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ARTICLES

Spatial Variability in Crop Yields: The Case of Cereals across Districts of Andhra Pradesh

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I

INTRODUCTION

The variability in the yield rate (kilograms per hectare) of a crop from year to year within a given region, and changes in such variability in the context of high-yielding variety (HYV) seeds, have been the subject of considerable analysis during the last two decades in India. But as Narayana and Ganesh Kumar (1992) point out, variability can also be viewed across regions, that is, 'spatial variability' or the variations (differences) in crop yields across regions during a given time period. Differences in the crop yields, grown under rainfed or irrigated condition, amongst different states in India have long been noted. But almost no analysis has been attempted to explain the magnitude of such inter-state or inter-district differences in crop yields. Raghavan's (1984) enquiry into the differences in the value of production of all crops per unit of land under cultivation amongst the different districts of Andhra Pradesh is one of the very few studies on spatial variability in crop yields. But, it not only takes all crops together, but also examines value productivity, not physical productivity, differences. One of the reasons for the difference in the level of agricultural well-being across regions is the difference in the physical productivity of the individual crops grown in these regions. A proper appreciation of the reasons for such differences in the yield rate may lead to measures to bridge the gap, thereby reducing regional differences in the level of well-being in agriculture. This paper seeks to analyse the changes in the variability of yield rates amongst the districts of the state of Andhra Pradesh in Southern India for five major cereal crops.

Differences in crop yields across districts may be expected due to the differences in the districts in natural/uncontrollable factors such as soil fertility and weather conditions, and in controllable factors like irrigation facilities, institutional factors, and the cultivation practices followed by farmers. The questions that arise here are: What is the extent of spatial variability in crop yields? A related question here is how to measure spatial variability? Is the extent of spatial variability in crop yields changing systematically over time? What are the factors that influence the spatial variability in crop yields? This paper seeks to study these questions in some detail for the annual aggregate yields of five major cereals grown in Andhra Pradesh, viz., rice, jowar (sorghum), bajra (pearlmillet), ragi and maize.

Inter-district differences in crop yields can arise due to differences in various factors across districts. Factors affecting the spatial variability in crop yields may be broadly classified as follows: (1) Agro-climatic factors - rainfall, soil fertility conditions, etc.; (2) Infrastructural

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factors - sources of irrigation and the extent of irrigation, etc.; (3) Agricultural practices - seed variety used, types and quantities of other material inputs applied, mechanisation of operations, labour used, and changes in the methods of application of inputs and labour, etc. and (4) Social and institutional factors - farmers' level of education, credit institutions and facilities, etc.

Five factors, falling in the first three of the above broad groups, are considered for analysis in this paper. These are: rainfall during the two main monsoon seasons - south-west and north-east; proportion of the net cultivated area of the district irrigated - total and by different sources of irrigation; aggregate cropping intensity, intensity of fertiliser use and cropwise gross irrigation proportions. Crop yields and all the explanatory variables, except the rainfall variables, are annual aggregates. For this reason, rainfall during the two monsoon seasons are considered here as nearly all rainfall in the year occur only during the two monsoon seasons. Rainfall is a crucial factor that affects crop cultivation, and inter-district variations in the quantum of rainfall may be an important factor affecting the spatial variability of crop yields. Differences across districts in the total net sown area irrigated may be a factor constraining more intensive crop cultivation thereby affecting yields. Further, inter-district differences in the quality of irrigation may also be an important determinant of the difference in the yield rates among districts. Since the quality of irrigation varies with the sources of irrigation, with tubewell irrigation and canal irrigation considered to be qualitatively better, five different sources are considered for the purpose: canals, tanks, tubewells, other (open) wells, and other sources. Availability of irrigation facilitates multiple cropping of land. Therefore, aggregate cropping intensity (ACI), defined as total gross sown area divided by the net sown area, is considered as another factor influencing yield differences amongst districts. Amongst the crop-specific input variables that have a bearing on crop yields, only fertiliser intensity and cropwise gross irrigation proportions are considered here. Other important crop-specific factors like seed variety used, cropwise labour application, pesticide application, mechanisation, etc., could not be considered here to due to data constraints. Indeed, with regard to fertiliser also, only an aggregate measure of fertiliser intensity is used here due to data limitations. It is measured by the total fertiliser use in the district divided by the total area under the five crops analysed in this paper.

The definitions, unit of measurement, notations and data sources for all the variables considered in this analysis are reported in the Appendix. The analysis in this paper covers the period 1960-61 to 1984-85 over which continuous time-series data on all the variables of interest are available at the district level for Andhra Pradesh. Presently, Andhra Pradesh has three geo-political regions - Coastal Andhra, Rayalaseema and Telangana - consisting of 23 districts following the reorganisation of some of its districts once in 1967 and again in 1979 when parts of some large districts were reorganised to form new districts. In this study, however, the data for such reorganised districts were aggregated so as to maintain uniformity over time. Thus, out of the present 23 districts, we have 18 districts for the analysis. There are five districts in Coastal Andhra region, namely, Srikakulam + Vizianagaram + Vishakhapatnam, East Godavari, West Godavari, Krishna, and Guntur + Prakasam + Nellore. Rayalaseema region consists of four districts, namely, Kurnool, Anantapur, Cuddapah and Chittoor. Nine districts form the Telangana region, namely, Ranga Reddy + Hyderabad, Nizamabad, Medak, Mehboobnagar, Nalgonda, Warangal, Khammam, Karimnagar and Adilabad.

The rest of the paper is organised as follows: Section II discusses the extent of spatial variability in yields and in the explanatory factors mentioned above. Trends, if any, in the spatial variability are also analysed in this section. Factors that explain the spatial variability in yields are analysed in Section III. Conclusions are provided in the final section.

II

DEGREE AND TRENDS IN SPATIAL VARIABILITY ACROSS DISTRICTS OF ANDHRA PRADESH

Spatial variability in a variable Y (crop yields, rainfall, etc.), as has been defined earlier, refers to the magnitude of the differences in Y across districts. Statistically speaking, one is referring to the cross-sectional second moment of Y, not to its levels. Accordingly, for any given year 't', spatial variability in Y is measured by its coefficient of variation (which is a normalised measure of the second moment - normalised with respect to the sample mean) across districts in that year, and denoted $CV(Y)_t$. Computed across districts, $CV(Y)_t$ is a measure of the disparity at time 't' across the districts in variable Y. Time-series of coefficient of variation (CV) across districts are computed for the period 1960-61 to 1984-85 for crop yields, rainfall, sourcewise net irrigation proportions, aggregate cropping intensity, cropwise gross irrigation proportions and fertiliser intensity. From these time-series of the CVs, reported in Table 1 for a few years only, trends in the spatial variability or disparity in these variables can be studied.

Spatial Variability in Crop Yields

The CV is essentially a measure of dispersion around the sample mean. Low (high) values for the CV indicate close (wide) scatter of observations around the sample mean. Surekha and Griffiths (1984) and Evans and King (1985) consider variations in a series with a CV less than 0.3 (greater than 0.5) to be 'mild' ('severe'). Using their cut-off limit of 0.3,[1] it can be seen from Table 1 that in general the yields of rice, jowar and maize (denoted YRCE, YJWR and YMZE respectively) show mild variation while those of bajra and ragi (denoted YBJR and YRGI respectively) show a high degree of variation across districts barring a few exceptional years. In the case of rice the CV exceeds 0.3 only once (in 1972-73) in a span of 25 years. CV (YJWR) and CV (YMZE) exceed 0.3 in only 5 and 3 years respectively out of the 25 years in the sample period. On the other hand, CV (YBJR) and CV (YRGI) are greater than 0.3 in most of the years: they are less than 0.3 only in 2 and 4 years respectively out of 25 years in the sample period. Thus it can be said that the degree of spatial variability (disparity) in crop yields across the districts is generally low in the case of rice, jowar and maize and generally high in the case of bajra and ragi.

Having identified the crops with a high/low degree of spatial variability in yields, let us now identify, for each crop, the relative ranking of each district with regard to their crop yields. Table 2 presents the classification of the districts into low value districts (LVD) and high value districts (HVD) based on whether the yield level in the district is below (above) the state's average level of yield. Such classification was done for all the years in the sample and changes, if any, in the relative ranking of districts, viz., LVD to HVD and vice versa, are also shown in Table 2.

TABLE 1. COEFFICIENT OF VARIATION (CV) ACROSS DISTRICTS OF ANDHRA PRADESH AND ITS TREND

Variable[1] (1)	1960-61 (2)	1965-66 (3)	1970-71 (4)	1975-76 (5)	1980-81 (6)	1984-85 (7)	F-test[2] (8)	T-test (9)	d-o-f[3] (10)
Crop yields									
YRCE	0.2778	0.2564	0.1738	0.1442	0.1814	0.2354	1.87	-1.17	20
YJWR	0.3396	0.2354	0.2836	0.3271	0.2364	0.3602	1.01	0.55	20
YBJR	0.4012	0.2970	0.3528	0.4642	0.4459	0.6769	1.77	3.07+	20
YRGI	0.2718	0.3841	0.3906	0.3213	0.3566	0.3975	3.69*	1.54#	16
YMZE	0.2401	0.0822	0.1824	0.1363	0.2737	0.3036	3.29*	2.20*	17
Rainfall									
RSW	0.4078	0.3610	0.3827	0.3724	0.6295	0.6641	-	-	-
RNE	1.3189	1.5158	1.1288	0.7900	1.5151	1.3437	-	-	-
Infrastructural variables									
TCNL	1.4089	1.4292	1.2617	1.2359	1.1824	1.1456	1.41	-3.19+	20
TANK	0.6151	0.6139	0.6387	0.6030	0.7640	0.8449	2.55#	2.58*	18
SWTR	0.8644	0.8214	0.7983	0.7829	0.8558	0.8143	1.23	-0.02	20
TBWL	2.1853	2.6260	2.8148	2.2997	2.2768	1.9240	4.89+	-2.99+	15
OTWL	0.8540	0.9414	0.8613	0.9567	0.8972	0.8426	2.01	-0.53	19
GWTR	0.8339	0.8280	0.7754	0.7433	0.6833	0.6268	1.215	-3.18+	20
OSRC	1.1542	0.8705	0.9883	0.7088	0.7434	0.6275	3.88*	-3.51+	16
TNAS	0.7502	0.6735	0.6847	0.6413	0.6205	0.6235	2.28	-4.86+	19
ACI	0.0991	0.1043	0.0912	0.1074	0.1209	0.1361	3.38*	2.72*	16
Crop input variables									
IRCE	0.1326	0.1213	0.1061	0.2390	0.0945	0.1021	10.28+	-0.53	13
IJWR	1.5783	1.9967	1.7301	1.4808	2.4443	1.6238	1.21	0.04	20
IBJR	0.8826	1.3918	1.6759	1.6867	1.6008	1.4812	3.58*	1.29	16
IRGI	1.1851	1.1567	1.2799	1.3340	1.1405	0.9571	2.20	0.83	19
IMZE	0.9581	1.3929	1.0705	0.9714	0.8537	0.9890	8.86+	-3.40+	13
FRT	0.9176	0.8541	0.6002	0.5942	0.6221	0.5684	5.33+	-5.24+	19

Notes: 1. See Appendix for variable definitions.
2. The degrees of freedom for the F-test are (10, 10).
3. Degrees of freedom for the T-test.
+, * and # denote significance at 1, 5 and 15 per cent level respectively.

