High-Yielding Varieties and Variability in Sorghum and Pearl Millet Production in India

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The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) invests heavily in screening and breeding for resistance to yield reducers. The benefits to this research are derived primarily from enhanced output, increased equity, and improved nutrition. In theory, improved yield stability from more pest resistant and stress tolerant varieties could also lead to reduced farm, regional, and national production variability.

Results from several studies suggest that variability in Indian foodgrain production has been increasing (Mehra 1981, Hazell 1982). Between 1954/55 to 1964/65 and 1967/68 to 1977/78 the coefficient of variation (cv) of detrended All India total cereal production increased by about 50 percent, from 0.04 to 0.059; the variance of All India production increased by 342 percent (Hazell 1982).

Hazell (1982) hypothesized that, if high-yielding varieties (HYVs) are a significant source of production variability, increased production variances within states should be large contributors to increases in the variance of cereal production. But his results show that only about 18 percent of the increase in variance of total cereal production can be accounted for by changes in crop production variances. The remaining 82 percent is explained by changes in the covariance components, particularly interstate covariances within crops, which contribute 41 percent to the change in variance in total cereal production. Changes in yield covariances were much more important than changes in yield variances. Hazell concluded that the increase in variability in India's cereal production between the two

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This chapter owes a great deal to the inspiration of Peter B. R. Hazell; the perspiration of E. Jagadeesh, A. Pavan Kumar, and S. Lalitha; the interpretative insight of Hans P. Binswanger; discussions with several colleagues in the ICRISAT and All India Coordinated Crop Improvement Programs, including B. S. Rana and N. G. P. Rao; the support of Murari Singh in the use of weighted least squares in the GENSTAT statistical package; and secondary data collected by P. Parthasarathy Rao and K. V. Subba Rao.

periods cannot be attributed to HYVs but rather to other causes. He additionally drew the implication that there is very confined scope for yield-stabilizing varietal technologies to decrease production variability in Indian agriculture.

In a later paper comparing the U.S. and Indian experience, Hazell (1984) saw a greater role for HYVs to play in influencing yield covariances. He speculated that narrowing of the genetic base of maize hybrids has led to increased regional covariances and augmented production variability in maize production in the United States. This chapter presents statistical evidence from district-level data to show that diffusion of sorghum (or jowar) and pearl millet (or bajra) hybrids are positively associated with increased production variability in the major producing districts in India.

The Diagnostic Approach

The decomposition methods described in chapter 2 are relied on to identify components and sources of change in production variability in 48 sorghum and 40 pearl millet growing districts of India. Initially, the 50 most important producing districts for each crop were chosen based on the area estimates for 1981/82 (Government of India 1983). Information was not available for two sorghum and 10 pearl millet growing districts in Haryana and Uttar Pradesh. The remaining 48 sorghum districts contributed about 70 percent to both All India production and area; the 40 remaining pearl millet districts accounted for about 70 percent of area and 60 percent of production. Two 12-year intervals, 1956/57 to 1967/68 and 1968/69 to 1979/80, which correspond to pre- and post-green revolution periods for sorghum and pearl millet, were selected for analysis. District area and yield data from the state government season and crop reports were linearly detrended for each period and their residuals were centered on the mean for each period. Detrended area and yield data were multiplied to give detrended production data for each period.

For a given crop, the change in production variance can be partitioned into two broad components: (a) the sum of production variances within districts, and (b) the sum of interdistrict production covariances, and each of these can, in turn, be attributed to some 11 sources (Hazell 1982, p. 21; ch. 2).

Increased Variability in Sorghum and Pearl Millet Production

Variability in sorghum and pearl millet production increased both absolutely and relatively from the first 12-year period to the second. For sorghum the cv of production increased from 0.08 to 0.16 ($z = 3.45$, highly significant); for pearl millet the change was even more marked, from 0.11

to 0.34 ($z = 7.20$, highly significant). The variances increased by 4,000 and 1,670 percent, repectively, and were also highly significant.

