2

Trial Testing Sites in the All India Coordinated Projects - How well do they represent Agro-ecological Zones and Farmers' Fields?

A.J. Packwood, D.S. Virk and J.R. Witcombe

Introduction

Multilocational trials in the All India Coordinated Crop Improvement Projects (AICCIPs) are used to test the new products from breeding programmes in the country. They are used to establish which entries, if any, are superior to existing ones and to measure the stability of performance across sites and years. The data are also used to establish the area of adaptation in which the cultivar will be recommended for cultivation.

Crucial issue in the conduct of multilocational trials is how to select the test sites and, once they are chosen, using management conditions that will most efficiently identify superior entries. Often multilocational trials are used to select cultivars with wide adaptation that perform well over a wide range of environments. This strategy requires trials with sites located over a wide area. In contrast, trials for specific adaptability aim to identify cultivars for particular agro-ecological niches, and trials need to be situated in the environments in question.

According to plant breeding theory, the resources allocated to each year of a trial, while they should remain constant (Finney, 1958), should be targeted towards different purposes. Both the number of test sites and their locations will, therefore, vary at each trial stage:

- Year 1 - Removal of most inferior entries, few test sites
- Year 2 - Selection for wide adaptation, more widely located test sites
- Year 3 - Selection for wide and specific adaptation, most widely located test sites

The management conditions under which the trials are conducted also affect the entries that are chosen. Trials can be conducted under different levels of input application, resulting in different varieties performing well because of genotype and environment interaction.

In this chapter, we ask three questions that relate to trial sites allocation in the multilocational trials:

- Do the trial locations adequately represent the important areas of production of the crop?
- Is there adequate zonation of the multilocational trials?
- Do the trials represent the environments in the farmers' fields.

Do the Trials Represent the Important Areas of Production?

Trials will succeed in predicting the agricultural performance of new varieties if the trial sites are congruent with the area of cultivation of the crop. Ideally the allocation of test sites must match the distribution of the crop measured by the area under cultivation and the amount of production. How well this is achieved was examined for a sample of AICCIP breeding trials. The analysis can be carried out for different geographical levels. Ideally, the analysis should be done on the basis of agro-ecological zones. However, statistics on area of production and amount of production are produced and are available only according to district level and state level political boundaries.

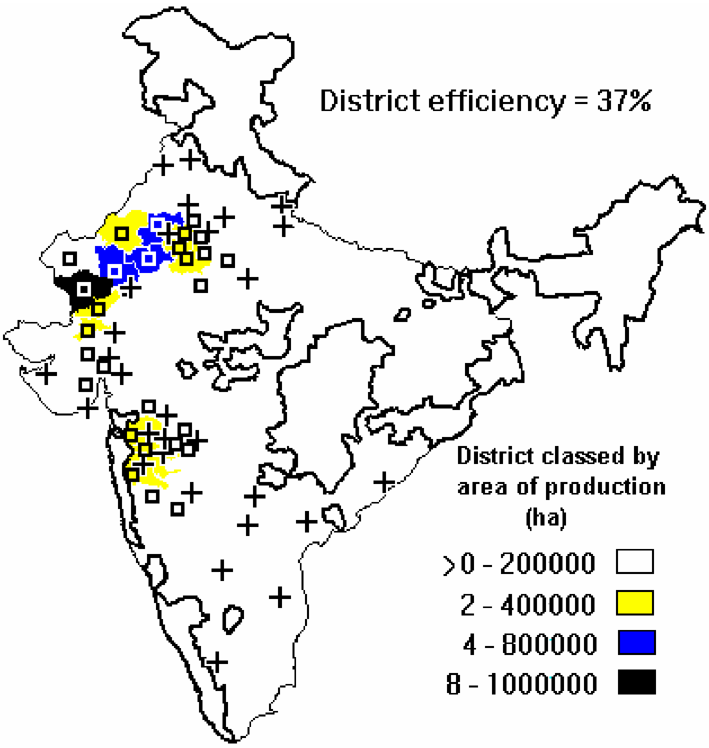
Hence, we were limited to an examination of how well the trials sites represented the important areas of production at the district and state levels. Analyses were also performed on amount of production, but as these analyses produce a bias towards farmers in high potential areas, and the results did not differ greatly from those for area, we only present the analyses relating to area of production.

The distribution of trial sites by district have been presented for a number of crops (Fig. 2.1). In each crop, the actual trial sites are shown, together with the area of production by district. The districts of highest production give some indication as to where the optimised trial sites should be located with respect to area of production. Efficiencies of site allocation by district were obtained from the ratio of the total area of production of those districts which contained AICCIP trial sites to the area of the districts in the optimised trial i.e., a trial in which the districts are allocated trial sites on the basis of having the highest area of production for the particular crop. In chickpea, groundnut, pearl millet and sorghum the district efficiency of site allocation by area of production varied from 30 to 52% (Fig. 2.1). The low efficiencies were confirmed when all of the trials were pooled across three years in five crops (Table 2.1).

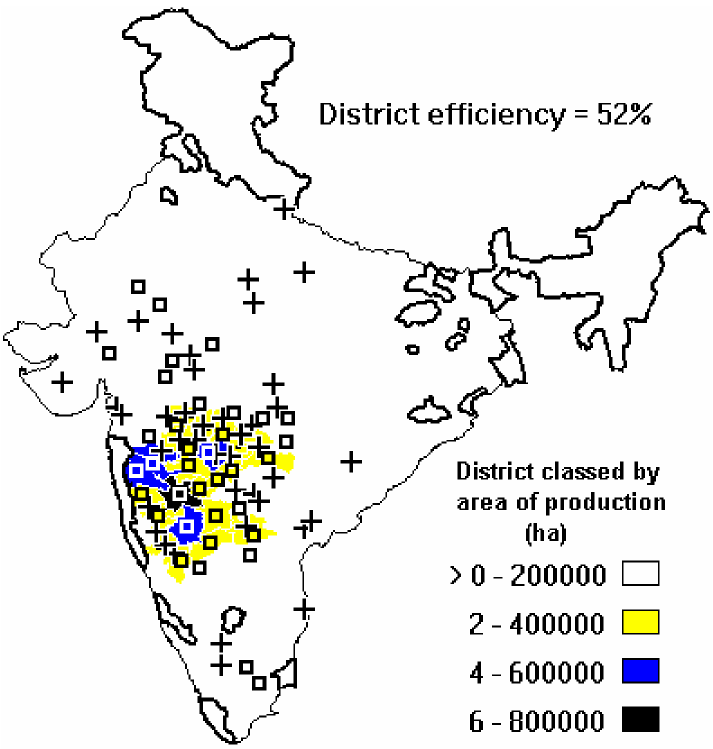
Table 2.1 Estimates of efficiency (%) of trials of five crops in AICCIPs averaged across all of the trials for each crop according to area of production and amount of production.