From Table 2, it can be seen that 17 out of the 18 districts have been HVD (yields)[2] for one or more crops at some time point or the other during the sample period. Only Warangal was never HVD (yields) for any crop during the sample period. Some districts have improved their rankings in yield levels from LVD (yields) to HVD (yields) over time. The converse is also observed, i.e., some HVD (yields) became LVD (yields) over time. In the case of rice, 2 districts (Nalgonda and Karimnagar) became HVD over time while 3 other districts (Guntur + Prakasam + Nellore, Anantapur and Nizamabad) turned LVD in the same period. In the case of jowar, 3 districts (Anantapur, Cuddapah and Khammam) became HVD and 5 districts (West Godavari, Krishna, Guntur + Prakasam + Nellore, Medak and Adilabad) became LVD by 1984-85. Bajra yields too witnessed changes in the rankings of the districts; 3 districts (East Godavari, Guntur + Prakasam + Nellore, and Cuddapah) became HVD while 4 districts (Kurnool, Anantapur, Ranga Reddy + Hyderabad, and Khammam) became LVD by 1984-85. In the case of ragi yields, however, the relative rankings of the districts have been more or less stable with only 2 districts (Anantapur and Nalgonda) turning HVD and 2 other districts (Krishna and Nizamabad) turning LVD by 1984-85. In the case of maize, only 1 district (Anantapur) became HVD while 3 districts (Srikakulam + Vizianagaram + Vishakhapatnam, Ranga Reddy + Hyderabad, and Nalgonda) became LVD by 1984-85.

Changes in the ranking of a district depend not only on the district's own performance but also on the performance of other districts over time. This point would be clear from the actual growth rates of crop yields in each district as estimated by semi-log time trend for the period 1960-61 to 1984-85 presented (along with those for a few other variables) in Table 3. From Tables 2 and 3, it may be noted that Guntur + Prakasam + Nellore with a growth rate of only 2.04 per cent per annum in YRCE moved from HVD to LVD over time; whereas Nalgonda and Karimnagar with impressive growth rates of 3.4 per cent per annum and 4.12 per cent per annum respectively moved from LVD to HVD. Further, it is possible that a district that showed slow growth can remain a HVD if the yield levels were sufficiently high initially. A case in point here is Chittoor with only 1.61 per cent per annum growth in YRCE, but which has remained a HVD all through. Similar examples may be found in the case of other crops also.

Now turning specifically to the movement of CVs over time, "are the CVs rising or falling or essentially fluctuating around a constant level?" A rise (fall) in CV would indicate a widening (narrowing) of the gap between the districts in their crop yield levels over time. CVs that are essentially fluctuating around a constant level would indicate constancy of the gap between the districts in their crop yield levels over time.

Estimating time trends to answer this question did not give satisfactory results with the fits in terms of $\bar{R}^2$ being too poor. Alternatively, a non-parametric approach based essentially on a T-test (and an associated F-test) was adopted. The theme of the T-test is to split the whole time-series of CV (yields) into two sub-samples (say, Period I and Period II), compute the means of the series over the sub-samples and test for equality of these two sub-sample means. In this analysis, the full sample period (1960-61 to 1984-85) is split into two sub-periods: 1960-61 to 1970-71 (Period I) and 1974-75 to 1984-85 (Period II), dropping the three middle years 1971-72 to 1973-74. At a given level of significance, a significant positive (negative) T statistic would indicate a significant increase (decrease) in the mean level of CV (yields) in Period II compared to Period I. An insignificant T statistic would indicate equality of the mean level of CV (yields) between the two sub-periods; i.e., CV (yields) is more or less constant over the full sample. The mathematical expression for the T statistic depends on whether the variances of the variable in question in the two sub-periods are equal or not. Hence, a F-test is conducted first to test the equality of the variances between the two sub-periods. Based on the F-test results the appropriate expression is used for the T-test (for more details on the test procedure, see Brockett and Levine, 1984; Kanji, 1993). The results of these tests for the CVs of all the variables of concern here (except for the rainfall variables) are reported in Table 1.

These results suggest that CV (YRCE) and CV (YJWR) (both of which are low) have remained unchanged over time while CV(YBJR), CV(YRGI) (both high) and CV (YMZE) (low CV) have increased over time. That is, the low level of disparities across districts in the yield levels of rice and jowar have largely remained constant over time whereas in the

TABLE 2. RELATIVE RANKING OF DISTRICTS - CROP YIELDS, INFRASTRUCTURAL AND CROP INPUT VARIABLES

Variable (1)	Low valued districts (LVD) (2)	High valued districts (HVD) (3)	LVD to HVD (4)	HVD to LVD (5)
YRCE	Srikakulam+Vizianagaram+Vishakhapatnam, Ranga Reddy + Hyderabad, Medak, Mehboobnagar, Warangal, Khammam, Adilabad	East Godavari, West Godavari, Krishna, Cuddapah, Chittoor	Nalgonda, Karimnagar	Guntur+Prakasam+Nellore, Anantapur, Nizamabad
YJWR	Srikakulam+Vizianagaram+Vishakhapatnam, East Godavari, Mehboobnagar, Nalgonda, Warangal, Karimnagar	Kurnool, Chittoor, Ranga Reddy+ Hyderabad, Nizamabad	Anantapur, Cuddapah, Khammam	West Godavari, Krishna, Guntur+Prakasam+Nellore, Medak, Adilabad
YBJR	Nizamabad, Medak, Mehboobnagar, Nalgonda, Warangal, Karimnagar, Adilabad	Srikakulam+Vizianagaram+Vishakhapatnam, West Godavari, Krishna, Chittoor	East Godavari, Guntur+Prakasam+ Nellore, Cuddapah	Kurnool, Anantapur, Ranga Reddy+Hyderabad, Khammam
YRGI	Srikakulam+Vizianagaram+Vishakhapatnam, Cuddapah, Chittoor, Medak, Mehboobnagar, Warangal, Khammam, Karimnagar, Adilabad	East Godavari, West Godavari, Guntur+Prakasam+Nellore, Kurnool, Ranga Reddy+Hyderabad	Anantapur, Nalgonda	Krishna, Nizamabad
YMZE	Krishna, Guntur+Prakasam+Nellore, Cuddapah, Chittoor, Medak, Mehboobnagar, Warangal, Adilabad	East Godavari, West Godavari, Kurnool, Nizamabad, Khammam, Karimnagar	Anantapur	Srikakulam+Vizianagaram+ Vishakhapatnam, Ranga Reddy+Hyderabad, Nalgonda
TCNL	Kurnool, Anantapur, Cuddapah, Chittoor, Ranga Reddy+Hyderabad, Medak, Mehboobnagar, Nalgonda, Warangal, Khammam, Karimnagar, Adilabad	Srikakulam+Vizianagaram+Vishakhapatnam, East Godavari, West Godavari, Krishna, Guntur+Prakasam+Nellore, Nizamabad		
TANK	Kurnool, Anantapur, Cuddapah, Ranga Reddy+Hyderabad, Mehboobnagar, Nalgonda, Adilabad	Srikakulam+Vizianagaram+Vishakhapatnam, Chittoor, Nizamabad, Medak, Warangal, Karimnagar		East Godavari, West Godavari, Krishna, Guntur+Prakasam+ Nellore, Khammam

(Contd.)

