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Fertilizer Use in Semi-Arid Tropical India: The Case of High-Yielding Varieties of Sorghum and Pearl Millet

D. Jha, S.K. Raheja, R. Sarin and P.C. Mehrotra

ICRISAT
International Crops Research Institute for the Semi-Arid Tropics
ICRISAT Patancheru P.O.
Andhra Pradesh 502 324, India

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FERTILIZER USE IN SEMI-ARID TROPICAL INDIA: THE CASE OF HIGH YIELDING VARIETIES OF SORGHUM AND PEARL MILLET

D. Jha, S.K. Raheja**, R. Sarin* and P.C. Mehrotra**

Sorghum and pearl millet are the two most important cereals grown on drylands in semi-arid tropical (SAT) areas of India. These have traditionally formed part of a highly unstable, low-cost, low-output farming system and are evaluated in the market as relatively inferior foodgrains (Jodha 1973). Unremunerative response (Kanwar et al. 1973) and high level of weather induced instability in yields (Bapna et al. 1979) have been hypothesized as the two main factors responsible for poor performance of these crops in regard to use of modern inputs like fertilizers which, in these areas, has been confined to (a) relatively higher valued, irrigated cereals like rice and wheat where the responses are higher and more stable, and (b) unirrigated commercial crops like cotton, chillies, tobacco, groundnut, etc. where the high value of output provides the needed incentives to take risks (Desai et al. 1973, Desai and Singh 1973). On both these scores the millets compare unfavorably with these crops.

*Economics Program, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru P.O., Andhra Pradesh 502 324, India and **Division of Sample Survey Methodology, Indian Agricultural Statistics Research Institute (IASRI), Library Avenue, New Delhi 110 012, India. The present paper is the result of a joint study undertaken by the two institutions. The authors are deeply indebted to Dr. J.S. Kanwar, Director of Research, ICRISAT, and to Dr. D. Singh, Director, IASRI for their keen interest and active involvement in this project. Messrs. A.S. Gupta and Mahesh Kumar, S-I scientists and M.S. Verma, Technical Assistant at IASRI provided valuable assistance in computer analysis and tabulation work. We are thankful to them. Drs. James Ryan, Hans Binswanger, Matthias von Oppen and Brian Hardaker have read the earlier drafts and offered useful suggestions. The authors, however, own full responsibility for any shortcomings.

This traditional pattern appears to be changing in the wake of introduction of high yielding varieties (HYV) and, despite the rather tardy performance of the HYV of sorghum and millets, farmers do seem to have started using fertilizers on these crops also (NCAER 1974, 1978). This is a trend which needs careful monitoring not only because of its impact on the yield levels of these crops but also because this may mark the beginning of intensive fertilizer use under dryland conditions -- a phenomenon of crucial importance in terms of potential growth in productivity and in fertilizer demand in India (Desai 1978).

The present investigation is an attempt in this direction. It provides information on levels of fertilizer use on HYV of sorghum and pearl millet in different areas, the pattern of fertilizer adoption and diffusion and, finally, on factors influencing fertilizer use on these crops. These issues are important for designing appropriate technological and development strategies. For example, evidence on extent of fertilizer use has a bearing on the 'less preferred crop' hypothesis referred to above (Jodha 1973) and for deciding on fertility levels relevant for breeding and improvement work on these crops. Information on trend in fertilizer use over time would be helpful in understanding the nature of the diffusion process in an environment where the gains from adoption are unstable. Similarly, analysis of important determinants of fertilizer use would help identify forces which can be manipulated to promote its productive use. Thus, the specific objectives of this paper are:

- to determine the extent and level of fertilizer use on HYV of sorghum and pearl millet in different areas,
- to compare fertilizer use on these crops with that on 'superior' irrigated cereals (rice or wheat) in the same areas,
- to examine the trend in fertilizer use and its diffusion over time,
- to identify and evaluate the impact of factors affecting fertilizer use decisions of farmers.

Details of data sources and procedures used are provided in the following section which also contains a brief description of the selected districts. The results pertaining to the first three objectives are presented and discussed in the third section. Analysis of determinants of fertilizer use is contained in the next section and the fifth summarizes the main findings and conclusions.

II. DATA SOURCES AND METHODOLOGY

The data used for this study have been taken from the results of the project entitled "Sample Surveys for Assessment of High Yielding Varieties Programme" undertaken by the Indian Agricultural Statistics Research Institute (IASRI), New Delhi in 88 districts spread over 15 states during the period 1969-70 to 1973-74. Five major cereals -- rice, wheat, maize, sorghum and pearl millet, were covered in the Survey. In each state, the top-ranking districts with respect to the targeted area of HYV of the crops studied were selected.

Two types of enquiries were conducted under the Survey -- one, known as the Agronomic and Agro-economic Enquiry (AAE), for estimating the area under HYV of the crop studied and the extent of adoption of improved practices on selected farmers' holdings, and the other, known as the Yield Estimation Survey (YES), for estimating the yield rates of high yielding and indigenous varieties of selected crops. Under the latter (YES), crop cutting technique was adopted for estimating yields of important varieties. For this purpose, 80 crop cutting experiments were conducted on HYV and an equal number on local varieties for each crop in a district. The design adopted for selection of fields under HYV was stratified multi -stage random sampling while the fields under the local varieties were selected in the neighborhood of the corresponding HYV fields and under similar conditions of soil and management to the extent possible. Information on important inputs used and costs were collected for each field. For the Agronomic and Agro-economic Enquiry (AAE), a sample of 320 cultivator households growing the crops studied in the districts were selected by stratified multi-stage random sampling design.[1]

Beginning 1974-75, the coverage was reduced to 38 districts spread over the same 15 states. Two more crops namely cotton and groundnut were added to the five cereals already mentioned. Annual reports giving

1. If two crops were studied in the same season, 160 cultivators were selected for each crop.

the results of the projects have been published by the IASRI for the years 1970-71 to 1975-76.

Data on fertilizer use on sorghum, pearl millet and other crops (rice or wheat) in the selected districts were taken from the Annual Report of the project (Raheja et al. 1976) for the year 1973-74.[2] Sorghum crop was studied in 20 districts in the kharif and one district in the rabi season. For pearl millet, the corresponding number of districts were 21 and 5, respectively (Raheja et al. 1976). Almost all these districts fall in the semi-arid tropical regions of the country.

For analyzing trend in fertilizer use over time, we have used data for only those districts which were covered continuously for 6-7 years, up to 1976-77. There were four such districts for both sorghum and pearl millet.

The analysis of determinants of fertilizer use was attempted at two levels.[3] In the first, plot level data on fertilizer use and other variables from the Yield Estimation Survey (YES) for 1973-74 were used with a view to explaining inter-plot differences in fertilizer use (in each district) in terms of factors such as soil, drainage, sowing time, rainfall, previous crop grown on the plot, fertilizer prices paid by the farmer, etc. This exercise was intended to show the effect of farm- and plot-specific characters on fertilizer use decisions. This was followed by an aggregative, regression-based analysis in which district-level estimates of fertilizer use for 1973-74 from the AAE survey were used as dependent variables and factors such as expected and actual seasonal conditions, soil type, irrigation, yield risk, credit, etc. were used as explanatory variables. This analysis focused attention on interdistrict variations in fertilizer use.

Description of selected districts and spread of HYV of sorghum and pearl millet

The survey on high yielding varieties of sorghum covered more than 3 900 cultivator households spread over 21 districts in four states. As can be seen from Appendix I, there was a high concentration in Maharashtra and

2. The coverage was substantially reduced from 1974-75 onwards which also happened to be the year when fertilizer prices rose sharply. These considerations prompted the selection of this particular year for our study.

3. The models are described in detail in Section IV.

Karnataka -- the major sorghum producing states. In almost all the districts selected (with the exception of Nanded, Wardha and Shimoga), sorghum was an important crop. The sample for pearl millet was more diffused and covered about 4 700 cultivators in 26 districts spread over eight states. Pearl millet was not a very important crop in 13 out of the 26 selected districts of Andhra Pradesh, Tamil Nadu (except Tirunelveli) and some districts of Maharashtra. This has to be borne in mind while interpreting the results.

Appendix I also shows that the selected districts covered a wide range of soil-rainfall conditions. Most of the sorghum districts had black or red soils and, with the exception of Shimoga, had less than 1 200 mm annual (normal) rainfall. Interdistrict variation in rainfall and soil type was higher in the pearl millet districts. The normal rainfall ranged from 219 mm in Rohtak to 1 211 mm in Chingleput and almost all major soil types were represented.

An overall idea regarding spread of the HYV in these districts is provided by Table 1 which shows the distribution of districts according to extent of coverage under HYV and also according to the extent of HYV area irrigated (Appendix I).

Table 1. Distribution of districts according to spread of HYV and extent of HYV area irrigated, 1973-74

Class interval (% area)	Sorghum		Pearl Millet	
	Crop area covered by HYV	HYV area irrigated	Crop area covered by HYV	HYV area irrigated
	Number of districts in different classes			
> 60	3	1	8(3)[a]	16(4)
41 - 60	4	5	5(3)	2(2)
21 - 40	4	5	8(6)	2(2)
11 - 20	7	3	1(0)	0(0)
< 10	3	7	4(1)	6(5)
Total	21	21	26(13)	26(13)

a. Figures in parentheses indicate distribution of the important pearl millet growing districts.

Table 1. Digitaria *collection from southern Africa, 1971*

Species	Collected in		Collected as		
	Wild	Culti-vated	Seed	Vege-tative	Total
D. adscendens (HBK.) Henr.	1			1	1
D. chevalieri Stapf		1	1		1
D. debilis (Desf.) Willd.	1			1	1
D. decumbens Stent.	1			1	1
D. didactyla Willd.		1		1	1
D. eriantha Steud.		2	1	1	2
D. friesii Pilger	1			1	1
D. gazensis Rendle		1		1	1
D. longiflora (Retz.) Pers.	2			2	2
D. macroglossa Henr.	5		5		5
D. milanjiana (Rendle) Stapf		28		28	28
D. milanjiana subsp. *eylesiana* Henr.		2	1	1	2
D. natalensis Stent.	5		2	3	5
D. natalensis subsp. *stentiana* Henr.	7		4	3	7
D. pentzii Stent.	16	39	8	47	55
D. pentzii var. *stolonifera* (Stapf) Henr.	12		3	9	12
D. polevansii Stent.	2	3	1	4	5
D. scalarum (Schweinf.) Chiov.		1		1	1
D. smutsii Stent.	2	65	54	13	67
D. ternata (Hochst. ex A. Rich.) Stapf	1			1	1
D. valida Stent.	9	81	6	84	90
Digitaria spp.	14	8	9	13	22
	79	232	95	216	311

didactyla Willd., *D. friesii* Pilger, and *D. natalensis* Stent., not included in the 1964 collection. Two of these species, *D. adscendens* and *D. didactyla*, belong in the Sanguinales section, an addition to the 1964 collection. The extent of variation in the collection is governed largely by the location and range of species. Some species in the collection may be of direct use in agriculture after completion of adaptation and evaluation studies. Certain species were sought for use in plant improvement programmes. Other species having little or no known agronomic value were collected in an effort to satisfy the requests of individuals engaged in cytotaxonomic research. Duplicate herbarium specimens were collected for the National Herbarium, Pretoria, South Africa and the National Herbarium, Smithsonian Institution, Washington, D.C. Field collection numbers permit cross-indexing for future reference. The specimens on deposit in the National Herbarium in Washington have been assigned U.S.D.A. plant introduction (P.I.) numbers.

The incidence of species in the area of collection and their economic importance resulted in the collection containing a preponderance of species belonging in the section Erianthae. The variable, tufted, rhizomatous perennial, *D. eriantha* Steud., is widely distributed in southern Africa where it is adapted to a wide range of soils and rainfall. It is an excellent species for the control of erosion and is a potential source of drought-resistant germ plasm.

The robust, rhizomatous, tufted species, *D. macroglossa* Henr., is most common in the sandy coastal soils of Mozambique and Natal. Its growth habit and tolerance of saline soils and salt spray contribute to the value of this species as a sand-binding and erosion-control plant. The stoloniferous

The table clearly shows that the pearl millet hybrids had higher coverage as compared to the sorghum HYV. In eight districts, more than 60% of the crop area was covered by hybrids (against 3 in sorghum) and in only five districts (against 10 in sorghum) the spread was less than 20%. Even if we exclude the 13 districts where the crop was unimportant, this superiority holds.

Another important feature brought out by the table was that in nearly half the districts studied the sorghum HYV were grown primarily under unirrigated (less than 20% area irrigated) conditions; on the other hand, in 16 out of 26 districts more than 60% of the area under pearl millet hybrids was irrigated. It was interesting to note that in 12 (out of 13) non-traditional districts spread over the southern states the pearl millet hybrids were grown predominantly under irrigated conditions. The remaining 13 traditional pearl millet producing districts (in Gujarat Haryana, Rajasthan, Madhya Pradesh and Maharashtra) presented an interesting contrast -- in four districts more than 60% of the hybrid area was irrigated, in five the hybrids were grown primarily under rainfed conditions and both the categories of districts were spread over a wide range of soil-climatic conditions. Thus, while there was an indication that irrigation was more important for pearl millet hybrids than for sorghum, the evidence from the traditional producing areas was not as overwhelming as the overall distribution in Table 1 indicated.

In general, coverage under HYV of sorghum was lower; but these were grown to a larger extent under rainfed conditions. The performance of th pearl millet hybrids was more diverse in this regard though there were indications that availability of irrigation was more important for this crop (Bapna and Murty 1976).

III. STATUS OF FERTILIZER USE ON HYV OF SORGHUM AND PEARL MILLET

Observed patterns of fertilizer use on a particular crop arise from three related decisions: (1) whether to use fertilizer or not, (2) what rate of application to use, and (3) how much area to cover. These decisions are influenced by a host of technological, socioeconomic and psychological variables. We shall examine these influences in Section IV. Here we present observed estimates of these parameters in order to provide an idea regarding the status of fertilizer use on HYV of sorghum and pearl millet. The average estimates have been taken from the published report of the High Yielding Varieties Survey (Raheja et al. 1976) for 1973-74; details regarding fertilizer use under irrigated and unirrigated conditions have been taken from unpublished tabulated results of the Survey.

1. Adoption of fertilizers

Table 2 shows the level of adoption of fertilizers for HYV of sorghum and pearl millet in different districts.[4] Considerable interdistrict variability in the percentage of farmers using fertilizers was noted even though, in general, adoption levels appeared to be fairly high -- in 7 (out of 21) and 9 (out of 22) districts for sorghum and pearl millet respectively, more than 80% of the farmers growing HYV used fertilizers. Correlations were worked out between adoption of fertilizers and variables like spread of HYV and rainfall. A positive and significant correlation (+0.45) was obtained between adoption and rainfall for sorghum; for pearl millet none of these variables were found to be significantly associated.

Data on proportion of fertilizer users resorting to fertilization of the unirrigated (HYV) crop are interesting. The table showed that fertilizer use under unirrigated conditions was a common and extensive practice, particularly for HYV of sorghum. In 16 out of 21 districts, more than 80% of the fertilizer adopters applied fertilizer to the unirrigated HYV crop of sorghum. For pearl millet hybrids, this was true only for 5 out of 22 districts; in as many as 12 districts, less than 10% of the fertilizer users resorted to this practice. It was also noted that most of the latter were unimportant pearl millet producing districts where, as we have stated earlier, the HYV were almost invariably grown under irrigation. The correlation between adoption under unirrigated condition and percentage area under the crop (pearl millet) was +0.44 and this also indicated that in the major producing districts, fertilizer use on the unirrigated crops was common.

4. These were obtained from the distribution of irrigated and unirrigated plots for each district in the Yield Estimation Survey. Because the data sources are different, one observes some inconsistencies while comparing fertilizer use under unirrigated conditions (Table 2) and percentage HYV area irrigated (Appendix I). The differences, however, are minor.