	District Efficiency (% of optimised) by:		State Efficiency (% of optimised)† by:	
Crop	**Area**	**Production**	**Area**	**Production**
Rice	43	36	16	20
Pearl millet	34	42	16	18
Sorghum	44	42	67	64
Groundnut	51	47	7	11
Chickpea	29	26	40	40

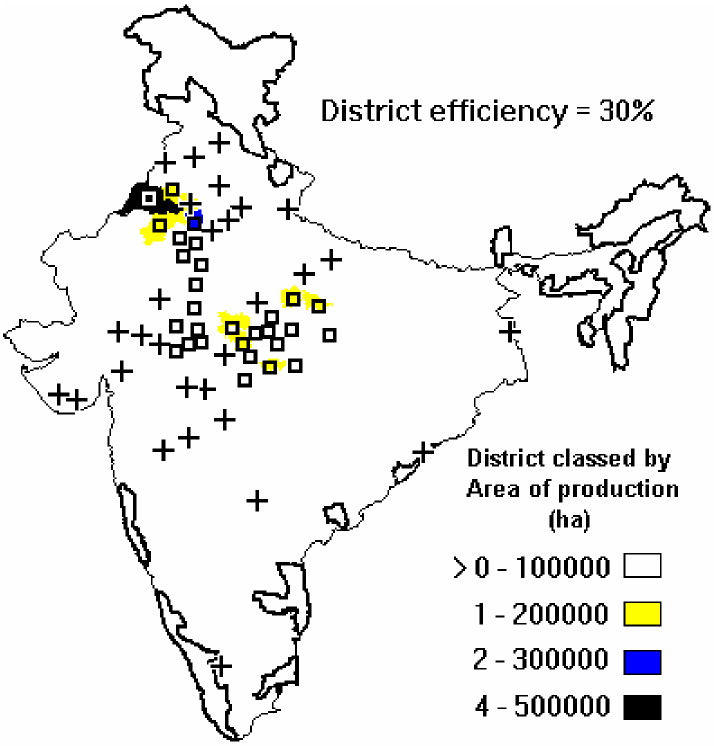
† For methods of calculation see “methods used”



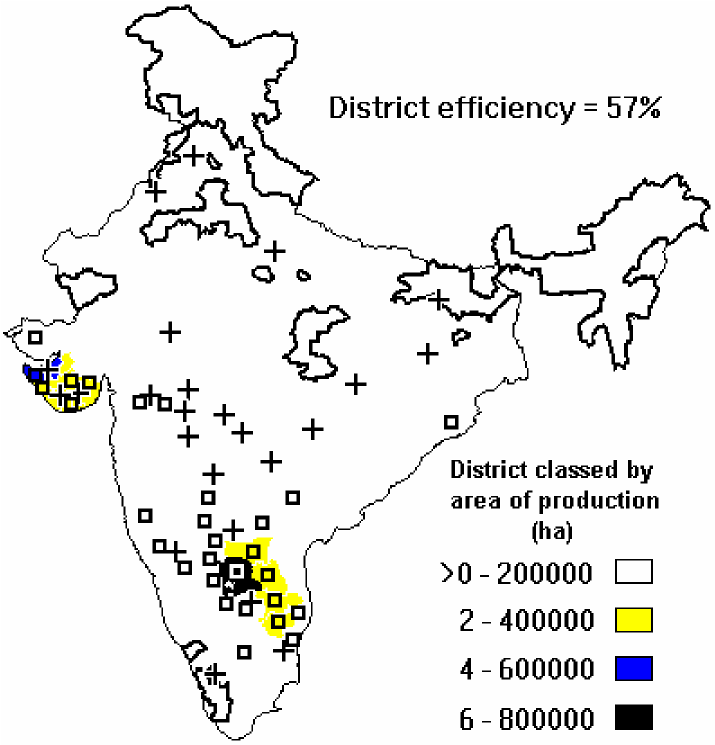
Pearl millet - AHT 1991 trial



Sorghum - AHT 1991 trial



Chickpea - AVT 1990 trial



Groundnut - AVT 1991 trial

Fig. 2.1 Location of AICCIP trial sites for pearl millet (1991), sorghum (1991), chickpea (1990) and groundnut (1991) in relation to area of production by district. Areas within the thicker black lines have no recorded cultivation of the crop. The original trial site locations (+) and the optimised locations (¹) are shown. ***This is a rough sketch only and it does not purport to depict the political boundaries of India.***

There are large discrepancies in the AICCIP trials between the actual location of test sites and those predicted from optimising trial site location on the basis of area of production. The discrepancies are present because trial site locations are determined by administrative and infrastructure considerations rather than being chosen to represent important areas of production for the crop. The discrepancies also occur because the number of test sites is generally too low to achieve an optimal distribution. Although the trials optimised by area of production could be adjusted to better represent the geographical spread of the crop (Fig. 2.1) the optimised sites are still widely spread. We conclude that adjustment of the optimised sites to further increase geographical spread will not greatly alter the conclusions.

A similar study was made for distributions at a state level. The mean efficiencies by state were, in general, lower than those by districts in all crops except sorghum because it has a more restricted area of cultivation (Table 2.1). There was a poor agreement between the actual and expected number of test sites in any state directly reflecting the very large discrepancies between the per cent area of production accounted by a state and the per cent of the trial sites allocated to it (Table 2.2) for any crop. A number of examples illustrate this clearly:

- In pearl millet, Rajasthan accounts for 46% of the area of production but has only 7% of the trials.
- In groundnut, Andhra Pradesh represents 27% of the area of production (the largest for any individual state) but has only 10% of the trials. Maharashtra represents 11% of the area of production but has 22% of the trials.
- In chickpea, Madhya Pradesh with 32% area of production has only 8% of the trial sites.

