Varietal Testing and Popularisation and Research Linkages[1]

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1. Introduction

The national co-ordinating agency for agricultural research in India, the Indian Council of Agricultural Research (ICAR), has created All India Coordinated Crop Improvement Projects (AICCIPs). These are interdisciplinary research networks linking ICAR institutes with the State Agricultural Universities, and their major activity is the testing and identification of improved crop cultivars. They have been instrumental in increasing crop yields through the adoption of high-yielding cultivars in resource-rich areas. However, there has not been a similar adoption of improved cultivars in rainfed farming systems.

Changes have recently been considered in the functioning of the AICCIPs to better meet the challenge of increased demands for food from a declining resource base (Rao, 1988; Paroda 1990; Rajan, 1992). Rajan (1992) suggested that policies, programmes, and procedures in the AICCIPs should be fundamentally changed. These were examined in a two-day workshop at Hyderabad in 1992 (ICAR, 1992). However, because the workshop did not pay particular attention to the needs of low-resource farmers in rainfed agriculture, no recommendations were made, such as the decentralisation of plant breeding, that would particularly benefit them. Instead, greater uniformity in data documentation of varietal trials and release procedures was recommended.

The major objective of the study reported here was to examine how well the AICCIP crop breeding programmes meet the needs of rainfed farming systems. This was done by:

- analysing the cultivars that are presently grown to quantify the extent of adoption of HYVs, and to whether low levels of adoption are particularly found among low-resource farmers;

- examining how the AICCIP trials system caters to the specific needs of low-resource farmers;

- reviewing the evidence in support of fresh approaches involving greater farmer participation.

We then suggest changes in the system intended to expand the range of acceptable varieties available to low-resource farmers, so contributing to more rapid cultivar replacement rates and higher adoption levels.

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2. Are Farmers Growing Modern Cultivars?

2.1 *How Many Farmers are Growing Modern Cultivars?*

Except for a few states for which district level data are published, statistics on the areas under modern varieties, which are always termed as High Yielding Varieties (HYVs) in Indian statistics, are only obtainable from Directorates of Agriculture, and Bureau of Economics and Statistics in each state. The International Crops Institute for the Semi-Arid Tropics (ICRISAT) has obtained such data for seven states, and Dr ML Whitaker of ICRISAT has kindly provided us with them. As an example, we examined the percentage uptake of HYVs of rice in 149 districts of Andhra Pradesh, Madhya Pradesh (MP), Tamil Nadhu, Karnataka, Maharashtra, Gujarat and Rajasthan. These were all of the districts for which ICRISAT obtained data for 1983.

We mapped these data (Fig. 1) after exporting them to the Idrisi Geographic Information System (Eastman, 1992). Many districts had low partial adoption of HYVs in rice; for example, in nearly all of the districts in MP, adoption was below 50% (Fig. 1). This may not be a problem if such districts account for a very small proportion of total production. However, nearly half of all the districts examined had less than 50% adoption of HYVs, and they accounted for 34 % of the area of production and 21% of the amount of production of the districts studied (Table 1).

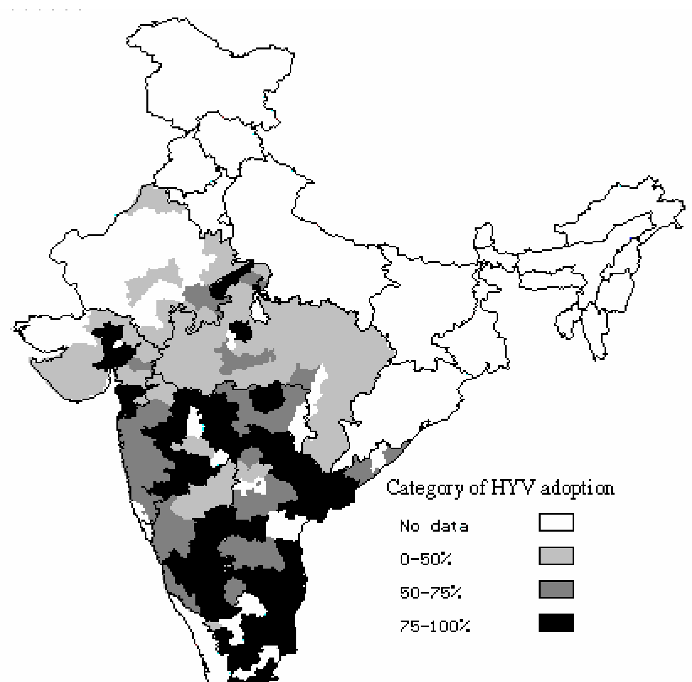


Figure 1 Adoption percentages of HYV's of rice by district in six states of India during 1983