Table 2. Adoption of fertilizers for HYV of sorghum and pearl millet in selected districts (1973-74)

Sorghum districts			Pearl Millet districts		
District (State)	% HYV growers using ferti-lizers	% users fertilizing unirrigated HYV crop	District (State)	% HYV growers using ferti-lizers	% users fertilizing unirrigated HYV crop
Jalgaon (Mah)	97	98	Gujarat[b]	NA	NA
Ahmadnagar (Mah)	72	45	Hissar[c] (Har)	69	5
Sangli (Mah)	72	81	Rohtak (Har)	43	44
Aurangabad (Mah)	24	88	Jaipur[c] (Raj)	50	75
Parbhani (Mah)	70	96	Jalgaon[c] (Mah)	90	100
Bhir (Mah)	14	100	Ahmadnagar[c] (Mah)	17	72
Satara (Mah)	81	85	Sangli (Mah)	18	0
Osmanabad (Mah)	28	100	Aurangabad[c] (Mah)	21	100
Buldhana (Mah)	74	98	Parbhani (Mah)	74	100
Akola (Mah)	73	98	Bhir[c] (Mah)	12	88
Amravati (Mah)	80	100	Sholapur (Mah)	47	40
Nanded (Mah)	35	100	Morena[c] (MP)	94	100
Wardha (Mah)	83	100	Guntur (AP)	41	2
Nagpur (Mah)	94	100	Chittoor (AP)	84	1
Mandsaur (MP)	47	100	Nellore (AP)	93	0
Belgaum (Kar)	88	77	Coimbatore (TN)	88	1
Bellary (Kar)	78	90	Madurai (TN)	46	30
Shimoga (Kar)	96	96	Tirunelveli[c] (TN)	94	0
Mysore (Kar)	54	76	Chingleput (TN)	81	7
Anantapur (AP)	76	12	Coimbatore[a] (TN)	81	2
Shimoga[a] (Kar)	100	1	Madurai[a] (TN)	50	0
			Chingleput[a] (TN)	50	6
			Bellary[a] (Kar)	100	2

Source: Yield Estimation Survey data. There is a minor difference with data on irrigated HYV reported in Appendix I.

a. Post-rainy season crop.

b. This information was not available for Banaskanta, Kaira and Rajkot districts in Gujarat, and Tirunelveli (post-rainy season) in Tamil Nadu.

c. Traditionally important pearl millet producing districts.

NA - not available.

Information on adoption of fertilizer thus revealed that fertilizer use on HYV of these two crops was a common practice. It also emerged that a relatively high proportion of farmers used fertilizer on the unirrigated crop.

2. Levels of fertilizer use

Two parameters -- rate of application and extent of crop area fertilized, determine the average level of fertilizer use measured as the rate of plant nutrients used per hectare of crop area. In Tables 3 and 4, data are provided on average rate and its two determinants for HYV of sorghum and pearl millet, respectively.

The level of total plant nutrients ($N+P_2O_5+K_2O$) used per hectare of crop area provides an idea regarding the average intensity of fertilizer use and figures reported in Tables 3 and 4 revealed wide interdistrict variability in this parameter. The average level was found to be less than 20 kg per hectare of crop area in 4 and 7 districts respectively for HYV of sorghum and pearl millet; in 6 and 9 districts for these two crops respectively, the levels exceeded 60 kg per hectare. In general, districts with higher adoption of fertilizers for sorghum also had higher average level of fertilizer use ($r = +0.56$) as had districts with higher rainfall ($r = +0.49$). Percentage area under HYV and HYV area irrigated were positively correlated with average level of fertilizer use but these were not statistically significant. The average rate of application for pearl millet hybrids was also significantly associated with adoption ($r = +0.61$) and extent of HYV area irrigated ($r = +0.45$). With other variables -- coverage under HYV and rainfall, the correlations were not significant. These results suggested the importance of rainfall (sorghum) and irrigation (pearl millet) as determinants of fertilizer use on these crops.

The tables also reveal that the local varieties of these crops were generally not fertilized or were fertilized at very low rates. In 15 districts for sorghum and 19 for pearl millet, the average rate was either zero or nominal (less than 5 kg N, P_2O_5, K_2O per hectare).

We now look at the determinants of average level of fertilizer use -- the actual rates of application per fertilized hectare and the extent of

Table 3. Average rate of fertilizer consumption, rate of application per fertilized hectare and extent of area fertilized for HYV of sorghum in selected districts (1973-74)

District (State)	Average rate ($N+P_2O_5+K_2O$) per hectare		Rate per fertilized hectare (HYV)			Percentage area fertilized (HYV)		
	HYV kg/ha	Local kg/ha	N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	N %	P_2O_5 %	K_2O %
Jalgaon (Mah)	50	19	40	27	12	78	63	18
Ahmadnagar (Mah)	45	0	72	29	Nil	53	24	Nil
Sangli (Mah)	30	0	60	25	15	39	19	15
Aurangabad (Mah)	18	0	55	27	12	24	15	7
Parbhani (Mah)	29	0	47	19	18	43	25	25
Bhir (Mah)	18	0	23	19	21	24	41	25
Satara (Mah)	48	0	59	27	13	64	26	22
Osmanabad (Mah)	23	2	29	21	16	38	32	32
Buldhana (Mah)	68	9	33	33	18	88	88	56
Akola (Mah)	40	0	48	27	17	52	42	21
Amravati (Mah)	71	5	42	29	22	90	72	56
Nanded (Mah)	19	0	31	15	4	47	28	14
Wardha (Mah)	39	1	44	18	15	60	43	34
Nagpur (Mah)	59	2	35	27	16	81	79	58
Mandsaur (MP)	84	22	63	24	29	81	71	54
Belgaum (Kar)	117	19	94	27	24	93	60	56
Bellary (Kar)	28	8	13	11	11	72	72	70
Shimoga (Kar)	75	21	38	24	23	90	89	85
Mysore (Kar)	27	0	49	36	32	31	17	17
Anantapur (AP)	11	0	47	Nil	Nil	24	Nil	Nil
Shimoga[a] (Kar)	113	0	57	35	33	97	95	74
	Distribution of districts in different classes							
≤ 10	0	17	0	1	3	0	1	3
11 - 20	4	2	1	5	11	0	3	4
21 - 30	5	2	2	12	5	3	4	4
31 - 40	2	0	5	3	2	3	1	2
41 - 60	4	0	10	0	0	5	4	5
61 - 80	3	0	2	0	0	3	5	2
> 80	3	0	1	0	0	7	3	1

Source: Raheja et al. 1976. Various tables.

a. Post-rainy season crop.

Table 4. Average rate of fertilizer consumption, rate of application per fertilized hectare and extent of area fertilized for HYV of pearl millet in selected districts (1973-74)

District (State)	Average rate ($N+P_2O_5+K_2O$) per hectare		Rate per fertilized hectare (HYV)			Percentage area fertilized (HYV)		
	HYV kg/ha	Local kg/ha	N kg/ha	P_2O_5 kg/ha	K_2O kg/ha	N %	P_2O_5 %	K_2O %
Banaskanta[a] (Guj)	11	2	50	0	0	23	0	0
Kaira[a] (Guj)	32	16	36	42	0	75	12	0
Rajkot[a] (Guj)	39	16	30	32	0	77	51	0
Hissar[a] (Har)	32	5	46	61	0	65	3	0
Rohtak[a] (Har)	39	17	46	0	0	84	0	0
Jaipur[a] (Raj)	28	4	36	17	0	70	18	0
Jalgaon[a] (Mah)	37	14	32	21	8	74	54	20
Ahmadnagar[a] (Mah)	66	5	64	37	28	84	28	8
Sangli (Mah)	28	1	60	0	0	47	0	0
Aurangabad[a] (Mah)	19	2	29	19	18	36	29	16
Parbhani (Mah)	12	0	27	12	12	29	16	16
Bhir[b] (Mah)	12	0	24	18	16	22	21	21
Sholapur (Mah)	8	0	28	0	0	27	0	0
Morena[a] (MP)	81	11	53	38	0	95	81	0
Guntur (AP)	55	1	56	28	16	62	48	45
Chittoor (AP)	107	0	75	34	33	98	54	46
Nellore (AP)	59	0	41	22	18	91	67	41
Coimbatore (TN)	141	5	99	42	33	90	74	66
Madurai (TN)	46	2	35	18	18	74	57	57
Tirunelveli[a] (TN)	82	8	74	28	28	80	40	40
Chingleput (TN)	82	0	44	31	27	91	75	71
Coimbatore[b] (TN)	79	20	52	31	30	86	56	56
Madurai[b] (TN)	19	1	18	6	6	78	42	42
Tirunelveli[a,b] (TN)	10	1	26	0	0	40	0	0
Chingleput[b] (TN)	71	0	48	26	24	86	63	57
Bellary[b] (Kar)	108	0	64	30	26	98	83	79
Distribution of districts in different classes								
≤ 10	2	20	0	6	12	0	6	11
11 - 20	5	6	1	5	6	0	3	3
21 - 30	2	0	6	6	6	4	3	1
31 - 40	5	0	4	6	2	2	1	1
41 - 60	3	0	10	2	0	1	7	7
61 - 80	3	0	4	1	0	9	4	3
> 80	6	0	1	0	0	10	2	0

Source: Raheja et al. 1976. Various tables.

a. Traditionally important pearl millet producing districts.

b. Post-rainy season crop.

crop area fertilized.[5] The last six columns of Tables 3 and 4 provide these data. Table 3 reveals that the modal classes for nitrogen, phosphorus and potash application were 41 kg to 60 kg, 21 kg to 30 kg and 11 kg to 20 kg per fertilized hectare respectively. It may be noted that the rate for nitrogen was less than 30 kg per fertilized hectare in only 3 districts (Bhir, Osmanabad and Bellary). In 10, 8 and 3 districts respectively, the percentage areas fertilized with nitrogen, phosphatic and potassic fertilizers exceeded 60% of the area under HYV.

The modal classes for nitrogen, phosphorus and potash application to HYV of pearl millet were 41 kg to 60 kg, 21 kg to 40 kg and less than 10 kg per fertilized hectare respectively. No phosphatic fertilizer was applied in five districts and potash was not used in ten. It was noted that in 8 out of 13 major producing districts, no potassic fertilizer was used on this crop. In 19, 6 and 3 districts respectively, the percentage areas fertilized with nitrogenous, phosphatic and potassic fertilizers respectively, exceeded 60%. Thus, this crop had relatively lower indicator values for potash use, but the number and proportion of districts falling in the above modal classes for N rate as well as percent area fertilized with nitrogen was higher for pearl millet as compared to sorghum.

In Table 5 below, some correlations have been shown. These provide the following indications:

(a) Rates of fertilizer application (both N and P_2O_5) for sorghum were not associated with spread of HYV, HYV area irrigated, adoption of fertilizer or rainfall. For pearl millet, irrigated HYV area was positively associated with N rates and adoption with P_2O_5 rates.

(b) The percentage sorghum areas fertilized with N and P_2O_5 were significantly correlated with adoption and rainfall. For pearl millet, spread of HYV, HYV area irrigated (with N), adoption of fertilizer and rainfall (with P_2O_5) were correlated positively with the area fertilized variables.

(c) The nitrogen and phosphorus rates were not correlated for sorghum but the area fertilized with these nutrients were positively correlated. For pearl millet, both rates and areas fertilized with nitrogen and phosphorus were correlated and the rate and area fertilized with the same nutrient was also positively correlated.

5. The district estimates presented in Tables 3 and 4 generally had high precision. The percentage standard errors for nitrogen rate estimates were below 20 in 19 districts for sorghum and 21 districts for pearl millet.

Table 5. Correlations between fertilizer use and other variables

Variables	Sorghum				Pearl Millet			
	Rate/fert. ha		% area fertilized		Rate/fert. ha		% area fertilized	
	N	P_2O_5	N	P_2O_5	N	P_2O_5	N	P_2O_5
% area under HYV	.131	-.288	.337	.349	-.095	.162	.473*	.438*
% HYV area irrigated	.396	-.269	.170	.076	.494*	.140	.464*	.127
Adoption of fertilizer	.234	-.025	.693**	.487*	.356	.425*	.600**	-.628**
Normal rainfall	-.080	-.429	.510*	.573*	.116	.185	.202	.546**
Rate of other nutrient	.235	.235	NR	NR	.507*	.507*	NR	NR
% area fertilized with same nutrient	.153	-.343	NA	NA	.553**	.435*	NA	NA
% area fertilized with other nutrient	NR	NR	.893**	.893**	NR	NR	.691**	.691**

*,** Statistically significant at 5 and 10% probability levels.

NR - not reported.

NA - not applicable.

These indicated that higher spread of HYV does not imply higher rates of fertilizer application. There was some indication that fertilized area was higher in districts with higher HYV area. Secondly, higher level of fertilizer adoption was more strongly associated with extent of area fertilized. Thirdly, rainfall was significantly associated with area fertilized. All these pointed towards area fertilized being more variable than rate of application. Finally, significant association between areas fertilized with nitrogen and phosphorus suggested efforts towards more balanced use of fertilizers. This was more strongly indicated for pearl millet for which both rates of application and areas fertilized with N and P_2O_5 tended to move together.

Pursuing our results further, district estimates presented in Tables 3 and 4 did not reveal any trend with respect to broad soil types (Appendix I). With respect to varietal differences in fertilizer use, the hybrid pearl millet districts showed some interesting results.[6] Varieties HB 1, HB 3 and HB 4 were dominant in 5, 15 and 6 districts respectively (Appendix I). The HB 1 and HB 4 districts showed some differences. In none of the 5 districts where HB 1 was the dominant variety[7] did fertilizer adoption exceed 50%, nor did the rates of application of nitrogen and potash exceed 60 kg and 30 kg respectively. On the other hand, the adoption level was above 80% in all the 6 districts where HB 4 was the dominant variety.[8] In three of these the rate of application of nitrogen exceeded 60 kg and that for potash exceeded 30 kg per hectare. In terms of percentage area fertilized also the HB 4 districts showed superiority, area fertilized with nitrogen exceeding 80% in all (only one HB 1 district belonged to this category). Thus, even the aggregate district level data revealed relatively higher fertilizer use parameters for HB 4. Interestingly, this ranking agrees with experimental evidence on the response of pearl millet hybrids to fertilizer application (Bapna and Murty 1976). This lends support to the hypothesis

6. Variety CSH 1 was dominant in 19 out of 21 districts studied (Appendix I). Therefore, no variety-based analysis was possible for sorghum.

7. These districts were Jaipur, Chingleput (post-rainy season), Guntur, Sangli and Bhir.

8. These were Nellore, Coimbatore, Chittoor, Chingleput, Morena and Bellary (post-rainy season).

that farmers are aware of the relative responses of different varieties and that this does affect their fertilizer use decisions.

Fertilizer use under irrigated and rainfed conditions

Appendix I shows that in several areas, the HYV are grown under irrigated conditions. From the point of view of SAT agriculture in general, there is greater interest in monitoring the situation for the primarily unirrigated crop which is quantitatively so important.

Tables 6 and 7 give estimates of actual rates of application and percent area fertilized with each nutrient under irrigated and unirrigated conditions. The data have been summarized in the form of frequency distributions and these have been shown in Figure 1.

Considering sorghum first, the modal classes for N, P_2O_5 and K_2O application were found to be 41-60 kg, 31-40 kg and 11-20 kg per fertilized hectare respectively under irrigated condition. Under unirrigated conditions, these were 21-40 kg, 21-30 kg and 11-20 kg, respectively. The differences between irrigated and unirrigated distributions (Fig 1) were not so sharp with respect to N rates and more than half the number of districts fell in the above modal classes. The areas fertilized with N, P_2O_5 and K_2O were clearly lower under unirrigated conditions though with respect to this parameter also, the case of nitrogenous fertilizers was not so sharply defined and a significant number of districts had more than 80% coverage under nitrogenous fertilizers even under unirrigated conditions.