Most of the major producing districts also experienced increased production variability. The cv and variance of production increased in 31 and 36, respectively, of the 48 sorghum-producing districts. Of the major pearl millet growing districts, 36 and all 40 were characterized by greater relative and absolute production variability, respectively.

Sources of Increased Production Variability

Increased production variance stemmed overwhelmingly from increased production covariance among major producing regions for both sorghum and pearl millet. More than 90 percent of the increase in production variance for both crops was attributed to changes in interdistrict production covariances (table 6.1). Changes in within-district production variance did not contribute appreciably to the changes in production variance. In a highly disaggregated analysis such as this one, this result is not surprising because, with the n variances, there are $n(n - 1)$ production covariances and their sum should increase with the sum of the production variances (Hazell 1984).

What is surprising is that these changes should be so dominated by changes in yield covariances. For both crops, changes in yield covariance

TABLE 6.1 Contribution of different sources to increased interregional covariance in sorghum and pearl millet production in India, 1956/57-1967/68 to 1968/69-1979/80

Source	Sorghum	Pearl Millet
	(percentage share)	
Change in mean yield	1.7	0.7
Change in mean area	3.1	0.6
Change in yield covariance	84.0	54.2
Change in area covariance	0.1	2.2
Interaction between changes in mean yields and mean areas	0.0	0.0
Change in area-yield covariance	−1.3	14.2
Interaction between changes in mean area and yield covariance	1.8	4.4
Interaction between changes in mean yield and area covariance	0.3	1.3
Interactions between changes in mean area and yield and changes in area-yield covariance	−0.8	6.0
Change in residual	6.0	8.5
Total	94.9	92.1

have been largely responsible for the increase in changes in production variance (table 6.1). Within each crop, the yields of sorghum and pearl millet have become increasingly covariate across districts, and this increased yield covariance has led to increased production variability.

Changes in area-yield covariance also accounted for an appreciable share (about 14 percent) of increased production variance in pearl millet. Farmers are apparently planting more area to pearl millet (bajra) in years when yields are higher. One explanation for this tendency is that many farmers, particularly in Gujarat, now have more water to plant irrigated summer bajra in more abundant rainfall years when rainfed yields are also heavier. A greater investment in irrigation and in HYVs has probably enhanced the potential for greater area-yield covariance. In contrast to bajra, little summer jowar (sorghum) is planted, and postrainy season (or rabi) sorghum is grown on residual soil moisture without irrigation.

The analysis thus far has raised the key empirical question: Why have sorghum and pearl millet yields become increasingly covariate over time across districts? There are several possible interrelated answers to this question although some are not amenable to measurement. Three potential causes are relatively easy to quantify: (a) changes in rainfall covariance, (b) changes in irrigated area, and (c) diffusion of HYVs.

The simplest hypothesis as to why detrended yields increasingly move together over time centers on changes in rainfall covariance. A severe drought, which Wolf Ladejinsky described as "never in a 100 years," occurred in 1972 in extensive sorghum and pearl millet growing tracts of peninsular India (Walinsky 1977). It is likely that such an extreme adverse rainfall event, where total annual rainfall in the affected districts was only 20-30 percent of the long-term average, would also be more covariate than more normal rainfall events.

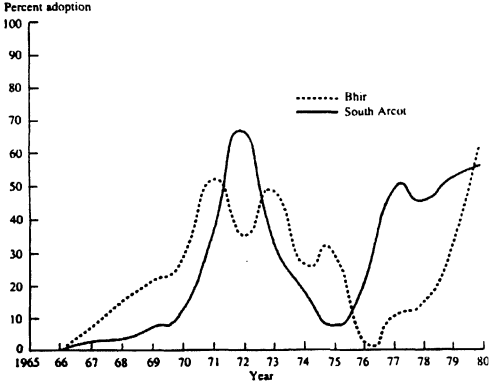
Understanding the relationship between changes in irrigated area and yield covariance is more complex. Irrigation for a given level of technology makes the production environment more homogenous, thus reinforcing tendencies toward greater yield covariance. Irrigation also contributes indirectly to yield covariances by inducing greater adoption of improved varieties and hybrids, and better agronomic practices. Those district pairs having more irrigated area in the second period would be characterized by more covariate yields. Likewise, district pairs with greater differences in irrigated area in the second period are expected to have less covariate yields.

