate together. The area sown with a crop tends to be larger (smaller) in those years when yields are high (low). Why this should happen is open to conjecture.

Moving further down Table 7, it can be seen that interaction terms are important in explaining the changes in the variances of crop production. In fact, when the three interaction effects are added together, they account for 25 percent of the increase in the variance of total cereal production, for one-third of the increase in the variance of rice production, and for one-half of the increase in the variance of wheat production. They are even more important for barley and small millets, but account for only 5 percent of the change in the variance of rice production.

Even though the interaction effects arise in part from increases in yield variability, they would not have arisen had the interacting variables not changed as well. Consequently, the interaction effects cannot be arbitrarily attributed to increases in yield instability, unless it can be argued that increased yield instability induced the changes in the interacting variables. This might happen, for example, if increases in yield variability induced a change in the behavior of farmers, which might affect the mean or the variance of the areas sown with different crops.

Finally, changes in the residual term R contribute only slightly to changes in the production variances for most crops. This is fortunate because the elements of the residual term are difficult to interpret (see Appendix I). They are important for small millet production but, considering that this is a minor crop and its variance changed only modestly between the two periods, it should not cause much worry.

Components of Change in Average Production

Increases in mean yield account for 48 percent of the increase in total cereal production, and increases in mean area account for 37 percent (Table 10). Increases in mean yield are about as important as increases in mean area in accounting for the growth of rice and wheat production, but they are much more important than mean area changes for bajra, barley, jowar, and ragi. Area changes are more important for maize and small millets.

Changes in covariances between areas and yields are not particularly important in accounting for increases in mean production, except for barley, where the covariance effect is negative. However, as should be expected from Figure 2, the interaction effect between changes in mean yield and mean area is large for most crops. It accounts for 14 percent of the increase in the average production of total cereals and for one-quarter of the increase in average wheat production. As ΔA is negative for barley and jowar (Table 2), the interaction effects are negative for these crops.

Effect of Yield Changes on the Relative Instability of Production

Changes in the variances of yield account for substantial shares of the increases in the

Table 9—Area-yield correlations, by crop and state, 1954/55-1964/65 and 1967/68-1977/78

State/Period	Rice	Wheat	Bajra	Barley	Jowar	Maize	Ragi	Small Millets	Total Cereals
					(percent)				
Andhra Pradesh									
First period	-0.316	...	...	...	0.328	0.035	-0.502	-0.145	-0.166
Second period	0.043	...	...	...	-0.131	0.016	-0.329	-0.277	0.528
Assam									
First period	-0.654	...	...	...	...	...	...	...	-0.654
Second period	-0.193	...	...	...	...	...	...	...	-0.193
Bihar									
First period	0.538	-0.373	...	0.099	...	0.614	0.061	...	0.877
Second period	-0.036	0.005	...	0.571	...	0.814	0.737	...	0.420
Gujarat									
First period	0.295	-0.448	0.776	...	...	0.657	-0.224	0.545	0.528
Second period	0.851	-0.318	0.472	...	...	0.089	0.359	0.282	0.779
Haryana									
First period	-0.437	-0.918	0.744	0.146	...	-0.158	...	...	-0.472
Second period	0.749	0.373	0.250	-0.131	...	0.388	...	...	0.223
Kerala									
First period	-0.201	...	...	...	...	...	...	...	-0.201
Second period	0.547	...	...	...	...	...	...	...	0.547
Karnataka									
First period	-0.242	...	...	...	-0.441	-0.824	-0.093	-0.229	-0.268
Second period	0.279	...	...	...	0.171	0.017	0.159	0.125	0.413
Madhya Pradesh									
First period	0.053	0.086	...	0.504	0.011	-0.317	...	0.044	0.248
Second period	-0.003	0.246	...	0.229	0.354	-0.230	...	0.249	0.035
Maharashtra									
First period	-0.941	-0.310	-0.233	...	0.304	...	-0.081	-0.563	0.115
Second period	0.717	0.531	0.168	...	0.797	...	0.191	-0.166	0.713
Orissa									
First period	-0.295	...	...	...	...	...	-0.830	-0.187	-0.249
Second period	0.040	...	...	...	...	...	-0.215	0.030	0.136
Punjab									
First period	-0.080	-0.387	...	0.317	...	-0.535	...	...	-0.357
Second period	0.661	0.538	...	-0.089	...	-0.383	...	...	0.464
Rajasthan									
First period	...	0.352	-0.177	0.782	...	0.889	...	...	0.137
Second period	...	0.084	0.294	-0.106	...	-0.824	...	...	0.097
Tamil Nadu									
First period	0.055	...	...	...	...	...	0.245	0.611	-0.019
Second period	0.873	...	...	...	...	...	0.579	0.496	0.829
Uttar Pradesh									
First period	-0.017	0.155	0.458	0.269	...	0.010	-0.466	0.242	0.402
Second period	0.506	0.287	0.509	0.369	...	0.117	0.402	0.749	0.422
West Bengal									
First period	0.725	-0.563	...	...	...	...	...	...	0.760
Second period	0.204	0.650	...	...	...	...	...	...	0.405
All India									
First period	-0.072	-0.188	0.037	0.359	0.245	-0.739	-0.300	-0.214	0.358
Second period	0.804	0.547	0.593	0.246	0.584	0.215	0.251	0.422	0.652

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.

Note: The first period is from 1954/55 to 1964/65; the second period is from 1967/68 to 1977/78.

Table 10—Components of change in mean production of individual crops, all India, 1954/55-1964/65 — 1967/68-1977/78

Source of Change										
Description	Symbols	Rice	Wheat	Bajra	Barley	Jowar	Maize	Ragi	Small Millets	Total Cereals
						(percent)				
Change in mean yields	$\Delta\bar{Y}$	47.92	38.05	76.56	1,203.89	153.05	13.36	95.87	10.26	47.69
Change in mean area	$\Delta\bar{A}$	44.65	36.62	19.76	-877.73	35.71	69.50	-5.71	93.32	36.59
Change in area-yield covariance	$\Delta Cov(A, Y)$	2.23	0.53	1.21	22.92	6.62	2.06	3.58	0.18	1.42
Interaction between changes in mean yield and mean area	$\Delta\bar{Y}, \Delta\bar{A}$	5.20	24.80	2.47	-203.23	-23.95	15.06	6.26	-3.40	14.30
Total change in mean production		31.8	141.9	50.9	1.8	8.7	51.7	12.6	-10.3	44.8
Total contribution of crop to change in mean production of cereals		34.8	48.9	6.3	0.2	2.6	7.1	0.8	0.8	100.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.
Notes: The figures for the components of change in mean production add to 100 percent in each column. A denotes area and Y, yield.

variance of production of the important cereal crops. At the same time, increases in mean yields contributed significantly to increases in average production. As the improved seed/fertilizer-based technologies are associated with increases in both the means and variances of yield, it is pertinent to ask what effect the combined changes have had on the relative instability of cereal production. More specifically, have the observed shifts in yield distributions increased or reduced the coefficient of variation of cereal production?

Table 11 shows how changes in yields might have affected the coefficients of variation of national production if the means and variances of areas sown had remained unchanged from the first period. The coefficient of variation of total cereal production increased by 45 percent between the two periods. However, if the means and variances of area had remained unchanged, and if the yield distributions had changed in such a way that the area-yield covariances did not change either,[8] then the coefficient of variation of total cereal production would have increased by 28 percent, or by 62 percent of its actual rise. Under these assumptions, changes in yield are seen to have had a net destabilizing effect on production of total cereals, rice, bajra, jowar, maize, ragi, and small millets, but they had a net stabilizing effect on production of wheat and barley (Table 11).

The assumption that the area-yield covariances remained constant is a strong one, requiring that changes in the area-yield correlations exactly offset changes in the standard deviations of yield (see footnote 8). Because it is difficult to estimate how these covariances would have changed if the variances of areas had remained constant,

Table 11—Changes in coefficients of variation of cereal production under different assumptions about changes in crop area, 1954/55-1964/65 — 1967/68-1977/78

Crop	Coefficient of Variation of Production in First Period	Change in Coefficient of Variation in Second Period Assuming: All Area and Yield Changes	No Changes in Mean Area, Area Variance or Area-Yield Covariance	No Changes in Mean Area or Area Variance
		(percent)		
Rice	5.25	36.4	18.9	44.0
Wheat	8.45	2.1	-25.3	-1.2
Bajra	8.53	225.2	174.3	222.8
Barley	11.16	21.9	-15.7	-15.9
Jowar	9.91	42.4	19.4	37.0
Maize	4.32	168.3	174.2	218.3
Ragi	4.12	193.0	135.3	174.7
Small millets	9.28	0.5	16.6	10.7
Total cereals	4.03	45.2	28.1	54.7

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.
Note: The first period is from 1954/55 to 1964/65; the second period is from 1967/68 to 1977/78.

[8] Using equation (14) and setting $\Delta\sigma_A = 0$, then

$$\Delta Cov(A, y) = \rho_1 \sigma_{A1} \Delta\sigma_y + \Delta\rho\, \sigma_{A1} (\sigma_{y1} + \Delta\sigma_y).$$

Given $\Delta\sigma_y \neq 0$, then

$$\Delta Cov(A, y) = 0 \text{ if } \Delta\rho = -\rho_1 \Delta\sigma_y / (\sigma_{y1} + \Delta\sigma_y).$$

the last column of Table 11 reports results obtained under the extreme assumption that the area-yield covariances would have changed to second-period values anyway. Under this assumption, the coefficient of variation of total cereal production would have increased by 55 percent over its first period value, an amount that is greater than the actual increase of 45 percent. Changes in yield would also have accounted for most of the observed changes in the coefficient of variation of production of all crops except wheat and barley. Changes in yields would continue to help stabilize the production of these two crops.

If the means and variances of the areas sown had remained unchanged, then as long as most of the Cov(A, Y) terms continued to be positive, the actual changes in the area-yield covariances would have fallen somewhere between the two extremes in Table 11. This leads to the conclusion that changes in the means and variances of yields account for at least two thirds of the increase in the coefficient of variation of total cereal production and for the lion's share of the increases in the instability of all crops except wheat and barley. Changes in yields did help stabilize wheat and barley production, but these effects were offset by destabilizing patterns of change in the areas sown with these crops.

5

THE IMPORTANCE OF COVARIANCES BETWEEN CROPS AND BETWEEN STATES

If the improved seed fertilizer-based technologies are assumed to account for much of the change in the mean and variance of yields, it is tempting to conclude from the analysis so far that these technologies are indeed a prime source of increased instability in India's foodgrain production. But this conclusion could be misleading.

Returning to equation (13), the variance of total cereal production for all India depends on production covariances between crops and between states, as well as on crop production variances within individual states. In the previous chapter the changes in the production covariances were not broken out from the changes in the production variances. Table 12 presents a more detailed analysis of the components of change in the variance of total cereal production using the disaggregation scheme in equation (13). All the entries in this table are expressed as a percent of the change in the variance of total cereal production for all India.