Table 1. **Area of production and amount of production of 149 districts classed by HYV adoption rates**				
District class	Number of districts	Production statistics of districts with different classes of adoption rates of HYVs		
		Area (000 ha)	Production (000 t)	Average yield (t ha^{-1})
Adoption 0-50%	62	5003.4	4895.8	0.98
Adoption 50-75%	34	3253.7	5577.2	1.71
Adoption 75-100%	53	6276.6	12782.4	2.04
All	149	14533.7	23255.4	1.60

The mean yields in the districts with low adoption of HYVs of rice is about 1 t ha^{-1}, which is much lower than that of the districts (about 2 t ha^{-1}) with high adoption of HYVs (Table 1). These highly significant differences ($P<0.001$) in yield are much too large to be explained simply by genetic causes. The districts with low adoption of HYVs are obviously those with the most marginal environments where the use of inputs is lower. Low-resource farmers in marginal areas benefit less from HYVs than farmers in more favoured regions although, as is argued later in the paper, suitable HYVs do exist in many crops. They are not exploiting a potential economic benefit of enormous value. If another 50% of the farmers were to adopt HYVs of rice in the 62 districts that currently have less than 50% adoption, the increase in the amount of production could have a value up to Rs. 2.5[1] billion or £50 million. The economic potential of higher adoption of HYVs is much greater when the whole of India is considered, and enormous sums are involved when the value of increased production is calculated for all crops.

2.2 *How Old are the Cultivars that are Being Grown?*

Farmers quickly replace old cultivars when continuously offered superior cultivars (Cuevas-Perez *et al.* 1995). Cultivar replacement rates are, therefore, a good index of success of the AICCIPs in releasing and popularising new cultivars. There are many different measures of varietal replacement (Johnson and Gustafson, 1963; Brennan, 1984; and Brennan and Byerlee, 1989). They can be determined from data on:

- Field surveys on the adoption of new varieties;
- Certified seed production statistics; and
- Statistics on breeder seed demand and production.

Field surveys are difficult and resource-demanding to carry out, whereas good statistics are available for India on the demand for breeder seed and on the production of breeder and certified seed.

[1] Assuming 50% of the farmers change from landraces to HYVs in the area of production having a low adoption ceiling of HYVs (2.5 m ha in the 149 districts studied), and very conservatively assuming that there is a 20% increase in per hectare yield (0.2 t ha^{-1}) associated with adoption of HYVs. In this area there will be an increase of 0.5 million tonnes in the amount of production. At a rate of £100 (Rs. 5000/-) per tonne, it will give an additional benefit of £50m (Rs. 2.5 billions).

We used three sources to obtain data on the number of varieties released per year for rice, wheat, pearl millet, sorghum, groundnut and chickpea cultivars (Tunwar and Singh, 1985; Govt. Of India, 1993; and Ministry of Agriculture and Cooperation, Government of India, 1985-93). In addition, we used statistics on breeder seed indents from two sources, the Directorate of Seeds, Government of India and AICCIP annual project reports. In pearl millet and sorghum, we indirectly assessed the age of hybrid cultivars from the indents for breeder seed of their parental lines.

Inaccuracies in estimating the age of cultivars grown by farmers from the age of cultivars under breeder seed production may arise for a number of reasons. Indents for breeder seed are not perfectly related to the amounts of production of breeder, foundation and certified seed. Uncertified or truthfully labelled seed is sold that is not produced from breeder seed. Seed of older or younger cultivars than average can spread from farmer to farmer. All of these variables can give rise to errors in either direction, and it is difficult to find reasons why such errors should be systematic. Hence, the estimates made from breeder seed demand are likely to be broadly accurate.