For pearl millet (Table 7) the modal classes for N, P_2O_5 and K_2O application were 41-60 kg, 21-30 kg, and less than 10 kg per fertilized hectare under irrigated conditions and 21-40 kg, less than 20 kg and less than 10 kg per fertilized hectare respectively under rainfed conditions. It was also noted that a significant number of districts belonged to the above modal classes for N and P_2O_5 application rates. With respect to area fertilized, the unirrigated distributions clearly indicated relatively lower values.

The conclusions are summarized in Table 8. Figure 1 and Table 8 clearly indicate higher fertilizer use parameters for unirrigated sorghum as compared to pearl millet. Under irrigated conditions, though the modal values for the two crops presented in Table 8 are similar, the

Table 6. Fertilizer use on HYV of sorghum under irrigated and unirrigated conditions in different districts (1973-74)

District (State)	Rate of application per fertilized hectare (kg)						Percent area fertilized with different nutrients					
	Irrigated crop			Unirrigated crop			Irrigated crop			Unirrigated crop		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Jalgaon (Mah)	25	16	0	50	30	13	86	72	0	74	56	22
Ahmadnagar (Mah)	77	33	b	64	22	0	67	47	b	42	13	0
Sangli (Mah)	65	24	15	63	27	12	69	34	32	16	8	2
Aurangabad (Mah)	b	b	b	56	30	15	b	b	b	25	15	7
Parbhani (Mah)	NA	NA	NA	47	19	18	NA	NA	NA	43	25	25
Bhir (Mah)	0	0	0	24	20	22	0	0	0	25	44	25
Satara (Mah)	56	26	15	61	27	12	100	37	37	57	24	19
Osmanabad (Mah)	40	18	14	26	21	16	43	34	34	37	31	31
Buldhana (Mah)	40	40	b	33	33	18	100	100	b	88	88	57
Akola (Mah)	NA	NA	NA	48	27	17	NA	NA	NA	52	42	21
Amravati (Mah)	42	31	21	42	27	23	97	79	74	84	66	44
Nanded (Mah)	0	0	0	30	15	4	0	0	0	50	30	15
Wardha (Mah)	35	17	15	45	18	15	58	58	48	60	43	33
Nagpur (Mah)	NA	NA	NA	35	27	16	NA	NA	NA	83	81	60
Mandsaur (MP)	NA	NA	NA	63	24	29	NA	NA	NA	81	71	54
Belgaum (Kar)	100	35	29	89	18	17	100	81	77	86	36	30
Bellary (Kar)	20	14	14	12	11	11	85	82	82	69	70	68
Shimoga (Kar)	44	25	25	38	25	23	78	75	65	92	92	88
Shimoga[a] (Kar)	57	35	33	NA	NA	NA	97	95	74	NA	NA	NA
Mysore (Kar)	60	38	32	36	30	31	91	86	80	19	4	5
Anantapur (AP)	50	b	0	b	0	0	41	b	0	b	0	0

Source: Unpublished tabulated results of IASRI assessment survey 1973-74

a. Post-rainy season crop.

b. Estimate not reported, based on very few observations.

NA - not applicable.

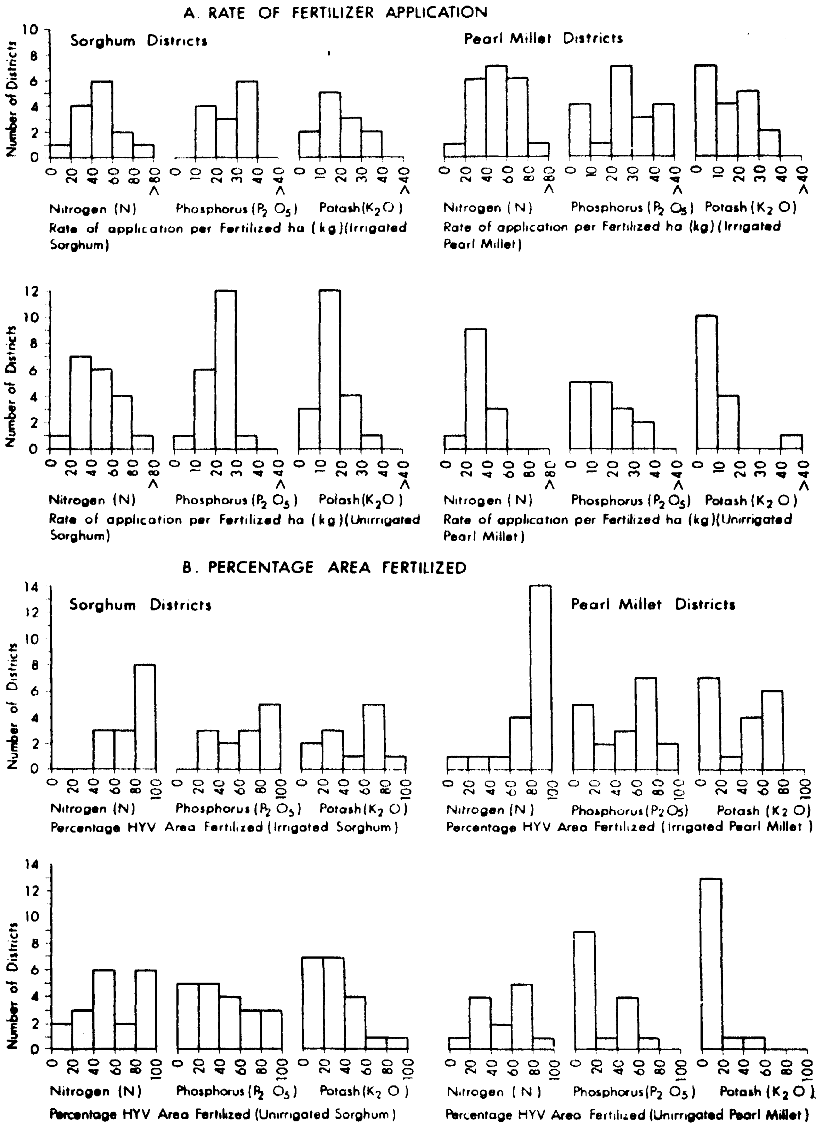
Table 7. Fertilizer use on HYV of pearl millet under irrigated and unirrigated conditions in different districts (1973-74)

District (State)	Rate of application per fertilized hectare (kg)						Percent area fertilized with different nutrients					
	Irrigated crop			Unirrigated crop			Irrigated crop			Unirrigated crop		
	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O	N	P_2O_5	K_2O
Banaskanta[a] (Guj)	NA	NA	NA	49	0	0	NA	NA	NA	23	0	0
Kaira[a] (Guj)	37	45	0	35	38	0	69	19	0	80	8	0
Rajkot[a] (Guj)	38	42	0	22	23	0	87	53	0	73	50	0
Hissar[a] (Har)	46	61	c	c	0	0	67	3	c	c	0	0
Rohtak[a] (Har)	47	0	0	23	0	0	92	0	0	21	0	0
Jaipur[a] (Raj)	37	0	0	34	16	0	72	0	0	70	60	0
Aurangabad[a] (Mah)	c	c	c	30	19	18	c	c	c	35	28	16
Parbhani (Mah)	NA	NA	NA	27	12	12	NA	NA	NA	29	16	16
Bhir[a] (Mah)	c	c	c	25	17	16	c	c	c	20	18	18
Jalgaon[a] (Mah)	c	c	c	32	21	8	c	c	c	77	56	21
Ahmadnagar[a] (Mah)	67	40	17	57	27	49	93	35	10	66	15	4
Sangli (Mah)	60	c	c	NA	NA	NA	47	c	c	NA	NA	NA
Sholapur (Mah)	28	c	c	c	0	0	31	c	c	c	0	0
Morena[a] (MP)	71	25	0	48	38	0	100	100	0	91	76	0
Guntur (AP)	65	28	16	c	0	0	64	64	45	c	0	0
Chittoor (AP)	76	34	32	NA	NA	NA	99	54	46	NA	NA	NA
Nellore (AP)	41	22	18	NA	NA	NA	91	67	41	NA	NA	NA
Coimbatore (TN)	99	42	33	NA	NA	NA	91	74	66	NA	NA	NA
Coimbatore[b] (TN)	49	26	21	NA	NA	NA	94	67	67	NA	NA	NA
Madurai (TN)	35	19	19	c	c	c	81	62	62	c	c	c
Madurai[b] (TN)	18	6	6	0	0	0	91	50	50	0	0	0
Tirunelveli[a] (TN)	77	30	30	20	13	13	87	38	38	48	48	48
Tirunelveli[a,b] (TN)	32	0	0	28	c	c	13	0	0	54	c	c
Chingleput (TN)	44	31	27	NA	NA	NA	94	77	74	NA	NA	NA
Chingleput[b] (TN)	49	26	21	c	c	c	94	67	67	c	c	c
Bellary[b] (Kar)	64	30	26	NA	NA	NA	98	83	79	NA	NA	NA

Source: Unpublished tabulated results of IASRI assessment survey 1973-74.
a. Traditionally important pearl millet producing districts.
b. Post-rainy season crop.
c. Estimate not reported, based on very few observations.
NA - not applicable.

FIGURE 1.

DISTRIBUTION OF DISTRICTS ACCORDING TO RATE OF FERTILIZER APPLICATION AND PERCENTAGE AREA FERTILIZED UNDER IRRIGATED AND UNIRRIGATED CONDITIONS FOR H Y V OF SORGHUM AND PEARL MILLET (1973 - 74)



overall distribution shown in Fig 1 indicated somewhat higher level of nitrogen use for pearl millet hybrids. Comparison of fertilized areas under irrigated and unirrigated conditions revealed that the areas fertilized with P_2O_5 and K_2O recorded sharper declines as compared to the area fertilized with N. This follows from the fact that there is an element of flexibility for nitrogen application (it can be applied during post-sowing stages also) but for the other two nutrients it is not so.

Table 8. Modal classes for rate of fertilizer application and percentage area fertilized: HYV of sorghum and pearl millet, 1973-74

Crop	Fertilizer	Modal classes for rate of application (kg per fertilized hectare)		Modal classes for percentage HYV area fertilized (%)	
		Irrigated	Unirrigated	Irrigated	Unirrigated
Sorghum	N	41 - 60	21 - 40	> 80	> 60
	P_2O_5	31 - 40	21 - 30	> 80	< 40
	K_2O	11 - 20	11 - 20	61 - 80	< 40
Pearl Millet	N	41 - 60	21 - 40	> 80	61 - 80
	P_2O_5	21 - 30	< 20	61 - 80	< 10
	K_2O	< 10	< 10	41 - 80	< 10

The modal rates presented in Table 8 compared favorably with those reported for different states by the National Council of Applied Economic Research (NCAER 1978) for 1975-76. The 1969-71 estimates for sorghum (All-India) also belonged to the modal classes obtained in this study (NCAER 1974). While this improves our confidence in these estimates, this comparison also suggests that rates of fertilizer application to these crops did not record any significant gains over 1969-70 to 1975-76. We shall come back to this later.

Stratification of these data by major soil types revealed that generally the rates of fertilizer application to unirrigated sorghum were higher on black soils as compared to red and lateritic soil groups -- medium black soils faring better than shallow black soils. For pearl millet, the unirrigated rates were higher on alluvial, grey-brown and black soils as compared to mixed red and black, red and red and lateritic soils. These trends are in line with the moisture holding capacities of different soils.

Summing up, the analysis of adoption levels and application rates revealed the following: (a) A substantial proportion of farmers growing HYV of sorghum and pearl millet used fertilizers on these crops. What is more important, they used fertilizers for the rainfed crops also. (b) There was evidence to show that in some districts at least, local varieties of these crops were also fertilized. (c) High spread of the HYV did not always lead to higher rates of fertilizer application but spread of HYV and extent of crop area fertilized were positively correlated. This implied that decisions to use fertilizers and superior varieties were related but decisions regarding rates of application were probably taken with other considerations in view. (d) The status of soil moisture appeared to be important in fertilizer use decisions. Accordingly, rainfall and irrigation both appeared to influence fertilizer use. (e) There was some evidence to suggest that farmers considered the relative responses of different varieties in making their fertilizer use decisions. (f) The rate of application as well as the area fertilized with different nutrients was lower under unirrigated conditions respectively for both these crops. The modal rates of application of nitrogen were 40-60 kg and 21-40 kg per fertilized hectare under irrigated and unirrigated conditions. The unirrigated rates were somewhat higher for sorghum while the irrigated rates were higher for pearl millet. Application of phosphorus and potash was more widespread for sorghum. Under unirrigated conditions, however, the extent of area fertilized with these nutrients was substantially lower, particularly in pearl millet districts. (g) Wide interdistrict variability was noticed in the fertilizer use parameters for both these crops, underscoring the need to study the determinants of this variability and also the adaptability and response behavior of different HYV in greater detail.

In the following chart, districts have been classified into 9 categories representing combinations of high, medium and low rate and area fertilized variables (for nitrogen only). Four of these are of special interest from a diagnostic point of view. We believe that this classification arises from the interaction of technological and institutional factors. Availability of regionally adapted, fertilizer-responsive varieties determines rates of fertilizer application and adequacy of institutional infrastructure (credit, fertilizer retail trade, etc.) influences the extent of crop area receiving fertilizers. Based on this

Classification of districts according to rate of application and percent area fertilized with nitrogenous fertilizers (1973-74)

CATEGORY[a]		IRRIGATED CROP	RAINFED CROP
I	HIGH RATE-HIGH SPREAD	Ahmadnagar(S), Sangli(S), Belgaum(S)/Ahmadnagar(P), Morena(P), Guntur(P), Chittoor(P), Coimbatore(P), Tirunelveli(P), Bellary(P)[b]	Jalgaon(S), Amravati(S), Mandsaur(S), Belgaum(S)/Morena(P), Ahmadnagar(P)
II	HIGH RATE-MED. SPREAD	---	Ahmadnagar(S), Satara(S), Parbhani(S), Akola(S), Wardha(S)
III	HIGH RATE-LOW SPREAD	---	Sangli(S), Aurangabad(S)/Banaskanta(P)
IV	MED. RATE-HIGH SPREAD	Satara(S), Amravati(S), Shimoga(S), Shimoga(S)[b], Mysore(S)/Hissar(P), Rohtak(P), Nellore(P), Coimbatore(P)[b], Chingleput(P), Chingleput(P)[b]	Buldhana(S), Nagpur(S), Shimoga(S)/Kaira(P), Jaipur(P), Jalgaon(P)
V	MED. RATE-MED. SPREAD	Anantapur(S)/Sangli(P)	---
VI	MED. RATE LOW SPREAD	---	Mysore(S)
VII	LOW RATE-HIGH SPREAD	Jalgaon(S), Buldhana(S), Bellary(S)/Kaira(P), Rajkot(P), Jaipur(P), Madurai(P), Madurai(P)[b]	Bellary(S)/Rajkot(P)
VIII	LOW RATE-MED. SPREAD	Osmanabad(S), Wardha(S)	Nanded(S)/Tirunelveli(P), Tirunelveli(P)[a]
IX	LOW RATE-LOW SPREAD	Sholapur(P), Tirunelveli(P)[b]	Bhir(S), Osmanabad(S)/Rohtak(P), Aurangabad(P), Parbhani(P), Bhir(P)

a. High rate -- >60 kg N/fert. ha for irrigated, >40 kg N/ha for unirrigated crop.
Medium rate -- 41-60 kg N/ha for irrigated, 31-40 kg N/ha for unirrigated crop.
Low rate -- <40 kg N/ha for irrigated, <30 kg N/ha for unirrigated crop.
High, medium and low spread indicate >60%, 41-60%, and <40% crop area fertilized with nitrogen respectively.

b. Post-rainy season crop.

S. Sorghum.

P. Pearl Millet.

reasoning, the HIGH RATE-HIGH SPREAD category represents a desirable situation, favorably endowed with both factors. In the HIGH RATE-LOW SPREAD districts (Category III), institutional inadequacy is indicated. The LOW RATE-HIGH SPREAD districts (Category VII) seem to have good institutional infrastructure but lack a suitable fertilizer responsive variety. The LOW RATE-LOW SPREAD districts (Category IX) have both problems. Thus, it is possible to identify areas where technological or institutional or both, factors play an inhibiting role in context of fertilizer use.