The variance column for each crop in the table is the sum of the changes in production variances within states. These sums account for remarkably small shares of the increase in the variance of total cereal production—only about 5 percent for rice,

Table 12—Disaggregation of the components of change in the variance of total cereal production, 1954/55-1964/65 — 1967/68-1977/78

Source of Change		Crop Variances[a]							
Description	Symbols	Rice	Wheat	Bajra	Barley	Jowar	Maize	Ragi	Small Millets
		(percent)							
Change in mean yield	Δy	0.26	0.21	0.07	0.02	0.03	0.01	0.00	0.00
Change in mean area	ΔA	2.80	1.57	0.03	0.06	0.04	0.19	0.00	0.00
Change in yield variance	$\Delta V(y)$	0.72	0.02	1.60	0.01	3.15	0.24	0.09	0.05
Change in area variance	$\Delta V(A)$	0.25	0.32	0.47	0.06	0.27	0.13	0.03	0.03
Interaction between changes in mean yield and mean area	$\Delta y, \Delta A$	0.26	0.08	0.00	0.00	0.00	0.01	0.00	0.00
Change in area yield covariance	$\Delta Cov(A,y)$	2.53	0.43	0.12	0.03	1.24	0.18	0.03	0.00
Interaction between changes in mean area and yield variance	$\Delta A, \Delta V(y)$	2.98	0.20	0.31	0.02	-0.02	0.09	0.00	-0.02
Interaction between changes in mean yield and area variance	$\Delta y, \Delta V(A)$	0.51	0.83	0.23	0.02	0.09	-0.01	0.01	0.00
Interaction between changes in mean area and yield and changes in area yield covariance	$\Delta y, \Delta A, \Delta Cov(A,y)$	1.14	0.84	0.03	0.00	0.02	0.10	0.00	0.00
Change in residual	ΔR	-0.26	0.01	0.04	0.00	-0.43	0.02	-0.01	-0.01
Total contribution to change in variance of production in all India		5.20	4.34	2.90	0.02	4.32	0.65	0.15	0.01

(continued on p. 30)

Table 12—Continued

Source of Change: Description	Symbols	Total Variances	Intercrop Covariances Within States	Interstate Covariances Within Crops	Covariances Between Crops and States	All India
				(percent)		
Change in mean yield	$\Delta\bar{y}$	0.60	0.22	0.27	0.34	1.43
Change in mean area	$\Delta\bar{A}$	4.50	0.86	−1.76	5.16	8.75
Change in yield variance	$\Delta V(y)$	5.85	5.66	14.17	11.52	37.20
Change in area variance	$\Delta V(A)$	1.23	0.15	1.82	2.77	5.97
Interaction between changes in mean yield and mean area	$\Delta\bar{y}, \Delta\bar{A}$	0.17	−0.01	−0.12	0.19	0.22
Change in area-yield covariance	$\Delta Cov(A,y)$	4.50	3.84	9.68	13.01	31.04
Interaction between changes in mean area and yield variance	$\Delta\bar{A}, \Delta V(y)$	−2.41	0.02	10.64	−0.91	7.34
Interaction between changes in mean yield and area variance	$\Delta\bar{y}, \Delta V(A)$	1.68	−0.15	1.67	−0.28	2.92
Interaction between changes in mean area and yield and changes in area-yield covariance	$\Delta\bar{y}, \Delta\bar{A}, \Delta Cov(A,y)$	2.12	1.30	7.69	1.19	12.30
Change in residual	ΔR	−0.65	−1.15	−2.83	−2.52	−7.16
Total contribution to change in variance of production in all India		17.57	10.75	41.21	30.47	100.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.

Note: A denotes area, y, yield, and V, variance.

[a] These figures are the sums of the variances within states for each crop.

for example. The share is even smaller for other crops. When added together, the changes in all the crop production variances account for only 17.6 percent of the increase in the variance of total cereal production.

Taken together, changes in the various production covariances between crops and states account for a whopping 82 percent of the increase in the variance of total cereal production. Half of this is due to changes in interstate production covariances within crops, 13 percent to changes in intercrop production covariances within states, and 37 percent to changes in covariances between the production of different crops in different states.

Within these groups of production covariance terms, changes in intercrop and interstate yield covariances account for the largest share of their contribution to increases in the variance of total cereal production. In fact, 31 percent (5.66 + 14.17 + 11.52) of the increase in the variance of total cereal production is attributable to changes in intercrop and interstate yield covariances. In contrast, the sum of the changes in yield variances for individual crops and states accounts for only 5.85 percent of the change in the variance of total cereal production.

If the improved seed/fertilizer-based technologies did contribute to increased yield variability, then their impact on the instability of total cereal production occurred largely through increases in intercrop and interstate yield covariances. But increases in yield variances alone are unlikely to account for the large increases in these yield covariances. Changes in intercrop and interstate yield correlations may also have been important.

Using an expansion similar to equation (14), the change in each of the intercrop and interstate yield covariances can be expressed:

$$\Delta \mathrm{Cov}(y_i, y_j) = [\rho_{ij}(\sigma_{y_i} \Delta\sigma_{y_j} + \sigma_{y_j} \Delta\sigma_{y_i} + \Delta\sigma_{y_i} \Delta\sigma_{y_j})] + [\Delta\rho\, \sigma_{y_i} \sigma_{y_j}] + [\Delta\rho(\sigma_{y_i} \Delta\sigma_{y_j} + \sigma_{y_j} \Delta\sigma_{y_i} + \Delta\sigma_{y_i} \Delta\sigma_{y_j})], \quad (15)$$

where i and j subscripts denote different crops grown in the same or in different states, and ρ is the correlation coefficient between the yields of crops i and j.

The expression on the right-hand side of equation (15) is arranged in three groups (delineated by brackets). The first group consists of terms that originate from changes in yield variances alone. Recalling that the total changes in intercrop and interstate yield covariances account for 31 percent of the increase in the variance of total cereal production (Table 12), then application of equation (15) to the relevant terms in Appendix 1, Table 18, leads to the result that 9.1 percent of this increase is due to changes in yield variances alone. The second group in equation (15) comprises a single term due to changes in the yield correlations between crops and between states. This term accounts for 36.4 percent of the total intercrop and interstate yield covariance effects in Table 12. The final group consists of interaction terms that arise from the simultaneous occurrence of changes in yield variances and intercrop and interstate yield correlations. This group accounts for 54.5 percent of the total intercrop and interstate yield covariance effects.

These findings clearly provide some vindication of the improved seed/fertilizer-based technologies. Even if these technologies are an important source of increases in yield variances, it is hard to see how they can be blamed for the increases in the yield correlation coefficients. Yet without these increases in the correlations, the total yield variance effect in Table 12 would be small.

More likely sources for these increased yield correlations might be changes in rainfall patterns or the more widespread use of fertilizers and irrigation on cereal crops that occurred during the second period. Irrigation may reduce yield risks for farmers, but by reducing the role of rainfall in determining yield outcomes, this could also lead to a reduction in offsetting patterns of yield variations between crops and states. Hannan Ezekiel has suggested that this effect could have been aggravated by the more widespread use of electric pumps in the second period, because irregularities in electric power supplies that have occurred in recent years are likely to have had similar and simultaneous effects on the yields of many crops in large areas of India. Irregularities in fertilizer supplies may have had a similar effect in reducing offsetting patterns of yield variation, because supply shortages will have occurred in many states at the same time.[9]

A further point of interest in Table 12 is the small share (4.5 percent) of the increase in the variance of total cereal production attributed to changes in area-yield covariances when the crop variance columns are added. This compares with a 26.5 percent share (3.84 + 9.68 + 13.01) for the area-yield covariances effects summed over the three intercrop and interstate covariance columns.

Using equation (14), changes in the intercrop and interstate area-yield covariances were also decomposed into parts that can be attributed separately to changes in the variances of yields and areas, to changes in area-yield correlations, and to interactions between these two sources of change. Of the 26.5 percent increase in the variance of total cereal production attributable to changes in intercrop and interstate area-yield covariances, only 2.8 percent can be attributed to changes in yield and area variances alone. However, changes in area-yield correlations account for 45.3 percent of the increase, and interaction terms account for the remaining 51.9 percent.

Again, changes in yield variances account for only a small part of the total covariance effect. Changes in area-yield correlations, which probably originate from sources that are not explained by the new technologies, are far more important.

[9] This suggestion was made during a conversation with Dr. Hannan Ezekiel, editor of *The Economic Times*, Bombay.

6

SOURCES OF INSTABILITY WITHIN STATES

Changes in the Variance of Total Cereal Production

Table 13 shows the decomposition of the components of change in the variance of total cereal production within each state.

Changes in yield variances are an important source of increased instability in most states. They account for nearly half of the increase in the variance of total cereal production in Andhra Pradesh, Karnataka, Orissa, Rajasthan, Tamil Nadu, Uttar Pradesh, and West Bengal, and for two thirds and three quarters, respectively, of the variance increases in Gujarat and Maharashtra. However, changes in yield variances had stabilizing effects on total cereal production in Assam, Bihar, Madhya Pradesh, and the Punjab. The Punjab result is to be expected because this state has the largest proportion of its total cereal area grown under irrigation. More generally, though, there does not appear to be any relationship between the yield variance effects in Table 13 and the extent of irrigation in each state. A linear regression of the yield variance effects in Table 13 regressed against data on the average proportion of the total cereal area irrigated in each state between 1971-72 and 1975-76 (Table 14) is statistically significant only at the 25 percent confidence level.

Changes in the means and variances of crop areas sown are most important in accounting for changes in the variance of total cereal production in those states in which the yield variance effects are negative. In Punjab, for example, increases in crop areas sown account for more than half of the increase in the variance of total cereal production.

Apart from yield variances, changes in area-yield covariances are the most consistently important source of instability in total cereal production within states. The covariance effect is destabilizing in all states except Bihar and accounts for more than one quarter of the change in the variance of total cereal production in eight states, as well as for all-India production. It is particularly important in Madhya Pradesh, accounting for 62 percent of the increase in the variance of total cereal production in that state.

Most of these covariance effects are associated with increases in the area-yield correlation coefficients for total cereals (Table 9). These correlations declined between the first and second periods in Bihar, Rajasthan, and West Bengal (hence the small or negative covariance effects in Table 13 for these states), but they increased in all other states.

Given the results in Chapter 5, it should come as no surprise that changes in interstate production covariances between both the same and different crops account for the lion's share (72 percent) of the increase in the variance of total cereal production. Interstate covariances also account for 60 percent and 81 percent, respectively, of the yield variance and area-yield covariance effects for India's total cereal production.[10]

To supplement this analysis, Tables 19 to 26 in Appendix 2 provide an analysis of the components of change in the variance of production of individual crops within each state. Some of the more interesting results in these tables are as follows.

First, changes in production covariances between states account for most of the increase in the variance of production of each crop at the all-India level. Jowar and ragi are exceptions. The production of these crops is concentrated heavily in a few states, and the increases in the variance of production are almost fully accounted for by only one or two states. Maharashtra accounts for 91 percent of the increase in the variance of all-India jowar production, and Karnataka

[10] The calculations are, for the yield variance effect, 31.37 ÷ 0.7173 = 37.20 = 0.605; for the area-yield covariance effect, 35.03 ÷ 0.7173 = 31.04 = 0.810.

Table 13—Components of change in the variance of total cereal production, by state, 1954/55-1964/65 — 1967/68-1977/78

Source of Change: Description	Symbols	Andhra Pradesh	Assam	Bihar	Gujarat	Haryana	Kerala	Karnataka	Madhya Pradesh	Maharashtra
						(percent)				
Change in mean yield	$\Delta\bar{y}$	1.25	−0.75	32.68	2.71	5.92	1.21	1.62	1.95	0.17
Change in mean area	$\Delta\bar{A}$	0.05	57.37	84.49	−1.43	3.50	3.31	−1.14	68.70	−0.17
Change in yield variance	$\Delta V(y)$	43.92	−36.65	−1.50	64.54	30.84	19.16	51.81	−12.30	74.09
Change in area variance	$\Delta V(A)$	10.74	85.28	10.26	3.68	−2.79	19.57	12.07	−25.38	6.67
Interaction between changes in mean yield and mean area	$\Delta\bar{y}, \Delta\bar{A}$	0.00	−0.28	3.73	−0.08	−1.76	−0.07	0.11	−0.39	0.00
Change in area-yield covariance	$\Delta Cov(A,y)$	32.87	5.60	−33.17	25.21	5.96	34.65	25.65	61.49	33.90
Interaction between changes in mean area and yield variance	$\Delta\bar{A}, \Delta V(y)$	0.18	−18.89	−0.48	−5.83	54.36	5.01	−10.18	−3.21	−1.64
Interaction between changes in mean yield and area variance	$\Delta\bar{y}, \Delta V(A)$	4.74	5.03	6.26	6.04	−6.26	6.99	16.36	−2.92	1.54
Interactions between changes in mean area and yield and changes in area-yield covariance	$\Delta\bar{y}, \Delta\bar{A}$ $\Delta Cov(A,y)$	6.68	1.49	−15.26	14.01	11.88	10.68	9.66	11.42	3.31
Change in residual	ΔR	−0.43	1.80	12.99	−8.86	−1.66	−0.51	−5.94	0.62	−17.88
Total contribution of state to change in variance of production in all India		1.41	0.02	0.46	1.89	0.93	0.02	1.76	0.58	9.63

Source of Change: Description	Symbols	Orissa	Punjab	Rajasthan	Tamil Nadu	Uttar Pradesh	West Bengal	Other States[a]	Interstate Covariances	All India
						(percent)				
Change in mean yield	$\Delta\bar{y}$	0.13	−0.52	1.07	1.11	4.32	6.17	...	0.99	1.43
Change in mean area	$\Delta\bar{A}$	19.34	52.30	2.81	0.08	25.95	26.98	...	8.57	8.75
Change in yield variance	$\Delta V(y)$	45.67	−4.41	56.02	44.23	40.68	43.26	...	31.37	37.20
Change in area variance	$\Delta V(A)$	−1.97	4.71	8.80	7.82	1.12	3.53	...	5.15	5.97
Interaction between changes in mean yield and mean area	$\Delta\bar{y}, \Delta\bar{A}$	−0.03	−2.65	0.04	0.00	0.50	0.93	...	0.29	0.22
Change in area-yield covariance	$\Delta Cov(A,y)$	19.62	15.49	4.06	34.56	6.15	0.61	...	35.03	31.04
Interaction between changes in mean area and yield variance	$\Delta\bar{A}, \Delta V(y)$	16.29	−8.63	21.43	2.97	15.55	19.92	...	9.20	7.34
Interaction between changes in mean yield and area variance	$\Delta\bar{y}, \Delta V(A)$	−0.07	11.27	4.10	5.0	0.83	1.73	...	2.22	2.92
Interactions between changes in mean area and yield and changes in area-yield covariance	$\Delta\bar{y}, \Delta\bar{A}$ $\Delta Cov(A,y)$	3.61	33.61	1.72	11.18	3.40	0.30	...	15.13	12.30
Change in residual	ΔR	−2.60	−1.18	−0.06	−6.94	1.49	−3.42	...	−6.94	−7.16
Total contribution of state to change in variance of production in all India		0.74	0.63	3.50	2.46	2.97	0.93	0.34	71.73	100.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.