The allocation of trial sites on the basis of existing infrastructure is clear. Delhi has 5% of the trial sites of chickpea, 2% of rice, and 4% of pearl millet, although the area devoted to the cultivation of these crops is negligible.

Table 2.2 Examples of under and over representation of states in the trials system of AICCIPs for four crops.

Crop	**State**	**Trials in state as % of all trials**†	**Mean area in state as % of all-India total area (1989 and 1990)** ‡
Rice	W. Bengal	7	14
	Madhya Pradesh	6	12
	Karnataka	8	3
	Rajasthan	4	0.3
	Delhi	2	0
Pearl millet	Rajasthan	7	46
	Maharashtra	24	18
	Delhi	4	0
Groundnut	Andhra Pradesh	10	27
	Gujarat	6	22
	Maharashtra	22	11
	Bihar	12	0.1
Chickpea	Madhya Pradesh	8	32
	Haryana	15	9
	Punjab	9	1
	Delhi	5	0

†Number of trial sites as a % of all AICCIP trial sites in India used in advanced trials, 1991-93

‡Area in state as a % of the total area of that crop in India

The state level analysis again showed that the distribution of trial sites was below optimal. In certain cases, such as pearl millet in Rajasthan, the reasons are clear. The unpredictable rainfall caused many trials to fail. More investment in infrastructure is required to reduce the failure of trials. The only possible strategy is to have an irrigated and a non-irrigated trial at most sites. The results from the irrigated trial would only be used if drought caused the unirrigated trial to fail, and irrigation would have to be applied at a level that was representative of the rainfall in an average year. Irrigated trials where significant rainfall following irrigation led to atypically high rainfall would have to be disregarded.

Do the Trials Represent the Agro-ecological Zones?

India is a vast country with very diverse agro-climatic conditions. Cropping patterns and practices of cultivation differ greatly from region to region. Hence cultivars developed and performing well in one area may not perform well in others. Zonalisation and grouping of test sites of the multilocational trials system can help in identification of varieties with specific adaptation while pooling data from all of the test sites serves to select varieties which have wide adaptation. Criteria are needed to divide the trial sites into groups that represent more homogeneous areas with specific agro-ecological features.

The major environmental factors affecting yield performance in a series of trials can be classified into location and year. Only location effects concern us here. Location effects are associated with environmental variables such as soil type, agronomic management and climatic differences between locations. Year and location effects do not act independently. A prolonged dry period in one year will have a different effect on crops grown in sandy soils than on those grown on heavier soils. To minimise location x year interactions within an agro-ecological zone, and to achieve regional recommendations of the same quality as overall recommendations, locations required within a region is almost as high as the minimum number needed overall (Talbot, 1996). (Of course, if the minimum number of locations is achieved in every region, there will be more than the required minimum number of locations for the overall analysis).

The Planning Commission has identified 15 agro-climatic regions, 14 in the mainland and one in the islands of Bay of Bengal and the Arabian Sea. The National Bureau of Soil Survey and Land Use Planning divided the country into 54 agro-ecological zones. Subsequently, the Bureau published a map with 21 zones. In the National Agricultural Research Project (NARP) of the ICAR, launched in 1979, 131 agro-ecological zones were defined (Fig. 2.2) (Ghosh, 1991).

The AICCIPs have characterised the crop growing regions into zones which can cross state boundaries (Annex 4) and an attempt has been made to identify further regions within the zones on the basis of adaptive trials conducted under the National Agricultural Research Project. Differences between the Coordinated projects in respect of zonalisation are great. The zones are much larger than those in the NARP because there are so few of them (Table 2.3 and Fig. 2.3), so in effect each AICCIP zone covers a wide diversity of agro-ecological conditions. Of all agencies, the AICCIPs use the fewest zones, no doubt because using a greater number will result in zones with few or no trials. We used the Planning Commission zones to examine the location of trial sites. In many zones where the crop is important there are no trial sites, conversely there are sites in some zones where the crop is not grown (Table 2.4).

Fig. 2.2 Agro-climatic zonal map of India of the National Agricultural Research Project (NARP). ***This is a rough sketch only and it does not purport to depict the political boundaries of India.***

Table 2.3 Number of zones and average number of locations within zones in the AICCIP trials system[†].

	Rice	Wheat	Pearl millet	Sorghum	Groundnut	Chickpea
Zones	3	7	2	1	5	5
Locations within zone	7	7	15	12	4	4

[†]Average over 1991 to 1993 for all crops, except chickpea, for which average is over 1990 to 1992

Table 2.4 **Number of sites in various AICCIP trials by the 14 agro-climatic zones† of the Planning Commission, in relation to the importance of the zone for the crop as described by the area of the crop in the zone expressed as a percentage of the all-India area.**

	Chickpea‡		Wheat‡		Rice‡		Sorghum‡		Maize‡		Pearl millet‡		Groundnut‡	
Zone†	No. sites in zone	Area(%) in zone	No. sites In zone	Area (%) in zone	No. sites in zone	Area (%) in zone	No. sites in zone	Area (%) in zone	No. sites in zone	Area (%) in zone	No. sites in zone	Area (%) in zone	No. sites in zone	Area (%) in zone
1	2	-§	2	4	1	2	0	0	1	11	1	-	0	0
2	0	-	0	1	1	9	0	0	0	3	0	0	1	-
3	1	-	0	1	0	9	0	0	0	-	0	0	0	-
4	1	5	1	17	0	14	0	-	1	15	0	1	1	-
5	4	7	2	22	0	7	1	2	0	12	6	7	0	1
6	7	16	6	23	3	6	0	1	3	4	4	5	2	1
7	0	5	0	1	5	22	0	2	0	7	0	-	2	3
8	4	38	3	19	3	3	4	11	3	19	3	11	1	4
9	5	18	8	6	0	1	14	50	2	12	6	19	5	14
10	3	4	2	1	4	7	8	27	2	9	7	7	4	39
11	1	-	0	0	3	13	0	1	1	1	1	2	1	13
12	0	-	0	0	0	5	0	-	0	-	0	0	0	1
13	4	2	1	3	0	2	4	6	0	6	1	12	2	24
14	0	5	0	1	0	0	0	1	0	0	3	36	0	-
Total	32		25		20		31		13		32		19	
Efficiency (%)¶	34		25		28		98		31		21		48	

† Zone 15 represents islands in Bay of Bengal and Arabian Sea, and is not included here. (See Annex 1 for full description of zones)
‡ For trials analysed see 'Methods Used'
§ - = less than 0.5
¶ see 'Methods Used'

A simple index of efficiency can be used to assess how well the sites are located according to the Planning Commission zones. In pearl millet the lowest efficiency was 21%, so the sites are poorly distributed in relation to the agro-ecological zones. Sorghum had a very high efficiency of 98% but the AICCIP for sorghum does not employ any zonation when assessing the performance of varieties or recommending where they should be released. Such a strategy makes it less likely that farmers will find varieties with localised adaptation that produce a higher yield under their conditions of cultivation. However, this low priority of breeding of varieties for specific adaptation in sorghum is mitigated by the unusually small geographical spread of the crop.