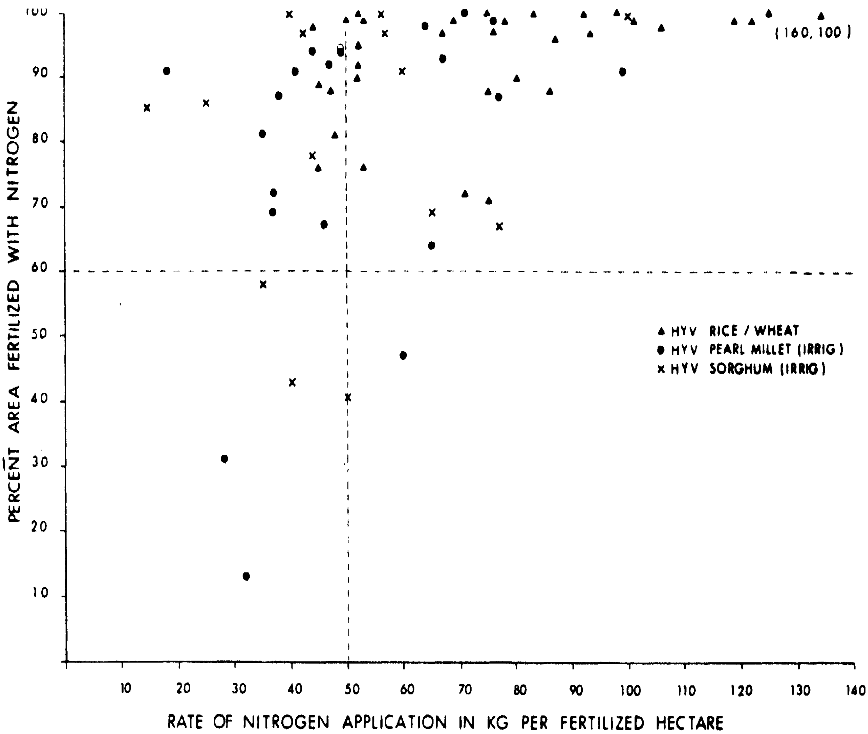
This chart shows that in 29 out of 35 districts under the irrigated category (both crops included), the spread was high. In nearly one-third of the districts the rates were low. This underscored the technology factor as being more important. Under rainfed conditions, both the factors appeared to be important. One must investigate regional variation in response of different high yielding varieties to fertilizer application (under irrigated as well as rainfed conditions) to come up with firm conclusions but even this simple analysis shows that all the varieties being adopted by farmers are not responsive to high fertilization rates.

3. Fertilizer use on irrigated crops

It has been argued (Jodha 1973) that crops like sorghum and pearl millet receive scant attention in terms of use of modern inputs primarily because of their low-response, low-value nature. It has been shown (Desai 1969) that farmers' fertilizer use decisions are based on profitability of responses, and under conditions of limited availability of working capital, rarely favor these crops. In this section we investigate whether the advent of fertilizer responsive HYV has made a difference in this traditional setting, by looking at fertilizer (nitrogen) use on irrigated HYV of sorghum and pearl millet on one hand and that on HYV of relatively higher-valued irrigated cereals like rice or wheat on the other in the same district.

Figure 2 shows the rate of application and percent area fertilized with nitrogen for irrigated sorghum, pearl millet, and rice or wheat in different districts. Appendix II shows the use level of nitrogen on rice or wheat in all the districts.

FIGURE : 2 RATE OF APPLICATION PER FERTILIZED HECTARE AND PERCENTAGE AREA FERTILIZED WITH NITROGEN FOR IRRIGATED SORGHUM / PEARL MILLET AND RICE / WHEAT IN SELECTED DISTRICTS (1973-74)



At first glance, the fertilizer use values for irrigated sorghum, pearl millet, and rice/wheat appear clustered together. Closer scrutiny, however, allows some discrimination. The two groups of crops -- millets and superior cereals, are not clearly distinguishable with respect to the area fertilized parameter. In both cases, most of the observations are clustered above the 60% level. The figure thus indicated that under assured environment, farmers resorted to high extent of fertilization for all crops. The mean percentage areas fertilized for sorghum and the superior cereals were not found to be statistically different from each other but for pearl millet, the values were found to be significantly lower (t = 2.87, df 20) as compared to rice or wheat. This diffference was also significant when observations for both sorghum and pearl millet were pooled (t = 3.59, df 34). Thus, even though the areas fertilized were high for both groups of irrigated crops, the superior cereals fared relatively better.

With regard to rates of nitrogen application, Figure 2 showed that the rate was less than 50 kg per fertilized hectare in only 6 (out of 33) districts for the superior cereals. The sorghum and pearl millet rates were below 50 kg in 21 (out of 34) districts. The mean rates of application for the two groups of crops were found to be significantly different from each other (t = 2.74, df 13 for sorghum; 4.45, df 20 for pearl millet; 3.59, df 34 for merged sorghum and pearl millet). Thus, commensurate with relative responses to fertilization, the rates of application were lower for sorghum and pearl millet as compared to those for rice or wheat.

This analysis, therefore, reveals that the millets are fertilized at lower levels under irrigated conditions. However, it should be noted that the absolute levels of fertilizer use for these crops are not very low. We have reported earlier that they claim a share in irrigation as well as fertilizers -- the most critical inputs in SAT agriculture. Clearly the main issue is availability of regionally adapted, high yielding varieties which are highly responsive to modern inputs. In areas where these have been made available, the millets compare favorably with the superior cereals. One unambiguously comes to the conclusion that the critical research task so far as these crops are concerned is development of such varieties.

4. Trend in fertilizer use

In order to provide an idea of the pattern of diffusion of fertilizer use and also of the firmness of the estimates presented in the earlier sections we looked at the trend in fertilizer use over time. Data on fertilizer use parameters were available for 6-7 years continuously for only eight districts. Sorghum crop was covered in Mandsaur, Akola, Shimoga (rainy season) and Shimoga (post-rainy season) and pearl millet in Jaipur, Kaira, Hissar and Aurangabad districts. Figure 3 shows the changes over time in rates of application per fertilized hectare and percentage areas fertilized with nitrogenous fertilizers for these two crops and also for irrigated rice (or wheat) in these districts.[9] The following important tendencies are revealed by the figure:

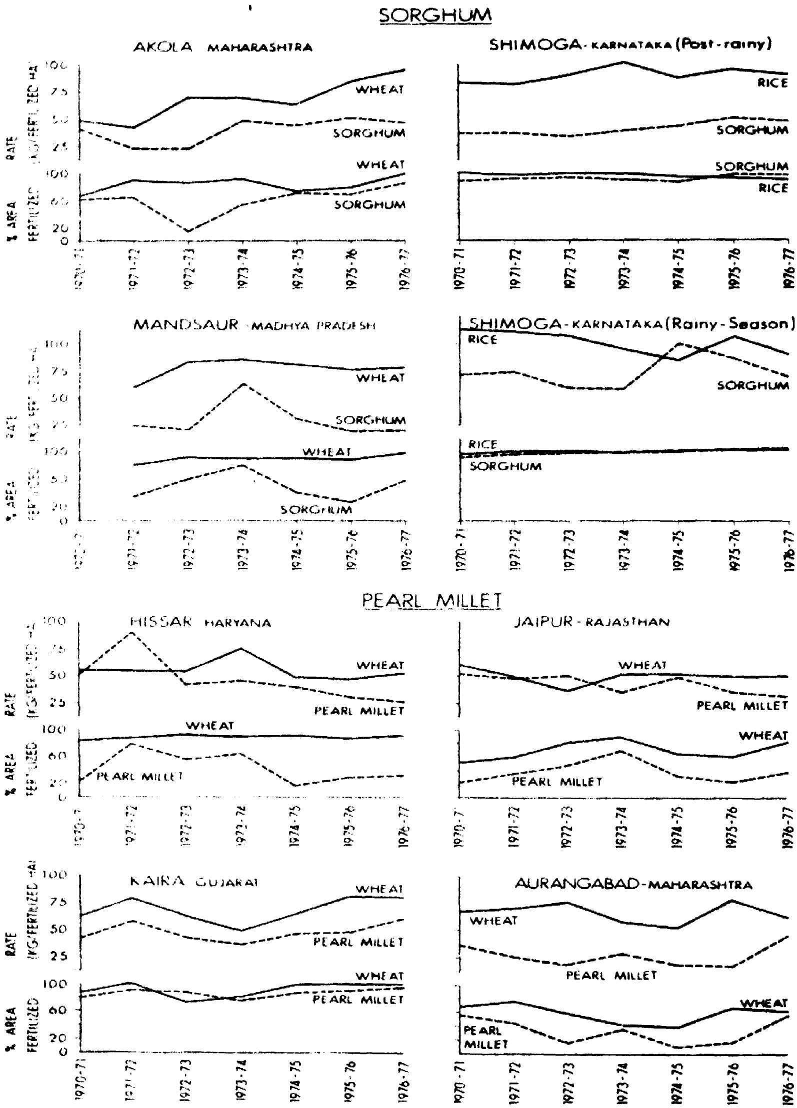
(a) In general, Figure 3 revealed no systematic trend either in rates of fertilization or percentage areas fertilized for HYV of sorghum and pearl millet. The HYV of other irrigated cereals -- rice or wheat, in their traditional production areas -- Shimoga, Mandsaur and Hissar, showed greater stability, particularly with regard to area fertilized. Looking at the position in Shimoga where the sorghum HYV were grown either as irrigated crop (post-rainy season) or under conditions of high and stable rainfall (rainy season), the stabilizing role of adequate moisture availability even for this crop is clearly brought out -- the rates are higher and the percentage area fertilized is high and stable as compared to the other two sorghum districts. But for pearl millet, this explanation does not seem to hold. Hissar is a predominantly irrigated HYV growing district and Figure 3 did not reveal a high or stable pattern in this district. We have too few districts to draw conclusions but the Hissar case does suggest the need to look for other variables like seasonal conditions, pest and disease incidence, etc. to obtain a fuller understanding of temporal variability in the fertilizer use parameters.

In other districts, fertilizer use for both the categories of crops -- millets as well as superior cereals, was fluctuating though one did note a stable (area fertilized in Kaira) or rising (rate in Akola and Jaipur) trend for wheat in some districts. The diffusion of fertilizers on crops like sorghum and millets or even irrigated crops in areas where

9. These data were not available separately for irrigated and unirrigated crops. Figure 3 is thus based on average values. One needs to note, however that in Mandsaur and Akola (sorghum) and Aurangabad (pearl millet), the HYV were grown primarily as rainfed crop. In Shimoga (post-rainy season sorghum) and Hissar (pearl millet), on the other hand, irrigated HYV was dominant. This does provide some scope for analyzing irrigated and rainfed crops.

FIGURE 3.

TREND IN USE OF NITROGENOUS FERTILIZERS FOR HYV OF SORGHUM/PEARL MILLET AND WHEAT/RICE IN SELECTED DISTRICTS 1970-71 TO 1976-77



the irrigation source and the environment are unstable[10] did not seem to follow the classical sigmoid route. It should also be noted that in more than ten years (beginning 1965-66) fertilizer use has not spread over the entire HYV area under sorghum and pearl millet in most of the unirrigated producing districts. It was noted (data not presented here) that there was considerable year-to-year variation in the proportion of fertilizer users also. All these factors imparted instability to the fertilizer use parameters. We hypothesize that this instability is primarily caused by variation in seasonal conditions conducive to fertilizer use. Later in this section, this hypothesis is examined further.

(b) Figure 3 also shows that the percentage area fertilized had relatively lower variability over time in districts where it had attained high levels (as in Shimoga for rainy and post-rainy season sorghum and Kaira for pearl millet). These seem to represent areas where fertilizer has been accepted as an essential component of the production technology for HYV. Several factors -- availability of adequate soil moisture, better adaptability, superior response, lower disease/pest incidence, etc. could be responsible for this. Other districts with lower coverage (Mandsaur, Akola, Aurangabad, Hissar and Jaipur) represented relatively uncertain response situations where both area fertilized and rates fluctuated often in the same direction.

(c) The tendency for the area fertilized to become stable as it reached a high level (as in most districts for irrigated rice/wheat HYV and also for sorghum in Shimoga and pearl millet in Kaira), suggested the hypotheses that during initial stages of adoption, one must look at the area fertilized parameter. Later, when adoption is widespread, fluctuations in fertilizer use became rate-dominated.

(d) Even though Figure 3 showed significant interyear variations, the 1973-74 data that were presented in the earlier section were not atypical. Most of the rate values in the figure ranged between 35 kg to 50 kg per hectare, irrigated post-rainy season sorghum in Shimoga an exception. Since 1973-74, the rate has fallen significantly only in Mandsaur; in other districts, they have remained more or less in the

10. It may be noted that in Akola, Aurangabad and Kaira, wheat cultivation has assumed importance only recently.

same modal class. The area fertilized has, however, shown a significant downward trend in several districts. Thus, while the modal rate estimates presented in Tables 7 and 8 appear to be fairly firm, one cannot say the same for the area fertilized parameter.

(e) The position in 1974-75 is of special interest because fertilizer prices went up substantially during this year. Figure 3 revealed that the rate of application for sorghum and millet went down in 4 districts (Mandsaur, Akola, Aurangabad and Hissar) and in 5 (Mandsaur, Aurangabad, Hissar, Jaipur and Shimoga, rainy season) the area fertilized declined as compared to 1973-74. It follows that one must look at both the parameters to get a correct picture of farmers' response to price changes. Even then Shimoga (for both rainy and post-rainy season sorghum), Akola (sorghum) and Kaira (pearl millet) stood out as exceptional districts recording increases in average level of nitrogen used per hectare in 1974-75. Further analysis revealed (data not presented here) that in these districts there was a substantial decline in the area under high yielding varieties, implying reductions in total quantity of fertilizer used. Thus, adjustment to price and other changes seemed to have several dimensions.

(f) Some regression results: It has been suggested earlier that seasonal conditions (rainfall, occurrence of pests/diseases, etc.) could play a role in farmers' fertilizer use decisions for unirrigated crops. An attempt was made to study the relationship between fertilizer use on HYV of sorghum and pearl millet and seasonal (June to August) rainfall on the basis of four years' data (1970-71 to 1973-74) for 17 rainy season sorghum and 10 rainy season pearl millet districts.[11] The Annual Reports for different years also provided information on borrowings for agricultural purposes and we have also included this variable as an indicator of credit availability in the regression model. This model thus hypothesized that seasonal conditions and capital were the main determinants of fertilizer use on these crops. Lagged output price was also considered initially but this did not emerge significant in any case and was subsequently dropped. The disease/pest variable could not be included because this information was not available.

11. The choice of these districts was exclusively determined by coverage in all the four years. The sorghum districts were Belgaum, Bellary, Mysore, Shimoga, Jalgaon, Satara, Sangli, Aurangabad, Parbhani, Bhir, Nanded, Osmanabad, Buldhana, Akola, Amravati, Wardha and Nagpur. The pearl millet districts were Guntur, Nellore, Chittoor, Jalgaon, Aurangabad, Bhir, Hissar, Rohtak, Chingleput and Coimbatore.

Six variables were used to indicate the fertilizer use level. These were: (i) percentage of farmers using fertilizer (ADOPTION), (ii) Average rate of application of $N+P_2O_5+K_2O$ in kilograms per hectare of crop area (AVNPK), (iii) rate of application of nitrogen in kg per fertilized hectare (NRATE), (iv) rate of application of phosphorus in kg per fertilized hectare (PRATE), (v) percentage area fertilized with nitrogen (NAREA), and (vi) percentage area fertilized with phosphorus (PAREA). Rainfall during the growth period (June to August) in millimeters (JUNAUGRF) was used as one of the explanatory variables. For the ADOPTION decision, rainfall during sowing and presowing period is relevant and, therefore, we considered rainfall during June-July (mm) only in this equation. The other independent variable used was the average borrowing per cultivator for agricultural purposes (CREDIT) during the season in rupees. These two variables were regressed against each of the six dependent variables mentioned above.