To estimate age of cultivars, we used the index of Byerlee and Heisey (1990). They used this index for field survey data and all we did was to calculate weightings not by the proportion of area sown to each variety but by the proportion of the total indent. Hence, we computed the average age of indented cultivars, measured in years from varietal release, weighted by the cultivar's proportion of the total indent in that year. In any year of seed production, Y_s, the age of a cultivar, A_t, is the number of years since its release, Y_r, i.e. $A_t = Y_s - Y_r$. This age was weighted by W_i = amount of seed indented for a variety/total seed indent of all varieties in a year. The total of the weighted breeder seed indents ($\Sigma A_t.W_i$) in any year gives the average age of the cultivars for which seed has been indented in that year.

The weighted average age of cultivars, based on breeder seed indents, was averaged for seven crops over 5 to 10 years (Table 2). The average age varied from 6 years in pearl millet to 17 years in maize (Fig. 2). The average age of the cultivars for which seed producers demand breeder seed is 9 years in wheat, 13 years in chickpea, 15 years in groundnut, 16 years in sorghum, and 17 years in maize.

The unweighted age of the oldest cultivars for which there was a demand for breeder seed was determined (Table 2). Except for pearl millet, most of these oldest cultivars were older than 20 years, and the oldest were 63 years in sorghum, and 53 years in groundnut.

State-level data for certified seed production for important crops were obtained in a CAZS (Centre for Arid Zone Studies), ODI (Overseas Development Institute), KRIBP (KRIBHCO Indo-British Rainfed Farming Project) study in three states: Gujarat (Jaisani, 1995), Madhya Pradesh (Upadhyaya, 1995) and Rajasthan (Vyas, 1995). For comparison, we estimated the age of wheat cultivars in certified seed production in the UK (1987-1993) using data from several publications of the National Institute of Agricultural Botany.

The estimates from certified seed production data in all three states were generally higher than that expected by adding 3-4 years to the ages calculated from breeder seed indents (Fig. 2). This probably reflects differences between national breeder seed data and state level certified seed data. The average age of cultivars in MP was the highest for maize (27 years), chickpea (26 years), and sorghum (17 years). The age of the cultivars grown by farmers is much higher than would be expected if popularisation and seed dissemination were efficient. Typical ages are 10-20 years in contrast with a more efficient system, such as wheat in the UK, where the cultivar age was less than 3 years (Fig. 2). Each additional year in the weighted average age of the cultivars in farmers' fields is a loss of one year of genetic gains due to plant breeding. Breeding new varieties produces annual increases in yield. Byerlee and Heisey (1990) estimated this annual genetic gain to be 1%, while Fiddian (1973) estimated it as 1.3%. Somewhat higher estimates of 2% for the increases per annum due to genetic causes were obtained by Evans (1981) for Mexico, and Godden and Brennan (1987) for Australia and the UK. These estimates were comparable to the gains achieved in India during the green revolution period (1960's and 1970's) with semi-dwarf wheats. The HYVs cultivated by farmers in India are about 15 years older than in an efficient system. Hence, farmers could realise a 15-30% increase in yield if they were growing modern HYVs, assuming a 1-2% genetic gain per annum. Over the whole of India, this represents a tremendous waste of economic opportunity, as billions of Rupees of increased production are forgone. The situation is likely to be worse for low-resource farmers, because the lower adoption ceilings that were found among low-resource farmers are likely to be associated with farmers growing older than average HYVs (see 2.1).