If new varieties are to be tested in an adequate range of environments there should be trials in each of the NARP zones. On a conservative requirement of two sites per zone, there should be 262 test sites in a crop that is grown throughout the country, and over 200 for most crops that are grown regionally. Clearly, the number of test sites within the AICCIP crop zones is far too low (Table 2.4) to provide the location-specific research envisaged in the NARP. The system will be able to produce widely adapted cultivars for resource-rich areas, but is not optimal for producing cultivars for specific, marginal environments.

When zones were created in all crops, they were based on gross geographical differences such as political boundaries (states), latitude (related to temperature) and longitude (related to rainfall). Exceptions to this are provided by rice where different ecosystems considered in the classification and location of trials. In groundnut, the habit group and season of cultivation are important considerations in zonation. In pearl millet, the amount of annual rainfall is an important factor.

However, these divisions are still on a very large scale and do not consider micro-climatic variables such as soil, weather and the availability of irrigation water that can be used to define agro-ecological zones within states. For example, even a small state like Punjab, that has only 1.5% of the area of India, is divided into six agro-climatic regions: sub-mountain undulating region, undulating plain region, central plain region, western plain region, western region, and flood-prone region. The cropping pattern in all these regions (subzones) are different because of differences in rainfall, underground water, soil type and climate (Gill, 1992).

The only way that zones can be made small enough is in a decentralised breeding and varietal testing system that permits a greater number of widely dispersed sites. Then it is possible to target zones within a state. If a coordinated project was to do this there would be, even with only two zones per major state, about 50 zones. A feasible strategy for the coordinated projects is to concentrate on supporting state level breeding by the zonal and national testing of proven cultivars from these programmes. In turn, state level breeding can only tackle the problem of an inadequate number of testing sites by involving farmers in varietal testing. Only when the number of testing sites is greatly increased can all agro-ecological zones be properly represented in a testing system.

Although it could be helpful, none of the coordinated projects use varietal response as a basis for defining zones. For example, the evaluation of a set of germplasm over several years across the whole range of environments will provide data for grouping of test sites that best differentiate the varietal responses. There are many ways to analyse varietal performance to provide data for zonalisation and these include:

(i) The technique of analysis of variance for grouping of environments with non-significant G x E effects (Shorter *et al.,* 1977; Horner and Frey, 1957).

(ii) Contribution of environments to genotype x location interaction (Plaisted and Patterson, 1959).

(iii) Correlation matrices (Guitard, 1960; Falconer, 1960; Shorter *et al.*, 1977; Hamblin *et al.,* 1980; Brennan and Byth, 1979).

(iv) Genetic parameters such as heritability and screening ability of environments (Johnson and Frey, 1967; Eagles *et al*., 1977; Allen *et al.,* 1978; Pollmer *et al.,* 1980).

(v) Multivariate analysis (Gower, 1966; Abou-El-Fittouh *et al.*, 1969; Williams and Gillard, 1971; Byth *et al.*, 1976; Shorter *et al.*, 1977; Johansen *et al.*, 1985; Gusmo *et al.*, 1989; Peterson and Pfeiffer, 1990).

At least in certain cases, the analysis of varietal responses across trials and years will provide a zonal classification that runs counter to the geographic zones. Thus, a balance has to drawn between arbitrary geographic zones and those based on varietal responses.

Do the Trials Represent Farmers' Fields?

Comparison of yield in trials and farmers' fields

Another major consideration is the degree to which the trials represent farmers' management practices. Exceptionally high yields compared with average farmers' yields would strongly suggests that the trial conditions do not represent the conditions in the farmers' fields[1].

There are no published statistics on the fertilisers that farmers apply to particular crops. We therefore indirectly examined the inputs used in trials and those used by farmers by comparing the mean yields of the trials with yields on farmers' fields.

The frequency distributions of the trial means and the district state yields were very different (Figs. 2.4 and 2.5). This difference could arise from:

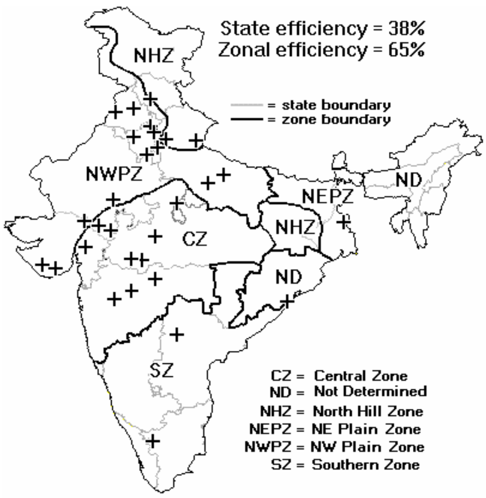
- The trials having superior genetic material to that grown by farmers.
- A difference in soil fertility, management and inputs applied, shown by the yield gap, after adjustment for genetic differences, between the trials and the districts in which the trials are conducted. High levels of inputs are applied in all research trials. For example, in the Initial Pearl Millet Hybrid Trial-I, 1994, the level of fertiliser varied at the various trial sites from 36 to 90 kg ha^{-1} N; 10 to 50 kg ha^{-1} P_2O_5; and 0 to 30 kg ha^{-1} K_2O. Also insecticides such as Thimet, Furadan, BHC 10% were applied at levels of up to 25 kg ha^{-1}. In contrast, farmers rarely, if ever, apply fertiliser to pearl millet at such high levels and very few farmers apply insecticides.
- Better physical locations of the research stations in more favourable agro-ecological situations. This would be shown by a yield gap between the districts in which the trials are conducted and the All-India mean.