District level estimates on these variables were available. In view of the limited number of years available for each district, data for all sorghum and all pearl millet districts were pooled and regressions were estimated for each crop using the error components model (Wallace and Hussain 1969, Barah 1976).[12] These equations are presented in Table 9.

The results indicate that the rate of application was not significantly influenced by rainfall or credit variables (PRATE equation for sorghum being an exception where the coefficient for credit appeared significant). Both these variables exercised significant positive influence over adoption and area fertilized decisions. It follows that low rainfall and inadequate capital restricted fertilizer use on HYV sorghum and pearl millet. The results came out less strongly for pearl millet. In seven out of ten districts for this crop, the hybrids were grown under irrigated conditions (Appendix I) and this may have affected the rainfall variable. These results suggest that fertilizer extension programs for these crops must be backed with adequate credit and must provide for flexibility to adjust according to seasonal conditions. It is appropriate that research recommendations on fertilizer use do emphasize the flexibility element now (Vijayalakshmi 1979, Singh 1979).

12. The regressions were estimated at the ICRISAT Computer Center with the help of the COMTAC (Combining Time Series and Cross Section) package.

Table 9. Effect of rainfall during growing period and credit on fertilizer use for HYV of sorghum and pearl millet.[a]

No. of districts	No. of years	Dependent variable	Regression coefficients		
			Intercept	JUNAUGRF	CREDIT
			Rainy season sorghum		
17	4	ADOPTION	26.140	0.033**	0.034***
				(2.180)	(4.403)
		AVNPK	29.368	0.023**	0.021**
				(2.122)	(2.230)
		NRATE	39.967	0.003	-0.005
				(0.362)	(0.771)
		PRATE	25.109	-0.003	0.016***
				(0.641)	(3.612)
		NAREA	42.334	0.028**	0.025**
				(2.450)	(2.523)
		PAREA	33.383	0.023**	0.017*
				(2.063)	(1.746)
			Rainy season pearl millet		
10	4	ADOPTION	48.030	0.045*	0.033***
				(1.898)	(3.729)
		AVNPK	45.816	0.025	-0.005
				(0.940)	(0.264)
		NRATE	55.295	-0.014	-0.007
				(0.677)	(0.513)
		PRATE	31.393	-0.017	0.003
				(0.878)	(0.209)
		NAREA	57.223	0.027	0.018
				(1.383)	(1.370)
		PAREA	28.561	0.039*	-0.014
				(1.934)	(0.954)

Figures in parentheses are t-values.

*, **, *** Significant at 10, 5 and 1% probability levels respectively.

a. Results based on pooled time series and cross-section data. Estimates obtained by COMTAC package available at the ICRISAT Computer Center.

The analysis of trend in fertilizer use over time revealed almost complete coverage of the HYV under irrigated conditions. Under rainfed conditions, however, a significant fraction of the HYV continued to be unfertilized even after 10'years. There was also considerable year-to-year fluctuation. It appeared that seasonal conditions played an important role in fertilizer use decisions -- particularly in decisions regarding whether to use fertilizer and what proportion of the crop area to cover.

IV. DETERMINANTS OF FERTILIZER USE

The analysis of determinants of fertilizer use has been done at two levels. The first focuses attention on interfarm variability (within a district) which is hypothesized to be caused by forces operating at the level of the individual farm, and the second looks at interregional (between districts) variation in fertilizer use in context of differences in broad agroclimatic and institutional environments. This two-step approach is intended to capture the influence of micro-, and macro-factors more fully than has been possible in most of the earlier studies which investigated the problem either from a macro (Desai 1969, Parikh 1965, Rao 1973, Jayaraman 1979) or a micro (NCAER 1974) angle. The basic hypotheses, model specification and empirical results obtained in the two analyses are described below.

In the first analysis, we have examined decisions regarding rates of application of different plant nutrients.[13] On the basis of past studies[14] we hypothesize that these decisions are influenced by two sets of forces. Firstly, there are factors which influence the response of the crop to fertilizer application and hence the profitability of fertilizer use. We call these response variables which include soil type, drainage, irrigation, timeliness of sowing, previous cropping history of the plot, incidence of diseases and pests, weather conditions, etc. Secondly, there are farmer-specific, socioeconomic variables such as education and experience of the farmer, capital position and credit availability, extent of commercialization, the socioeconomic status of the farmer, prices of fertilizer and output, risk aversion, etc.

13. Further work in this area is being pursued with other data sources.
14. See Timmer 1974, Jha 1980 for detailed reviews on this aspect.

Plotwise data for each district from the Yield Estimation Survey (YES) for 1973-74 were used for this analysis. As has been indicated earlier, 80 HYV fields were chosen for the crop cutting experiments in each district and information on input use and output were collected from these plots.[15] Unfortunately, data on all the above mentioned variables were not available and the analysis had to be done with selected plot and farm-specific variables. These are specified below.

Dependent variables -- three dependent variables were specified and separate regression equations were estimated for each. These were: total plant nutrients ($N+P_2O_5+K_2O$) used in kg per fertilized hectare (NPKRATE), quantity of nitrogen (N) used in kg per fertilized hectare (NRATE) and quantity of phosphorus (P_2O_5) used in kg per fertilized hectare (PRATE).

Independent variables -- (i) Data were available on soil texture of the plot on which the crop was grown as light, or heavy soil. A dummy variable (SOILDMY) was defined with value unity if the plot had heavy soil and zero otherwise. It was hypothesized that sorghum or pearl millet grown on relatively heavier soil would receive more fertilizers. (ii) Opinion of the farmer on the status of drainage for the plot concerned was also recorded. A dummy variable (DRAINAGE) having value unity for poorly drained or waterlogged plots and zero otherwise, was defined. A negative coefficient for this variable was hypothesized. (iii) It was hypothesized that plots which were sown at the normal time would tend to receive higher levels of fertilizers. Farmers' responses regarding timeliness of sowing (early, normal or late) were used to generate a dummy variable (TIMELYSOWN) for plots sown at the normal time. (iv) There is some evidence from past studies (Desai et al. 1973) to suggest that farmers adjusted their current fertilization rates downwards if the preceding crop grown on the plot was heavily fertilized. In the absence of data on past fertilization status of the plot, a dummy variable was used as proxy to capture this effect. This variable (PREVCROP) took the value unity if the plot was put to a commonly fertilized crop (like sugarcane, tobacco, cotton, vegetables, HYV of cereals, groundnut, etc.) or legume, during the preceding season. As such, a

15. Scrutiny of data for each district revealed that information on fertilizer prices were not collected for plots where no fertilizers were used. Such observations were deleted for purposes of this analysis. Also, no regressions were estimated for districts where the number of observations was less than 20.

negative influence was hypothesized for this variable. (v) Adequacy of rainfall during the crop season, again in the opinion of the farmer, was represented by another dummy variable (RAINFALL) which took zero values if rainfall was not adequate, and unity if it was so. A positive coefficient for this variable was hypothesized.

These were the plot-specific variables.[16] In addition, two farm -specific variables were also included in the model. (vi) Data were collected on fertilizer prices for all plots on which fertilizers were used. This (FERTPRICE) was used as an explanatory variable. Average prices per kg of total plant nutrients, per kg of nitrogen and per kg of phosphorus were used in the NPKRATE, NRATE and PRATE equations, respectively.[17] (vii) Finally, farm size (FARMSIZE), measured as operational holding in hectares was used as another variable to capture the effect of size. Past evidence on the influence of this variable is mixed and we have hypothesized that farm size is inversely related with fertilization rates.

Three linear regression equations were estimated for each district with NPKRATE, NRATE and PRATE as dependent variables. The model, thus, was of the following type:

NPKRATE or NRATE or PRATE = f (SOILDMY, DRAINAGE, TIMELYSOWN, PREVCROP, RAINFALL, FERTPRICE, FARMSIZE)

The estimated equations for each district are reported in Appendix III and Table 10 summarizes the significant results. In general, Appendix III revealed low R^2 values. This was not surprising in view of the omission of some relevant variables and the presence of a number of subjectively measured variables in the equations. It also showed that only a few variables were usually significant in each equation and sometimes the signs behaved erratically. No attempt has been made to interpret

16. An irrigation dummy was also considered but in all districts this variable had either zero variability or was collinear with some other variable. In view of the fact that we have relatively better prior information about irrigation as compared to the other plot-specific variables included in the model, it was decided to pursue the latter and the irrigation variable was dropped.

17. Fertilizer quantities and prices were recorded for each plot. Where straight fertilizers were used, the price of individual nutrient (N or P_2O_5) was directly available. For complex and mixed fertilizers, prices of individual nutrients were obtained by apportioning the total expenditure on fertilizers in terms of the quantities of individual nutrients weighted by the prices of these nutrients in straight fertilizers. Average price per kg of ($N+P_2O_5+K_2O$) was also obtained by a similar weighting procedure.

Table 10. Variables explaining inter-plot variability in fertilizer use on HYV of sorghum and pearl millet (IASRI 1973-74 data).[a]

DISTRICTS	DEP. VA-RIABLE	SOIL-DMY	DRAIN-AGE	TIMELY-SOWN	RAIN-FALL	PREV-CROP	FERT-PRICE	FARM-SIZE
Ho:		b>o	b<o	b>o	b>o	b<o	b<o	b<o
				Sorghum districts				
Jalgaon	NPKRATE						(+)	
	PRATE					(+)	(+)	
Ahmadnagar	NPKRATE	(+)					(+)	
	NRATE		(+)					
Osmanabad	NPKRATE						(+)	
Nagpur	NPKRATE	(+)				(-)		
	NRATE		(-)	(+)		(-)	(-)	
	PRATE	(+)				(-)		
Amravati	NPKRATE							(-)
	NRATE							(-)
	PRATE	(+)			(+)			
Bellary	NPKRATE				(+)			
	NRATE				(+)		(-)	
	PRATE				(+)		(-)	
Satara	NPKRATE						(-)	
	NRATE	(-)					(-)	
	PRATE	(-)			(-)			
Parbhani	NPKRATE				(+)			(+)
	NRATE	(+)			(+)			(+)
Anantapur	NPKRATE	(-)			(-)			
	NRATE	(-)	(+)		(-)	(-)	(-)	
Sangli	NRATE					(-)		
	PRATE	(+)						
Shimoga	NPKRATE				(+)		(-)	
	NRATE				(+)			
	PRATE				(+)		(-)	
Shimoga[a]	NPKRATE					(+)	(-)	(+)
	NRATE				(+)	(+)	(-)	(+)
	PRATE						(-)	
Krishna[a]	PRATE			(+)				(+)
				Pearl Millet districts				
Nellore	NPKRATE							(+)
	NRATE							(+)
	PRATE						(-)	
Jalgaon	NPKRATE				(-)		(-)	
	NRATE				(-)		(-)	
Coimbatore	NPKRATE	(+)				(-)	(-)	
	NRATE	(+)				(-)	(-)	
Rohtak	NPKRATE					(-)	(-)	
	NRATE						(-)	
Morena	NRATE						(-)	
	PRATE					(+)	(-)	

Table 10 continued

DISTRICTS	DEP.VA-RIABLE	SOIL-DMY	DRAIN-AGE	TIMELY-SOWN	RAIN-FALL	PREV-CROP	FERT-PRICE	FARM-SIZE
Ho:		b>o	b<o	b>o	b>o	b<o	b<o	b<o
Parbhani	NPKRATE	(+)	(-)	(+)			(-)	
	NRATE	(+)		(+)			(-)	
	PRATE	(+)		(+)			(-)	
Jaipur	NPKRATE				(+)			
Guntur	NRATE			(+)				
	PRATE			(+)			(-)	
Chittoor	NPKRATE				(-)		(-)	
	NRATE				(-)		(-)	
Hissar	NPKRATE			(+)		(-)		(+)
Bellary[b]	NPKRATE				(+)			
	NRATE				(+)			
	PRATE			(-)	(+)			
Madurai[b]	NPKRATE			(+)	(-)			
	NRATE			(+)	(-)			
	PRATE				(-)			
Coimbatore[b]	NPKRATE	(+)						
	NRATE			(+)	(-)			

a. The significance level used to test the hypotheses was 5% using a one-tail t test.

b. Post-rainy season crop.

See Appendix III for regressions.

each equation, rather we have tried to integrate evidence on the influence of different variables. The following paragraphs summarize the results for each variable.

(i) Soil type (SOILDMY): Regrèssion coefficients for this variable indicated that crops grown on heavier textured plots were fertilized at higher rates. For some districts (like Satara and Anantapur for sorghum) negative coefficients were obtained, but in others where this variable was significant, the above relation seemed to hold.

(ii) Drainage (DRAINAGE): This variable was not found to be significant in most of the districts -- in others the signs were not uniformly consistent. It may be noted that neither of these crops were grown on plots prone to waterlogging and this might have led to indifferent responses to questions on drainage. The results do not permit any conclusions regarding the influence of this variable.

(iii) Timeliness of sowing (TIMELYSOWN): This variable was statistically significant in 2 equations for sorghum and in 10 for pearl millet and seemed to exert a positive influence of fertilizer rates. The evidence showed up relatively more strongly for nitrogen use on pearl millet.

(iv) Previous crop (PREVCROP): This variable also fared relatively better in the pearl millet equations. For sorghum, the results were mixed. The hypothesized influence on fertilizer use for pearl millet showed up even more clearly at 20% probability level, particularly for nitrogen use. We expected more positive results for phosphorus rates (where residual effects are more important) but the regression coefficients did not suggest any clear trend.

(v) Rainfall during crop season (RAINFALL): Adequacy of rainfall during the crop season influenced fertilizer use on sorghum positively. For pearl millet, in 8 out of 12 equations in which this variable was significant, the coefficients were negative. At 20% probability level, results for pearl millet become inconclusive. This could be due to the fact that the pearl millet hybrids were more frequently grown under irrigated conditions. It may be noted that the regressions based on four years data presented earlier also showed a stronger influence of rainfall on fertilizer use for sorghum, though the effect was discernible only on fertilized area and not on rates.

(vi) Farm size (FARMSIZE): The farm size variable did not behave in the expected manner. In 11 equations it was found to be significant and in

8 it had a positive sign. The hypothesis of negative influence of farm size on fertilization rates was based on the logic that due to greater pressure to use land-augmenting practices, the small farms would have more input-intensive cultivation. One must note, however, that this variable could also be interpreted as a proxy for socioeconomic status, which is likely to be positively related with fertilizer use. The results suggest that in most cases, this latter effect dominates. Thus, while the postulated hypotheses cannot be accepted, the results pertaining to this variable could be interpreted as supporting the latter.

(vii) Fertilizer price (FERTPRICE): This variable emerged significant in fairly large number of districts and in most cases it showed the hypothesized negative influence on rates of fertilizer application. The fact that we are able to identify price effects from a cross-sectional data set suggested that even within a small area (district) there was considerable interfarm variation in fertilizer prices. We consider it as a major contribution because almost all studies based on cross-section data assume that such variations do not exist and do not even include a price variable in the model. It should be noted that in our model, price variability arises from two sources -- from interfarm differences in prices paid for the same fertilizer material and also from use of different fertilizer materials (mixtures or complex fertilizers) which leads to different prices for individual nutrients depending on the weight these nutrients carry in the total fertilizer mix. Significant coefficients for this variable imply that farmers are aware of this subtle price differentiation phenomenon. This finding has implications for retail trade in fertilizers and we shall come back to it later.

The micro-level exercise attempted above does not yield conclusive results for some variables.[18] However, there is enough evidence to establish that forces operating at the farm or plot level do influence fertilizer use decisions. This implies that farmers are conscious of the forces which influence response of crops to fertilizer application and do try to adjust accordingly. The evidence that they respond rationally to variables like soil texture, timeliness of sowing and

18. It should be noted that all plots with zero fertilizer use were deleted from this analysis. This could have adversely affected the results, particularly with respect to variables for which a negative influence was hypothesized.

and rainfall during crop season, suggests awareness regarding factors which influence the technical efficiency of fertilizer use.