Notes: The figures for the components of change in the variance of production add to 100 percent in each column. A denotes area, y, yield, and V, variance.

[a] Because the changes in the variance of production of other states were small, an analysis of their components was not included.

Table 14—Average share of area irrigated, by crop and state, 1971/72-1975/76

State	Rice	Wheat	Bajra	Barley	Jowar	Maize	Total Cereals
				(percent)			
Andhra Pradesh	94.5	...	...	...	0.9	21.7	44.2
Assam	33.8	...	...	...	...	...	33.6
Bihar	32.6	59.0	...	15.7	...	6.5	33.1
Gujarat	30.1	69.2	6.0	...	...	4.3	15.4
Haryana	89.8	85.9	10.2	52.6	...	29.4	54.1
Kerala	53.4	...	...	...	...	...	52.9
Karnataka	64.7	...	...	...	5.3	76.0	18.4
Madhya Pradesh	13.8	21.0	...	28.4	n.a.	0.5	11.0
Maharashtra	23.1	37.8	3.2	...	5.4	...	10.2
Orissa	23.5	...	...	...	...	...	26.5
Punjab	95.1	88.1	...	57.8	...	71.0	84.3
Rajasthan	...	68.6	1.3	72.1	...	7.5	19.5
Tamil Nadu	92.0	...	...	...	...	...	61.8
Uttar Pradesh	18.7	71.7	1.0	55.1	...	14.5	35.2
West Bengal	28.7	40.5	...	...	...	...	28.3
All India	38.7	58.4	4.7	52.3	4.3	17.5	29.6

Source: India, Ministry of Agriculture and Irrigation, Directorate of Economics and Statistics, *Estimates of Area and Production of Principal Crops in India* (Delhi: Controller of Publications, various issue).

Note: n.a. means not available.

accounts for 46 percent of the increase in the variance of all-India ragi production. This leaves relatively small shares of the variance increase for the covariance effects.

Second, the yield variance effects for wheat are small or negative in all states except Maharashtra and Rajasthan. In these states they account for 56 percent and 30 percent, respectively, of the increase in the variance of wheat production.

Third, there are now some interstate associations between the yield variance effects and the intensity of irrigation that were not apparent in the total cereal aggregates of Table 13. The Punjab is the most intensively irrigated state for cereal production, and this is reflected in the small yield variance effects for all crops in this state, except maize. (The maize result is not reliable because the change in the variance of its production was small, leading to an unstable decomposition analysis.) More generally, though, these relations are not as strong for other states. Regressions for individual crops using state data on the yield variance effect and the average proportion of the area of that crop that is irrigated lead to insignificant associations at the 5 percent confidence level.[11] However, when the data for individual crops are pooled, there is a significant association. The estimated equation is

$$Z_{ij} = \underset{(8.59)}{60.647} - \underset{(-4.38)}{0.63602}\, A_{ij};$$

$$R^2 = 0.309;\ F(1,43) = 19.2\ ,$$

where Z_{ij} denotes the yield variance effect for crop i in state j taken from Appendix 2, Tables 19 to 26, and A_{ij} is the average percent of the area of crop i in state j irrigated between 1971/72 and 1975/76 (Table 14). The figures in parentheses under the regression coefficient are t-statistics.

As the percentage of crop area irrigated

[11] Regressions were not made for ragi and small millets because the irrigation data were not available.

increases, changes in yield variances account for smaller shares of increases in the variance of crop production, which suggests that irrigation has a stabilizing effect for individual crops and states.

Changes in Mean Production

Table 15 contains the results of decomposing the changes in the mean production of total cereal production within each state. Tables 27 to 34 in Appendix 2 provide a supplementary analysis of the components of change in the average production of individual crops by state.

Changes in mean yields were an important source of growth in total cereal production within states. They were particularly important in Gujarat and Karnataka, where yield increases more than offset reductions in the total land area sown with cereals. Yield increases also played an important role in Maharashtra, where again the average area sown with cereals declined. In this case, however, there was a strong area-yield covariance effect, which also helped to offset the loss in area.

Increases in the average area sown with total cereals accounted for most of the production increases in Assam, Madhya Pradesh, and Orissa. Area increases were also important in all states except Gujarat, Karnataka, and Maharashtra, and they interacted strongly with changes in mean yields in Bihar, Haryana, Punjab, and West Bengal.

Table 15—Components of change in average production of total cereals, by state, 1954/55-1964/65 — 1967/68-1977/78

Source of Change: Description	Symbols	Andhra Pradesh	Assam	Bihar	Gujarat	Hary-ana	Kerala	Kar-nataka	Madhya Pradesh	Maha-rashtra	Orissa	Punjab	Rajas-than	Tamil Nadu	Uttar Pradesh	West Bengal	Other States	All India
		(percent)																
Change in mean yield	$\Delta\bar{y}$	65.44	10.89	46.19	102.53	27.81	53.31	107.60	35.21	87.80	18.16	38.45	42.14	77.12	50.47	38.33	20.96	47.69
Change in mean area	$\Delta\bar{A}$	24.16	86.57	31.08	−5.58	47.97	39.81	−12.01	62.88	−0.39	75.83	33.60	48.01	14.69	35.61	38.56	73.41	36.59
Change in area-yield covariance	$\Delta Cov(A, y)$	−0.11	0.02	0.26	1.35	0.65	0.32	1.10	0.36	15.45	0.81	0.23	0.56	2.17	0.21	0.54	−9.14	1.42
Interaction between changes in mean yield and mean area	$\Delta\bar{y}, \Delta\bar{A}$	10.50	2.52	22.56	1.69	23.56	6.56	3.31	1.53	−2.87	5.20	27.73	9.30	6.01	13.71	22.57	−3.51	14.30
Total contribution of state to change in mean production in all India		4.14	1.48	8.20	3.55	9.86	1.04	4.66	4.51	2.10	2.27	16.72	4.44	4.64	17.84	7.61	6.91	100.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.
Note: The figures for the components of change in average production add up to 100 percent in each column. A denotes area and y, yield.

7

APPROACHES TO REDUCING FOODGRAIN INSTABILITY

The analysis in this paper relies exclusively on decomposing changes in the variability of foodgrain production by means of statistical identities. This approach enables measurement of the contributions of different components of increased production variability, but it offers little formal insight into why they arose. For example, whereas the analysis identifies the importance of changes in area-yield correlations in accounting for increased production instability, it does not explain why fluctuations in area and yield have become more synchronized. To identify policy interventions to reverse these changes, such explanations are needed. Nevertheless, much can be done within the present framework to identify the key issues for targeting policy interventions, even if delineation of their precise form requires further research.

Effectiveness of Policies to Stabilize Yield and Area

Increases in yield variability have been an important source of increased instability in total cereal production for all India. However, this increase in instability has arisen less from direct yield variability at the farm level than from a shift toward more positive (or less negative) covariances between the yields of different crops, both within and between states, from a simultaneous increase in the variance of individual crop areas sown, and from a shift toward more positive (or less negative) covariances between crop areas and crop yields, both within and between states.

The results in Table 12 show that changes in yield variances and area-yield covariances for individual crops within states account for only 10.4 percent of the increase in the variance of total cereal production for all India. On the other hand, changes in yield and area-yield covariances between crops both within and between states account for 57.9 percent of the increase in the variance of total cereal production. This figure ignores the contribution of these covariances to interaction terms, which contribute a further 20 percent.

What are the implications of these results for policies to reduce instability in India's foodgrain production? Mehra and Barker, Gabler, and Winkelmann[12] recommend that greater emphasis be placed in agricultural research on developing technologies that are less risky. Mehra also stresses the importance of irrigation in helping to stabilize yield fluctuations, though Barker, Gabler, and Winkelmann provide evidence suggesting that irrigation increases yield instability at the farm level. Evenson et al. discuss ways of reducing yield variability through plant breeding methods.[13] But how effective can such approaches be in reducing foodgrain instability for all India?

The results of this study show that the payoff from reducing the yield variance for individual crops within states would be small if these reductions did not also lead to reductions in some of the important yield and area-yield covariance terms. It is clear from equations (14) and (15) that the area-yield and yield covariances will decline if the standard deviation of yields is reduced. But the reduction in these covariances will not be very large if there are other autonomous factors at work that continue to increase the correlation coefficients. If weather patterns are changing in India, or if, as suggested in Chapter 5, the increased use of irrigation and fertilizers on cereal crops acts to increase

[12] Mehra, *Instability in India's Agriculture*; and Barker, Gabler, and Winkelmann, "Long-term Consequences of Change."

[13] Robert E. Evenson et al., "Risk and Uncertainty as Factors in Crop Improvement Research," in *Risk, Uncertainty and Agricultural Development*, ed. J. A. Roumasset, J. M. Boussard, and I. Singh (Laguna, Philippines: Southeast Asian Regional Center for Graduate Study and Research in Agriculture and the Agricultural Development Council, 1979).

intercrop and interstate yield covariances, then yield correlations may be increasing in ways that cannot be controlled by simply developing less risky technologies. This clearly needs to be researched further.

Another approach to reducing production instability could be to focus on reducing the variability of crop areas sown. The variances of crop areas sown show an increase between the first and second periods, and they contribute to the area-yield covariance terms. As such, they are an important component of the changes reported in Table 12. Policies to reduce area variances might be more successful in the short run than attempts to reduce yield variances. Price support policies, more assured fertilizer supplies, or even crop insurance schemes might be useful here.

In order to assess the relative sizes of the gains from policies to reduce the variances of yields or areas sown, the results of the decomposition analysis are used for some rough simulations.

The coefficient of variation of India's total cereal production increased by 45.2 percent between the first and second periods (Table 11). Suppose that the yield variances of each crop in each state had been contained at their first-period values, but that their mean yields had been successfully increased to second-period values. How much would the coefficient of variation of production have increased then?

As shown in equation (15), this would also have reduced the changes in the covariances between yields, both within and between crops and states. However, the covariances would still have increased because of the term $\Delta\rho\ \sigma_{Y_i}\ \sigma_{Y_j}$ in equation (15); this is because of autonomous influences on the correlation coefficients between crop yields. In Chapter 3 it was calculated that these autonomous increases in the yield correlations accounted for 36.4 percent of the intercrop and interstate yield covariance effects in Table 12, or for 14.3 percent of the increase in the variance of total cereal production. For the purposes of these calculations it is assumed that this part of the variance increase would still have occurred.

Area-yield covariances would also have been affected, as can be seen in equation (14). When $\Delta\sigma_{A_i} = 0$, this becomes

$$\Delta \mathrm{Cov}(A, Y) = \Delta\rho\ \sigma_{Y_H}\ \sigma_{A_I} + \rho_I\ \sigma_{Y_I}\ \Delta\sigma_{A_I}.$$

Because it is impossible to tell how the area-yield correlation, $\Delta\rho$, would have changed, the rough-and-ready assumption is made that the sum of all the intercrop and interstate covariances between areas and yields would have increased by half the amount of their actual increase between the first and second periods.