TABLE 2 *(Contd.)*

Variable (1)	Low valued districts (LVD) (2)	High valued districts (HVD) (3)	LVD to HVD (4)	HVD to LVD (5)
SWTR	Kurnool, Anantapur, Cuddapah, Chittoor, Ranga Reddy+Hyderabad, Medak, Mehboobnagar, Nalgonda, Warangal, Khammam, Karimnagar, Adilabad	Srikakulam+Vizianagaram+ Vishakhapatnam, East Godavari, West Godavari, Krishna, Guntur+Prakasam+Nellore, Nizamabad	-	-
TBWL	Srikakulam+Vizianagaram+Vishakhapatnam, Kurnool, Anantapur, Chittoor, Ranga Reddy+ Hyderabad, Nizamabad, Medak, Mehboobnagar, Nalgonda, Warangal, Karimnagar, Adilabad	East Godavari, West Godavari, Krishna, Guntur+Prakasam+Nellore, Cuddapah, Khammam	-	-
OTWL	Srikakulam+Vizianagaram+Vishakhapatnam, East Godavari, West Godavari, Krishna, Kurnool, Mehboobnagar, Khammam, Adilabad	Cuddapah, Chittoor, Medak, Nalgonda, Warangal, Karimnagar	Anantapur, Ranga Reddy+Hyderabad, Nizamabad	Guntur+Prakasam+Nellore
GWTR	Srikakulam+Vizianagaram+Vishakhapatnam, East Godavari, Krishna, Kurnool, Anantapur, Ranga Reddy+Hyderabad, Nizamabad, Mehboobnagar, Nalgonda, Warangal, Khammam, Adilabad	Guntur+Prakasam+Nellore, Cuddapah, Chittoor, Medak, Karimnagar	West Godavari	-
OSRC	Kurnool, Anantapur, Cuddapah, Ranga Reddy+Hyderabad, Medak, Mehboobnagar, Nalgonda, Warangal, Adilabad	Srikakulam+Vizianagaram+Vishakhapatnam, East Godavari, West Godavari, Krishna, Guntur+Prakasam+Nellore, Khammam, Karimnagar	Nizamabad	Chittoor
TNAS	Kurnool, Anantapur, Cuddapah, Ranga Reddy+Hyderabad, Medak, Mehboobnagar, Nalgonda, Warangal, Khammam, Adilabad	Srikakulam+Vizianagaram+Vishakhapatnam, East Godavari, West Godavari, Krishna, Guntur+Prakasam+Nellore, Nizamabad	Karimnagar	Chittoor
ACI	Kurnool, Anantapur, Cuddapah, Ranga Reddy+ Hyderabad, Medak, Mehboobnagar, Khammam, Karimnagar, Adilabad	Srikakulam+Vizianagaram+Vishakhapatnam, East Godavari, West Godavari, Krishna, Guntur+Prakasam+Nellore,	Nizamabad, Nalgonda, Warangal	Chittoor

(Contd.)

TABLE 2 *(Concld.)*

Variable (1)	Low valued districts (LVD) (2)	High valued districts (HVD) (3)	LVD to HVD (4)	HVD to LVD (5)
IRCE	Srikakulam+Vizianagaram+Vishakhapatnam, Kurnool, Ranga Reddy+Hyderabad, Medak, Mehboobnagar, Khammam, Adilabad	East Godavari, West Godavari, Krishna, Guntur+Prakasam+ Nellore, Anantapur, Cuddapah, Nalgonda, Warangal, Karimnagar	-	Chittoor, Nizamabad
IJWR	Krishna, Nizamabad, Medak, Mehboobnagar, Nalgonda, Warangal, Khammam, Karimnagar, Adilabad	Guntur+Prakasam+Nellore, Anantapur, Chittoor	East Godavari, West Godavari, Kurnool, Cuddapah,	Srikakulam+Vizianagaram+ Vishakhapatnam, Ranga Reddy+ Hyderabad
IBJR	Srikakulam+Vizianagaram+Vishakhapatnam, East Godavari, West Godavari, Krishna, Anantapur, Ranga Reddy+Hyderabad, Medak, Mehboobnagar, Nalgonda, Warangal, Khammam, Adilabad	Guntur+Prakasam+Nellore, Cuddapah, Chittoor, Nizamabad, Karimnagar	-	Kurnool
IRGI	Srikakulam+Vizianagaram+Vishakhapatnam, East Godavari, West Godavari, Krishna, Chittoor, Ranga Reddy+Hyderabad, Nizamabad, Medak, Mehboobnagar, Warangal, Khammam, Karimnagar, Adilabad	Guntur+Prakasam+Nellore, Anantapur, Cuddapah, Nizamabad,	-	Kurnool
IMZE	East Godavari, Guntur+Prakasam+Nellore, Ranga Reddy+Hyderabad, Nizamabad, Medak, Mehboobnagar, Nalgonda, Khammam, Adilabad	Kurnool, Cuddapah, Chittoor, Warangal, Karimnagar	West Godavari, Krishna, Anantapur	Srikakulam+Vizianagaram+ Vishakhapatnam
FRT	Srikakulam+Vizianagaram+Vishakhapatnam, Kurnool, Anantapur, Chittoor, Ranga Reddy+ Hyderabad, Medak, Mehboobnagar, Nalgonda, Warangal, Khammam, Karimnagar, Adilabad	East Godavari, West Godavari, Krishna, Guntur+Prakasam+Nellore, Nizamabad	Cuddapah	-

Notes: (1) See Appendix for variable definitions and their measurement units.
(2) LVD (HVD) are districts whose level for the variable under consideration is below (above) the state level average for that variable.
(3) Columns (2) and (3) report districts whose relative ranking has remained the same over the period 1960-61 to 1984-85.
(4) Columns (4) and (5) report districts whose relative ranking has changed over time during the period 1960-61 to 1984-85.

TABLE 3. ESTIMATED GROWTH RATES FOR THE PERIOD 1960-61 TO 1984-85

(per cent)

District (1)	YRCE (2)	YJWR (3)	YBJR (4)	YRGI (5)	YMZE (6)	CANALS (7)	TANKS (8)	SURF.WTR (9)	O.WELLS (10)	GR.WTR (11)	TNIA (12)	ACI (13)	FRT (14)
Srikakulam+Vizianagaram+ Vishakhapatnam	0.00	0.00	1.87	0.00	4.56	1.02	0.00	0.00	-6.24	-3.73	0.18	0.00	9.74
East Godavari	2.25	0.00	0.00	0.00	4.92	0.00	0.00	0.00	0.00	7.83	0.00	0.78	7.57
West Godavari	2.83	0.00	2.19	0.93	5.20	0.00	0.00	0.00	-9.19	9.05	0.38	0.68	7.22
Krishna	1.80	0.00	1.77	1.11	4.72	0.48	0.00	0.00	0.00	5.30	0.00	0.80	7.57
Guntur+Prakasam+Nellore	2.04	0.00	0.00	0.00	4.78	3.18	-1.88	1.80	1.74	3.85	1.60	0.00	11.19
Kurnool	2.12	3.16	0.00	0.00	4.69	3.02	-4.25	1.14	0.00	0.00	1.35	0.00	10.14
Anantapur	1.17	4.18	0.00	2.69	5.08	2.38	-4.11	0.00	2.76	2.83	1.27	0.00	14.02
Cuddapah	1.73	0.00	3.96	3.04	4.86	-1.88	0.00	-1.89	1.29	1.56	0.00	0.00	11.34
Chittoor	1.61	0.00	0.00	0.00	6.58	0.00	-2.72	-2.21	3.14	3.21	0.00	0.00	10.78
Ranga Reddy+Hyderabad	2.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.99	2.82	1.05	0.00	0.00
Nizamabad	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.37	7.52	1.09	0.44	9.35
Medak	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.66	4.67	1.09	0.00	11.23
Mehboobnagar	2.20	0.00	0.00	0.00	3.62	2.70	0.00	0.00	3.97	3.99	0.00	0.00	14.54
Nalgonda	3.40	0.00	0.00	5.02	2.60	7.09	0.00	2.64	0.00	0.00	1.27	0.36	16.65
Warangal	3.24	0.00	0.00	0.00	3.17	-7.07	0.00	0.00	4.85	4.98	1.58	0.61	15.69
Khammam	2.61	0.00	0.00	0.00	0.00	5.08	0.00	0.00	8.04	10.84	1.61	0.00	16.00
Karimnagar	4.12	0.00	0.00	0.00	4.22	3.69	0.00	0.00	5.20	5.20	2.36	0.37	14.22
Adilabad	2.34	0.00	0.00	0.00	0.00	4.71	0.00	0.00	7.73	8.01	1.42	0.00	13.22
Andhra Pradesh	2.31	0.00	0.00	1.25	3.29	1.54	-1.49	0.00	2.75	3.68	0.80	0.24	9.88

Notes: (1) The growth rates reported are $\hat{\beta} \times 100$ from the regression: $\log Y_t = \alpha + \beta TIME_t + U_t$.

(2) YRCE, YJWR, YBJR, YRGI, YMZE, ACI and FRT are as defined in the Appendix.

(3) CANALS, TANKS, SURF.WTR, O.WELLS, GR.WTR and TNIA refer to net irrigated area (000 hectares) by canals, tanks, surface water (canals + tanks), other wells, groundwater (tubewells + other wells) sources and total net irrigated area over all sources respectively.

case of bajra, ragi and maize, the yield disparities across the districts have actually widened.

Given the definition of CV, it is obvious in our context that if the yields of a crop grow exactly at the same rate in all the districts, then CV does not change at all. However, generally all districts do not grow at the same rate. In fact, crop yields in some districts may grow, while in some other districts they may fall and in still some others they may remain stagnant.

In a situation where some districts show positive growth rates while others show negative growth rates with overall mean μ, however, remaining constant, then movements in CV purely depend on the movements in the standard deviation σ. If, for example, HVD are the ones showing negative growth rates while LVD are the ones showing positive growth rates, then CV obviously comes down. On the other hand, if HVD are the ones showing positive growth while LVD are the ones showing negative growth, CV goes up. In a situation where all districts show positive but unequal growth rates, μ certainly goes up; but whether CV goes up or down depends on the growth pattern. If HVD grow faster than LVD then CV increases whereas if LVD grow faster than HVD CV would fall. Thus, in general, when the growth pattern varies across districts the movements in CV depend on the relative movements in μ and σ.

From the growth rates presented in Table 3, let us first note that none of the districts have shown a negative growth rate for any crop yields in Andhra Pradesh.

YRCE has grown in all the districts except in Srikakulam + Vizianagaram + Vishakhapatnam, Nizamabad and Medak. The rate of growth in YRCE was found to be different across districts. In fact the growth rates recorded by some LVD (YRCE) (Nalgonda, Warangal and Karimnagar) are higher than the growth rates recorded by any of the HVD (YRCE). But the other LVD (YRCE) (Srikakulam + Vizianagaram + Vishakhapatnam, Guntur + Prakasham + Nellore, Kurnool, Ranga Reddy + Hyderabad, Medak, Mehboobnagar, Khammam and Adilabad) did not grow adequately enough to reflect in a significant fall in CV (YRCE). Thus the inter-district disparity in YRCE has remained more or less constant over time (though, visibly, there seems to be a mild downward trend in it).