HYVs usually have a narrower genetic background than local varieties and landraces. For example, the bulk of HYV sorghum area in India is planted to four hybrids—CSH-1, CSH-5, CSH-6, and CSH-9—the last three being descended from the same male parent CS3541. Most of the commercially available pearl millet hybrids originate from closely related parents.

Although statistical evidence from secondary data is hard to find, it is also common knowledge that the first generation of pearl millet hybrids (HB-1, HB-3, and HB-4) were extremely susceptible to downy mildew resulting in significant economic losses in the early 1970s, after inoculum had built up on farmers' fields (Kanwar 1975). In response to those losses, farmers in several major producing regions reverted to local types and hybrid adoption rates plummeted. In the mid- and late-1970s, hybrid adoption again picked up as farmers accepted the second-generation hybrids which, at that time, were much less susceptible to downy mildew. Similar but atypical adoption patterns in producing regions as distant as Tamil Nadu and Maharashtra bear ample testimony to the problem of increasing production covariance caused by the release of supersusceptible cultivars (figure 6.1).

Sorghum production was not affected by such a cultivar susceptible source of risk as the downy mildew epidemic in pearl millet, but the 1971-

FIGURE 6.1 Adoption of pearl millet hybrids in Bhir (Maharashtra) and South Arcot (Tamil Nadu), 1966-1980



73 drought certainly slowed the uptake of sorghum hybrids in Maharashtra and northern Karnataka. Inspection of adoption curves suggests that the 1971–73 drought contributed to making the pattern of diffusion across sorghum-growing districts more covariate than it otherwise would have been.

The less tangible sources of changes in yield covariance are power and fertilizer shortages, and greater economic growth and development. Power "outages" and fertilizer shortages are an appealing explanation because more subsidized inputs in the form of electricity, fuel, irrigation water, and fertilizer were used in the second period, and because these shortages did occur cyclically and sporadically across regions (H. Ezekiel as cited by Hazell 1982). Their influence is expected to be much more significant for wheat and rice, which command a much larger share of these resources than do sorghum and pearl millet.

Economic development is also synonymous with increased covariance and interdependence. More literate and better educated agents have a greater capacity to process better quality information coming from more thoroughly linked factor and product markets. While the effects of these linkages are real, they are also difficult, if not impossible, to quantify.

Another potential explanation for higher yield covariances is that sorghum and pearl millet are increasingly grown on more marginal land. The marginal land hypothesis is, however, more consistent with increasing production variances within districts than rising production covariances between regions.

Data Description

To test the hypothesized role of rainfall, irrigation, and varieties in increasing yield covariances across districts, a regression analysis was undertaken. The analysis is based on district pairwise observations. Taking combinations of the 48 sorghum and 40 pearl millet districts two at a time gives 1,128 observations for sorghum and 780 for pearl millet.

The independent variables, pertaining to levels of HYV adoption (SUMADT and DIFADT), levels of irrigation (SUMIRR and DIFIRR), and changes in rainfall covariances (RFCOVCHG), are described in table 6.2 together with the dependent variable, the change in yield covariance (YCOVCHG). The rationale for having two regressors for each independent variable stems from the nature of the pairwise data set. For example, for any district pair it is to be expected that the genotypes in farmers' fields become more similar as HYV adoption increases because the HYVs are narrower in genetic composition than the local landraces that differ from district to district. Thus, a more positive change would be expected for a district pair with a (80,70) percent rate of adoption than another pair with

TABLE 6.2 Means and ranges of the data used to explain the increase in interregional yield covariance in sorghum and pearl millet production in India

Variable Name	Definition	Crop Sorghum	 Pearl Millet	Expected Sign
YCOVCHG	Change in yield covariance from the second period to the first (Mt^2)	4 (−43, 64)[a]	7 (−125, 169)	n.a.
SUMADT[b]	Sum of direct pairwise HYV area in percent of total area planted to the crop	40 (0.1, 111)	53 (0.0, 186)	+
DIFADT[b]	Absolute value of the difference in percent HYV area	17 (0.2, 60)	30 (0.0, 95)	−
SUMIRR[b]	Sum of district pairwise irrigated area in percent of total area planted to the crop	10 (0.0, 67)	8 (0.0, 51)	−
DIFIRR[b]	Absolute value of the percent difference in irrigated area	8 (0.0, 38)	6 (0.0, 28)	−
RFCOVCHG	Change in total rainfall covariances from the second period to the first	7	13	+

[a] Ranges are in parentheses.