Under these assumptions, the coefficient of variation of total cereal production would have been 17 percent higher in the second period than in the first, a significant reduction from the actual 45.2 percent increase.

Turning now to policies that stabilize area, suppose all the individual crop area variances had been contained at their first-period values. In addition to removing the effects of increases in area variances, this would also have reduced all the intercrop and interstate covariances between crop areas sown, and the changes in the area-yield covariances. It is assumed that these components would have increased by only half of their actual amounts.

Under these assumptions, the coefficient of variation of total cereal production would have increased 34 percent between the two periods. This is not as attractive as the reduction attained when the changes in yield variances are contained, but it is still only two thirds of the actual increase of 45.2 percent.

It must be stressed that these calculations are based on rough assumptions and that the numerical results should be viewed with extreme caution. Nevertheless, they do illustrate the relative sizes of the gains involved. In particular, they confirm that policies to reduce yield variations are likely to be more effective than attempts to stabilize year-to-year variations in the crop areas sown.

Reducing Instability by Modifying Production Patterns

The overwhelming importance of production covariances between crops and states in accounting for the variability in India's total cereal production suggests that well-conceived changes in both the aggregate mix of crops grown and the regional allocation of their production could lead to substantial reductions in instability. Policies to achieve these changes might be difficult to

implement and probably would conflict with other policy objectives of the government, as well as with the workings of efficient markets. Nevertheless, it is instructive to explore whether such policies could achieve any substantial reduction in India's foodgrain production.

This hypothesis is tested with the aid of a linear programming model. The model is used to derive the optimal amounts of each crop to be produced in each state. These amounts add up to the average of total all-India cereal production as observed in the period 1967/68-1977/78, but they also minimize the standard deviation of total cereal production. Such solutions are risk-efficient and can be compared to actual production figures to evaluate how much foodgrain instability can be reduced. Alternatively, this comparison reveals how risk-efficient existing market forces and government policies were in arriving at the observed production patterns in the second period.

A linear programming model has the advantage of permitting constraints to be added to reflect the agroclimatic and resource limitations impinging on production patterns. Such constraints are incorporated in the model. However, no attempt is made to take into account other policy objectives, which might suffer from too narrow a focus on reducing foodgrain instability.

The Model

The production activities in the model are expressed in tons of average production. They will be denoted by P_{ij}, where j designates the crop, i designates the state, and P measures the average number of tons produced. With this notation, total cereal production in state i is $\Sigma_j P_{ij}$, and aggregate all-India production is $\Sigma_i \Sigma_j P_{ij}$.

The "production choice" problem is to find a set of values for the P_{ij}'s that aggregate to the same amount of total cereal production that occurred on average in the second period, that minimize the standard deviation of total cereal production, and that are feasible considering agroclimatic and resource limitations.

In measuring the standard deviation of production it is assumed that on an average-per-ton basis the yield and area variability observed in the second period would not change as P_{ij} changes. Let Q_{ijt} denote the actual production (after detrending) of crop j grown in state i in year t, and let Q_{ij} denote the average production during the second period. Then the production deviation in the t*th* year for one ton of the P_{ij}*th* activity is $(Q_{ijt} - Q_{ij})/Q_{ij} = Q_{ijt}/Q_{ij} - 1$.

The production deviation in the t*th* year for one ton of total cereal production for all India is then

$$\Sigma_i \Sigma_j (Q_{ijt}/Q_{ij} - 1),$$

and the standard deviation of total cereal production over T years is

$$\sigma = (1/T-1)\Sigma_t [\Sigma_i \Sigma_j (Q_{ijt}/Q_{ij} - 1) P_{ij}]^2. \quad (16)$$

Equation (16) is the model's objective function and is minimized.[14]

To ensure that the all-India output of total cereals is equal to 95.02 million tons (the average during the second period), equation (17) is added as a constraint:

$$\Sigma_i \Sigma_j P_{ij} = 95.02 \text{ million}. \quad (17)$$

As formulated, the model could lead to production patterns that are not technically feasible. Rather than undertaking the elab-

[14] The model maximand is quadratic. To facilitate computations, the model was reformulated as a Linear Programming MOTAD problem (Peter B. R. Hazell, "A Linear Alternative to Quadratic and Semivariance Programming for Farm Planning Under Uncertainty," *American Journal of Agricultural Economics* 53 [February 1971]: 53-62).

If new variables are defined so that $z_t \geq 0$, then equation (16) is replaced by

$$\text{Min} \sum_t z_t \text{ so that } \sum_i \sum_j (P_{ijt} - P_{ij}) - z_t \leq 0, \text{ all t.}$$

The z_t activities measure positive deviations in total cereal production from the mean and are zero when the deviations are negative. Estimates of the standard deviation of production are calculated ex post using the classical estimation formula.

orate and expensive exercise of specifying a set of regional farm models that adequately describe the production possibilities for each crop, a more direct approach is taken here.

The production of each crop in each state is constrained so that the area planted cannot exceed the maximum area planted with that crop in any year during the second period. Let A_{ij} denote the area of crop j in state i selected by the model, and let A_{ij}^{max} denote the maximum area of that crop planted in state i during the second period; the constraint can then be written as

$$A_{ij} \leq A_{ij}^{max}, \text{ all i, j.}$$

By multiplying both sides of the inequality by the average yield of crop j in state i, the following variant of the constraint is included in the model:

$$P_{ij} \leq P_{ij}^{max}, \text{ all i, j.} \quad (18)$$

The model could still select production levels for each crop in each state that are not feasible with respect to each state's resources. Consequently, the average production of total cereals in each state is also constrained so as not to exceed that of the second period. That is,

$$\Sigma_j P_{ij} \leq Q_i, \text{ all i.} \quad (19)$$

where Q_i denotes the average production of total cereals observed in state i during the second period.

A final set of constraints requires that none of the production activities can be negative in the model solution. That is,

$$P_{ij} \geq 0, \text{ all i, j.} \quad (20)$$

As formulated above, the model is free to select values for the aggregate production of individual crops that depart from the average values observed during the second period for all India. Thus, although the aggregate level of total cereal production is assured, the composition of this output could be changed. Analyzing model solutions that have this flexibility of choice is useful. However, as significant changes in the crop mix of India's total cereal production could have important price and consumption ramifications, a second variant of the model is also solved in which the crop mix for all India is constrained to the average production level of the second period. Specifically,

$$\Sigma_i P_{ij} = Q_j, \text{ all j.} \quad (21)$$

where Q_j is the average production of the *jth* crop for all India during the second period.

Optimal Production Patterns

During the second period, production of total cereals averaged 95.02 million tons for all India, and this was achieved with a standard deviation of 5.56 million tons. Table 1 shows the allocation of average production by crop and state during the second period.

The model defined by equations (16) through (20) also produces 95.02 million tons of cereal on average, but the standard deviation is reduced to 4.53 million tons—a reduction during the second period of about 19 percent. The coefficient of variation of total cereal production is also reduced from 5.85 percent to 4.77 percent.

This is not a trivial reduction; the details of how it is achieved are worth exploring. Table 16 shows the production levels in the model solution by crop and state.

The model solution calls for a 3.46 million-ton reduction in aggregate rice production, a decline of 8.1 percent from the second period. Most of the desired reduction is allocated to Gujarat, Bihar, Madhya Pradesh, Maharashtra, Punjab, and Uttar Pradesh, but there are also significant production increases in Andhra Pradesh, Tamil Nadu, and West Bengal.

Wheat is a less risky crop; thus aggregate output is increased by 3.44 million tons or by 14 percent. Production is increased in all the wheat-growing states except Haryana and West Bengal, with particularly large increases in Bihar, Madhya Pradesh, Punjab, Rajasthan, and Uttar Pradesh.

The model solution calls for increases in the average production of barley (up 38 percent), jowar (up 16 percent), and maize (up 1 percent) over the second-period actuals, but reductions in the production of bajra (down 20 percent), ragi (down 46 percent), and small millets (down 24 percent). Maize production is eliminated in Andhra Pradesh and Gujarat, ragi production in

Table 16—Optimal allocation among states of production with variable crop shares, 1967/68-1977/78

State	Rice	Wheat	Bajra	Barley	Jowar	Maize	Ragi	Small Millets	Total Cereals
				(1,000 metric tons)					
Andhra Pradesh	5,452.5	...	...	...	1,395.5	...	322.5	...	7,170.5
Assam	2,065.7	...	...	...	...	...	...	...	2,065.7
Bihar	3,379.7	3,061.1	...	223.9	...	911.3	109.2	...	7,685.2
Gujarat	217.2	1,126.4	1,383.3	...	...	...	48.6	116.2	2,891.7
Haryana	658.6	2,585.5	278.8	314.2	...	516.1	...	...	4,353.2
Kerala	1,294.8	...	...	...	...	...	...	...	1,294.8
Karnataka	2,136.7	...	...	...	2,170.1	502.6	...	174.3	4,983.7
Madhya Pradesh	2,548.6	2,822.3	...	196.2	1,895.7	604.0	...	385.7	8,452.5
Maharashtra	1,004.4	716.6	658.0	...	3,385.6	...	176.9	97.6	6,239.1
Orissa	4,161.1	...	...	...	...	...	...	97.6	4,258.7
Punjab	146.0	5,966.8	...	204.1	...	871.7	...	...	7,188.6
Rajasthan	...	2,197.6	481.0	979.7	...	721.1	...	...	4,379.4
Tamil Nadu	5,302.1	...	...	...	...	...	216.1	...	5,518.2
Uttar Pradesh	2,435.7	8,184.4	728.8	1,662.1	...	1,206.7	249.2	295.7	14,762.6
West Bengal	6,620.2	338.3	...	...	...	...	...	...	6,958.5
Other States	1,675.0	967.7	669.4	165.0	2,167.8	845.0	45.7	276.9	6,812.5
All India	39,098.3	27,966.7	4,399.3	3,745.2	11,014.7	6,178.5	1,168.2	1,444.0	95,014.9
Share of crop in cereal production in all India (percent)	41.2	29.4	4.6	3.9	11.6	6.5	1.2	1.5	100.0

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.

Karnataka and Orissa, and small millet production in Andhra Pradesh and Tamil Nadu.

The changes in the product mix for all India are substantial and may not be acceptable. Consequently, the model is solved again with the addition of equation (21). That is, the average output of each crop is constrained to be the same as during the second period.

Again the average production of total cereals is assured at 94.02 million tons. However, the accompanying standard deviation can now be reduced to only 4.92 million tons, or 12 percent less than the standard deviation observed during the second period. As the previous model solution was able to reduce the standard deviation by 19 percent, about one third of this reduction can be attributed to changes in the crop production mix and about two thirds to changes in the spatial reallocation of crops between states. Table 17 shows the allocation of production by crop and state for the new solution.

Rice production is again increased in Andhra Pradesh and West Bengal but not in Tamil Nadu. Bihar, Gujarat, and Maharashtra are again required to reduce rice output, but Madhya Pradesh and the Punjab are required to increase their rice output above second period amounts.

Wheat production is again increased in Bihar, Gujarat, Maharashtra, and Rajasthan, but production is reduced in Haryana, Madhya Pradesh, Punjab, and West Bengal. The changes in the spatial allocations of other cereals from their second-period pattern are quite modest. However, barley is eliminated in Bihar and maize in Andhra Pradesh and Gujarat.