The differences are much too large to be attributed only to genetic differences. For example, at the district level, the difference between the mean yields of the trials and the districts in which they were located was 257%, i.e., over 1 t ha^{-1} in pearl millet and 272%, i.e., over 2 t ha^{-1} in sorghum. At the state level, the difference between the mean yields of the trials and the states in which they were located was 458%, i.e., over 2.8 t ha^{-1} in sorghum and 196%, i.e., about 2 t ha^{-1} in wheat. Consistently, they were over 1 t ha^{-1} in all crops. Clearly, to have such large differences, the trials were conducted with much better management and with higher applications of inputs than those of most farmers. However, in the legumes (groundnut and chickpea) the differences were smaller (Figs. 2.4 and 2.5). This may be because there is less difference in nitrogen levels between research stations and farmers' fields in legumes than in cereals.

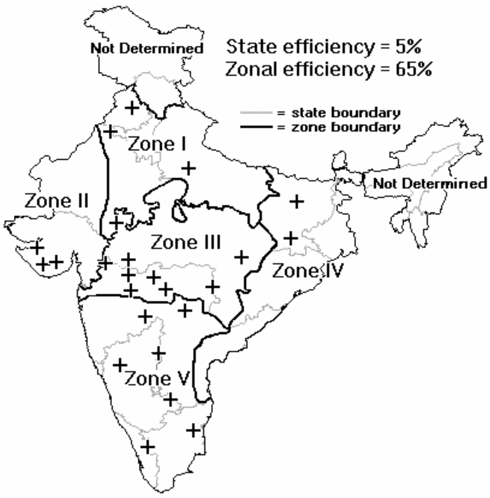
Mean yields were slightly higher in those districts where the trials were conducted than in the whole of India (Fig. 2.5). The locations of the research station, therefore, do not account for the differences between the trial means and the all-India mean. In pearl millet, mean yields were higher in those states where the trials were conducted than in the whole of India (Fig. 2.5). It also indicates

[1]Trial mean yields are reported in the AICCIP annual reports, and farmers' yields were assessed by the mean yields in the districts in which the trials were conducted. District mean yields were obtained from district level area and production data. State mean yields were obtained from Government of India (1992, 1995), New Delhi.

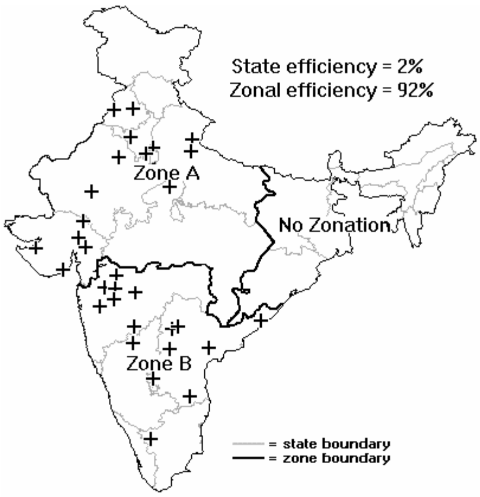
that research stations are not located in the more marginal districts, probably because research institutes have avoided highly risky, drought-prone areas when choosing the sites for research stations.



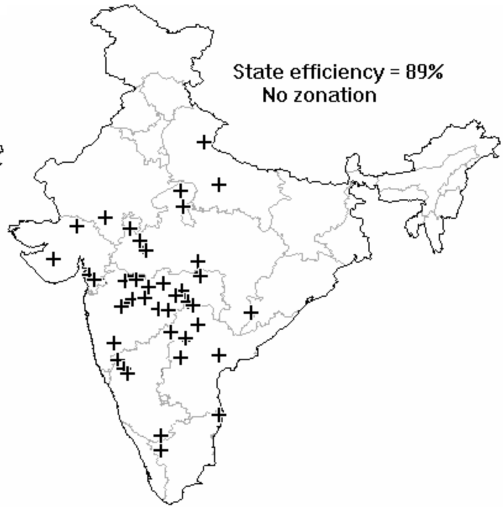
Chickpea - AVT 1990 trial



Groundnut - AVT 1991 trial



Pearl millet - AHT 1991 trial



Sorghum - AHT 1991 trial

Fig. 2.3 **Location sites of AICCIP trials for chickpea (1990), groundnut (1991), pearl millet (1991) and sorghum (1991) in relation to crop zonation.**

These differences are increased by the methods used to analyse the trials. In most of the AICCIPs, trials having a mean yield less than the relevant state average are not even considered in the data analysis for determining promotion and release of entries. If we assume that yield on farmers' fields is normally distributed then half of the fields would be expected to yield less than the state mean. Consequently, trials that are rejected because they are below the state mean, are representative of 50% of the farmers' fields.

The bias towards high-input farming systems, so well illustrated in Figs. 2.4 and 2.5, causes large genotype x environment interactions between the research station trials and low-resource farmers' fields.