[b] Mean value for each district for three cropping years from 1976/77 to 1978/79.

a (20,20) rate. The summed adoption rates would then be 150 and 40, and SUMADT should be signed positively. By the same token, an (80,20) pair should have more genetic variation than a (50,50) pair although the SUMADT is the same for both district pairs. For a given SUMADT more disparity in adoption rates within district pairs signals greater genetic variation and is expected to be accompanied by a reduction in the change in yield covariance. Hence, having two regressors leads to a more powerful test of the hypothesis that HYV adoption is responsible for increased yield covariance.

For about 78 and 66 percent of the sorghum and pearl millet district pairs, respectively, yield covariance increased in the second period. Wide ranging values for SUMADT and DIFADT reflect substantial interregional variation in HYV adoption. Large mean differences between SUMADT and SUMIRR also suggest that both sorghum and pearl millet hybrids have been planted exclusively in dryland agriculture. Positive values for RFCOVCHG confirm the suspicion that total annual rainfall was more covariate in the second period. Rainfall became more covariate in the second period for 68 percent of the sorghum and 75 percent of pearl millet district pairwise observations.

Empirical Results

To assign greater importance to those districts where more sorghum and pearl millet is grown, weighted least squares regression analysis is used. The weights are the mean proportions of area planted to the crop for each district pair relative to All India estimates of planted area during the last three cropping years of the second period.

The regression estimates reported in table 6.3 have very low explanatory power and suggest a noisy data set. The signs of the estimated coefficients, however, are generally consistent with expectations and, for the

TABLE 6.3 Estimated regression coefficients of the determinants of changes in interregional yield covariance in sorghum and pearl millet production

	Crop	
Variable	Sorghum	Pearl Millet
SUMADT	89*	110*
	(5.26)	(4.61)
DIFADT	−59*	−113*
	(−2.24)	(−3.84)
SUMIRR	100*	−462*
	(2.28)	(−3.40)
DIFIRR	−214*	108
	(−3.61)	(0.65)
RFCOVCHG	70*	14*
	(4.42)	(4.86)
Intercept	2,295	7,162
R^2	0.07	0.04

Note: *t* values are in parentheses.
*Indicates statistical significance at the 0.05 level.

most part, the coefficients are significantly different from zero at the 5 percent confidence level. Greater adoption of hybrids has increased interregional yield covariances in both sorghum and pearl millet production. More covariate rainfall events have also led to significantly more covariate interregional yields. For sorghum, change in irrigated area behaves as expected; however, irrigation leads to reduced interregional pearl millet yield covariances. This puzzling result could stem from the fact that irrigated pearl millet often entails only one or two applications of water and is largely cultivated where water supply is most uncertain. A closer look at changes in irrigated area by source may shed some light on this result.

Conclusions

Having shown that adoption of HYVs is positively correlated with, if not partially responsible for, increased sorghum and millet production variability, it would be facile but unwarranted to conclude that scientists in the sorghum and pearl millet All India coordinated crop improvement programs should have released hybrids and varieties with a broader genetic background and should have pursued a more regional or location specific release strategy to mitigate the adverse effect of increasing interregional yield covariance and rising production variability. Even with hindsight, it is impossible to say whether the benefits from following a more regional release policy and emphasizing selection and breeding from genetically more diverse populations would compensate for the productivity gains forgone from pursuing a more single-minded, national yield improvement strategy. Moreover, a judicious mix of international trade and storage policies can cost-effectively offset most, if not all, of the variability costs of increasing yield covariance. These issues are addressed more fully in part III of this book.