The stagnant CV (YJWR), unlike that in rice, reflects stagnant YJWR in almost all districts. Only 2 districts (Kurnool and Anantapur) showed positive growth rates in YJWR, but that has not been enough to bring a change in the overall CV (YJWR).

YBJR grew only in 4 (Srikakulam + Vizianagaram + Vishakhapatnam, West Godavari, Krishna and Cuddapah) out of 18 districts in Andhra Pradesh. In the rest of the districts it has remained stagnant. From Table 2 we know that all the 4 districts showing growth in YBJR are HVD (YBJR). This growth pattern, naturally, has led to an increase in the inter-districts disparity in YBJR as shown by the increase in CV (YBJR).

Similar is the case of YRGI which grew only in 5 (West Godavari, Krishna, Anantapur, Cuddapah and Nalgonda) districts, of which 4 (except Nalgonda) districts are HVD (YRGI). YRGI has been stagnant in all the remaining 13 districts. The increase in CV (YRGI), though significant only at 15 per cent level, reflects this growth pattern.

YMZE has grown in most of the districts, although maize is an unimportant crop in most of them. Thirteen of the 18 districts in Andhra Pradesh have shown positive growth in YMZE, which are in general far higher than the growth rates recorded for other crops in any of the districts (except YRGI in Nalgonda). Of these 13, 5 (East Godavari, West Godavari, Kurnool, Anantapur and Karimnagar) are HVD (YMZE) with growth rates above 4.2 per cent per annum. The remaining 8 districts are all LVD, of which 3 (Mehboobnagar, Nalgonda and Warnagal) show far lower growth rates. Besides, 3 other LVD (Ranga Reddy + Hyderabad, Medak and Adilabad) did not show any growth at all. Thus the increase in the standard deviation of YMZE is more than the increase in the overall mean, resulting in significant increase in CV (YMZE).

The overall growth pattern of the crop yields is as follows: The superior cereal rice has experienced growth in almost all districts, particularly the LVD (YRCE) showing faster growth than the HVD (YRCE). Among the inferior cereals, while jowar yields have remained stagnant in almost all districts, bajra and ragi yields grew only in a few districts which are already HVD (YBJR) and HVD (YRGI). The case of maize is opposite to that of rice, where several districts show growth but HVD (YMZE) growing faster than LVD (YMZE). This explains the movement over time in CV (yields) presented above.

Before proceeding to explain the spatial variability in crop yields in terms of our explanatory variables mentioned earlier, let us first look at the spatial variability in the explanatory variables themselves.

Spatial Variability in Rainfall

The rainfall variables considered here are rainfall (in mm) during the two monsoons - South-West monsoon (RSW) and North-East monsoon (RNE). Spatial variability across the districts in rainfall during the two monsoon seasons can be studied from the time-series of CV (RSW) and CV (RNE) reported in Table 1. It can be seen that both CV (RSW) and CV (RNE) are high exceeding the cut-off level of 0.3 for all the years in the sample period. Further, amongst the two rainfalls, RNE has higher CVs, often exceeding 1.0, implying that the standard deviation is greater than the mean level. RSW and RNE being climatic factors, their dispersion across districts are unlikely to show any systematic change over time. Hence, the T-test for equality of means of the two sub-periods are not conducted on the time-series of CV (RSW) and CV (RNE).

Spatial Variability in Infrastructural Variables

The infrastructural variables considered in this analysis are the sourcewise net irrigation, as a proportion to the total net sown area (NSA) over all crops. Further, aggregate cropping intensity (ACI), defined as the ratio of gross cropped area over all crops to the net sown area over all crops, representing the extent of multiple cropping is another factor considered in this analysis.

(A) *Sourcewise net irrigation proportions*

The sources of irrigation considered are canals, tanks, tubewells, other wells, and other sources. Apart from these five individual sources of irrigation, three aggregated variables - surface water component (= canals + tanks), groundwater component (= tubewells + other wells) and the total net irrigation by all the five sources - are also considered.

Before discussing spatial variability in the sourcewise net irrigation proportions, let us first note some general features of irrigation development across the districts of Andhra

Pradesh, specifically the extent and the relative importance of the various sources of irrigation, as observed from the time-series data over the period of interest. The data suggest the following:

(i) In the state as a whole, growth in the total net irrigated area (TNIA) has been slow with only 6.13 million hectares (mha) being added over the 25 years of our sample. By 1984-85, only one-third of the total net sown area is irrigated in the state by some source or the other.

(ii) Wide disparities in TNIA exist among the districts. By 1984-85, the Coastal districts are by far better irrigated accounting for nearly 59 per cent of the states TNIA while Rayalaseema and Telangana districts are less irrigated, accounting for only 13 per cent and 28 per cent of the states TNIA respectively. This is also reflected in terms of the net irrigated area as a proportion to the net sown area in these districts. This picture at the end of the sample period emerges despite the relatively faster growth in TNIA in many of the Telangana and Rayalaseema districts over our sample period (see Table 3).

(iii) The two surface water sources, canals and tanks, put together are the most important sources of irrigation in all the districts of Andhra Pradesh.

(iv) Canal irrigation has grown in most of the districts. In some districts, over the years, canals, instead of tanks, have become the major source of irrigation under surface water component.

(v) Over the years, tank irrigation is being neglected in most of the districts as shown by the fall in the net irrigated area by tanks in most of the districts.

(vi) Regarding the groundwater component (tubewells and other wells), while in some districts these are fairly developed, in other districts these are negligible.

(vii) Tubewells as a source of irrigation are of negligible importance in most of the districts except in East Godavari and West Godavari.

The above features of irrigation development in Andhra Pradesh is reflected in the spatial variability in the sourcewise net irrigation proportions (ratio of sourcewise net irrigated area to the net sown area over all crops) across the districts, as measured by the CVs reported in Table 1. From this table it can be seen that the spatial variability (disparities) across districts is high for each of the five sources of irrigation as also for the three aggregated variables, SWTR, GWTR and TNAS (CVs > 0.3). Amongst the various sources of irrigation, tubewells have the highest CVs, followed by canals.

In terms of the relative ranking of districts, all the five Coastal districts are HVD for TCNL and SWTR while all the districts of Rayalaseema and Telangana with the sole exception of Nizamabad are LVD (see Table 2). Further, the relative rankings of the districts as LVD and HVD have not changed over time for both TCNL and SWTR. Recall that the coastal districts are HVD with respect to most of the crop yields also. The deterioration of the situation with respect to tanks as an important source of irrigation can also be seen from Table 2. Over the years, 5 districts - East Godavari, West Godavari, Krishna, Guntur + Prakasam + Nellore, and Khammam - have turned LVD (TANK) even as tank irrigation proportion in the state as a whole declined.

In the case of tubewells, TBWL in 1960-61 was negligible in all the districts. By 1984-85, however, most of the Coastal districts (East Godavari, West Godavari, Krishna, Guntur + Prakasam + Nellore), Cuddapah and Khammam had witnessed some development in this source and these districts became HVD (TBWL). By 1984-85, although in some of these districts TBWL was as high as about 15 per cent, in the state as a whole it is still a negligible source of irrigation. The other wells component is the dominant source under groundwater in all districts, though groundwater itself is not the dominant source of irrigation in general. Groundwater sources contribute little to irrigation in the Coastal districts while in several of the Rayalaseema and Telangana districts, they are important. In all the districts except in Srikakulam + Vizianagaram + Vishakhapatnam, Kurnool and Nalgonda, GWTR has witnessed high growth rates (see Table 3). These growth rates are in general higher in the relatively drier districts of Rayalaseema and Telangana than in the Coastal districts. The growth in GWTR came essentially through the development of tubewells component (practically with no development at all in the other wells component) in Coastal districts, whereas it is essentially through other wells component in the non-Coastal districts. The relative ranking of the districts for GWTR, however, has remained more or less stable with only West Godavari becoming HVD (GWTR) over time.

With regard to the other sources of irrigation proportion in total net sown area (OSRC), the relative rankings of the districts have been more or less stable. The Coastal districts are HVD. The Rayalaseema districts are mostly LVD. The Telangana districts except Nizamabad did not witness any change in their relative positions with Ranga Reddy + Hyderabad, Medak, Mehboobnagar, Nalgonda, Warnagal and Adilabad remaining LVD and Khammam and Karimnagar remaining HVD. Nizamabad is the only Telangana district that turned HVD over time.

Thus, in general, efforts at irrigation development seem to be somewhat non-uniform across various districts in different regions in Andhra. In particular, the districts in Rayalaseema seem to be unfavourably positioned in this context.

Turning to movements over time in the CVs of the sourcewise net irrigation proportions, the T-test results reported in Table 1 suggest that the disparities across districts in the overall net irrigation proportion have declined over time as indicated by the fall in CV (TNAS) over time. This, however, is not true in the case of all the individual sources of irrigation. Amongst the two surface water sources, canals and tanks, the inter-districts disparity in canal irrigation proportion has fallen as shown by the fall in CV (TCNL); whereas the disparity in tank irrigation proportion has risen over time as shown by the rise in CV (TANK). As mentioned above, TCNL has grown in all the districts, both HVD and LVD, and its growth pattern has been in a manner that led to a reduction in its CV. Tank irrigation, both in absolute (hectares) and as a proportion to the total net sown area, however, has declined in most, but not all, of the districts. As a result, its CV has increased over time. The movement in opposite directions in TCNL and TANK has resulted in SWTR being stagnant in almost all the districts. Thus CV (SWTR) has also remained stagnant over time.