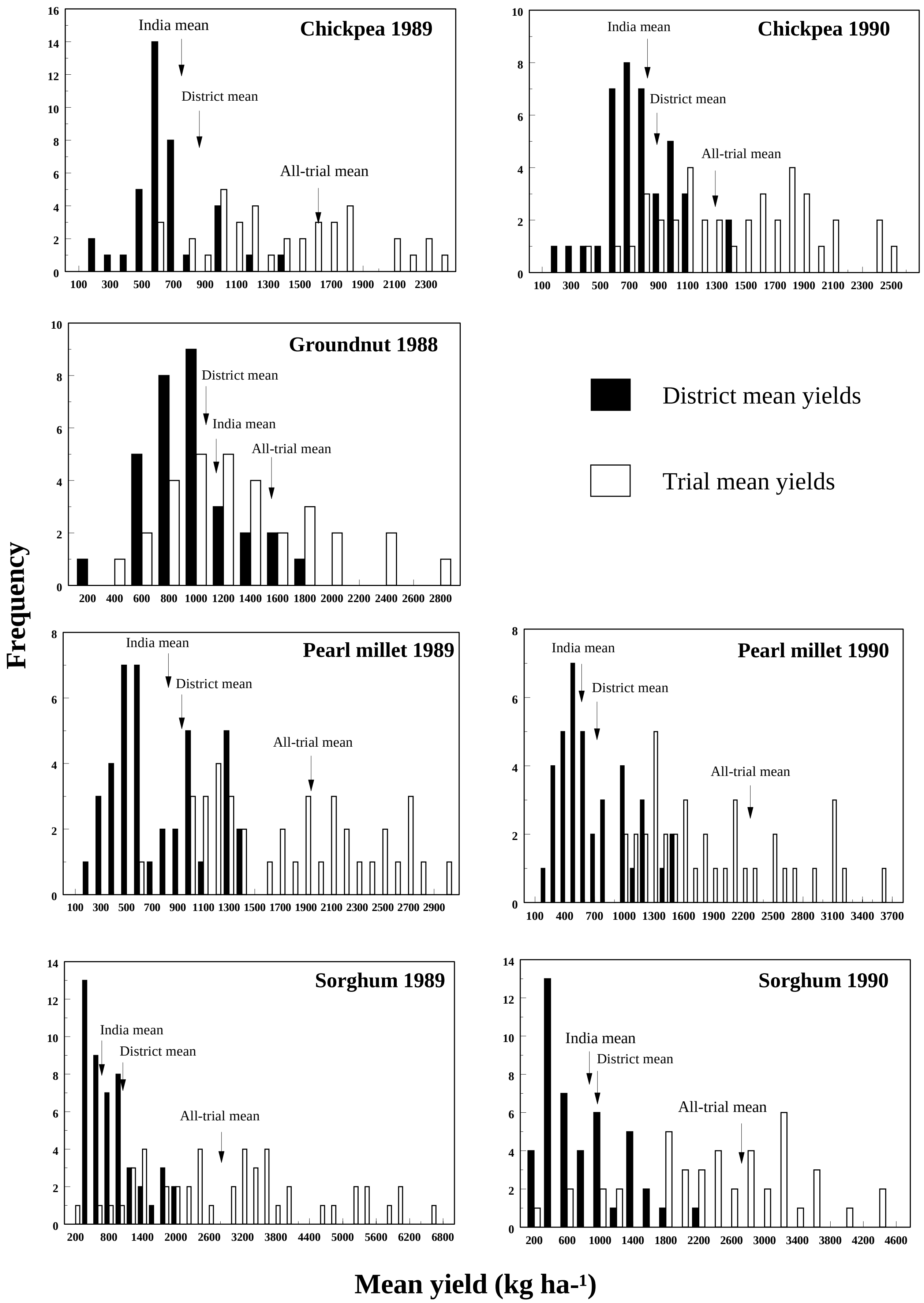


Fig. 2.4 **Frequency distribution of AICCIP trial mean yields for four crops and the mean yields in the districts where the trials were conducted**

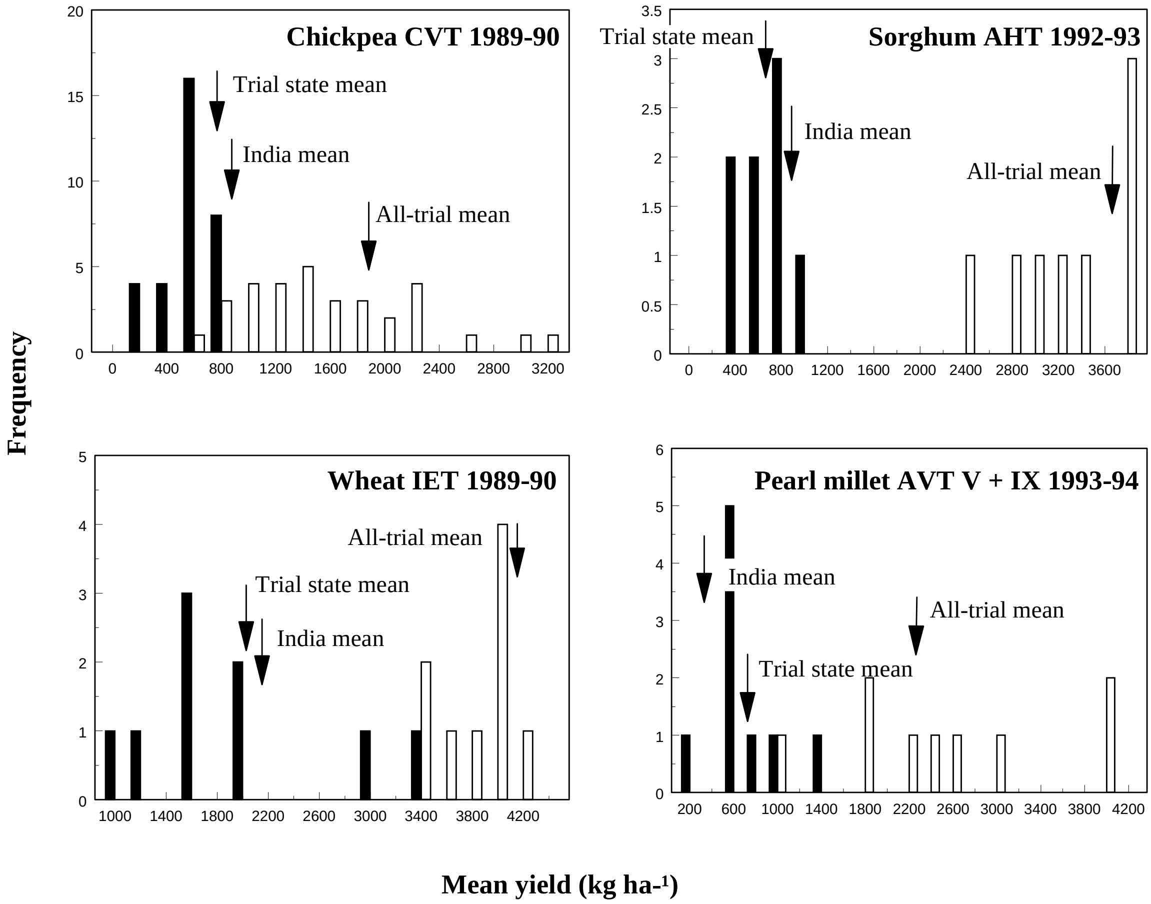


Fig. 2.5 **Frequency distribution of AICCIP trial mean yields for four crops and the mean yields in the states where the trials were conducted.**

An example of high genotype x environment interaction

Very high genotype x environment interactions can be induced by applying much higher inputs than those in farmers' fields: In AICCIP sorghum trials, conducted at ICRISAT, Maldandi, a very old but highly popular *rabi* sorghum, performed poorly when insecticides and fertilisers were applied at the rates recommended for the trial. However, when no insecticides are sprayed, and no fertilisers are applied to any of the cultivars, Maldandi is the top performing entry (MM Anders, ICRISAT, pers. comm.).