Efficient Trade-Offs Between Average Output and Reduced Instability

The model has been used so far to explore the possibility for reducing foodgrain instability while constraining the average

Table 17—Optimal allocation among states of production with fixed crop shares, 1967/68-1977/78

State	Rice	Wheat	Bajra	Barley	Jowar	Maize	Ragi	Small Millets	Total Cereals
					(1,000 metric tons)				
Andhra Pradesh	5,463.2	...	...	...	1,266.1	...	322.5	118.7	7,170.5
Assam	2,065.7	...	...	...	...	...	...	...	2,065.7
Bihar	3,603.6	3,061.1	...	...	...	911.3	109.2	...	7,685.2
Gujarat	217.2	1,126.4	1,383.3	...	...	...	48.6	116.2	2,891.7
Haryana	658.6	2,585.5	278.8	314.2	...	516.1	...	...	4,353.2
Kerala	1,294.8	...	...	...	...	...	...	...	1,294.8
Karnataka	2,136.7	...	...	...	1,559.0	502.6	611.1	174.3	4,983.7
Madhya Pradesh	3,515.2	1,855.7	...	196.2	1,895.7	604.0	...	385.7	8,452.5
Maharashtra	1,004.4	716.6	858.0	...	3,385.6	...	176.9	97.6	6,239.1
Orissa	3,939.5	...	...	...	...	...	221.6	97.6	4,258.7
Punjab	1,581.0	4,531.8	...	204.1	...	871.7	...	...	7,188.6
Rajasthan	...	2,097.6	641.2	979.7	...	660.9	...	...	4,379.4
Tamil Nadu	4,780.3	...	...	...	...	...	390.0	347.9	5,518.2
Uttar Pradesh	4,007.2	7,249.3	728.8	1,025.7	...	1,206.7	249.2	295.7	14,762.6
West Bengal	6,620.2	338.3	...	...	...	...	...	...	6,958.5
Other states	1,675.0	967.7	1,630.3	...	1,371.9	845.0	45.7	276.9	6,812.5
All India	42,562.6	24,530.0	5,520.4	2,719.9	9,478.3	6,118.3	2,174.8	1,910.6	95,014.9

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.

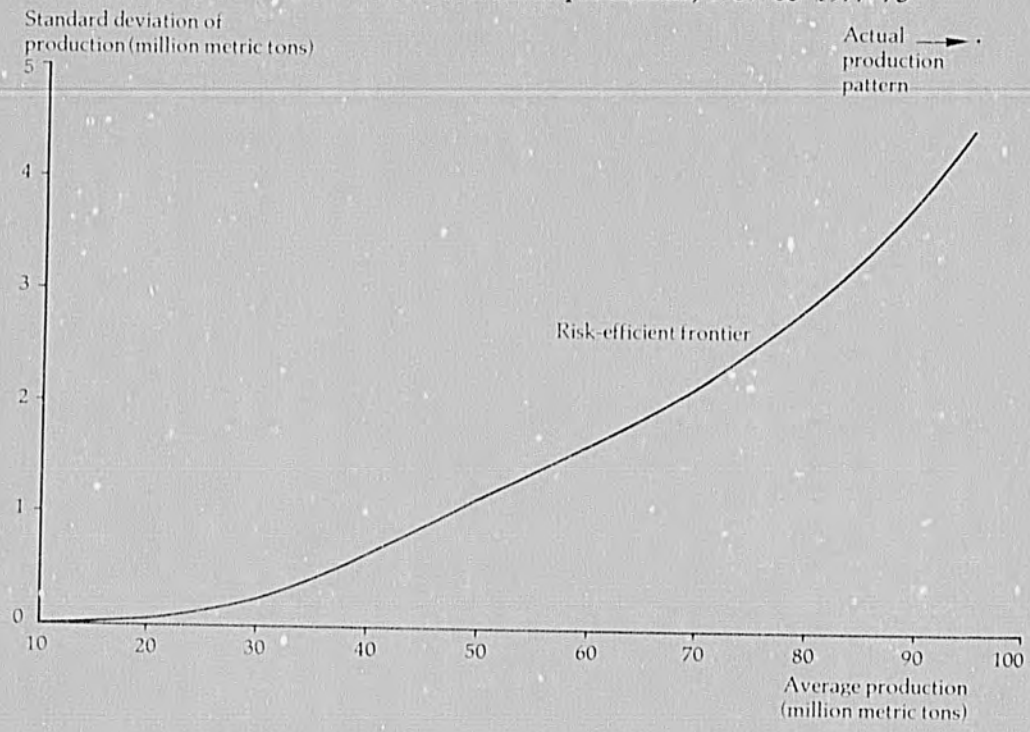
output of total cereals to 95.02 million tons. It is now appropriate to ask whether even larger reductions in foodgrain instability might be achieved if some sacrifice in average output is permitted. To this end, model experiments are repeated for a range of values of average total cereal production in equation (17). As total average production can only be varied downward given the other constraints in the model, the aggregate product mix is allowed to depart from second-period values. Equation (21) is not used in these model experiments.

Figure 3 portrays the derived trade-off between average total cereal production and the standard deviation of production. The graphed function defines the risk-efficient frontier. That is, each point on the graph has the minimum possible standard deviation for that level of average output. All other feasible production patterns must lie above and to the left of the frontier. This is illustrated by the actual production pattern for the second period, which is plotted in the top right-hand corner of the figure.

Of greatest interest are points on the risk frontier that involve little sacrifice in mean production from the second-period value of 95.02 million tons. For the first reduction of 5 million tons in average production, each million-ton loss is matched by a reduction in the standard deviation of approximately 150,000 tons. Put another way, a 1 percent sacrifice in mean output leads to a decline of about 3 percent in the standard deviation and of about 2 percent in the coefficient of variation of production.

When these results are combined with the reductions in the standard deviation that were possible with an average but optimally allocated production of 95.02 million tons, it is clear that the average production patterns observed in the second period were not risk-efficient. By changing both the crop mix and the spatial allocation of crops in an optimal way, the standard deviation of production could have been reduced by 19 percent (or 1.03 million tons) without any sacrifice in average output. It can now be seen that if the production pattern had been further modified optimally with a 2.5 percent reduction in the total average production (from 95.02 million to 92.64 million tons), then the standard devi-

Figure 3—Risk-efficient frontier for total cereal production, 1967/68–1977/78



ation could have been further reduced by 0.36 million tons. This would have provided a total reduction in the standard deviation of 1.39 million tons (or 25 percent) and a 23 percent reduction in the coefficient of variation of production.

As stated before, the results of this model must be viewed with caution. The purpose is simply to obtain some indication of the size of the gain that might be obtained by changing production patterns in a more risk-efficient way. In terms of the percentage reductions in the standard deviation and the coefficient of variation of production, the results are impressive. However, even with a 2.5 percent reduction in total average production and an optimal change in the aggregate crop mix, the coefficient of variation of production would still be 4.17 percent, compared to its actual value of 5.85 percent during the second period. The size of this gain hardly justifies a major realignment of India's agricultural policies, particularly if the desired crop reallocations run contrary to other policy objectives or are inconsistent with free market allocations.

8

CONCLUSIONS

India is occasionally subject to severe droughts, which drastically curtail national foodgrain production. Two such droughts occurred in 1965/66 and 1966/67, when total cereal production fell 20 percent below trend in both years. Catastrophes of this kind are so rare and severe (see Figure 1) that they can be considered a separate phenomenon from the more usual year-to-year fluctuations in foodgrain production. Such a distinction is particularly useful in formulating policy. Whereas carrying emergency food stocks might be an appropriate way to safeguard consumption against the ravages of drought, entirely different policies may be relevant for stabilizing supplies in the face of the more usual year-to-year fluctuations in production.

The coefficient of variation of total cereal production was 5.85 during the second period (1967/68-1977/78) when measured around the trend. This was nearly 50 percent larger than the coefficient of variation (4.03 percent) during the first period (1954/55-1964/65). It is still quite modest by international standards, but because of the high proportion of production retained by farm families, these fluctuations can cause substantial price instability.

This analysis confirms that changes in the variability of yields of individual crops within states have been an important contributor to the increase in the coefficient of variation of total cereal production. However, increases in crop yield variances within states have been far less important for the instability of all-India production than increases in intercrop and interstate yield covariances and increases in area-yield covariances both within and between crops and states. Increases in yield variances only account for a small part of these increases in the yield and area-yield covariances. More important sources of increase have been a definite change toward more positive correlations between the yield fluctuations of different crops in the same and in different states and an increase in the variability of crop areas sown, which now are also more positively correlated with yields. The sources of these fundamental shifts in patterns of association are difficult to identify, but they probably have less to do with the improved seed/fertilizer-based technologies than with changes in weather patterns and the more widespread use of irrigation and fertilizers at a time when the supplies of these inputs are not reliable.

Several researchers have argued for the development of less risky technologies as a direct means of reducing production instability.[15] This approach is likely to be a difficult and long-term strategy, requiring changes in agricultural research priorities. But even if the approach were successful, the results from this analysis suggest that only modest reductions would be achieved in the variability of India's total cereal production. This is because reducing yield variability at the micro level fails to confront the more basic problem of reducing the large increases in yield and area-yield correlations that have occurred between crops in the same and in different states. Policies to stabilize the supplies of fertilizers and electric power for irrigation pumps might be more effective in this respect.

Another approach to achieving increased stability is through stabilization of the year-to-year adjustments in crop areas sown. The results show that this approach would be even less effective than yield stabilization. Also, because most of the contribution of increased area variances arises through increases in area-yield covariances between crops and states, it is difficult to identify policies that might effectively stabilize production by acting on area variability.

As most of the increased instability in India's total cereal production must be attributed to increases in various intercrop and interstate production covariances,

[15] Mehra, *Instability in Indian Agriculture*, and Barker, Gabler, and Winkelmann, "Long-term Consequences of Change."

another approach to reducing instability is to take advantage of these covariances and distribute production among crops and states in a more risk-efficient way. The results in this study show that there are potential gains to be had from this approach, but they may require policy changes that could be inconsistent with other public objectives. For example, the coefficient of variation of total cereal production could be reduced by encouraging greater production of wheat and jowar at the expense of rice, providing these changes were made in an optimal way in terms of their size and state reallocations (Table 16). It might be relatively easy to change consumer prices to bring about the desired changes in aggregate consumption, but obtaining the correct regional allocations of production is unlikely to be feasible without introducing major distortions into producers' markets. Although it has been useful to identify the problem and to measure the potential gains in terms of reduced instability, no practical policy implications seem to follow from this approach.

Policies that can effectively reduce the instability of aggregate foodgrain production remain elusive. There is still a need for further research directed at providing a better understanding of the sources of the increased yield and area-yield correlations between crops in the same and in different states. Such research might delineate more precisely how policies to stabilize fertilizer and electricity supplies could reduce production instability, as well as possibly revealing other causal factors that can be controlled through policy interventions. But a large part of the increase in production instability probably has to be accepted as a necessary consequence of successful agricultural growth.

Because continued growth in foodgrain production is of paramount importance to India, the most promising approach is to focus on maximizing growth and to offset the resulting effects of increased production instability through policies designed to stabilize consumption rather than production. As other IFPRI work has shown,[16] this can be effectively achieved through appropriate storage and international trade policies.

[16] Alberto Valdés, ed., *Food Security in Developing Countries* (Boulder, Colo.: Westview Press, 1981).

APPENDIX 1

DECOMPOSITION OF CHANGES IN COVARIANCE TERMS

Bohrnstedt and Goldberger provide an exact expression for the covariance of two products of random variables.[17] Maintaining the same notation as in Chapter 3, the use of their expansion for intercrop or interstate production covariances leads to:

$$\begin{aligned}
\mathrm{Cov}(A_i y_i, A_j y_j) = {} & \bar{A}_i \bar{A}_j \mathrm{Cov}(y_i, y_j) + \bar{A}_i \bar{y}_j \mathrm{Cov}(y_i, A_j) \\
& + \bar{y}_i \bar{A}_j \mathrm{Cov}(A_i, y_j) + \bar{y}_i \bar{y}_j \mathrm{Cov}(A_i, A_j) \\
& + \bar{A}_i E[(y_i - \bar{y}_i)(A_j - \bar{A}_j)(y_j - \bar{y}_j)] - \mathrm{Cov}(A_i, y_i)\,\mathrm{Cov}(A_j, y_j) \\
& + \bar{y}_i E[(A_i - \bar{A}_i)(A_j - \bar{A}_j)(y_j - \bar{y}_j)] \\
& + \bar{A}_j E[(A_i - \bar{A}_i)(y_i - \bar{y}_i)(y_j - \bar{y}_j)] \\
& + \bar{y}_j E[(A_i - \bar{A}_i)(y_i - \bar{y}_i)(A_j - \bar{A}_j)]. \qquad (22)
\end{aligned}$$

Goodman's expression for the variance of the product of two random variables is a special case of equation (22), which holds when $i = j$.[18]

The last four terms of the expansion involve higher order cross moments than the covariance terms, and for the most part these turn out to be small. In this paper these four terms are added together and treated as a residual, R.