Amongst the groundwater sources (tubewells and other wells), the inter-districts disparity in tubewell irrigation proportion has declined over time as shown by the fall in CV (TBWL), though the magnitude of CV (TBWL) itself is very high as seen in Table 1. Other wells irrigation proportion has, however, not witnessed any change (rise/fall) in its inter-districts disparity as shown by the constant levels of CV (OTWL) (which is also high). As mentioned earlier, TBWL has grown in all the districts, although it remains negligible in all but the two Godavari districts. The growth pattern in TBWL across districts has resulted in a fall in its CV. Other wells, which form the major component of GWTR, have also grown in most of the districts, although its growth pattern has not affected its CV. As a result of the growth in both TBWL and OTWL, GWTR grew in most of the districts in such a manner that has resulted in a fall in CV (GWTR).

With respect to OSRC, the results show that its inter-districts disparity has reduced over time as shown by the fall in CV (OSRC).

(B) *Aggregate cropping intensity*

Cropping intensity is a measure of the intensity of cultivation on a given plot of land, i.e., the number of harvests of different crops raised on a given plot of land in one year. It is defined as the ratio of gross cropped area under a crop to the net sown area under that crop. Time-series data on gross cropped area are available for individual crops and over all crops. However, data on net sown area are available only over all crops but not for individual crops. Hence, aggregate cropping intensity (ACI) over all crops alone is considered here. ACI is defined as the ratio of the sum of gross cultivated area of all crops to the total net cultivated area over all crops.

Since water is an important input for cultivation, irrigation, especially assured irrigation, can be expected to play an important role in promoting ACI. Canals and well irrigation are generally considered to be the sources that offer assured irrigation. Indeed, the following linear regression of ACI on TCNL and OTWL, at the Andhra Pradesh State level, confirms the expected positive relationship between ACI and these two sources of irrigation (t-statistics are reported in parentheses; all coefficients are significant at 1 per cent level).

$$ACI_t = \underset{(51.05)}{1.0168} + \underset{(3.46)}{0.6698}.TCNL_t + \underset{(3.12)}{0.6626}.OTWL_t + U_t\,. \quad \bar{R}^2 = 0.77. \quad DW = 1.95.$$

As described above, these two sources have shown different growth pattern across the districts, which would result in differences across districts in the ACI.

Disparity in ACI across districts of Andhra Pradesh, as measured by its CV, has been 'low' (< 0.3) throughout the period under consideration (see Table 1). In fact, CV (ACI) is far lower than the CV of the irrigation variables discussed earlier. This would imply that the level of ACI, unlike irrigation, is more or less uniform across the districts. From Table 2 it can be seen that all the five Coastal districts have remained HVD (ACI) throughout. While Nizamabad, Nalgonda and Warangal from Telangana have improved from LVD to HVD, the remaining Telangana districts (Ranga Reddy + Hyderabad, Medak, Mehboobnagar, Khammam, Karimnagar and Adilabad) have been LVD throughout. The same is true with the Rayalaseema districts of Kurnool, Anantapur, Cuddapah and Chittoor, of which Chittoor was initially HVD though.

If, as the above-mentioned regression results suggest, irrigation facilities contribute to ACI, the differences in the magnitudes of CVs of ACI and irrigation facilities are worth more consideration. CV (ACI) is far lower than CV (TCNL) and CV (OTWL). This only implies that though irrigation facilities do contribute to ACI, the response of ACI with respect to irrigation development is different in different districts. The above relation between ACI and irrigation actually suggests that the elasticity of ACI with respect to irrigation is likely to be higher, the higher the irrigation proportion. In fact, the growth rates in ACI reported in Table 3 are higher in the Coastal districts than in the non-Coastal districts. This suggests that CV(ACI) is likely to go up over time.

Indeed, a visual observation itself of the CV (ACI) (see Table 1) indicates that it has increased over time. This is also confirmed by the T-test result in Table 1. Recall that ACI has grown over time only in a few districts (East Godavari, West Godavari, Krishna, Nizamabad, Nalgonda, Warangal and Karimnagar) while it has remained stagnant in the rest of the districts (see Table 3). The increase in CV (ACI) reflects this growth pattern across districts.

Spatial Variability in Crop-Specific Inputs

The crop-specific inputs considered in this analysis are the cropwise gross irrigation proportions and fertiliser availability.

(A) *Gross irrigation proportions*

Gross irrigation proportion (sometimes referred to as "irrigation intensity") for a crop is defined as the ratio of gross irrigated area under a crop to the gross cultivated area under that crop. The gross irrigation proportions of rice, jowar, bajra, ragi and maize are denoted as IRCE, IJWR, IBJR, IRGI and IMZE respectively. Time-series of the CVs across districts for the gross irrigation proportions for the period 1960-61 to 1984-85 are reported in Table 1.

From this table it can be seen that CV (IRCE) is low (< 0.3) all through the sample period. The corresponding CVs for the remaining four crops are, however, high (> 0.3), often exceeding 1.0. Of them, IJWR has the highest CV for several years, followed closely by CV (IBJR). CV (IRGI) and CV (IMZE) are generally less than CV (IJWR) and CV (IBJR) with CV (IRGI) being higher than CV (IMZE) for most of the later years in the sample period. These figures suggest that the levels of irrigation intensity for rice cultivation are more or less uniform across the districts whereas it is not so for other crops.

Rice is a highly irrigated crop in all the years in all the districts of Andhra Pradesh. This explains the low CV (IRCE) in general. In 1984-85, IRCE ranged only from 0.623 (Adilabad) to 1.0 (Nalgonda) with the state average being 0.945. Further, the relative rankings of the districts with respect to IRCE have been more or less maintained with only Chittoor and Nizamabad slipping from HVD to LVD over the 25 years. It may be noted here that about 76 per cent of the state's rice production in 1984-85 came from HVD, of which 58 per cent came from East Godavari, West Godavari, Krishna, and Guntur + Prakasam + Nellore alone.

Jowar is grown mainly under unirrigated condition in all the districts. In 1984-85, IJWR ranged from 0.0 (Srikakulam + Vizianagaram + Visakhapatnam, Krishna, Medak, Mehboobnagar, Nalgonda, Warnagal and Khammam) to 0.147 (Chittoor) with only 0.008 being the state average; i.e., less than 1 per cent of the jowar acreage in the state was under irrigation. All HVD (IJWR) put together accounted for only about 40 per cent of the state's production in 1984-85, of which about 20 per cent came from Kurnool alone. That is, the districts that contributed 60 per cent of the state total production of jowar sparsely used irrigation for its cultivation.

The case of irrigation intensity for bajra cultivation (IBJR) across districts is more interesting than the cases of rice and jowar cultivation discussed above. Though the low state average level of IBJR (0.120) indicates that bajra too, like jowar, is mainly an unirrigated crop in Andhra Pradesh in some districts, however, IBJR is very high. In 1984-85, IBJR ranged between as low as 0.0 (Srikakulam + Vizianagaram + Vishakhapatnam, East Godavari, Krishna, Medak, Nalgonda, Warangal and Khammam) to as high as 0.993 (Nizamabad) with three districts having more than 50 per cent of the crop under irrigation. These are Guntur + Prakasam + Nellore (50.3 per cent), Cuddapah (57.2 per cent) and Nizamabad (99.3 per cent). The contributions of these districts in 1984-85 to the state's bajra production are: Guntur + Prakasam + Nellore (21 per cent), Cuddapah (10 per cent) and Nizamabad (< 1 per cent). The case of Nizamabad is unique as very little bajra is grown in that district but almost completely under irrigation. This may be contrasted with Srikakulam + Vizianagaram + Vishakhapatnam, which accounted for 32 per cent of the state total in 1984-85 but where only 9 per cent of bajra was cultivated under irrigation. This shows that there are wide differences across districts in bajra cultivation practices. The share of the five HVD (IBJR) in the state's production of bajra in 1984-85 is about 38 per cent, of which 37 per cent came from Guntur + Prakasam + Nellore, Cuddapah and Chittoor. Amongst LVD (IBJR), Srikakulam + Vizianagaram + Vishakhapatnam, Ananatapur and Nalgonda are substantial contributors (32 per cent, 8 per cent and 9 per cent in 1984-85 respectively) to the state's production.

Turning to ragi, in 1984-85, IRGI also ranged between 0.0 (East Godavari, West Godavari, Krishna, Ranga Reddy + Hyderabad, Nizamabad, Medak, Warangal, Khammam, Karimnagar and Adilabad) and 0.993 (Cuddapah), the state average being 0.326. While in the state as a whole a third of ragi cultivation is under irrigation, in as many as 10 of the total 18 districts ragi is grown under completely unirrigated conditions. The share of HVD (IRGI) in the state's output of ragi in 1984-85 was about 36 per cent, almost all of which came from Guntur + Prakasam + Nellore, Anantapur and Cudappah. Amongst LVD (IRGI), the major contributors in 1984-85 were Srikakulam + Vizianagaram + Vishakhapatnam (30 per cent), Chittoor (14 per cent), Ranga Reddy + Hyderabad (6 per cent) and Mehboobnagar (11 per cent).

In the case of maize also, the crop's irrigation intensity (IMZE) ranged between 0.0 (Nalgonda) and 1.0 (Cudappah) while the state average is 0.204. A feature of maize cultivation in Andhra Pradesh is that in almost all the districts, at least some amount of maize is grown under irrigation. While in some districts IMZE is as high as 0.7 or even more, it is less than 0.5 in the four districts that are major contributors to the state's total maize production - Nizamabad (24 per cent), Medak (10 per cent), Warangal (10 per cent) and Karimnagar (44 per cent) which together accounted for about 88 per cent of the state's production in 1984-85. In 1984-85, IMZE was 0.136, 0.026, 0.274 and 0.401 in these four districts respectively.

Thus it emerges that in the case of superior cereal rice, the major contributors to the state's output are the districts where the crop is mostly under irrigated conditions, whereas in the case of inferior cereals, the major contributing districts are the ones where these crops are mostly under unirrigated conditions.

Turning now to changes, if any, over time in the CVs of the cropwise irrigation intensities, visual observation of the CVs reported in Table 1 does not indicate any change in CV (IRCE), CV (IJWR), CV (IBJR) and CV (IRGI). CV (IMZE), however, seems to show a fall towards the end of the period. These observations are confirmed by the T-tests reported in Table 1, which indicate that only in the case of maize there is a significant fall in the mean levels of

CV (IMZE) in the second sub-period. In the remaining four crops, however, there has been no significant change in the CV between the two sub-periods.