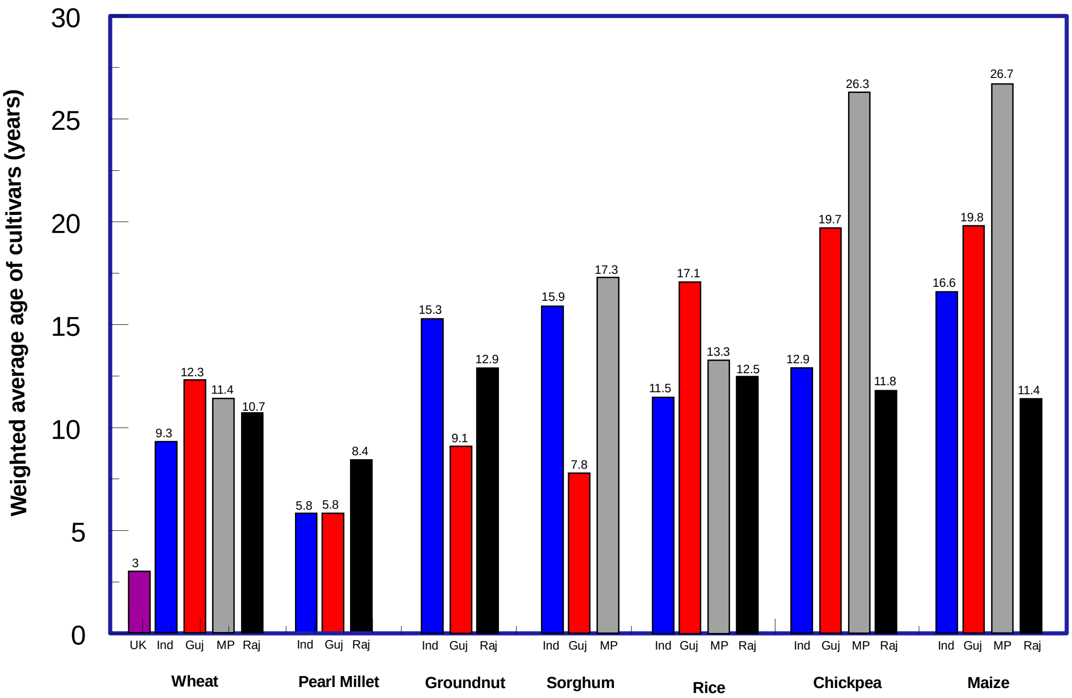


Figure 2 Weighted average age of cultivars of important crops estimated from breeder seed indents in India (1984-03), and certified seed production statistics for Gujarat (1992-93), Madhya Pradesh (1993-94) and Rajasthan (1992-93). The age of certified seed of wheat in the UK is also indicated for 1987 to 1993.

2.3 *Is the Situation Improving?*

Perhaps the current situation is better than that found from an analysis of past data on the production of breeder and certified seed. However, the trend in rice, pearl millet, sorghum and groundnut was for the weighted age of breeder seed to increase significantly over time. The rate of increase in weighted age of pearl millet cultivars (regression coefficient, b = 0.96 ± 0.2**) was equal to the increase in years, while in rice the weighted age of cultivars increases by about six months for each year (b = 0.42 ± 0.1*) (Fig. 3). The linear regressions were positive but a poor fit for wheat and chickpea, while there was no relationship at all in maize. Pearl millet has the lowest average age but there has been a three-fold increase in the average age of breeder seed from 1986 to 1993. The main reason for the low average age was the rapid adoption of new cultivars that were resistant to downy mildew, to replace cultivars susceptible to the disease. Replacement rates have subsequently slowed because the new cultivars have remained resistant to downy mildew.

Table 2. **Per cent of total breeder seed indents of the three oldest cultivars in several crops**

Crop	Year analysed	Cultivar	Year of release	Unweighted age in 1993	Per cent of total indent
Rice	1986-88, 90-93	Jaya	1968	25	3
		IR20	1970	23	5
		Ratna	1970	23	3
		Total			11
Wheat	1984-93	C 306	1965	28	4
		Sonalika	1967	26	18
		UP 262	1977	16	12
		Total			34
Pearl millet	1986,87, 89-93	K 560-230	1975	18	8[1]
		5141A	1975	18	6[1]
		WC-C-75	1982	11	17
		Total			31
Sorghum	1989-93	M-35-1	1930	63	5
		MSCK 60A	1964	29	3[2]
		IS 84	1964	29	2[2]
		Total			10
Groundnut	1986-93	TMV 2	1940	53	10
		AK-12-24	1940	53	4
		SB-XI	1965	28	5
		Total			19
Chickpea	1985-92	Ujjain-21	1955	38	4
		C 235	1960	33	14
		Radhey	1968	25	8
		Total			26

[1] Parent of BK 560 (5141A x K560-230) hybrid.
[2] Parent of CSH 1 (MSCK 60A x IS 84) hybrid.

The situation is worsening in most crops because it is more difficult to replace improved cultivars than landraces. High yielding varieties can rapidly replace landraces because they have a large yield advantage over them. Once landraces are replaced, cultivar replacement can only continue if new HYVs, with a smaller yield advantage, replace old HYVs. This is a likely explanation of the worsening situation in many crops, where the age of cultivars in farmers' fields is increasing over time.