Using I and II subscripts to denote the first and second time periods, and expressing all second-period variables as their first-period values plus the change in the variable between the two periods, that is, $\bar{A}_{II} = \bar{A}_I + \Delta\bar{A}$, where $\Delta\bar{A} = \bar{A}_{II} - \bar{A}_I$, the covariances for the first period are:

$$\begin{aligned}
\mathrm{Cov}(A_{Ii} y_{Ii}, A_{Ij} y_{Ij}) = {} & \bar{A}_{Ii} \bar{A}_{Ij} \mathrm{Cov}(y_{Ii}, y_{Ij}) \\
& + \bar{A}_{Ii} \bar{y}_{Ij} \mathrm{Cov}(y_{Ii}, A_{Ij}) \\
& + \bar{y}_{Ii} \bar{A}_{Ij} \mathrm{Cov}(A_{Ii}, y_{Ij}) \\
& + \bar{y}_{Ii} \bar{y}_{Ij} \mathrm{Cov}(A_{Ii}, A_{Ij}) \\
& - \mathrm{Cov}(A_{Ii}, y_{Ii})\,\mathrm{Cov}(A_{Ij}, y_{Ij}) \\
& + R_I, \qquad (23)
\end{aligned}$$

and for the second period,

$$\begin{aligned}
\mathrm{Cov}(A_{IIi} y_{IIi}, A_{IIj} y_{IIj}) = {} & (\bar{A}_{Ii} + \Delta\bar{A}_i)(\bar{A}_{Ij} + \Delta\bar{A}_j)[\mathrm{Cov}(y_{Ii}, y_{Ij}) + \Delta\mathrm{Cov}(y_i, y_j)] \\
& + (\bar{A}_{Ii} + \Delta\bar{A}_i)(\bar{y}_{Ij} + \Delta\bar{y}_j)[\mathrm{Cov}(y_{Ii}, A_{Ij}) + \Delta\mathrm{Cov}(y_i, A_j)] \\
& + (\bar{y}_{Ii} + \Delta\bar{y}_i)(\bar{A}_{Ij} + \Delta\bar{A}_j)[\mathrm{Cov}(A_{Ii}, y_{Ij}) + \Delta\mathrm{Cov}(A_i, y_j)] \\
& + (\bar{y}_{Ii} + \Delta\bar{y}_i)(\bar{y}_{Ij} + \Delta\bar{y}_j)[\mathrm{Cov}(A_{Ii}, A_{Ij}) + \Delta\mathrm{Cov}(A_i, A_j)] \\
& - [\mathrm{Cov}(A_{Ii}, y_{Ii}) + \Delta\mathrm{Cov}(A_i, y_i)][\mathrm{Cov}(A_{Ij}, y_{Ij}) \\
& + \Delta\mathrm{Cov}(A_j, y_j)] + (R_I + \Delta R). \qquad (24)
\end{aligned}$$

[17] G. W. Bohrnstedt and A. S. Goldberger, "On the Exact Covariance of Products of Random Variables," *Journal of the American Statistical Association* 64 (1969): 1439-1442.

[18] L. A. Goodman, "On the Exact Variance of Products," *Journal of the American Statistical Association* 55 (1960): 708-713.

The change in the covariance between the two periods is then calculated as equation (24) − equation (23) = $\Delta Cov(A_i y_i, A_j y_j)$. The terms in this expression have been collected in Table 18 so that they can be attributed to different sources.

Table 18—Components of change in production covariances

Source of Change		
Description	Symbols	Components of Change
Change in mean yield	$\Delta\bar{y}$	$\bar{A}_{ii}\,\Delta\bar{y}_i\,Cov(y_{ii}, A_{ii}) + \bar{A}_{ii}\,\Delta\bar{y}_i\,Cov(A_{ii}, y_{ii})$ $+ [\bar{y}_{ii}\,\Delta\bar{y}_i + \bar{y}_{ii}\,\Delta\bar{y}_i + \Delta\bar{y}_i\,\Delta\bar{y}_i]\,Cov(A_{ii}, A_{ii})$
Change in mean area	$\Delta\bar{A}$	$\bar{y}_{ii}\,\Delta\bar{A}_i\,Cov(A_{ii}, y_{ii}) + \bar{y}_{ii}\,\Delta\bar{A}_i\,Cov(y_{ii}, A_{ii})$ $+ [\bar{A}_{ii}\,\Delta\bar{A}_i + \bar{A}_{ii}\,\Delta\bar{A}_i + \Delta\bar{A}_i\,\Delta\bar{A}_i]\,Cov(y_{ii}, y_{ii})$
Change in yield variance	$\Delta V(y)$	$\bar{A}_{ii}\,\bar{A}_{ii}\,\Delta Cov(y_i, y_i)$
Change in area variance	$\Delta V(y)$	$\bar{y}_{ii}\,\bar{y}_{ii}\,\Delta Cov(A_i, A_i)$
Interaction between changes in mean yield and mean area	$\Delta\bar{y}, \Delta\bar{A}$	$\Delta\bar{A}_i\,\Delta\bar{y}_i\,Cov(y_{ii}, A_{ii}) + \Delta\bar{y}_i\,\Delta\bar{A}_i\,Cov(A_{ii}, y_{ii})$
Change in area-yield covariance	$\Delta Cov(y, A)$	$\bar{A}_{ii}\,\bar{y}_{ii}\,\Delta Cov(y_i, A_i) + \bar{y}_{ii}\,\bar{A}_{ii}\,\Delta Cov(A_i, y_i) - [Cov(A_{ii}, y_{ii})$ $+ \Delta Cov(A_i, y_i)]\,\Delta Cov(A_i, y_i) - Cov(A_{ii}, y_{ii})\,\Delta Cov(A_i, y_i)$
Interaction between changes in mean area and yield variance	$\Delta\bar{A}, \Delta V(y)$	$[\bar{A}_{ii}\,\Delta\bar{A}_i + \bar{A}_{ii}\,\Delta\bar{A}_i + \Delta\bar{A}_i\,\Delta\bar{A}_i]\,\Delta Cov(y_i, y_i)$
Interaction between changes in mean yield and area variance	$\Delta\bar{y}, \Delta V(A)$	$[\bar{y}_{ii}\,\Delta\bar{y}_i + \bar{y}_{ii}\,\Delta\bar{y}_i + \Delta\bar{y}_i\,\Delta\bar{y}_i]\,\Delta Cov(A_i, A_i)$
Interactions between changes in mean area and yield and changes in area-yield covariance	$\Delta\bar{y}, \Delta\bar{A}, \Delta Cov(y, A)$	$[\bar{y}_{ii}\,\Delta\bar{A}_i + \bar{A}_{ii}\,\Delta\bar{y}_i + \Delta\bar{A}_i\,\Delta\bar{y}_i]\,\Delta Cov(y_i, A_i)$ $+ [\bar{y}_{ii}\,\Delta\bar{A}_i + \bar{A}_{ii}\,\Delta\bar{y}_i + \Delta\bar{y}_i\,\Delta\bar{A}_i]\,\Delta Cov(A_i, y_i)$
Change in residual	ΔR	$\Delta R = \Delta Cov(A_i y_i, A_j y_j)$ − sum of the other components

Note: A denotes area sown, y, yield, and V, variance.

APPENDIX 2

SUPPLEMENTARY TABLES

Table 19—Analysis of the components of change in the variance of rice production, by state, 1954/55-1964/65 — 1967/68-1977/78

Source of Change in Variance of Production	Symbols	Andhra Pradesh	Assam	Bihar	Gujarat	Haryana	Kerala	Karnataka	Madhya Pradesh	Maharashtra	Orissa	Punjab	Tamil Nadu	Uttar Pradesh	West Bengal	Other States[a]	Interstate Covariances	All India
										(percent)								
Change in mean yield	$\Delta\bar{y}$	1.46	−0.75	−20.86	3.31	−0.25	1.21	1.06	−0.01	0.30	0.16	0.32	1.06	1.04	11.83	...	−2.05	−0.69
Change in mean area	$\Delta\bar{A}$	2.19	57.37	−26.55	−7.80	68.79	3.31	0.86	71.29	0.21	13.55	39.55	0.25	38.37	46.81	...	−10.82	1.68
Change in yield variance	$\Delta V(y)$	27.17	−36.65	104.96	115.26	−5.07	19.16	51.39	25.28	56.75	56.83	−3.03	33.85	−8.69	61.98	...	46.36	40.05
Change in area variance	$\Delta V(A)$	34.06	85.28	−35.04	0.94	4.46	19.57	12.43	2.79	−15.47	−1.09	9.00	9.74	10.40	3.36	...	5.35	5.20
Interaction between changes in mean yields and mean areas	$\Delta\bar{y}, \Delta\bar{A}$	−0.11	−0.28	−0.45	−0.21	−2.49	−0.07	−0.04	0.00	−0.18	−0.05	−0.24	0.00	−0.01	1.20	...	0.32	1.23
Change in area-yield covariance	$\Delta Cov(A, y)$	8.77	5.60	88.40	34.05	18.79	34.65	19.77	−1.30	58.46	18.28	9.32	34.41	45.77	−29.97	...	27.86	31.89
Interaction between changes in mean area and yield variance	$\Delta\bar{A}, \Delta V(y)$	6.15	−18.89	6.41	−30.42	−20.78	5.01	4.00	5.79	3.51	12.76	−14.64	5.70	−2.18	18.81	...	36.18	18.08
Interaction between changes in mean yield and area variance	$\Delta\bar{y}, \Delta V(A)$	14.33	5.03	−14.47	0.60	4.09	6.99	10.37	−0.02	−5.37	−0.07	18.00	6.77	3.71	1.24	...	0.38	2.19
Interactions between changes in mean area and yield and changes in area-yield covariance	$\Delta\bar{y}, \Delta\bar{A}$ $\Delta Cov(A, y)$	2.80	1.49	19.86	3.42	40.19	10.68	8.05	−0.13	11.41	2.57	29.99	14.06	13.86	−10.06	...	11.09	13.17
Change in residual	ΔR	3.18	1.80	−22.24	−19.16	−7.74	−0.51	−7.90	−3.68	−9.61	−2.94	11.71	−5.85	−2.28	−5.19	...	−14.67	−12.79
Total contribution of state to change in variance of production in all India		3.55	0.09	−0.91	0.33	0.11	0.09	0.88	1.04	1.89	2.51	0.49	8.12	0.68	1.32	−0.82	80.65	100.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.
Note: The figures for the components of change in the variance of production add to 100 percent in each column.

[a] Because the changes in the variance of production of other states were small, an analysis of their components was not included.

Table 20—Analysis of the components of change in the variance of wheat production, by state, 1954/55-1964/65 — 1967/68-1977/78

Source of Change in Variance of Production	Symbols	Bihar	Gujarat	Haryana	Madhya Pradesh	Maha-rashtra	Punjab	Rajasthan	Uttar Pradesh	West Bengal	Other States[a]	Interstate Covariances	All India
							(percent)						
Change in mean yield	$\Delta\bar{y}$	1.04	50.19	1.33	20.17	0.63	−0.18	62.90	4.81	1.02	...	5.31	5.02
Change in mean area	$\Delta\bar{A}$	10.85	1.74	27.44	12.45	−0.23	16.87	39.69	84.50	2.87	...	8.00	15.75
Change in yield variance	$\Delta V(y)$	4.67	8.14	0.34	−17.48	55.95	1.51	30.38	−5.44	0.52	...	1.34	1.12
Change in area variance	$\Delta V(A)$	14.83	7.89	−0.03	22.58	6.90	9.24	−10.66	3.71	3.16	...	6.65	6.86
Interaction between changes in mean yields and mean areas	$\Delta\bar{y}, \Delta\bar{A}$	−1.36	−2.39	−11.31	0.14	0.02	−1.24	3.62	0.94	−1.47	...	−1.55	−1.65
Change in area-yield covariance	$\Delta Cov(A,y)$	1.10	−1.91	22.04	22.55	24.65	13.55	−26.62	7.03	1.56	...	12.77	11.98
Interaction between changes in mean area and yield variance	$\Delta\bar{A}, \Delta V(y)$	22.06	3.05	1.73	−2.33	−2.44	2.59	20.16	−7.02	25.46	...	13.40	10.95
Interaction between changes in mean yield and area variance	$\Delta\bar{y}, \Delta V(A)$	43.54	30.78	−0.04	10.11	11.01	28.16	−8.35	4.08	24.45	...	12.48	14.29
Interactions between changes in mean area and yield and changes in area-yield covariance	$\Delta\bar{y}, \Delta\bar{A}$ $\Delta Cov(A,y)$	4.12	−3.00	59.24	6.35	14.36	31.49	−19.26	8.40	38.77	...	36.34	31.63
Change in residual	ΔR	−0.85	5.50	−0.73	25.48	−10.86	−1.99	8.14	−1.01	3.67	...	5.25	3.88
Total contribution of state to change in variance of production in all India		7.26	0.56	3.22	1.28	0.87	4.24	0.43	8.23	1.35	0.21	72.36	100.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.
Note: The figures for the components of change in the variance of production add to 100 percent in each column.