IRCE, IJWR and IRGI have remained more or less unchanged in all the districts. Thus their CVs across districts also have not changed over time. IBJR has grown in a few districts (Guntur + Prakasam + Nellore, Cuddapah and Nizamabad) while in the rest of the districts it has remained unchanged. The growth observed in these few districts, however, has not been sufficient enough to result in a significant increase in CV(IBJR). IMZE, on the other hand, has grown in almost all the districts and this seems to have reduced its inter-districts differences as shown by the significant fall in CV(IMZE).

(B) *Fertiliser availability*

With respect to fertiliser, continuous time-series data on cropwise fertiliser use are not available both at the state and at the district level. Instead, data on fertiliser consumption only over all crops are available.[3] Hence, in this analysis we consider the ratio of total fertiliser consumed to the total cultivated acreage under the five cereal crops, as a measure of fertiliser 'availability' per acre of the five cereals crops (denoted FRT). From the districtwise data, time-series of CV(FRT) computed for the period 1960-61 to 1984-85 is reported in Table 1.

It can be seen that CV(FRT) has been high (> 0.3) throughout the sample period. In 1984-85, FRT ranged between 3.2 kg/ha (AD) to about 32.9 kg/ha (Guntur + Prakasam + Nellore) with the state average being about 15.6 kg/ha. (see Table 2). West Godavari, Krishna, Guntur + Prakasam + Nellore, Cuddapah and Nizamabad are the districts using relatively high levels of fertiliser compared to others. The T-test for assessing the changes in the CV over time shows that CV (FRT) has fallen significantly over the 25 years, implying that the inter-districts disparity in fertiliser use has fallen over time.

III

FACTORS EXPLAINING SPATIAL VARIABILITY IN CROP YIELDS

What are the factors that explain the changes in the spatial variability of crop yields over time reported earlier? In other words, why is the magnitude of the differences in crop yields across districts what it is? Towards answering this question, regression equations that relate CV (Yields) to the CVs of the explanatory factors are estimated. Such a regression equation involving only the CVs, it must be noted here, cannot and in fact is not meant to answer the question "why is the crop yield level in various districts what it is". Only a regression equation in the levels of the variables can answer this latter question. Indeed the latter question is not within the scope of the paper at all.

The explanatory factors considered here are the sourcewise net irrigation proportions, fertiliser availability, cropping intensity and seasonal rainfalls. The perspective maintained here is to analyse districtwise crop yield disparities in terms of disparities in development levels as manifested in the infrastructural variables (sourcewise irrigation proportions and cropping intensity). As a result, the disparities in cropwise irrigation intensities remain only in the background since these intensities are essentially determined by availability of irrigation facilities from different sources.

For each crop under study, a linear relationship is estimated in which CV(YRCE), CV(YJWR), CV(YBJR), CV(YRGI) and CV(YMZE), reported in Table 1, are the dependent variables. The explanatory variables are CV(RSW), CV(RNE), CV(TCNL), CV(TANK), CV(OTWL), CV(SWTR), CV(GWTR), CV(ACI) and CV(FRT), which are all reported in Table 1. Amongst the different individual sources of irrigation, TBWL and OSRC are negligible in most districts and hence these two sources of irrigation are not considered in this analysis. TCNL, TANK and OTWL are the most important sources of irrigation in all the districts. All of surface water and most of the groundwater are accounted for by these three sources in all the districts.

Before estimating any regression, simple correlation coefficients between the explanatory variables are computed to check for multicollinearity, if any, among these variables. These correlations were found to be generally low, implying that multicollinearity is not a serious problem among the explanatory variables.

Initially keeping SWTR and GWTR along with the rainfall, fertiliser availability and cropping intensity as the explanatory variables to explain CV(Yield) for each crop, the following linear relationship is estimated:

$$CV(Y)_{it} = \beta_{0i} + \beta_{1i}CV(RSW)_t + \beta_{2i}CV(RNE)_t + \beta_{3i}CV(FRT)_t + \beta_{4i}CV(ACI)_t + \beta_{5i}CV(SWTR)_t + \beta_{6i}CV(GWTR)_t + U_{it} \quad \ldots\ldots(1)$$

[3]

$i = 1, \ldots, 5$ are the crops; $t = 1, \ldots, T$ are the years (=25).

Equation (1) covers five cases - one for each of the five cereal crops, rice, jowar, bajra, ragi and maize, studied here. Note that all the explanatory variables are the same in all the five equations of (1). SWTR is all the net area irrigated by surface water sources (canals and tanks) as a proportion to total net sown area. SWTR, thus defined, is a measure of the availability of irrigation from surface water sources for crop cultivation in general. Various crops may compete with each other in utilising this available surface water irrigation. This would imply that the five equations of (1) are not completely unrelated regressions. Under such a situation, the random disturbances in say CV(YRCE) may be correlated with the random disturbances in say CV(YMZE) during the same period; i.e., we may expect contemporaneous correlation in the random disturbances of the five equations of (1). In the presence of such contemporaneous correlations single equation estimators would not be efficient. Hence, the five equations are simultaneously estimated using Zellner's Seemingly Unrelated Regressions (SUR) procedure (Zellner, 1962).

If the contemporaneous correlations equal zero (or are very small), it would imply that contemporaneous correlations do not exist (or is not severe) between the random disturbances across equations. Indeed, the results of the SUR estimation[4] showed that the random disturbances were all mostly uncorrelated across the five equations of (1). The contemporaneous correlations were all mostly less than 0.4 except in one case where it turned out to be 0.6 (between the residuals of rice and ragi equations). In such a situation there is not much efficiency loss due to estimation as single equations.

As for the coefficients themselves, the SUR estimation results showed that in the case of rice, the CVs of RSW, ACI and GWTR had insignificant coefficients, while in the case of bajra, RSW, RNE and FRT had insignificant coefficients and in the case of ragi, RSW and FRT had insignificant coefficients. For jowar and maize, however, specification (1) fared badly and alternative explanatory variables to SWTR and GWTR may have to be considered. The individual sources of irrigation (TCNL, TANK and OTWL), i.e., the disaggregated components of surface water and groundwater, are the alternative explanatory variables considered and all the equations were re-estimated as single equations.

In the case of CV(YRCE), the disaggregation of the explanatory variables did not help at all. Hence, only CV(SWTR) and CV(GWTR) are retained here along with the other explanatory variables, of which CV(GWTR) turned insignificant. In the case of CV(YBJR), the tank component of surface water and total groundwater both turn significant along with other explanatory variables. Turning to ragi and maize, while only the tank component of surface water is significant but not groundwater in the case of CV(YRGI), only the other wells component of groundwater but nothing of surface water is significant in the case of CV(YMZE). In the cases of CV(YRCE), CV(YRGI) and CV(YMZE), the disparities in rainfall and fertiliser availability also explain their CV(Yields). Only in the cases of CV(YBJR) and CV(YRGI), the disparity in ACI also appears as an explanatory variable. However, in the case of jowar, none of these variables could explain the disparities in its yields. The final results of our regression analysis are presented in Table 4. It can be seen that the fits obtained are only moderate with $\overline{R}^2$ being the highest for CV(YBJR) at 0.6546, followed by CV(YRCE), CV(YRGI) and CV(YMZE) in that order. In the case of jowar, none of the explanatory variables considered here including the disparities in the rainfalls could explain the disparities in its yields across districts. The fit, in terms of $\overline{R}^2$, turned out to be too poor. Hence, we discuss below the cropwise results for rice, bajra, ragi and maize only.

Coefficient of Variation in Rice Yields

The explanatory variables appearing in the regression for CV(YRCE) are CV(RNE), CV(FRT) and CV(SWTR), all of them with significant positive coefficients. As noted earlier, CV(YRCE) is low (< 0.3) whereas the above three explanatory variables are all high (> 0.3).

Yields depend on several factors including fertiliser used and the quantum of water provided to the crop. Rice is a water intensive crop. Water input comes from rainfall and/or irrigation sources. Amongst the two rainfall terms, RSW and RNE, only CV(RNE) turns out to be significant. CV(RNE), being a climatic aspect, is unlikely to change over time (at least in the short run). Apart from this, as far as irrigation is concerned, almost all the districts have high irrigation intensity for this crop. This irrigation obviously has to come from surface water and/or groundwater sources. In the regression equation only CV(SWTR) turns out to be significant. Recall that CV(SWTR) is generally high (see Table 1) with a further feature that it has not changed over time. Thus these two explanatory variables, CV(RNE) and CV(SWTR), which are unchanging over time, are unlikely to cause any change in the disparities in rice yields over time.

With regard to fertilisers, CV(FRT) has fallen significantly over time as seen earlier. With a positive relation with CV(YRCE) as the estimated regression equation shows, the falling trend in CV(FRT) brings forth a falling tendency in the latter. Indeed the time-series of CV(YRCE) reported in Table 1 seem to show a slight, though not a significant, fall over time. Two points need to be noted here. Firstly, fertiliser use and adoption of HYV seeds are generally highly related. Secondly, HYV adoption for rice in Andhra Pradesh is very high (81 per cent in 1984-85) but not 100 per cent though. Thus it is possible that with further spread of HYV the disparities in fertiliser intensity could fall further which, as the results point, could reduce the already low disparities in rice yields further.

Coefficient of Variation in Bajra Yields

Two estimated regression equations have been reported in Table 4. The first equation has CV(ACI), CV(SWTR) and CV(GWTR) as the explanatory variables. While CV(ACI) and CV(GWTR) have significant negative coefficients, CV(SWTR) has a significant positive coefficient. Note that none of the two rainfall variables or fertiliser appears in this regression. As pointed out earlier, CV(YBJR) is high and has increased over time (see Table 1). The positive coefficient of CV(SWTR) which is high and unchanging over time and the negative coefficient of CV(GWTR) which is also high but falling over time, both explain the high and increasing value of CV(YBJR). The rising trend of CV(ACI) due to its inverse relationship with CV(YBJR), however, dampens the rising trend in the latter.