2. Aggregate district level analysis

This exercise was attempted with a view to study the influence of macro -level, regional factors on fertilizer use decisions, and sought to explain interdistrict variability in extent and rates of fertilization. District estimates of rate of fertilizer application and percentage area fertilized for HYV of sorghum and pearl millet were used as dependent variables in a regression model with three sets of independent variables. The first included variables which are important in context of explaining interregional (district) variations in response of these crops to fertilizer application -- we call these response variables -- and this set included soil type, irrigation and seasonal rainfall conditions. The second set included variables which depict the experience of farmers regarding factors which have a bearing on their current fertilizer use decisions and included their perception of risk and expected seasonal conditions[19] -- these are called experience variables. The third set included institutional variables like credit availability, extent of commercialization, and subsistence pressure.

For this analysis, data for 20 rainy season sorghum and 21 rainy season pearl millet districts (1973-74) were used. In view of the limited number of observations available, we had to eliminate some variables in the preliminary stage. The variables used in the regression model are defined below:

Dependent variables: District estimates of average level of total plant nutrients ($N+P_2O_5+K_2O$) used in kg per fertilized hectare (AVNPK), rate of nitrogen application in kg per fertilized hectare (NRATE) and rate of phosphorus application in kg per fertilized hectare (PRATE) were used as three dependent rate of application variables. Two variables -- percentage area fertilized with nitrogenous fertilizer (NAREA) and percentage area fertilized with phosphatic fertilizers (PAREA), were used to depict the extent of fertilization variable. Thus, for each crop, five equations were estimated corresponding to these five dependent variables.

19. Expected output price (defined as lagged price) and overall educational status in the district (defined as extent of rural literacy) were also tried but these did not give significant results in any case and were subsequently dropped.

Independent variables: Five response variables were used in the equations. (i) Two dummy variables were used to specify three broad soil groups: SOILDMY 1 for districts with black soils dominating and SOILDMY 2 for mixed black and red soil districts, all other soil types were put in the excluded category. (ii) Percentage area under irrigation in the district (IRRIGATE) was used as an independent variable to capture the effect of irrigation. (iii) Rainfall during June and July 1973 were included as two rainfall variables -- JUNERF and JULYRF.

It was hypothesized that farmers' fertilizer use decisions were influenced by their expectation regarding weather. We used normal rainfall during June (JUNENOR) and July (JULYNOR) in the district as proxies for expected weather conditions. A risk variable (RISK), specified as the coefficient of variation of the detrended yield series for the crop concerned (sorghum or pearl millet) in each district, was used to represent farmers' perception of the inherent instability of the environment. These three variables represented the experience of farmers.

Three variables were used to depict the influence of the institutional environment. As an indicator of credit availability, district estimates of average borrowings per cultivator for agricultural purposes in 1973-74, given in the survey report (Raheja et al. 1976) were used to define a credit (CREDIT) variable. Percentage area under commercial crops (COMCROPS) in the district was used to depict the extent of commercialization of agriculture. Finally, the extent of subsistence pressure (SUBSIST) in each district was measured as the percentage of holdings of less than two hectares.

The final equations are presented in Appendix IV and Table 11 summarizes the salient results in terms of significant effects only.

The results support the hypothesis that inter-district differences in responses to fertilizer application affected the levels of fertilizer use. It was observed that as compared to other soil types (mixed red and black, red, alluvial, etc.), the average levels of fertilizer use were higher on black soils. The effect of irrigation did not show up as clearly as the earlier discussion suggested. Rainfall during growing season exercised a positive influence on fertilizer use for sorghum, mainly through a favorable effect on area fertilized. For pearl millet, the results were not clear. It may be noted that similar results were obtained in the preceding plot-level analysis also. Considered along with regressions presented in Appendix III and Table 11, this analysis seemed to establish firmly that for mainly unirrigated sorghum HYV, favorable seasonal conditions did result in decisions to extend fertilizer use.

Results were relatively less clear with respect to the experience variables. The risk variable emerged significant only in the case of pearl millet. Interestingly, its effect was discernible on fertilized area and not on rates of application. Most of the work on effect of risks on fertilizer use, on the other hand, emphasize the impact on rates of application. This is clearly an aspect which needs further investigation. Rainfall expectations (based on long term experience)were hypothesized to influence both rate and area fertilized parameters in a stable fashion. The results for sorghum indicated that higher expected rainfall during presowing period had a favorable effect on P_2O_5 rates and a negative influence on percent area fertilized with nitrogen, while the expected situation during sowing period (July) affected N rates and area fertilized positively. The results for pearl millet were inconsistent or nonsignificant with respect to rates of application, but for area fertilized, a positive influence was discernible.

One must note that variability in sowing time across regions poses problems in interpreting the rainfall effects confidently, yet the results obtained, particularly for the predominantly rainfed sorghum HYV, suggest two influences. Firstly, rainfall expectations influence decisions regarding rates as well as area fertilized. In general, farmers in lower rainfall areas tend to be cautious with regard to use of fertilizers. Secondly, there is a short run adjustment phenomenon which shows that they do try to take advantage of weather conditions as they unfold. This effect operates more strongly on area fertilized rather than rates. It perhaps makes sense to do so because higher rates would be useful only if the soil moisture conditions remain favorable for a spell long enough to ensure its absorption -- this is uncertain. Extension of fertilized area (at moderate rates) enables farmers to take advantage of a short spell of adequate soil moisture conditions (about which they are sure).

Of the three institutional variables considered, credit emerged as the most significant one, reinforcing the view that inadequacy of capital plays a restrictive role. There was also some evidence to show

Table 11. Variables explaining inter-district variability in fertilizer use on HYV of rainy season sorghum and pearl millet (1973-74).[a]

Variable	Rainy season sorghum					Rainy season pearl millet				
	AVNPK	NRATE	PRATE	NAREA	PAREA	AVNPK	NRATE	PRATE	NAREA	PAREA[b]
<u>Response variables</u>										
SOILDMY[b]	(+)	(+)				(+)				(+)
IRRIGATE					(-)					(+)
JUNRF	(+)			(+)	(+)			(-)		
JULYRF	(+)				(+)		(+)		(-)	(-)
<u>Experience variables</u>										
RISK									(-)	(-)
JUNENOR	(-)	(+)	(+)	(-)		(-)	(-)			
JULYNOR	(+)	(+)		(+)					(+)	(+)
<u>Institutional variables</u>										
CREDIT		(+)				(+)	(+)	(+)	(+)	
COMCROPS		(-)				(+)				
SUBSIST		(+)	(+)							

a. See Appendix IV for regressions. The significance level used to test the hypotheses was 5% using a one-tail t test.

b. In this equation, rainfall during June to August has been considered.

that higher subsistence pressure led to higher fertilizer use. It should be noted that this variable could be given an alternative interpretation also. In general, farm sizes are small in areas having better agroclimatic endowments. Thus, the finding that fertilizer use is higher in districts where small farms predominate, could as well be indicative of the effect of favorable agroclimatic endowments. No firm conclusions could be drawn regarding the effect of commercialization -- this variable was found to be significant in only one equation.

The aggregative analysis thus reinforced the findings obtained in the microlevel analysis and also provided some additional insights. This two-step approach led to the following conclusions:

(a) Farmers' decisions regarding fertilizer use on these two crops are influenced by the expected responses to fertilizer application. This conclusion follows from the evidence that observed patterns of fertilizer use are influenced by factors which affect response -- soil type, timeliness of sowing, previous fertilization practices and rainfall during crop season. Adjustment to these variables also implies an awareness of the factors which influence technical efficiency of fertilizer use. Thus, farmers in SAT areas are found to be willing to use fertilizers if the responses are attractive, they also seem concerned about how to use this fertilizer efficiently. Both these aspects highlight rationality.

(b) Fertilizer use on rainfed crops (sorghum) is influenced by rainfall in two ways. Expectations regarding rainfall during the crop season affects fertilizer use decisions. Actual rainfall during this period is also important. The latter reflects an attempt by farmers to adjust to seasonal conditions as they unfold.

(c) Evidence on the impact of instability of environment -- risk, was not so strong as initially expected. Also, this variable seemed to be more crucial for decisions on area to be fertilized than on rates of application.

(d) Credit emerges as a powerful factor. This underscores the importance of inadequacy of working capital in SAT agriculture.

(e) Evidence on the influence of fertilizer prices on fertilizer use was quite strong. It should be noted that fertilizer prices are regulated and within a district one would not, a priori, expect significant cross -sectional variability in fertilizer prices. Our results indicate that such variations exist and are important. These could arise from (i) transportation costs, (ii) differences in timing of fertilizer purchases, (iii) differences in the kind and composition of fertilizer material purchased, and (iv) imperfections in retail trade of fertilizer. In fact, with the exception of the first, all the others imply inefficiencies in retail trade or imperfections in knowledge imparted to farmers.

V. SUMMARY AND CONCLUSIONS

This analysis was attempted to provide information regarding the status of fertilizer use on HYV of sorghum and pearl millet -- the two most important cereals grown on drylands of SAT India. It also sought to identify forces which influenced farmers' decisions regarding fertilizer use. Data from 21 predominantly SAT districts for sorghum and 26 for pearl millet were taken from the study entitled Sample Surveys for Assessment of High Yielding Varieties Programme conducted by the Indian Agricultural Statistics Research Institute (ICAR), New Delhi during 1973-74 (Raheja et al. 1976).

Data on adoption of fertilizers, extent and rates of fertilization for the HYV of these two crops negated two popularly held beliefs. Firstly, the view that farmers in the SAT do not use fertilizers for these low-valued, inferior cereals was not supported by data which clearly showed that in majority of districts studied, a substantial proportion of farmers did use fertilizers for these crops. Secondly, the data also contradicted the view that the unirrigated millets received no fertilizers. The data, particularly for sorghum showed that majority of farmers in most of the districts used fertilizers quite extensively for the unirrigated HYV also. The pearl millet hybrids lagged behind in this regard not because farmers were unwilling to use fertilizers but because the adoption of these varieties itself was confined largely to irrigated lands. However, one must qualify the above influences. The spread of the HYV of these two crops has not been very high and the local varieties which cover most of the area are largely unfertilized. So, it is not the low-value which is important, it is lack of fertilizer responsiveness of the traditional varieties which is responsible for non-fertilization of these crops.[20]

It was observed that the spead of HYV did not always lead to higher rates of fertilizer application, but spread of HYV and the extent of crop area fertilized were positively correlated. This implied that decisions to use fertilizers and superior varieties were related but decisions regarding rates of application were probably taken with other considerations in view.

As expected, fertilizer use varied under irrigated and unirrigated conditions and considerable interdistrict variability existed under both situations. The modal classes for application rates (per fertilized hectare) of N, P_2O_5 and K_2O were 41-60 kg, 31-40 kg and 11-20 kg for irrigated sorghum and 41-60 kg, 21-30 kg and less than 10 kg for irrigated pearl millet hybrids. The corresponding unirrigated rates were 21-40 kg, 21-30 kg and 11-20 kg for sorghum and 21-40 kg, less than 20 kg and less than 10 kg respectively for the pearl millet hybrids. These and the data for extent of crop area fertilized showed better values for sorghum under unirrigated conditions, but under irrigated conditions, the pearl millet hybrids had higher fertilizer use indicators. Further analysis of data for 8 districts over the period 1970-71 to 1976-77, and also evidence from other studies indicated that though there were interyear fluctuations, the modal rates reported above were fairly firm over time.

These findings have important implications for research work on these crops from two angles. Firstly, these can be treated as benchmark levels of existing fertilization practices of farmers. Frequently one comes across the question: what is the fertility level against which the new varieties, agronomic practices, etc. should be evaluated? The question is important because in almost all cases significant interactions exist between techniques and fertility levels. The above estimates are useful in providing some guidelines in this regard. Secondly, our analysis shows that there are areas where fertilizer use is quite high even under irrigated conditions. This implies differential adaptation of the HYV and underscores the need to develop regionally adopted, fertilizer response varieties. The argument is particularly relevant for pearl millet in which

20. Field experience of researchers (and our own data) suggests that farmers do sometimes apply nitrogenous fertilizers in small quantities (if the weather conditions are favorable) primarily to boost their sorghum fodder yields (Dr. N.K. Sanghi, All India Coordinated Research Project for Dryland Agriculture (AICRPDA), Hyderabad -- personal communication). We need to take a critical look at the fertilizer response data from this angle.

case, lack of adaptation to unirrigated conditions appears to be a major constraint.

The other important feature revealed by our analysis was that the modal rates mentioned above were attained within 4-5 years after the HYV were introduced. These have remained stable since then. While this provides yet another evidence of rapid response of SAT farmers to innovations, we need to investigate the reasons why the levels are not rising over time. Only a detailed analysis of the fertilizer response data for these crops will provide an answer to this puzzle.

Analysis of trend in fertilizer use parameters did not show any systematic pattern. Comparison of data for sorghum and millets with those for rice/wheat provided some evidence on the stabilizing effect of irrigation, particularly on the area fertilized variable. This analysis also revealed that it was important to keep all the fertilizer use parameters -- adoption, rates, as well as area fertilized, in perspective while studying fertilizer use pattern. One often observed these parameters moving in opposite directions implying that it is not always enough to look at one. This is an important methodological point and past studies have often failed in this respect. It should be noted that unlike the case of irrigated crops where once a farmer is convinced, he usually stays with fertilizers, for rainfed crops even the decision to use fertilizers has to be taken every time afresh. The data for irrigated pearl millet districts showed wider fluctuations. It was argued that apart from other factors, one needs to examine the occurrence of diseases and pests in order to understand the fluctuations fully.

Data showing higher fertilizer use on irrigated sorghum, pearl millet and other cereals, lend strong support to the hypothesis that if gains from adoption were high and stable, farmers in the SAT (as anywhere else) did not lag behind. In general, fertilization levels were found to be higher for the irrigated superior cereals (rice or wheat) as compared to the millets. This indicated that farmers did accord some priority to the higher valued (and higher response) crops in allocating their scarce irrigation and liquid capital resources. In terms of fertilizer use, therefore, the SAT presents a hierarchy of coexisting situations. To start with, there are irrigated (or unirrigated) high value crops which claim high priority; than follow the irrigated and unirrigated HYV of crops like sorghum and pearl millet which respond much more to fertilizer application as compared to their local counterparts; and at the bottom are the large number of unirrigated food crops which rarely figure in fertilizer use decisions (Jha 1980).

The two-level analysis on determinants of fertilizer use revealed some important macro, and micro-influences on fertilizer use decisions. It was found that factors like soil type, seasonal rainfall conditions and irrigation (for the pearl millet hybrids) which affected regional response patterns, were important. Farmers were also found to be guided by their long term experience regarding the production environment and factors like expectation of rainfall and risk were significant. Credit also emerged as an important constraint inhibiting fertilizer use on these crops. This effect was perhaps sharpened by the fact that crops like sorghum and millets occupied, as stated above, a relatively inferior position in the hierarchy of crops as compared to higher valued and irrigated crops which used up the best of farmers' resources. Hence the effect of capital scarcity is more acutely reflected on these crops.