[a] Because the changes in the variance of production of other states were small, an analysis of their components was not included.

Table 21—Analysis of the components of change in the variance of bajra production, by state, 1954/55-1964/65 — 1967/68-1977/78

Source of Change in Variance of Production	Symbols	Gujarat	Haryana	Maharashtra	Rajasthan	Uttar Pradesh	Other States[a]	Interstate Covariances	All India
					(percent)				
Change in mean yield	$\Delta\bar{y}$	13.38	6.47	0.16	0.12	13.71	...	0.15	0.81
Change in mean area	$\Delta\bar{A}$	−5.18	4.09	−0.34	1.45	−20.87	...	−0.65	−0.15
Change in yield variance	$\Delta V(y)$	75.76	71.99	54.74	56.23	71.88	...	59.19	57.98
Change in area variance	$\Delta V(A)$	3.91	−0.61	25.19	3.05	5.58	...	−2.74	3.09
Interaction between changes in mean yields and mean areas	$\Delta\bar{y}, \Delta\bar{A}$	−0.67	0.64	0.01	−0.02	−0.36	...	0.16	−0.15
Change in area-yield covariance	$\Delta Cov(A,y)$	11.76	−1.83	13.09	9.06	26.49	...	24.93	18.52
Interaction between changes in mean area and yield variance	$\Delta\bar{A}, \Delta V(y)$	−10.28	24.62	−9.96	17.08	−5.28	...	8.28	8.99
Interaction between changes in mean yield and area variance	$\Delta\bar{y}, \Delta V(A)$	9.70	−1.52	21.89	1.70	2.80	...	−0.31	2.27
Interactions between changes in mean area and yield and changes in area-yield covariance	$\Delta\bar{y}, \Delta\bar{A}$ $\Delta Cov(A,y)$	8.77	−2.15	3.13	3.90	4.77	...	11.49	8.43
Change in residual	ΔR	−7.15	−1.69	−7.91	7.43	1.28	...	−0.37	0.21
Total contribution of state to change in variance of production in all India		3.67	1.33	3.49	19.31	0.18	2.84	69.18	100.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.
Note: The figures for the components of change in the variance of production add to 100 percent in each column.

[a] Because the changes in the variance of production of other states were small, an analysis of their components was not included.

Table 22—Analysis of the components of change in the variance of barley production, by state, 1954/55-1964/65 — 1967/68-1977/78

Source of Change in Variance of Production	Symbols	Bihar	Haryana	Madhya Pradesh	Punjab	Rajasthan	Uttar Pradesh	Other States[a]	Interstate Covariances	All India
						(percent)				
Change in mean yield	$\Delta\bar{y}$	−14.48	6.19	−11.06	0.95	2.60	−18.56	...	6.12	15.08
Change in mean area	$\Delta\bar{A}$	62.59	10.40	−4.35	2.66	2.38	80.49	...	−18.14	−46.59
Change in yield variance	$\Delta V(y)$	55.32	14.91	43.89	−2.48	18.89	39.89	...	−2.66	−7.88
Change in area variance	$\Delta V(A)$	25.29	21.05	27.88	58.81	83.57	8.54	...	50.96	76.50
Interaction between changes in mean yields and mean areas	$\Delta\bar{y}, \Delta\bar{A}$	0.78	0.43	−0.08	0.08	0.10	2.10	...	0.02	−0.73
Change in area-yield covariance	$\Delta Cov(A,y)$	−6.57	−8.15	51.35	−3.54	−21.70	3.55	...	4.76	−8.27
Interaction between changes in mean area and yield variance	$\Delta\bar{A}, \Delta V(y)$	−36.15	11.50	1.63	−1.15	3.87	−19.46	...	−2.39	8.55
Interaction between changes in mean yield and area variance	$\Delta\bar{y}, \Delta V(A)$	9.97	54.37	3.77	41.78	15.21	4.95	...	46.77	52.22
Interactions between changes in mean area and yield and changes in area-yield covariance	$\Delta\bar{y}, \Delta\bar{A}$ $\Delta Cov(A,y)$	2.01	−12.21	4.40	−2.06	−4.19	−0.36	...	5.71	2.22
Change in residual	ΔR	1.24	1.50	−17.45	4.94	−0.72	−1.13	...	8.88	8.91
Total contribution of state to change in variance of production in all India		−2.08	9.05	−1.87	5.04	37.68	−38.65	1.37	89.47	100.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.
Note: The figures for the components of change in the variance of production add to 100 percent in each column.

[a] Because the changes in the variance of production of other states were small, an analysis of their components was not included.

Table 23—Analysis of the components of change in the variance of jowar production, by state, 1954/55-1964/65 — 1967/68-1977/78

Source of Change in Variance of Production	Symbols	Andhra Pradesh	Karnataka	Madhya Pradesh	Maharashtra	Other States	Interstate Covariances	All India
					(percent)			
Change in mean yield	$\Delta\bar{Y}$	−1.17	−2.75	9.57	−0.07	...	182.30	2.71
Change in mean area	$\Delta\bar{A}$	−3.22	−18.61	61.53	0.29	...	−270.75	−3.81
Change in yield variance	$\Delta V(Y)$	106.15	63.13	−42.74	73.35	...	−1,408.80	56.79
Change in area variance	$\Delta V(A)$	41.71	19.87	1.37	4.26	...	−85.53	5.28
Interaction between changes in mean yields and mean areas	$\Delta\bar{Y}, \Delta\bar{A}$	0.01	1.44	0.03	0.00	...	−21.72	−0.19
Change in area-yield covariance	$\Delta Cov(A, Y)$	−41.44	28.29	71.21	30.93	...	716.92	36.12
Interaction between changes in mean area and yield variance	$\Delta\bar{A}, \Delta V(Y)$	−4.56	−22.38	−9.43	1.34	...	600.67	6.13
Interaction between changes in mean yield and area variance	$\Delta\bar{Y}, \Delta V(A)$	−2.66	37.49	0.28	−0.19	...	163.20	3.87
Interactions between changes in mean area and yield and changes in area-yield covariance	$\Delta\bar{Y}, \Delta\bar{A}$ $\Delta Cov(A, Y)$	2.21	10.33	15.26	−0.42	...	700.39	8.02
Change in residual	ΔR	2.97	−16.81	−7.06	−9.49	...	−476.67	−14.91
Total contribution of state to change in variance of production in all India		1.67	5.66	1.55	90.88	−0.84	1.09	100.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.
Note: The figures for the components of change in the variance of production add to 100 percent in each column.

[a] Because the changes in the variance of production of other states were small, an analysis of their components was not included.

Table 24—Analysis of the components of change in the variance of maize production, by state, 1954/55-1964/65 — 1967/68-1977/78

Source of Change in Variance of Production	Symbols	Andhra Pradesh	Bihar	Gujarat	Haryana	Karnataka	Madhya Pradesh	Punjab	Rajas-than	Uttar Pradesh	Other States[a]	Interstate Covariances	All India
							(percent)						
Change in mean yield	$\Delta\bar{Y}$	2.46	−1.05	0.05	−0.20	0.06	0.14	324.44	−1.96	0.21	...	0.37	0.55
Change in mean area	$\Delta\bar{A}$	24.49	9.35	18.28	14.58	4.30	32.85	−22,847.51	16.30	55.88	...	−8.69	3.92
Change in yield variance	$\Delta V(Y)$	33.68	59.62	51.65	29.09	0.83	36.37	9,402.86	92.68	16.84	...	53.59	48.17
Change in area variance	$\Delta V(A)$	1.24	−0.56	1.08	8.17	2.57	2.16	−4,372.56	3.02	2.11	...	−0.46	−7.08
Interaction between changes in mean yields and mean areas	$\Delta\bar{Y}, \Delta\bar{A}$	0.11	−0.13	0.01	−0.07	−1.08	0.07	311.86	−0.36	0.00	...	0.29	−0.19
Change in area-yield covariance	$\Delta Cov(A,Y)$	0.00	17.12	−5.08	20.28	0.10	−4.31	1,250.67	−55.91	4.05	...	14.76	19.13
Interaction between changes in mean area and yield variance	$\Delta\bar{A}, \Delta V(Y)$	31.93	29.53	27.52	9.69	62.88	32.98	17,682.37	51.60	13.74	...	35.29	28.47
Interaction between changes in mean yield and area variance	$\Delta\bar{Y}, \Delta V(A)$	2.40	0.06	0.01	9.43	32.78	−0.41	−2,457.51	−0.60	0.23	...	1.54	0.60
Interactions between changes in mean area and yield and changes in area-yield covariance	$\Delta\bar{Y}, \Delta\bar{A}$ $\Delta Cov(A,Y)$	0.00	2.62	−1.26	14.11	3.22	−1.05	1,395.10	−6.47	1.71	...	3.81	7.56
Change in residual	ΔR	3.68	−16.57	7.73	−5.05	−5.66	1.21	−589.73	1.70	5.24	...	−0.49	−1.14
Total contribution of state to change in variance of production in all India		0.62	13.25	2.44	0.44	1.27	2.33	−0.01	4.85	7.29	0.29	67.24	100.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.
Note: The figures for the components of change in the variance of production add to 100 percent in each column.

[a] Because the changes in the variance of production of other states were small, an analysis of their components was not included.

Table 25—Analysis of the components of change in the variance of ragi production, by state, 1954/55-1964/65 — 1967/68-1977/78

Source of Change in Variance of Production	Symbols	Andhra Pradesh	Bihar	Gujarat	Karnataka	Maha-rashtra	Orissa	Tamil Nadu	Uttar Pradesh	Other States[a]	Interstate Covariances	All India
							(percent)					
Change in mean yield	$\Delta\bar{y}$	-7.00	0.58	-14.97	0.36	0.06	5.41	2.03	1.24	...	1.54	1.24
Change in mean area	$\Delta\bar{A}$	-78.89	-0.54	-22.91	-0.76	-0.76	46.64	-3.10	1.25	...	6.37	2.34
Change in yield variance	$\Delta V(y)$	-113.29	54.97	218.53	63.32	120.48	-4.45	47.04	11.92	...	57.67	58.66
Change in area variance	$\Delta V(A)$	222.08	1.33	-48.68	23.53	4.66	-1.61	16.26	23.74	...	17.28	20.44
Interaction between changes in mean yields and mean areas	$\Delta\bar{y}, \Delta\bar{A}$	2.91	0.00	-1.20	0.00	0.00	-13.79	-0.06	-0.20	...	0.48	0.13
Change in area-yield covariance	$\Delta Cov(A,y)$	-44.90	40.50	81.07	16.35	10.51	27.43	37.10	21.52	...	32.07	24.32
Interaction between changes in mean area and yield variance	$\Delta\bar{A}, \Delta V(y)$	23.15	-3.49	-85.72	-2.24	-22.57	-27.86	-9.34	4.61	...	-16.57	-9.14
Interaction between changes in mean yield and area variance	$\Delta\bar{y}, \Delta V(A)$	79.59	0.06	15.31	4.65	0.33	-0.85	5.32	14.54	...	5.79	5.34
Interactions between changes in mean area and yield and changes in area-yield co-variance	$\Delta\bar{y}, \Delta\bar{A}$ $\Delta Cov(A,y)$	-1.78	-0.40	-28.75	1.23	-0.72	62.77	1.18	10.71	...	-1.27	0.67
Change in residual	ΔR	18.13	7.00	-12.67	-6.44	-12.01	6.31	3.58	10.68	...	-3.37	-3.99
Total contribution of state to change in variance of production in all India		0.39	1.28	0.09	45.54	1.66	0.64	3.81	2.76	-0.21	44.03	100.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.
Note: The figures for the components of change in the variance of production add to 100 percent in each column.

[a] Because the changes in the variance of production of other states were small, an analysis of their components was not included.