In most of the districts where some bajra is grown under irrigated conditions, surface water is the dominant source of irrigation such as, for example, in Srikakulam + Vizianagaram + Vishakhapatnam (90 per cent), West Godavari (76 per cent), Guntur + Prakasam + Nellore (80 per cent), Kurnool (81 per cent), Nizamabad (76 per cent), Khammam (72 per cent), Karimnagar (55 per cent) and Adilabad (80 per cent) where the figures in parentheses are the percentages of surface water component in the total irrigation in 1984-85. Even in Cuddapah and Chittoor, this component has been dominant until recently. Of all these districts, Guntur + Prakasam + Nellore, Cuddapah, Chittoor, Nizamabad and Karimnagar are in fact HVD (IBJR), i.e., relatively more irrigation intensity for bajra than in other districts. Thus it appears that surface water is the main source for irrigated cultivation of bajra. Then our results suggesting that the disparities in surface water proportions are positively related to the disparities in bajra yields are tenable.

TABLE 4. FINAL ESTIMATION RESULTS

Dependent variable (1)	Constant (2)	CV (RSW) (3)	CV (RNE) (4)	CV (FRT) (5)	CV (ACI) (6)	CV (SWTR) (7)	CV (TANK) (8)	CV (GWTR) (9)	CV (OTWL) (10)	$\overline{R}^2$ (11)	D-W (12)
CV (YRCE)	-0.3923 (-3.06)*		0.0698 (2.50)**	0.1033 (2.18)**		0.5467 (3.93)*				0.4742	1.81
CV (YBJR)	0.5807 (1.31)				-3.5118 (-2.02)***	1.4056 (4.29)*		-1.2197 (-3.53)*		0.4879	1.82
	0.8002 (2.34)**				-4.1322 (-2.87)*		0.8966 (6.12)*	-0.6719 (-2.39)**		0.6546	1.81
CV (YRGI)	0.5575 (1.65)		0.0794 (1.63)	-0.1977 (-1.87)***	-2.9131 (-2.24)**	0.5280 (2.09)***		-0.3560 (-1.11)		0.4325	1.51
	0.5174 (3.01)*		0.0773 (1.66)	-0.2186 (-2.51)**	-2.6677 (-2.61)**		0.3029 (2.22)**			0.4659	1.75
CV (YMZE)	1.011 (3.20)*	0.2138 (1.41)		-0.1676 (-1.99)***					-0.8642 (-2.89)*	0.4252	2.23

Notes: (1) See Appendix for variable definitions.
(2) t-values are given in parentheses.
(3) *, ** and *** indicate significance at 1, 5 and 10 per cent level respectively.

However, the growth rates in the area irrigated by surface water as a whole are negligible whereas the growth rates in the area irrigated by groundwater are significantly positive in most of the districts. The latter has grown in all the districts except Kurnool and Nalgonda where it has remained stagnant and in Srikakulam + Vizianagaram + Vishakhapatnam, it has declined over time (see Table 3). This pattern of growth in groundwater irrigation across the districts has resulted in a significant decline in CV(GWTR). At the same time, YBJR, on the other hand, has remained stagnant in most districts with only Srikakulam + Vizianagarm + Vishakhapatnam, West Godavari, Krishna and Cuddapah registering a growth. Thus it is clear that growth in groundwater irrigation did not contribute to growth in YBJR in most of the districts. However, CV(GWTR) still figures in the estimated regression as a significant explanatory variable. This is perhaps explainable by taking into account the possible changes in the cropping pattern as irrigation develops. For example, when groundwater becomes available for irrigation, some other crops (including cash crops) may be cultivated now where bajra was being cultivated earlier. That is, bajra continues to remain under unirrigated cultivation and hence bajra yields do not grow. While this is the general pattern applicable to most of the districts, however, four districts - Srikakulam + Vizianagarm + Vishakhapatnam, West Godavari, Krishna and Cuddapah - stand as exceptions. Here, in fact, the bajra yields grew up significantly while in all other districts it did not grow. Thus CV(YBJR) could go up while CV(GWTR) has fallen over time.

Disaggregation of GWTR into its component sources did not give satisfactory results. Hence, CV(GWTR) is retained here. Disaggregation of SWTR into its component sources, TCNL and TANK, however, was found to explain CV(YBJR) better. Of these two individual surface water sources, only CV(TANK), but not CV(TCNL), was found to be an important variable in explaining CV(YBJR). CV(TANK), with significant positive coefficient (same as that of CV(SWTR)), as an explanatory variable, instead of CV(SWTR), improved the fit substantially (see Table 4). CV(TANK) is high and increasing over time (see Table 1) as a result of the fall in irrigated area under tanks in some districts while it remained stagnant in other districts. The high and increasing levels of disparities in tank irrigation proportion seem to push up the disparities in bajra yields across districts.

ACI, which is a measure of multiple cropping, increases with increase in irrigation facilities. When irrigation becomes available it is possible, for example, to raise two crops instead of one crop in a year. Then it is likely that one crop is grown under irrigation, while the other may be less irrigated/unirrigated crop. Obviously, given the farmers' preferences, rice would be the irrigated crop and inferior cereal such as bajra, ragi, etc., would be the unirrigated crop. Thus bajra yields continue to remain unirrigated in most of the districts which would result in a fall in CV(YBJR). Thus an increase in CV(ACI) is likely to result in a fall in CV(YBJR). The net effect of the increase in CV(ACI) through its negative relation with CV(YBJR) has been to dampen the increase in the latter.

Coefficient of Variation in Ragi Yields

Two estimated equations have been reported for CV(YRGI) in Table 4. The explanatory variables in the first regression are CV(RNE), CV(FRT), CV(ACI), CV(SWTR) and CV(GWTR). Of these CV(RNE) and CV(SWTR) have significant positive coefficients, while CV(FRT) and CV(ACI) have significant negative coefficients. The coefficient of CV(GWTR) is negative but insignificant. From Table 1 we know that CV(YRGI) is high and has increased over time. All the explanatory variables except CV(ACI) are high valued (i.e., the CVs are > 0.3) and this explains the high levels of CV(YRGI). CV(SWTR) which has not showed any change over time is unlikely to cause any change in CV(YRGI) over time. The downward trend in both CV(FRT) and CV(GWTR), because of their negative coefficients, results in an upward trend in CV(YRGI). The upward trend in CV(ACI) with a negative coefficient, however, dampens the upward trend in CV(YRGI).

The positive coefficients of both CV(RNE) and CV(SWTR) imply a direct relation between these two variables and CV(YRGI) in a way is similar to that in the case of rice described earlier. Disaggregation of SWTR into its component sources (TCNL and TANK) was found to explain CV(YRGI) better. Of these two sources, only CV(TANK), but not CV(TCNL), was found to have significant and positive coefficient. The fit also improved slightly (see Table 4). CV(TANK), as noted earlier, is high and increasing over time. Thus the high and increasing levels of disparities in tank irrigation proportion have resulted in a high level of disparity in ragi yields, which too is increasing over time. The coefficient of CV(GWTR) is insignificant and its disaggregation into OTWL did not help in explaining CV(YRGI). In fact, CV(GWTR) is dropped in the second regression reported in Table 4.

Turning to FRT, CV(FRT) is high but falling over time and it has a negative coefficient in the regression for CV(YRGI). That is, the falling levels of disparity in fertiliser availability would actually push up the disparities in YRGI across districts. This may be explained as follows: Note that CV(FRT) has a positive coefficient with respect to CV(YRCE), which implies that falling disparities in fertiliser availability would lead to falling disparities in YRCE. Rice is mostly a HYV seed-based crop in Andhra Pradesh, which is both irrigation and fertiliser intensive. In 1984-85, 81 per cent of rice acreage in Andhra Pradesh was under HYV seeds while ragi is fully a traditional variety seed-based crop. Rice, being a superior cereal unlike ragi, is also a more remunerative crop. Thus not only rice takes away a large share of the total fertiliser that is usually available only in limited quantities, but also with increased fertiliser availability (often accompanied with increased HYV adoption), farmers may prefer to allocate more land for rice cultivation. Besides, a falling CV(YRCE) implies that yield levels in LVD (YRCE) are moving closer to those levels in HVD(YRCE). This implies that relatively fertile land gets allocated to rice rather than to other crops. Thus ragi. and other inferior cereals move over time to less and less fertile lands and also end up with only marginal amounts of the limited available fertilisers. Thus a falling CV(FRT) is associated with a rise (fall) in CV(YRGI) (CV(YRCE)). This pattern can be seen in the case of CV(YMZE), also discussed below. These results might change once fertilisers become freely available at prices affordable by farmers.

The negative coefficient of CV(ACI) in these regressions can be explained exactly in the same way as in the case of bajra earlier.

Coefficient of Variation in Maize Yields

The finally chosen regression for CV(YMZE) has CV(RSW), CV(FRT) and CV(OTWL) as the explanatory variables. CV(FRT) and CV(OTWL) have significant negative coefficients (see Table 4). The coefficient of CV(RSW), which is positive, is significant only at 17 per cent significance level.

As mentioned earlier, CV(YMZE) is low but it has increased over time (see Table 1)

From the same table we also know that all the three explanatory variables here are high valued. The constant term and the high values of CV(RSW) with positive coefficient seem to compensate to a large extent the high values of CV(OTWL) and CV(FRT), both of which have negative coefficients, resulting in a low valued CV(YMZE).

The observed trend in CV(YMZE) must be explained in terms of trends in the explanatory variables. RSW being a climatic variable, no trend is expected in its pattern across districts; i.e., CV(RSW) is taken to show no trend. From Table 1 we find that CV(OTWL) does not show any trend but CV(FRT) has fallen over time. It is this fall in CV(FRT) which, due to its inverse relationship with CV(YMZE), explains the rise in the latter.