2.4 *How Many Cultivars are in Seed Production?*

The production of breeder seed is the first step in the production of certified seed via foundation seed. Seed producers place written demands for breeder seed (called indents) to the Ministry of Agriculture, New Delhi and the data on indents and ensuing breeder seed production are compiled by the Ministry.

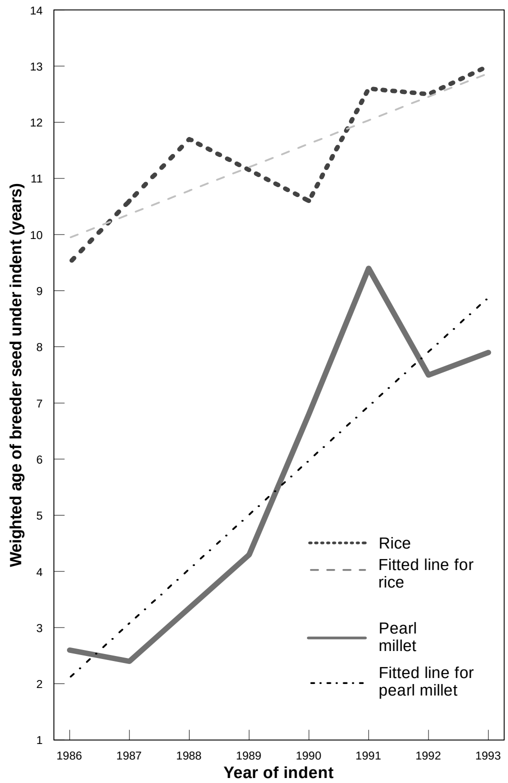


Figure 3 Age of breeder seed indented by seed producers from 1986 to 1993 in rice and pearl millet

During 1993, seed producers placed indents for breeder seed of 20 varieties of rice, 32 of wheat, 8 of pearl millet (including parents of hybrids), 14 of sorghum (including parents of hybrids), 52 of groundnut, and 54 of chickpea. However, in every crop only a few of these varieties were in great demand. In rice, IR36 released in 1981, was the most popular variety by far accounting for 30% of the total indent (Fig. 4). Over a seven year period it constituted a quarter of the total indent (Table 3). A similar situation was found for other crops. A large proportion of the total quantity of seed demanded by seed producers was for the three most popular varieties (Table 3). This proportion ranged from 29% in chickpea to more than half in sorghum. Only a few of the released cultivars seem to become popular with farmers.

Seed producers are providing a small choice of varieties. To avoid risk, seed producers tend to estimate demand from farmers, rather than promoting unknown new cultivars. This is consistent with seed producers not placing indents for new varieties immediately (Fig. 4). It takes many years following release before seed producers try new cultivars with farmers on a sufficient scale to create any significant demand from the farmers. Limited choice has a greater adverse effect on low-resource farmers since they have diverse environments that require several or many environment-specific cultivars.

One example, pearl millet variety ICMV 221, is worthy of mention. ICMV 221 was released in 1993 and is a replacement for the bold-grained and early maturing variety ICTP 8203 released in 1988. In spite of its significantly higher grain and fodder yield in trials over many years, seed producers have rarely undertaken its seed production but continue with the large-scale seed production of ICTP 8203.

2.5 *Farmers Grow a Limited Number of Old Cultivars because of Limited Dissemination of Information*