At the farm level, fertilizer use was found to be influenced by a number of plot specific and farm level factors. There was evidence to show that farmers used more fertilizers on heavier as compared to light textured soils, on plots which were timely sown and plots which did not grow a fertilized or legume crop in the preceding season. We had earlier noted that the fact that farmers attempted to make balanced use of different nutrients and that they were also able to discriminate between varieties of the same crop which varied in their response to fertilizers. All these indicate that farmers in the SAT are becoming conscious of the finer points of fertilizer use technology. They were also found to respond to favorable weather conditions by deciding to extend fertilizer use. This result was obtained in all the three regression-based analyses. This also reflects on the enterprise of the SAT farmers and signifies a rational approach in a situation where the status of the most critical production input -- soil moisture, is uncertain. It follows that recommendations regarding fertilizer use on unirrigated crops must take this factor into account and shift from single-valued fertilizer rate recommendations to a flexible recommendation basket which minimizes the chances of a large capital loss in the event of crop failures, yet provides for strategies which enable the farmers to make technically optimal decisions depending upon seasonal conditions as they unfold.[21]

Interesting results were obtained with regard to the influence of fertilizer prices on fertilization rates. The fact that the price effect could be estimated indicates the presence of cross-sectional price differentials despite prices being statutorily fixed. It is doubtful that these arise from transportation costs alone.[22] We are inclined to attribute this differential to imperfections in the retail trade in addition to transportation costs. Thus, from policy point of view, significance of the price variable implies high payoffs to improvement in retail trade of fertilizers -- by way of increase in the number of retail points, easy and timely availability, free access to fertilizer credit, availability of the right kind of fertilizer, etc.

The results of this analysis suggest the hypothesis that barriers to fertilizer use on unirrigated crops do not arise from irrationality. The traditional "reluctance" can be easily explained by non-remunerativeness and instability of response to fertilizer application for most of the local varieties of unirrigated (food) crops. Thus, development of regionally-adapted, fertilizer responsive varieties should continue to receive the highest priority. Provision of credit and improvements in retail trade are the other two essentials in the strategy to promote fertilizer use and augment the productivity of unirrigated crops. Finally, the extension system must change from the traditional 'fixed package of practices' to a highly flexible approach designed to take maximum advantage of random seasonal conditions which play such a crucial role in SAT agriculture.

21. This recognition is emerging and the All India Coordinated Research Project on Dryland Agriculture now recommends split application of fertilizers depending upon seasonal conditions (AICRPDA 1979). The extension programs, however, have yet to fully integrate this recommendation.

22. The farmers were just asked about fertilizer prices paid by them. No probing questions were asked on this and we presume that in most cases, their responses were confined to actual prices paid by them.

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Appendix I. Important agroeconomic features of selected districts (1973-74).

District (State)	Normal annual rainfall (mm)	Major soil type	Percentage area under sorghum/ pearl millet	Percent crop area under HYV 1973-74	Percent HYV area irrigated 1973-74	Dominant HYV in 1973-74	Fertilizer consumption per ha of cropped area[a] (kg)	Number of cultivators in the AAE sample
(A) Sorghum districts								
Jalgaon (Mah)	741	MDB	18	38	44	CSH 1	26.8	150
Ahmadnagar (Mah)	579	MDB	54	67	47	CSH 1	15.3	123
Sangli (Mah)	625	SDB	35	30	56	CSH 1	26.6	159
Aurangabad (Mah)	726	SDB	25	41	21	CSH 1	9.1	156
Parbhani (Mah)	821	MDB	33	12	0	CSH 2	8.2	136
Bhir (Mah)	668	SDB	24	18	21	CSH 1	9.1	48
Satara (Mah)	803	SDB	34	51	15	CSH 1	20.4	156
Osmanabad (Mah)	810	MB	33	12	19	CSH 1	7.1	249
Buldhana (Mah)	803	SMB	33	36	1	CSH 1	12.7	318
Akola (Mah)	847	MB	29	16	0	CSH 1	12.1	319
Amravati (Mah)	877	SMB	23	19	39	CSH 1	15.2	301
Nanded (Mah)	901	MDB	38	7	8	CSH 1	8.7	151
Wardha (Mah)	1090	MB	29	15	8	CSH 1	21.1	301
Nagpur (Mah)	1196	SMB	35	8	0	CSH 1	20.5	158
Mandsaur (MP)	592	MR/B	23	21	0	Vidisba	14.5	310
Belgaum (Kar)	785	MB	25	10	48	CSH 1	21.0	150
Bellary (Kar)	575	R	33	42	15	CSH 1	35.3	158
Shimoga (Kar)	1526	R/L	11	83	23	CSH 1	48.2	153
Shimoga[b] (Kar)	1526	R/L	NA	97	100	CSH 1	48.2	121
Mysore (Kar)	762	R	18	46	25	CSH 1	21.4	139
Anantapur (AP)	544	MR/B	14	3	44	CSH 1	6.8	159
(B) Pearl Millet districts								
Banaskanta (Guj)	627	D/GB	57	23	1	HB 3	5.0	313
Kaira (Guj)	815	GB	34	85	48	HB 3	49.4	320
Rajkot (Guj)	590	MR/B/A	22	80	51	HB 3	22.0	320
Hissar (Har)	515	A	21	54	98	HB 3	14.1	320
Rohtak (Har)	219	A	16	43	85	HB 3	10.8	317
Jaipur (Raj)	548	A	36	30	37	HB 1	4.4	311

Appendix I continued ...

District (State)	Normal annual rainfall (mm)	Major soil type	Percentage area under sorghum/ pearl millet	Percent crop area under HYV 1973-74	Percent HYV area irrigated 1973-74	Dominant HYV in 1973-74	Fertilizer consumption per ha of cropped area[a] (kg)	Number of cultivators in the AAE sample
Aurangabad (Mah)	726	SDB	13	45	1	HB 3	9.1	150
Parbhani (Mah)	821	MDB	1	14	0	HB 3	8.2	24
Bhir (Mah)	668	SDB	13	33	3	HB 1	9.1	112
Jalgaon (Mah)	741	MDB	13	72	4	HB 3	26.8	153
Ahmadnagar (Mah)	579	MDB	12	23	64	HB 3	15.3	158
Sangli (Mah)	625	SDB	3	5	100	HB 1	26.6	160
Sholapur (Mah)	584	MDB	2	7	86	HB 3	10.3	292
Morena (MP)	436	MB	19	22	2	HB 4	17.2	313
Guntur (AP)	832	R/DB	6	2	95	HB 1	59.7	151
Chittoor (AP)	823	R	5	65	100	HB 4	19.1	127
Nellore (AP)	952	R/L	6	94	100	HB 4	22.0	134
Bellary[b] (Kar)	575	R	6[c]	94	100	HB 4	35.3	138
Coimbatore (TN)	1030	MR/B	5	33	100	HB 4	53.8	115
Coimbatore[b] (TN)	1030	MR/B	NA	40	99	HB 3	53.8	100
Madurai (TN)	855	MR/B	4	51	87	HB 3	36.4	160
Madurai[b] (TN)	855	MR/B	NA	68	85	HB 3	36.4	159
Tirunelveli (TN)	815	MR/B	11	22	95	HB 3	31.4	120
Tirunelveli[b] (TN)	815	MR/B	NA	10	34	HB 3	31.4	99
Chingleput (TN)	1211	R/L	1	70	100	HB 4	74.4	76
Chingleput[b] (TN)	1211	R/L	NA	45	70	HB 1	74.4	62

Source: Raheja et al. 1976. Various tables. Data in column 1 and 2 taken from the 1970-71 report.

a. Data pertain to 1975-77.

b. Post-rainy season crop.

c. Total pearl millet (rainy and post-rainy season)

MB, MDB, SDB, SMB -- medium black, medium-deep black, shallow-deep black, shallow-medium black

MR/B, R, L, D/GB, R/DB, A -- mixed red and black, red, laterite, desert grey-brown, red deep black, alluvial.

Appendix II. Rate of application per fertilized hectare and percent crop area fertilized with nitrogen for HYV of irrigated rice or wheat in selected districts (1973-74).

District	Crop	Rate of N per fertilized ha (kg)	% area fertilized with N	District	Crop	Rate of N per fertilized ha (kg)	% area fertilized with N
Jalgaon	Wheat	52	92	Sholapur	Wheat	50	99
Ahmadnagar	Wheat	53	76	Guntur	Rice	52	100
Sangli	Wheat	76	97	Morena	Wheat	67	97
Aurangabad	Wheat	58	42	Bellary[a]	Rice[a]	92	100
Parbhani	Wheat	36	67	Nellore	Rice	47	88
Satara	Wheat	80	90	Coimbatore	Rice	160	100
Osmanabad	Wheat	45	76	Coimbatore[a]	Rice[a]	122	99
Akola	Wheat	68	91	Madurai	Rice	86	88
Amravati	Wheat	52	95	Madurai[a]	Rice[a]	69	99
Nanded	Wheat	56	44	Tirunelveli	Rice	119	99
Wardha	Wheat	71	72	Tirunelveli[a]	Rice[a]	106	98
Nagpur	Wheat	68	90	Chingleput	Rice	53	99
Belgaum	Wheat	75	71	Chingleput[a]	Rice[a]	75	100
Mandsaur	Wheat	86	90	Chittoor	Rice	87	96
Bellary	Rice	125	100	Banaskanta	Wheat	66	83
Anantapur	Rice	83	100	Kaira	Wheat	48	81
Mysore	Rice	98	100	Rajkot	Wheat	78	99
Shimoga	Rice	101	99	Hissar	Wheat	75	88
Shimoga[a]	Rice[a]	93	97	Rohtak	Wheat	45	89
Bhir	Wheat	46	33	Jaipur	Wheat	52	90
Buldhana	Wheat	44	98				

Source: Raheja et al. 1976. Various tables.

a. Post-rainy season crop.

Appendix III. Regressions explaining inter-plot variability in fertilizer use on sorghum and pearl millet in different districts: 1973-74 IASRI-YES data.

District	Dep. variable	n	Inter-cept	SOILDMY	DRAINAGE	TIMELYSOWN	RAINFALL	PREVCROP	FERTPRICE	FARMSIZE	R^2
					Rainy season sorghum (HYV)						
JALGAON	NPKRATE	68	40.816	15.168	-19.224	17.382	7.024	22.435	3.874*	-0.803	0.148
				(0.960)	(0.502)	(0.622)	(0.486)	(1.652)	(1.791)	(0.517)	
	NRATE	68	37.515	7.750	-11.466	9.452	3.430	6.591	-0.609	-0.351	0.[illegible]40
				(0.782)	(0.477)	(0.542)	(0.381)	(0.077)	(0.357)	(0.361)	
	PRATE	52	16.949	6.828	-6.303	6.118	-4.669	10.255*	0.703*	-0.784	[illegible]26
				(1.196)	(0.356)	(0.588)	(0.824)	(1.744)	(1.773)	(1.414)	
AHMADNAGAR	NPKRATE	24	-3.445	53.058**	51.735	-5.334	20.229	19.049	39.922*	-1.335	0.576
				(2.389)	(1.178)	(0.425)	(1.277)	(1.378)	(1.978)	(0.449)	
	NRATE	24	25.669	20.784	69.538*	7.464	8.669	11.418	20.348	-1.755	0.367
				(1.105)	(1.888)	(0.716)	(0.670)	(0.967)	(0.914)	(0.706)	
OSMANABAD	NPKRATE	21	-6.900	-2.282		3.666	-8.689	-22.836	34.614**	1.154	0.466
				(0.116)		(0.185)	(0.549)	(1.463)	(2.547)	(0.581)	
	NRATE	21	18.108	2.016		4.327	0.270	-11.204	2.463	0.043	0.183
				(0.186)		(0.393)	(0.031)	(1.397)	(0.371)	(0.039)	
NAGPUR	NPKRATE	66	156.290	28.536**	-14.315	12.886	5.640	-23.614*	-29.363	-0.832	0.150
				(2.081)	(0.473)	(1.169)	(0.250)	(1.912)	(1.648)	(0.847)	
	NRATE	66	112.961	12.422	-37.106*	12.333*	0.350	-13.571*	-28.234***	-0.605	0.274
				(1.524)	(1.904)	(1.867)	(0.026)	(1.804)	(3.615)	(1.029)	
	PRATE	60	39.187	7.768**	-3.603	0.669	1.616	-7.710**	-2.829	-0.142	0.163
				(2.109)	(0.410)	(0.220)	(0.268)	(2.185)	(1.001)	(0.524)	
BELGAUM	NPKRATE	60	76.057	-44.680	43.811	0.085	40.447	16.642	-7.940	1.183	0.073
				(0.623)	(0.226)	(0.037)	(1.307)	(0.734)	(0.496)	(0.911)	
	NRATE	60	50.075	0.779	-15.236	-9.907	22.921	10.826	-3.865	0.725	0.081
				(0.019)	(0.145)	(0.799)	(1.326)	(0.865)	(0.520)	(1.006)	
	PRATE	49	29.853	-1.169	24.596		12.030	0.302	-1.730	0.102	0.037
				(0.154)	(0.326)		(0.982)	(0.038)	(0.389)	(0.228)	
AKOLA	NPKRATE	48	58.129	27.243	25.855	5.752	-14.252	17.796	-10.495	0.427	0.276
				(1.186)	(1.418)	(0.523)	(0.873)	(1.532)	(1.275)	(0.916)	
	NRATE	48	59.477	18.740	12.692	-3.988	-15.061	6.337	-10.468	-0.252	0.182
				(1.003)	(0.848)	(0.447)	(1.136)	(0.667)	(1.543)	(0.665)	
	PRATE	33	22.368	-2.107	-1.914	-4.086	-0.376	9.876	-2.550	0.293	0.281
				(0.235)	(0.221)	(0.675)	(0.049)	(1.629)	(1.070)	(1.550)	

Appendix III continued ...

District	Dep. variable	n	Inter-cept	SOILDMY	DRAINAGE	TIMELYSOWN	RAINFALL	PREVCROP	FERTPRICE	FARMSIZE	R^2
BULDHANA	NPKRATE	54	42.886	12.315	-24.137	17.231	-17.030	17.586	-4.176	0.847	0.108
				(0.975)	(0.637)	(1.364)	(1.313)	(1.207)	(0.325)	(0.6[illegible])	
	NRATE	54	52.056	14.959	-22.670	12.649	-1[illegible].750	4.096	-10.307	0.[illegible]	0.124
				(1.556)	(0.781)	(1.310)	([illegible]384)	(0.395)	(1.113)	(0.[illegible]	
	PRATE	39	3.143	-1.129	-2.066	8.455	-[illegible].131	8.794	2.562	-0.[illegible]	0.1[illegible]3
				(0.207)	(0.147)	(1.594)	([illegible].134)	(1.217)	(0.558)	(0.[illegible]	
MYSORE	NPKRATE	41	103.522	-1.127			1.124	-33.802	-11.677	3.0[illegible]	0.071
				(0.058)			(0.050)	(0.913)	(0.727)	(1.259)	
	NRATE	41	59.545	7.339			-8.231	-23.801	-8.344	0.999	0.091
				(0.691)			(0.664)	(1.166)	(0.920)	(0.757)	
	PRATE	38	-1.725	1.246			9.549	-9.362	5.885	0.724	0.081
				(0.176)			(1.178)	(0.702)	(0.634)	(0.845)	
AMRAVATI	NPKRATE	56	51.310	11.264	-32.398	7.896	0.627	4.922	6.222	-2.656***	0.190
				(0.820)	(1.010)	(0.819)	(0.071)	(0.381)	(0.541)	(2.739)	
	NRATE	53	62.150	3.795	-8.042	4.204	-4.047	2.299	-4.882	-2.227***	0.159
				(0.336)	(0.297)	(0.515)	(0.548)	(0.213)	(0.532)	(2.796)	
	PRATE	41	19.764	10.585**		1.740	6.610**	3.106	-2.686	-0.097	0.258
				(2.262)		(0.454)	(1.986)	(0.659)	(1.160)	(0.251)	
BELLARY	NPKRATE	55	76.727	-13.849	5.516	4.641	17.781*	-8.788	-13.965	0.511	0.161
				(0.962)	(0.151)	(0.396)	(1.936)	(0.954)	(1.630)	(0.705)	
	NRATE	55	35.694	-6.862	2.907	3.884	13.657**	-3.456	-8.975*	0.401	0.173
				(0.691)	(0.116)	(0.480)	(2.179)	(0.538)	(1.818)	(0.803)	
	PRATE	53	35.542	-5.072	-1.163	4.369	6.105*	-2.229	-6.422***	-0.092	0.221
				(0.897)	(0.086)	(1.033)	(1.801)	(0.677)	(2.907)	(0.355)	
SATARA	NPKRATE	37	190.657	-70.060	45.558	14.685	-2.269	2.507	-46.481**	2.632	0.257
				(1.409)	(0.551)	(0.479)	(0.083)	(0.096)	(2.407)	(0.406)	
	NRATE	37	96.618	-52.925**	69.332	25.599	14.476	-22.337	-19.610*	0.966	0.421
				(2.079)	(1.637)	(1.633)	(1.050)	(1.682)	(1.884)	(0.290)	
	PRATE	28	101.920	-35.046**	-5.962	-4.772	-26.046**	-6.687	-16.589***	0.927	0.495
				(2.083)	(0.216)	(0.439)	(2.444)	(0.602)	(3.506)	(0.283)	
NANDED	NPKRATE	24	70.310	-4.615		-30.523	14.531	5.039	10.194	-0.346	0.192
				(0.196)		(1.544)	(0.619)	(0.254)	(1.064)	(0.159)	
	NRATE	24	50.339	-11.329		8.460	-3.364	-7.577	-2.493	0.008	0.033
				(0.511)		(0.448)	(0.150)	(0.409)	(0.319)	(0.004)	

Appendix III continued ...