As a result of these large differences, it is difficult to predict the yield on low-resource farmers' fields of new varieties that are released on the basis of their superiority to checks in the research station trials. These large differences can be somewhat reduced even if trials are not relocated. Trials should not be rejected because they have a low mean yield. Nor should they be rejected for having a high coefficient of variation (that is often found in low-yielding trials) unless there is no statistically significant difference between the entries. It is simple to reduce the amounts of inputs applied to the trials.

The most effective way of catering for the needs of resource-poor farmers is to conduct trials on farmers' fields with farmer-level inputs (Maurya *et al.,* 1988; Sperling *et al.,* 1993; Joshi and Witcombe, 1995; Joshi *et al*., 1996).

The analysis of trial sites allocation and zonation in the AICCIPs has shown that:

- Trial sites are not congruent with the area of production of a crop.
- Trial zones do not adequately represent the agro-ecological regions of the crop as:
  - they are too few in number;
  - are too large, and
  - have insufficient test sites within them.
- Trials are grown under high input conditions that do not represent the conditions in farmers' fields.

Greater participation of farmers in the multilocational trials system can make the system much more relevant to farmers' needs. This can be done by the formal involvement of farmers in the evaluation of on-station trials and by the conduct of farmer-managed on-farm trials. This has the advantage of:

- having more testing sites;
- improved targeting of specific environments;
- improved definition of the recommendation domains of cultivars;
- identifying for release only those cultivars which are acceptable to farmers, and
- better representing the environments of farmers' fields.

At present, data from farmer participatory research do not command the scientific respectability of data from replicated yield trials, but in a farmer-orientated system they would be the primary data for setting standards. The number of test sites possible within a farmer-managed on-farm system may be constrained by various factors but it is more flexible than the formal varietal testing system, where the number and locations of test sites is pre-determined by the existence of research stations in the region.

Discussion

There is growing evidence that for selection to be most effective it must be carried out in the target environments. Simmonds (1991) concluded that selection for low-yielding environments must be conducted in low-yielding environments, and found that alternative strategies were ineffective. These included the use of selection environments with intermediate yield levels and alternating selection cycles in low- and high-yielding environments (shuttle breeding). Similarly, Ceccaralli *et el.* (1994) and Smith *et al.* (1990) concluded that selection under low-input management is essential if significant yield gains for such conditions are to be achieved.

The AICCIPs are rooted in the GOI philosophy that superior technologies must be produced by the public sector and transferred to farmers for them to adopt as part of a recommended package of practices. Accordingly, the trials must be conducted using this package. However, the assumption that farmers should be able to use a package of practices is often incorrect, since limitations on farmers' resources and their well-justified aversion to risk have been inadequately taken into account. Joshi and Witcombe (1995) found that farmers did not provide additional inputs for many justifiable reasons; because they had no access to them, because they could not afford to purchase them, or because they were unprepared to take the risk of applying inputs to a crop that had a high chance of failure. They also found that, using participatory varietal selection, farmers could obtain significantly higher yields by merely changing variety without any change in management. Similar results have been found by several other workers including Maurya *et al.* (1988), and Sperling *et al.* (1993). These results are powerful arguments for unpacking the package which has been developed to maximise yield rather than maximise profit and minimise risk. Trials need to be conducted to select for cultivars that perform well under low-input management. An additional benefit of abandoning the package approach is that it will accelerate adoption rates by farmers who are currently reluctant to try new cultivars that will require additional inputs.

Methods Used

We used data of breeding trials from AICCIP annual reports: 1991 to 1993 for rice, pearl millet, wheat, sorghum and groundnut, and 1990 to 1992 for chickpea. The trials which were selected were classified by district, state and zone. For all crops except groundnut, the corresponding area for the district, state and zone levels were obtained for 1989 and 1990 from the '*Agricultural Situation in India (1993)'*, Government of India. Mean values for the two years were used in the analysis. For groundnut, only data for 1988 were available from '*Statistical Tables-District wise Area and Production 1988-89 for India'*. The 1988 data can be used with confidence since annual fluctuations in the area of production are too small to seriously influence the outcome of the analyses.

Trial and crop database

A table was created in Microsoft Access for each crop with trial names and year (as columns) against location (town or test centre) as the rows. For each location an integer '1' for yes or '0' for no was used to indicate whether a particular trial was carried out at that location for a particular year. One aim was to display this information using the Idrisi geographic information system (GIS), so the geographic position of test sites was also required. Therefore, an additional table was created in Access containing the district, state, latitude and longitude of all the locations. Maps of India, the Times Atlas, and personal communications were used to obtain this information. It followed that the district and state of the location could be determined from this information. This table was constructed for all test site locations for all crops. Zonal information is crop specific and was therefore kept in the crop trial tables. A further table was created in Access using the information from the *'Statistical Tables-Districtwise Area and Production'* data that are collected by the state departments of agriculture and published by the Directorate of Economics and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi in the series: '*Agricultural Situation in India'* containing all the information at the district level. The Access database was used to examine the relationship between area/production and test site location on a national, zonal, state, and district level.

It is important to note that not all the trials for all crops could be given an exact location. The district information was the most difficult to obtain because often the AICCIPs classified the trials by either zone (e.g., groundnut) or state (e.g., rice). It follows that sites with missing district information also have no latitude and longitude information. Rice had the poorest quality of information and pearl millet and groundnut the best. A problem with the names of some of the trial sites was also apparent in that the same place can differ in spelling between different crops and sometimes even with the same crops within the same or different years. This problem also occurs with the name of the districts, sometimes the name/spelling, depending on the source of the information.

India maps

For the map analysis the Idrisi GIS (Geographical Information System) was used. A digitised map of districts was obtained from Dr. Meri L. Whitaker, ICRISAT (Fig. 2.6). This map was converted to the Idrisi format and the districts polygonised (converted from lines to solid areas). The districts were identified and linked to the information in the database. With the link established any district crop information could be displayed on the district map. The maps in Figs. 2.2 and 2.3 were produced by creating district areas of production maps for various crops and reclassifying the values to a few categories for displaying purposes.