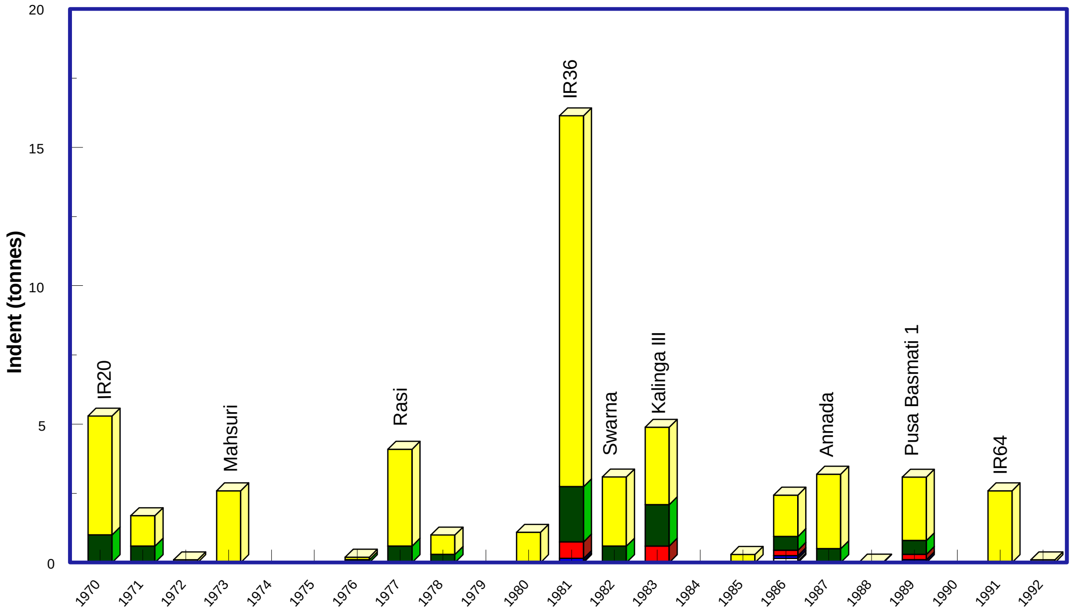


Figure 4   Breeder seed indents of rice varieties by year of release for 1993 in rice and pearl millet

Table 3. **Per cent of total breeder seed indents of the three most popular cultivars in several crops**					
Crop	Year analysed	Cultivar	Year of release	Age in 1993	Per cent of total indent
Rice	1986-88,90-93	IR36	1981	12	25
		Rassi	1977	16	7
		Masuri	1973	20	6
		Total			38
Wheat	1984-93	Sonalika	1967	26	18
		HD 2285	1982	17	15
		UP 262	1977	16	12
		Total			45
Pearl millet	1986,87, 89-93	WC-C-75	1982	11	17
		81A	1986	7	14[1]
		ICTP 8203	1988	5	9
		Total			40
Sorghum	1989-93	MS 296A	1981	12	22[2]
		CS 3541	1974	19	21[2,3]
		MS 2077A	1974	19	12[3]
		Total			55
Groundnut	1986-93	JL 24	1978	15	29
		TMV 2	1940	53	10
		GG 2	1984	9	8
		Total			47
Chickpea	1985-92	C 235	1960	33	14
		Radhey	1968	25	8
		Phule G 5	1986	7	7
		Total			29

[1] Parent of ICMH 451 hybrid.
[2] Parent of CSH 9 hybrid.
[3] Parent of CSH 5 hybrid.

Extension workers and seed producers do little or nothing to promote new cultivars until several years after their release (Jaisani, 1995; Upadhyaya, 1995; and Vyas, 1995). In part, this is due to poor information flows to the seed producers and particularly to the extension workers. At the national level, the only published description of varieties is by Tunwar and Singh (1985). Eight years later a catalogue of varieties (Govt. of India, 1993) was produced, but it does not describe varietal characteristics. Varietal descriptions, post 1985, are only available in the minutes of the Central Varietal Release Committee (Ministry of Agriculture and Cooperation, 1985-1993). These minutes are neither circulated widely nor are they freely accessible.

Information about the release of new varieties is often not available in the annual coordinated project reports. Even breeders and other crop scientists may not become aware of new varieties and their characteristics. The proceedings of the Central Sub-Committee on Crop Standards, Notification and Release of Varieties are not widely circulated, and do not reach the lower rungs of the extension services or seed sector.

Dissemination of information from the Central or State Variety Release Committees and the extension agencies follows a long official channel. Unaware of new releases, state departments of agriculture and farm science centres, *Krishi Vigyan Kendras* (KVKs), continue their extension activities with old cultivars. They do not experiment with the newly released cultivars from other states, either because they do not have access to them or because they do not appear on the list recommended by their own state (Jaisani, 1995; Upadhyaya, 1995; Vyas, 1995). There should be a 'freer trade' of cultivars between states. To enable this to happen information on new varieties released at a national and state level needs to be quickly and widely disseminated (Tables 4, 5). SAUs, KVKs, and NGOs should then be encouraged to test them with farmers (Table 4).