Disparities in rainfall (South-West rather that North-East monsoon) have a direct effect on the disparities in maize yield levels. This is similar to the relationship between CV(RNE) and CV(YRCE) as explained earlier.

The negative coefficients of both CV(OTWL) and CV(FRT) imply inverse relationship with these two variables, which need some explanation. Note from Table 3 that in 13 out of 18 districts, YMZE shows significant positive growth rates. In 7 (Guntur + Prakasam + Nellore, Anantapur, Cuddapah, Chittoor, Mehboobnagar, Warangal and Karimnagar) of these 13 districts, other wells irrigation area also simultaneously recorded significant positive growth rates with surface water irrigation area not growing at all (except in Guntur + Prakasam + Nellore). In the remaining 6 districts (Srikakulam + Vizianagaram + Vishakhapatnam, East Godavari, West Godavari, Krishna, Kurnool and Nalgonda), YMZE grew despite stagnant/falling levels of other wells irrigation area. Thus it appears that other wells irrigation area's contribution, if any, to growth in YMZE is restricted to only the above mentioned 7 districts. But it also turns out that in these 7 districts where other wells may have contributed to growth in YMZE, 4 (Guntur + Prakasam + Nellore, Cudddapah, Chittoor and Warangal) of them are LVD(YMZE) and HVD(OTWL) showing growth in both of them. Growth in OTWL in already HVD(OTWL) implies an increase in over all CV(OTWL). Whereas growth in YMZE in LVD(YMZE) implies a decrease in over all CV(YMZE). Thus there is the possibility of the negative coefficient for CV(OTWL) in the estimated regression equation.

However, the growth in OTWL across all districts has not resulted in any significant increase/decrease in CV(OTWL) (see Table 1). That is, the unchanging levels of CV(OTWL) over time would only keep CV(YMZE) at an unchanging level over time. However, from Table 1 we also know that CV(YMZE) has increased over time. The increase in CV(YMZE) is due to its negative relationship with CV(FRT) which has been falling over time. This negative relationship can be explained, as in the case of CV(YRGI), in terms of changes in cropping pattern and cropwise fertiliser allocations.

IV

CONCLUSIONS

In this paper, spatial variability in yields of the five cereal crops across the districts of Andhra Pradesh was studied. As measured by coefficient of variation across the districts, the pattern of growth and spatial variability observed is as follows:

Yields of all five crops show either positive growth or are stagnant. None of the five crops show falling yields in any district. Yield disparities across districts for rice and jowar are low and remained unchanged over time. Yield disparity for maize is also low but shows an increase over time. Yield disparities for ragi and bajra are high and have increased over time.

The overall growth pattern of the crop yields is that the superior cereal rice has experienced growth in almost all districts, particularly the LVD(YRCE) showing faster growth than the HVD(YRCE). Among the inferior cereals, while jowar yields have remained stagnant in almost all districts, bajra and ragi yields grew only in a few districts which are already HVD(YBJR) and HVD(YRGI). The case of maize is opposite to that of rice, where several districts show growth but HVD(YMZE) growing faster than LVD(YMZE). This growth pattern explains the movement over time in CV(Yields) presented above.

Rainfall disparities are high, with rainfall during North-East monsoon showing higher disparity than during South-West monsoon.

Canal irrigation area shows growth in most districts while tank irrigation area is either falling/stagnant in all the districts. Total surface water irrigation area, however, is stagnant in most districts. Canal irrigation proportion shows high disparity which decreased over time. Tank irrigation proportion too shows high disparity which, however, increased over time. As a result, the high disparity in surface water irrigation proportion remained unchanged over time.

Tubewells irrigation area shows positive growth in most of the districts while other wells irrigation area shows positive growth in some, but not in all districts. Thus the total groundwater irrigation area is growing in almost all districts. Tubewell irrigation proportion shows high disparity, which decreased over time while the high disparity in other wells irrigation proportion remained unchanged over time. Groundwater irrigation proportion as a whole shows high disparity, which decreased over time.

Total (by all sources together) net irrigation area is growing in almost all districts; total net irrigation proportion shows high disparity, which decreased over time.

Thus, in general, efforts at irrigation development seem to be somewhat non-uniform across various districts in different regions of Andhra Pradesh. In particular, the districts in Rayalaseema seem to be unfavourably positioned in this context.

Aggregate cropping intensity is increasing in all districts; it shows low disparity but increasing over time. ACI is shown to be positively related to canal and other wells irrigation proportions. However, CV(ACI) is far lower than CV(TCNL) and CV(OTWL). This only implies that though irrigation facilities do contribute to ACI, the response of ACI with respect to irrigation development is different in different districts. The above relation between ACI and irrigation actually suggests that the elasticity of ACI with respect to irrigation is likely to be higher than the irrigation proportion. This suggests that CV(ACI) is likely to go up over time.

The cropwise irrigation intensities of rice show low disparity, which has remained unchanged over time. The cropwise irrigation intensities of jowar, bajra, ragi and maize show high disparities, of which the disparities in the irrigation intensities of jowar and ragi remained unchanged; while the disparity in the irrigation intensity of bajra increased and that of maize decreased over time.

Fertiliser intensity shows high disparity, which decreased over time.

The factors influencing the spatial variability in crop yields were studied by relating the

CV(yields) to the CVs of sourcewise irrigation intensities, cropping intensity, fertiliser availability and to seasonal rainfalls (South-West and North-East monsoons). This analysis shows that:

1. Rainfall (during South-West monsoon or North-East monsoon or both) was found to affect directly the spatial variability of yields of all crops except bajra;
2. Among the infrastructural factors the disparity across districts in sourcewise net irrigation proportions was found to affect the spatial variability in yields of all cereal crops grown in Andhra Pradesh except jowar.
3. Among the various sources, the disparities in surface water sources proportion as a whole affect directly the disparities in the yields of rice, bajra and ragi. In the case of bajra and ragi yields, disparities in tank irrigation proportion in particular affect directly the disparity in their yields.
4. Disparities in groundwater sources proportion as a whole affect inversely the disparities in bajra yields, and in the case of maize, it is the disparities in the other wells component of groundwater that affects (inversely) the disparities in maize yields.
5. Disparities in ACI were found to have an inverse relation with the disparities in bajra and ragi yields only.
6. Differences in fertiliser intensity affect directly the disparities in rice yields, and inversely ragi and maize yields.

Among several factors that may affect the spatial variability of yields, some important ones like seed variety (HYV or traditional - though indirectly accounted for by the fertiliser variable), labour, mechanisation, cost of cultivation of different crops and various other institutional factors could not be incorporated here for want of appropriate time-series data on these factors at the district level. Inclusion of these variables in our analysis, though not possible given the current data availability, might further improve our understanding of the spatial variability in yields. In the absence of such data some of the explanations offered in interpreting the results obtained, particularly those relating to inter-crop substitutions, may seem hypothetical. These explanations, however, can be confirmed when detailed crop-specific data on the various explanatory variables become available. Also, detailed acreage response studies may help in this context.

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APPENDIX

VARIABLE NOTATIONS, DEFINITIONS AND MEASUREMENT UNITS

Notation (1)	Description (2)
YRCE	Rice yields = rice output (kilograms) per hectare.
YJWR	Jowar yields = jowar output (kilograms) per hectare.
YBJR	Bajra yields = bajra output (kilograms) per hectare.
YRGI	Ragi yields = ragi output (kilograms) per hectare.
YMZE	Maize yields = maize output (kilograms) per hectare.
RSW	Rainfall during South-West monsoon (millimetres).
RNE	Rainfall during North-East monsoon (millimetres).
TCNL	Canal irrigation proportion = Net irrigated area by canals ÷ Net sown area over all crops.
TANK	Tank irrigation proportion = Net irrigated area by tanks ÷ Net sown area over all crops.
SWTR	Surface water (canals + tanks) irrigation proportion = Net irrigated area by surface water sources (canals + tanks) ÷ Net sown area over all crops.
TBWL	Tubewells irrigation proportion = Net irrigated area by tubewells ÷ Net sown area over all crops.
OTWL	Other wells irrigation proportion = Net irrigated area by other wells ÷ Net sown area over all crops.
GWTR	Groundwater (tubewells + other wells) irrigation proportion = Net irrigated area by groundwater sources (tubewells + other wells) ÷ Net sown area over all crops.
OSRC	Other sources irrigation proportion = Net irrigated area by other sources ÷ Net sown area over all crops.
TNAS	Total (all sources) net irrigation proportion = Net irrigated area by all sources ÷ Net sown area over all crops.
ACI	Aggregate cropping intensity = Gross cropped area over all crops ÷ Net sown area over all crops.
IRCE	Rice irrigation proportion = Gross irrigated area under rice ÷ Gross cropped area under rice.
IJWR	Jowar irrigation proportion = Gross irrigated area under jowar ÷ Gross cropped area under jowar.
IBJR	Bajra irrigation proportion = Gross irrigated area under bajra ÷ Gross cropped area under bajra.
IRGI	Ragi irrigation proportion = Gross irrigated area under ragi ÷ Gross cropped area under ragi.
IMZE	Maize irrigation proportion = Gross irrigated area under maize ÷ Gross cropped area under maize.
FRT	Fertiliser availability (kilograms per hectare) = Total fertiliser consumed ÷ Total gross cropped area under the five cereals (rice, jowar, bajra, ragi and maize).

Data Sources: (1) *Season and Crop Reports of Andhra Pradesh*, Government of Andhra Pradesh, Hyderabad (various issues).

(2) *Fertiliser Statistics*, Fertiliser Association of India, New Delhi (various issues).

NOTES

1. In the rest of this paper, this cut-off of 0.3 is used in deciding whether the disparities are low or high.
2. In the rest of the paper, for a variable Y, HVD(Y) refers to high value districts and LVD(Y) refers to low value districts in comparison to the state average value of Y.
3. In fact, the data on fertiliser consumption pertain to farmers' purchase of fertilisers including for stocking purposes.
4. These results are not reported here in order to conserve space. They would be made available on request.

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