Using the database, crop trial site location for particular trials and years can be linked to map co-ordinates and displayed over other maps as in Fig. 2.2 for example. This provides a good visual picture of the relationship between district area of production and trial site locations.

Using the database, district information can be summed for whole states. In this way state crop statistic maps are created, on which trial locations can be overlaid as for the district maps. The zones for each of the crops was estimated using the trial site locations information in the database. Each site, by the AICCIP trials, is given a zonal designation and this together with the actual trial sites location gives some indication of the zonal patterns over India for each crop. To simplify the zonal maps, unless stated otherwise, the state boundaries were taken as the zone boundaries. Some states were allocated to a zone even if they did not themselves contain any trial locations, their zone designation was calculated from adjacent states. However for some states it was not possible to determine the zonal allocation, if the crop is not grown there and no trials are conducted in these areas the zone class was not designated and marked 'not determined' on the maps.

If national crop zonation systems followed closely the state and district boundaries (as the Planning Commission agro-climatic zones) then national zonal maps can easily be created from our district maps. However some zonal systems do not, such as the ICAR agro-ecological regions. In these cases new maps need to be created (i.e. digitised from a paper map).

Fig. 2.6 The districts and states of India used in the analysis. (Map of India, after Brigadier Gupta, 1988)
This is a rough sketch only and it does not purport to depict the political boundaries of India.

Analysis of efficiency

District level
The efficiency of site allocation, on an area basis, was calculated in percentages:

{total area in districts of trial locations (A)/total area of districts in an optimised system(B)} * 100.

'A' is the area of crop production in districts in which at least one trial was conducted. If there are more than one location in a district the area is still counted only once. 'B**'** is the area of crop production in the districts in which locations are situated in an optimised system where the locations are assigned to represent the greatest area of production where no district has more than one trial site. This corresponded to the total of 'n' top districts arranged in descending order for area of production in respect of total of 'n' sites at which a trial was conducted. A similar analysis can be done for amount of production.

The efficiencies of site allocation by district were plotted as bar diagrams for comparing them across crops for variation over years, trial types, and special situations such as ecosystems in rice, kind of cultivar (hybrid or variety) in pearl millet, seasons in sorghum and habit groups in groundnut (data not presented here).

State level
The allocated number of sites for any trial was matched with the optimal number of test sites for each state. The efficiency of a trial is optimal when the distribution of sites across states corresponds perfectly to the relevant importance of the states either for area or amount of production for that particular crop. Hence, the optimal number of trials in a state equals, n (a/b), where n = total number of trial sites, a = the area of production in the state, and b = total area of production in India.

To obtain a single figure for trials efficiency the coefficients of determination (r^2_A) of number of sites against area or amount of production was computed. A similar correlation analysis was performed for the optimal number of sites with their area and production. This sets the maximum limit of r^2, termed r^2_B. Efficiency (%) of site allocation on a zonal basis was derived as:

$(r^2_A / r^2_B)*100$

The r^2_B makes little difference when the number of sites in a trial are high as it is very near to 1. It becomes an important factor when a low number of sites prevents the optimisation from being efficient.

Only those states that at least had one trial were included in the calculations. For some trials, negative correlations were obtained for the actual site locations and these were excluded from the computation of efficiency. When all states had a constant number of trial sites or when the number of states was only two, no correlation analysis could be performed.

Zonal level (Coordinated project zones)

Total area of production and amount of production for each zone were computed from the area and production of the states allocated to the zone. There were instances when different regions within a state were allocated to more than one zone. For example, there were three sites in Maharashtra state that were allocated to three different zones, i.e. Talod to zone II, Akola to zone III and Digraj to zone V in groundnut. Therefore, the area and amount of production of Maharashtra were divided and allocated to these three zones according to the proportion of the districts in which these locations are situated.

The efficiency of site allocation was computed from the optimal number of sites for each zone using the same methodology as for states. However, because of fewer degrees of freedom the r^2 statistic was not used. Instead, the deviations between the actual and expected (optimal) number of test sites were converted into χ^2 values which were statistically tested for their significance. The χ^2 values, however, do not yield a measure of trial efficiency in percentage which is comparable to the analysis performed for districts and states. A novel way was devised to convert absolute deviations (deviations ignoring signs) into per cent efficiencies. In this analysis, the ratio of total absolute deviations across zones for the actual to the worst trial site allocations is computed which gives the extent of the actual inefficiency achieved out of the maximum possible inefficiency. Subtraction of achieved inefficiency from 1.0 gives an estimate of the efficiency of the trial which was expressed in per cent. Thus the trial efficiency is:

[1 - total absolute deviations / total worst absolute deviations] x 100.

The worst allocation of trial sites is the one where all trial sites are located in a zone that has the lowest proportion of area of production or amount of production. Total worst absolute deviations thus set the maximum limit of inefficiency that can be ever achieved from inappropriate trial site allocations, and the total absolute deviations from the actual trial site allocations reflect the extent of inefficiency observed.

Zonal level (Planning Commission Zones)

The constraints of a limited number of zones in the coordinated projects does not apply when the planning commission zones are considered. Hence the r^2 statistics, r^2_A and r^2_B used for the state level analysis were employed. The analysis presented in Table 2.5 was on the following trials, all of which were sown in 1990: Chickpea: AVT; Wheat: AVT 8; Rice: AYT-IM; Sorghum: AVT(K); Maize: Trial 68 (Medium maturing composites under rainfed/irrigated conditions; Pearl millet: APMPTV; Groundnut: IVT(SB).

Summary

The statistics used for these various analyses are summarised in Table 2.5

Table 2.5 Types of analyses performed for estimation of efficiency at different levels of hierarchy.

Level	Measure of efficiency	Statistical test
District	Area or amount of production of districts in actual versus optimal allocation of trial sites expressed as a per cent.	None available. Correlation coefficients can not be used since actual and optimised districts rarely coincide.
State and Planning Commission Zones	r^2_A/r^2_B * 100 (see methods used).	r^2 of site numbers in zone or state against the importance of that state or zone by area (or amount of production).
Coordinated Project Zones	Total absolute deviations (i.e., without sign) of the actual trial as a proportion of the absolute deviations in the worst possible trial allocations, subtracted from 1, and then expressed as a percentage efficiency (see methods used).	Deviations between actual and optimised allocation of trial sites expressed as χ^2 statistic. χ^2 instead of r^2 that cannot be used due to the low number of degrees of freedom for zones.