Table 26—Analysis of the components of change in the variance of small millets production, by state, 1954/55-1964/65 — 1967/68-1977/78

Source of Change in Variance of Production	Symbols	Andhra Pradesh	Gujarat	Karnataka	Madhya Pradesh	Maha-rashtra	Orissa	Tamil Nadu	Uttar Pradesh	Other States[a]	Interstate Covariances	All India
							(percent)					
Change in mean yield	$\Delta\bar{Y}$	−4.98	9.27	1.21	−1.05	−8.54	2.32	−6.87	74.05	...	2.59	2.16
Change in mean area	$\Delta\bar{A}$	−3.29	74.12	−2.42	−19.80	−9.07	11.53	−2.23	−216.39	...	35.73	17.78
Change in yield variance	$\Delta V(Y)$	246.52	−83.24	135.51	18.63	173.09	3.53	95.64	−121.83	...	−31.03	−179.94
Change in area variance	$\Delta V(A)$	7.75	27.63	2.28	78.97	−0.95	12.94	17.21	56.92	...	−73.27	45.26
Interaction between changes in mean yields and mean areas	$\Delta\bar{Y}, \Delta\bar{A}$	−0.14	−1.42	0.07	−0.01	−0.29	−0.39	0.13	−5.30	...	0.28	0.41
Change in area-yield covariance	$\Delta Cov(A,Y)$	−48.66	41.66	13.79	2.98	−58.42	1.87	56.34	264.39	...	111.03	75.57
Interaction between changes in mean area and yield variance	$\Delta\bar{A}, \Delta V(Y)$	−118.81	45.04	−54.09	10.63	7.14	62.01	19.54	40.08	...	−10.16	73.43
Interaction between changes in mean yield and area variance	$\Delta\bar{Y}, \Delta V(A)$	−1.49	−3.52	0.40	1.01	0.34	2.55	−2.94	40.89	...	10.38	6.83
Interactions between changes in mean area and yield and changes in area-yield covariance	$\Delta\bar{Y}, \Delta\bar{A}$ $\Delta Cov(A,Y)$	17.15	−15.38	−2.21	0.78	10.67	6.95	−10.62	19.63	...	3.98	−1.49
Change in residual	ΔR	5.94	5.84	5.45	7.86	−13.98	−3.31	−27.13	−52.42	...	50.46	59.99
Total contribution of state to change in variance of production in all India		−22.21	7.37	−35.53	124.45	3.55	−0.49	−41.14	−4.51	1.77	66.72	100.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.
Note: The figures for the components of change in the variance of production add to 100 percent in each column.

[a] Because the changes in the variance of production of other states were small, an analysis of their components was not included.

Table 27—Analysis of the components of change in average rice production, by state, 1954/55-1964/65 — 1967/68-1977/78

Source of Change in Mean Production	Symbols	Andhra Pradesh	Assam	Bihar	Gujarat	Hary-ana	Kerala	Kar-nataka	Madhya Pradesh	Maha-rashtra	Orissa	Punjab	Tamil Nadu	Uttar Pradesh	West Bengal	Other States	All India
									(percent)								
Change in mean yield	$\Delta\bar{y}$	59.84	10.89	84.74	230.08	17.87	53.31	86.67	−3.95	74.35	21.77	22.83	72.77	54.28	50.69	−30.58	47.92
Change in mean area	$\Delta\bar{A}$	33.52	86.57	13.50	−116.39	58.46	39.81	9.35	104.42	14.09	75.08	44.13	19.50	38.91	42.31	138.11	44.65
Interaction between changes in mean yield and mean area	$\Delta\bar{y}, \Delta\bar{A}$	6.43	2.52	2.55	−32.68	22.48	6.56	3.31	−0.43	2.26	2.32	32.29	5.89	6.42	7.18	−28.85	5.20
Change in area-yield covariance	$\Delta Cov(A,y)$	0.21	0.02	−0.79	18.99	1.19	0.32	0.67	−0.05	9.29	0.83	0.74	1.84	0.39	−0.17	21.32	2.23
Total contribution of state to change in mean production in all India		11.89	4.24	9.31	0.47	3.37	2.98	5.66	3.08	2.79	4.88	7.76	13.85	8.55	15.25	6.92	100.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.
Note: The figures for the components of change in average production add to 100 percent in each column.

Table 28—Analysis of the components of change in average wheat production, by state, 1954/55-1964/65 — 1967/68-1977/78

Source of Change in Mean Production	Symbols	Bihar	Gujarat	Haryana	Madhya Pradesh	Maha-rashtra	Punjab	Rajasthan	Uttar Pradesh	West Bengal	Other States	All India
							(percent)					
Change in mean yield	$\Delta\bar{y}$	26.21	76.16	18.02	71.95	101.28	43.56	46.55	37.60	9.58	37.16	38.05
Change in mean area	$\Delta\bar{A}$	37.07	10.82	54.37	22.88	−3.65	27.96	40.22	43.01	29.84	40.45	36.62
Interaction between changes in mean yield and mean area	$\Delta\bar{y}, \Delta\bar{A}$	36.48	13.13	26.71	4.65	−2.23	28.30	13.49	19.31	58.37	18.78	24.80
Change in area-yield covariance	$\Delta Cov(A,y)$	0.25	−0.12	0.90	0.52	4.60	0.19	−0.27	0.08	2.21	3.61	0.53
Total contribution of state to change in mean production in all India		10.42	3.62	13.95	3.76	1.60	25.47	5.27	27.74	4.63	3.48	100.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.
Note: The figures for the components of change in average production add to 100 percent in each column.

Table 29—Analysis of the components of change in average bajra production, by state, 1954/55-1964/65 — 1967/68-1977/78

Source of Change in Mean Production	Symbols	Gujarat	Haryana	Maharashtra	Rajasthan	Uttar Pradesh	Other States	All India
					(percent)			
Change in mean yield	$\Delta\bar{y}$	116.14	74.91	142.51	54.83	124.41	25.31	76.56
Change in mean area	$\Delta\bar{A}$	−9.43	13.67	−37.08	31.29	−20.67	68.60	19.76
Interaction between changes in mean yield and mean area	$\Delta\bar{y}, \Delta\bar{A}$	−8.17	11.87	−13.62	7.78	−4.66	9.93	2.47
Change in area-yield covariance	$\Delta Cov(A,y)$	1.45	−0.44	8.18	6.11	0.91	−3.85	1.21
Total contribution of state to change in mean production in all India		26.95	14.44	6.85	20.62	5.53	25.60	100.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.
Note: The figures for the components of change in average production add to 100 percent in each column.

Table 30—Analysis of the components of change in average barley production, by state, 1954/55-1964/65 — 1967/68-1977/78

Source of Change in Mean Production	Symbols	Bihar	Haryana	Madhya Pradesh	Punjab	Rajasthan	Uttar Pradesh	Other States	All India
					(percent)				
Change in mean yield	$\Delta\bar{y}$	−59.43	60.46	86.94	53.94	46.53	−254.90	128.52	1,203.88
Change in mean area	$\Delta\bar{A}$	135.26	22.41	24.47	36.68	52.11	282.26	0.22	−877.73
Interaction between changes in mean yield and mean area	$\Delta\bar{y}, \Delta\bar{A}$	24.44	20.01	1.60	11.29	4.54	72.49	0.02	−203.23
Change in area-yield covariance	$\Delta Cov(A,y)$	−0.27	−2.88	−13.01	−1.91	−3.18	0.15	−28.76	−22.92
Total contribution of state to change in mean production in all India		−130.72	201.79	24.72	76.14	229.41	−318.76	17.41	100.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.
Note: The figures for the components of change in average production add to 100 percent in each column.

Table 31—Analysis of the components of change in average jowar production, by state, 1954/55-1964/65 — 1967/68-1977/78

Source of Change in Mean Production	Symbols	Andhra Pradesh	Karnataka	Madhya Pradesh	Maharashtra	Other States	All India
				(percent)			
Change in mean yield	$\Delta\bar{y}$	58.35	188.68	45.34	−1,190.73	296.75	153.05
Change in mean area	$\Delta\bar{A}$	39.13	−53.07	48.22	491.71	−164.36	−35.71
Interaction between changes in mean yield and mean area	$\Delta\bar{y}, \Delta\bar{A}$	−1.27	−37.10	4.76	−10.82	−27.00	−23.96
Change in area-yield covariance	$\Delta Cov(A,y)$	3.79	1.49	1.68	809.84	−5.39	6.62
Total contribution of state to change in mean production in all India		−9.55	59.87	35.96	0.76	12.96	100.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.
Note: The figures for the components of change in average production add to 100 percent in each column.

Table 32—Analysis of the components of change in average maize production, by state, 1954/55-1964/65 — 1967/68-1977/78

Source of Change in Mean Production	Symbols	Andhra Pradesh	Bihar	Gujarat	Haryana	Karnataka	Madhya Pradesh	Punjab	Rajasthan	Uttar Pradesh	Other States	All India
							(percent)					
Change in mean yield	$\Delta\bar{y}$	51.28	−36.26	2.24	67.06	8.57	−40.96	22.33	−107.79	12.68	11.78	13.37
Change in mean area	$\Delta\bar{A}$	28.43	138.15	99.68	22.16	24.64	157.05	62.33	253.05	82.65	67.11	69.50
Interaction between changes in mean yield and mean area	$\Delta\bar{y}, \Delta\bar{A}$	20.29	−8.08	0.53	10.36	66.68	−15.60	15.57	−26.70	4.41	5.10	15.06
Change in area-yield covariance	$\Delta Cov(A,y)$	0.00	6.18	−2.46	0.42	0.11	−0.48	−0.24	−18.56	0.26	16.01	2.06
Total contribution of state to change in mean production in all India		9.82	5.69	2.56	8.93	14.33	5.22	20.28	2.78	16.22	14.16	100.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.
Note: The figures for the components of change in average production add to 100 percent in each column.

Table 33—Analysis of the components of change in average ragi production, by state, 1954/55-1964/65 — 1967/68-1977/78

Source of Change in Mean Production	Symbols	Andhra Pradesh	Bihar	Gujarat	Karnataka	Maha-rashtra	Orissa	Tamil Nadu	Uttar Pradesh	Other States	All India
						(percent)					
Change in mean yield	$\Delta\bar{y}$	425.60	239.65	49.28	120.11	-52.55	10.06	430.58	53.33	94.53	95.87
Change in mean area	$\Delta\bar{A}$	-277.73	-331.37	63.15	-22.73	149.91	71.73	-296.44	35.12	3.33	-5.71
Interaction between changes in mean yield and mean area	$\Delta\bar{y}, \Delta\bar{A}$	-45.96	-7.73	-10.86	-2.15	5.18	17.06	-45.09	9.48	3.79	6.26
Change in area-yield covariance	$\Delta Cov(A,y)$	-1.91	199.44	-1.57	4.76	-2.54	1.15	10.96	2.07	-1.65	3.58
Total contribution of state to change in mean production in all India		4.32	0.37	-9.19	25.37	-4.86	43.06	4.89	27.57	8.48	100.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.
Note: The figures for the components of change in average production add to 100 percent in each column.

Table 34—Analysis of the components of change in average small millets production, by state, 1954/55-1964/65 — 1967/68-1977/78

Source of Change in Mean Production	Symbols	Andhra Pradesh	Gujarat	Karnataka	Madhya Pradesh	Maha-rashtra	Orissa	Tamil Nadu	Uttar Pradesh	Other States	All India
						(percent)					
Change in mean yield	$\Delta\bar{y}$	28.40	17.73	-55.12	2.46	112.47	2.53	49.13	390.47	27.68	10.26
Change in mean area	$\Delta\bar{A}$	78.91	86.74	146.99	97.51	-11.50	89.07	59.34	-227.09	71.18	93.32
Interaction between changes in mean yield and mean area	$\Delta\bar{y}, \Delta\bar{A}$	-7.96	-5.72	12.39	0.62	2.30	8.37	-5.30	-70.60	-3.87	-3.40
Change in area-yield covariance	$\Delta Cov(A,y)$	0.65	1.25	-4.26	-0.59	-3.26	0.03	-3.17	7.22	5.01	-0.18
Total contribution of state to change in mean production in all India		66.48	26.25	11.49	-34.93	9.17	-27.64	31.67	-9.95	27.45	100.00

Source: Calculated from data provided to Shakuntla Mehra by the Directorate of Economics and Statistics of the Indian Ministry of Agriculture and Irrigation.
Note: The figures for the components of change in average production add to 100 percent in each column.

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