District	Dep. variable	n	Inter-cept	SOILDMY	DRAINAGE	TIMELYSOWN	RAINFALL	PREVCROP	FERTPRICE	FARMSIZE	R^2
PARBHANI	NPKRATE	50	80.605	32.039	28.545	-3.016	36.455***	-12.343	-10.481	1.922*	0.286
				(1.004)	(0.844)	(0.158)	(2.795)	(1.019)	(1.201)	(1.691)	
	NRATE	50	61.337	37.441*	7.838	-6.613	31.681***	-13.142	-9.293	1.374*	0.387
				(1.709)	(0.326)	(0.505)	(3.539)	(1.597)	(1.503)	(1.766)	
	PRATE	35	20.998	1.301	13.456	9.701	8.612	-7.967	-1.470	0.207	0.211
				(0.101)	(1.049)	(1.089)	(1.384)	(1.365)	(0.559)	(0.426)	
MANDSAUR	NPKRATE	35	42.258	31.516	-17.974	-15.822		8.644	5.827	-1.382	0.174
				(1.526)	(0.643)	(1.286)		(0.769)	(0.389)	(0.869)	
	NRATE	35	-44.059	35.549	-13.458	-12.109		18.213	34.989	-1.901	0.265
				(1.638)	(0.459)	(0.927)		(1.432)	(1.321)	(1.120)	
	PRATE	26	19.839	-6.158		1.538		-8.596	-0.500	1.056	0.199
				(0.728)		(0.300)		(1.683)	(0.095)	(1.374)	
ANANTAPUR	NPKRATE	35	117.502	-62.341**	39.497	10.224	-27.149*	-18.300	-11.883	-0.380	0.287
				(2.365)	(0.806)	(0.331)	(1.739)	(1.202)	(0.903)	(1.385)	
	NRATE	35	104.628	-57.126***	56.062**	1.163	-16.241**	-20.537***	-11.004*	-0.322**	0.570
				(4.413)	(2.341)	(0.077)	(2.123)	(2.783)	(1.839)	(2.413)	
SANGLI	NPKRATE	53	66.774	12.999		-4.539	12.267	8.176	-5.911	-0.558	0.143
				(1.198)		(0.253)	(1.455)	(0.945)	(1.028)	(0.477)	
	NRATE	53	72.358	-5.618		-20.130	5.217	9.484	-6.578*	0.433	0.182
				(0.726)		(1.573)	(0.870)	(1.539)	(1.729)	(0.520)	
	PRATE	24	20.665	13.732**		7.183	2.284	-4.306	-3.305	0.181	0.416
				(2.369)		(0.576)	(0.470)	(0.816)	(1.497)	(0.197)	
SHIMOGA	NPKRATE	74	157.488	-15.881		-21.462	39.929***	-0.118	-29.112*	0.225	0.210
				(0.645)		(1.543)	(3.203)	(0.010)	(1.825)	(0.119)	
	NRATE	74	61.260	-1.454		-12.688	23.740***	3.126	-10.253	1.150	0.216
				(0.103)		(1.605)	(3.342)	(0.464)	(1.440)	(1.059)	
	PRATE	74	58.493	-5.868		-3.267	7.198**	-3.246	-9.232**	-0.568	0.184
				(0.793)		(0.797)	(1.998)	(0.954)	(2.058)	(1.022)	
						Post-rainy season sorghum (HYV)					
SHIMOGA	NPKRATE	71	123.761	-26.301	-72.181	22.346	14.391	34.875*	-23.891**	3.876*	0.182
				(1.107)	(1.049)	(0.949)	(0.882)	(1.953)	(2.055)	(1.706)	
	NRATE	71	61.321	-14.648	-33.860	12.267	13.913*	14.670*	-12.325**	2.209**	0.228
				(1.354)	(1.097)	(1.131)	(1.849)	(1.768)	(2.398)	(2.144)	
	PRATE	70	43.030	-12.385	-18.875	7.246	-2.483	9.704	-5.757**	0.080	0.155
				(1.433)	(0.764)	(0.906)	(0.439)	(1.507)	(2.429)	(0.105)	

Appendix III continued ...

District	Dep. variable	n	Inter-cept	SOILDMY	DRAINAGE	TIMELYSOWN	RAINFALL	PREVCROP	FERTPRICE	FARMSIZE	R^2
KRISHNA	NPKRATE	39	41.835	-33.772		10.387	2.483	-10.511	4.168	2.314	0.111
				(1.438)		(0.697)	(0.171)	(0.697)	(0.392)	(1.461)	
	NRATE	39	23.837	-12.656		12.205	6.230	-10.970	0.838	0.972	0.087
				(0.731)		(1.076)	(0.571)	(0.961)	(0.109)	(0.825)	
	PRATE	38	20.004	-8.489		6.809**	3.930	-2.438	-0.457	1.176***	0.395
				(1.280)		(2.069)	(1.128)	(0.658)	(0.232)	(3.634)	
						Rainy season pearl millet (HYV)					
NELLORE	NPKRATE	70	104.048	-49.288	-43.929	-6.534	-8.471	6.120	-9.805	1.544**	0.116
				(0.989)	(0.906)	(0.427)	(0.702)	(0.488)	(1.028)	(2.018)	
	NRATE	70	56.014	-25.399	-11.985	-2.219	3.289	6.673	-4.026	1.181**	0.120
				(0.862)	(0.420)	(0.246)	(0.462)	(0.905)	(0.778)	(2.620)	
	PRATE	40	50.984	-3.339			-2.243	0.245	-5.128***	-0.044	0.240
				(0.966)			(0.549)	(0.062)	(3.017)	(0.222)	
TIRUNELVELI	NPKRATE	36	57.067	9.072		4.493	26.002	0.682	3.218	5.456	0.271
				(0.175)		(0.205)	(1.268)	(0.036)	(1.274)	(1.356)	
	NRATE	36	44.868	-14.187		19.358	0.331	-0.759	0.713	3.433	0.171
				(0.437)		(1.399)	(0.025)	(0.065)	(0.312)	(1.352)	
	PRATE	23	21.433	-4.789		-3.643	2.657	-2.698	0.327	2.218	0.179
				(0.245)		(0.343)	(0.261)	(0.283)	(0.740)	(1.359)	
JALGAON	NPKRATE	61	115.736	28.815		10.846	-33.177**	-15.575	-16.980**	1.526	0.225
				(1.425)		(0.608)	(2.188)	(1.213)	(2.640)	(0.739)	
	NRATE	61	80.428	12.653		-1.243	-20.073*	-9.724	-9.502*	0.322	0.138
				(0.850)		(0.094)	(1.786)	(1.018)	(1.964)	(0.214)	
	PRATE	43	26.226	-0.146		8.981	-4.054	0.560	-3.037	0.129	0.070
				(0.022)		(1.348)	(0.589)	(0.110)	(1.052)	(0.172)	
MADURAI	NPKRATE	27	19.274			29.959	7.015	37.734	1.782	-2.872	0.182
						(0.503)	(0.130)	(1.136)	(0.087)	(0.205)	
	NRATE	27	23.263			17.224	4.457	17.975	-0.707	-1.857	0.097
						(0.370)	(0.105)	(0.712)	(0.045)	(0.168)	
COIMBATORE	NPKRATE	58	195.020	155.408**		-20.314	-5.808	-34.713**	-21.207*	-2.244	0.334
				(2.637)		(1.106)	(0.322)	(2.304)	(1.709)	(0.958)	
	NRATE	58	103.199	78.605**		-6.506	5.905	-20.236**	-12.987*	-0.833	0.311
				(2.423)		(0.652)	(0.647)	(2.582)	(1.712)	(0.694)	
	PRATE	37	54.353	27.818		-5.587	-1.258	-6.926	-2.674	-0.642	0.248
				(1.525)		(0.821)	(0.198)	(1.183)	(1.138)	(0.496)	

Appendix III continued ...

District	Dep. variable	n	Inter-cept	SOILDMY	DRAINAGE	TIMELYSOWN	RAINFALL	PREVCROP	FERTPRICE	FARMSIZE	R^2
CHINGLEPUT	NPKRATE	46	33.625	4.924			15.556	10.856	19.838	1.476	0.055
				(0.341)			(1.017)	(0.755)	(0.746)	(0.353)	
	NRATE	46	36.283	0.616			0.465	3.214	3.013	-1.954	0.037
				(0.086)			(0.060)	(0.452)	(0.304)	(0.935)	
	PRATE	40	61.276	1.732			0.241	-7.199	-6.189	-0.730	0.110
				(0.374)			(0.051)	(1.480)	(1.212)	(0.561)	
ROHTAK	NPKRATE	30	243.143	17.540			44.011	-52.943*	-77.441***	-2.057	0.462
				(0.810)			(1.638)	(2.049)	(4.258)	(0.897)	
	NRATE	30	98.493	7.073			22.847	-22.187	-23.887*	-0.957	0.147
				(0.512)			(1.322)	(1.368)	(1.743)	(0.654)	
MORENA	NPKRATE	68	83.811			-18.064	12.661	17.901	-5.632	-0.057	0.083
						(1.076)	(1.558)	(1.456)	(0.464)	(0.097)	
	NRATE	68	88.523			-9.965	2.460	3.625	-14.351**	-0.077	0.116
						(0.942)	(0.479)	(0.462)	(2.058)	(0.207)	
	PRATE	50	47.222			-0.185	2.346	7.374**	-6.542***	-0.116	0.179
						(0.048)	(1.037)	(2.119)	(2.957)	(0.846)	
PARBHANI	NPKRATE	35	100.548	94.482**	-45.549*	38.838**	-8.273	-1.706	-37.820***	0.236	0.371
				(2.326)	(1.706)	(2.376)	(0.772)	(0.185)	(2.931)	(0.421)	
	NRATE	35	48.871	48.638**	-14.832	18.754**	5.509	-5.911	-17.862***	0.165	0.396
				(2.475)	(1.378)	(2.630)	(1.328)	(1.505)	(3.112)	(0.679)	
	PRATE	25	42.768	40.379**		15.279**	0.380	-0.187	-12.649***	0.014	0.413
				(2.573)		(2.237)	(0.077)	(0.051)	(3.252)	(0.068)	
JAIPUR	NPKRATE	28	-79.269	11.318		21.172	28.846*	3.559	50.932	-1.818	0.240
				(0.460)		(0.748)	(1.895)	(0.250)	(1.372)	(0.470)	
	NRATE	28	20.897	-5.006		10.676	20.542	3.371	9.976	-0.560	0.129
				(0.203)		(0.395)	(1.397)	(0.248)	(0.234)	(0.152)	
GUNTUR	NPKRATE	31	75.294	8.968		-2.099	3.159	-2.806	-2.948	-0.153	0.032
				(0.355)		(0.185)	(0.273)	(0.248)	(0.398)	(0.237)	
	NRATE	31	28.154	9.697		15.179*	1.258	5.506	-2.119	-0.472	0.179
				(0.470)		(1.819)	(0.159)	(0.675)	(0.483)	(0.972)	
	PRATE	22	40.016	-5.254		5.776*	-5.473	0.455	-3.625*	0.087	0.425
				(0.743)		(1.755)	(1.618)	(0.137)	(1.815)	(0.452)	
CHITTOOR	NPKRATE	59	173.763	-45.371		-5.657	-39.586**	25.620	-31.751**	2.754	0.210
				(0.742)		(0.298)	(2.238)	(1.209)	(2.621)	(1.102)	

Appendix III continued ...

District	Dep. variable	n	Inter-cept	SOILDMY	DRAINAGE	TIMELYSOWN	RAINFALL	PREVCROP	FERTPRICE	FARMSIZE	R^2
CHITTOOR	NPKRATE	59	138.410	-38.048		-6.833	-25.616**	-3.529	-19.730***	0.577	0.224
				(0.976)		(0.567)	(2.255)	(0.262)	(3.264)	(0.364)	
	PRATE	41	31.456	-1.011		0.873	-6.480	8.226	-2.140	0.187	0.081
				(0.053)		(0.121)	(0.911)	(0.717)	(1.115)	(0.218)	
HISSAR[a]	NPKRATE	46	41.007			17.520**	-1.056	-14.202*	-4.656	2.940***	0.206
						(2.284)	(0.175)	(1.744)	(0.179)	(5.338)	
SHOLAPUR	NPKRATE	22	59.912			8.825	-24.236	11.924	1.722	-0.227	0.073
						(0.215)	(0.926)	(0.396)	(0.479)	(0.134)	
	NRATE	22	24.458			11.534	-18.460	0.838	2.758	0.007	0.139
						(0.478)	(1.179)	(0.047)	(1.061)	(0.007)	
	PRATE	20	19.651			3.818	-7.799	16.514	-0.396	-0.170	0.155
						(0.196)	(0.590)	(1.156)	(0.602)	(0.213)	
					Rainy season pearl millet (HYV)						
BELLARY	NPKRATE	74	125.258	20.874	-8.982	-22.312	38.635**	17.762	-3.475	1.704	0.121
				(1.098)	(0.134)	(1.383)	(2.064)	(1.136)	(0.360)	(0.664)	
	NRATE	74	65.118	11.603	24.770	2.294	35.739***	8.628	-3.957	2.272	0.166
				(0.923)	(0.567)	(0.217)	(2.957)	(0.838)	(0.888)	(1.358)	
	PRATE	66	39.149	4.648	-24.227	-9.872**	11.440**	2.984	-2.319	0.033	0.192
				(0.917)	(1.368)	(2.243)	(2.205)	(0.703)	(1.633)	(0.039)	
MADURAI	NPKRATE	34	74.377			62.834*	-59.196**	-15.487	3.183	-0.528	0.327
						(1.936)	(2.156)	(0.583)	(1.003)	(0.396)	
	NRATE	34	38.957			32.955**	-28.278**	-6.517	0.365	-1.243	0.338
						(2.475)	(2.434)	(0.597)	(0.252)	(0.181)	
	PRATE	20	71.887			2.814	-50.831***	-4.408	-0.242	-0.116	0.875
						(0.330)	(8.720)	(0.885)	(0.895)	(0.043)	
COIMBATORE	NPKRATE	50	131.653	130.592*		15.532	-11.628	2.266	-11.384	0.840	0.147
				(1.772)		(0.573)	(0.484)	(0.095)	(0.798)	(0.382)	
	NRATE	50	49.955	13.326		23.204**	-18.030*	4.966	-0.613	-0.699	0.219
				(0.428)		(2.134)	(1.839)	(0.497)	(0.115)	(0.755)	
	PRATE	38	32.183	42.048		12.926	-10.611	4.280	-1.292	0.806	0.238
				(1.571)		(1.388)	(1.078)	(0.413)	(0.297)	(1.005)	

a. For Hissar, the NPKRATE and NRATE equations are the same because there is no use of phosphorus or potash.
Figures in parentheses are t values.
*,**,*** Statistically significant at 10, 5 and 1% probability level. See text for definition of variables.