The non-availability of seed of new varieties appears to be another major constraint in the rapid popularistion of new cultivars. Normally, there is a delay of 4 to 6 years between the official notification of a variety and its commercial cultivation (Vyas, 1995). There is a long process involved from the placing of indents for breeder seed to the production of certified seed (see 2.4). Further, though the information is given in the release proposal, the source of breeder seed is not widely known. There are many cases where breeder seed production is delayed, and cases of released cultivars of which breeder seed is never produced. There is no central procurement mechanism for small quantities of seeds of released varieties. For

example, Joshi and Witcombe (1995) experienced a great difficulty in procuring seed of several released rice cultivars for farmer participatory trials; the seed of some of them could not be obtained for several years.

We have argued above that one of the major reasons for low adoption ceilings and replacement rates is poor popularisation. However, an additional explanation is that breeders have simply not yet produced superior material. For instance, the continuing popularity of the very old sorghum cultivar, M-35-1, is almost certainly because new superior alternatives have not yet been developed. Other cases of very old but still popular cultivars, such as Sonalika wheat (1967), JL-24 groundnut (1978) and C-235 chickpea (1960), may be for the same reason. This can not be known unless farmer participatory varietal selection (discussed in detail below) is tried. Would farmers, when exposed to a range of appropriately matched, newer cultivars, adopt any of them?

Table 4. **Summary of problems, causes and suggested solutions in view of needs of low-resource farmers**		
Problem	Cause	Solution
Released cultivars are not widely adopted	inadequacies in the testing and release procedures	- disseminate release information widely - create cultivar databases - have zonal trials of released cultivars in AICCIPs, state and adaptive trials - have trials of released varieties in AICCIPs - approve out-of-state released cultivars on one year testing - incorporate data from farmer participatory trials into release decisions - encourage NGOs to test cultivars - encourage SAU breeders to recommend out-of-state releases - encourage KVKs to test all national or other state releases
Multilocational trials do not represent the crops area	trial sites are not located in accordance with the importance of area	- allocate trial sites in important areas of the crop - increase number of trial sites using extension worker and farmer participation
Multilocational trials do not represent agro-ecological zones	too few sites to represent all zones	- increase the number of test sites according to zonal importance using farmer participation - increase the number of zones
Trials do not represent farmers' field conditions	research station trials are conducted at better sites and under applied inputs	- grow trials with inputs similar to those typically used by farmers - use farmer participation in trials - do not exclude trials with mean yield less than state mean - do not exclude trials with high CV

Multilocational trials select against specific adaptation	breeders do not ebter phenotypically extreme entries in the trials (they expect them to fail)	- create separate trials for different maturity ranges
		- have more trials for specific
		    - situations,
		    -traits, and
		    -zones
		- decentralise plant breeding and have more farmer participation

Non-yield or farmer-relevant traits are not considered	yield is the primary criterion of promotion of entries in AICCIPs and many farmer-relevant traits are not recorded	- give weight to non-yield, farmer-relevant traits - use farmer evaluation (on or off station) of trials for non-yield traits
Adoption of package of practices too difficult and risky for low-resource farmers	Extension services promote package of practices, and AICCIPs conduct trials under high input packages	- conduct some AICCIP trials under low inputs - unpack package for low-resource areas, i.e., test one intervention at a time - first adopt improved variety to give higher yield. Subsequent interventions are then less risky.

Table 5. **A summary of type of linkages required to be strengthened**	
Linkage	Why required?
CVRC[1] and SVRC with seed producers, SAUs, KVKs, and SDAs	To improve information and seed flow.
Seed producers with AICCIPs, SAUs	To appreciate the value of newly released materials.
Seed producers, SAUs, KVKs, SDAs with NGOs and other seed producers	To enable farmer participatory varietal selections to be widely adopted and not restricted to the limited number of villages currently covered. To ensure availability of seed of all cultivars.
AICCIPs with farmers	To test materials on farms, under farmer managed conditions, and to make the recommendation domain more farmer-oriented.
SAUs with Out-of-State SAUs, and CVRC	To promote free exchange of seed material into the state system.

[1]CVRC = Central Variety Release Committee; SVRC = State Variety Release Committee; SAU = State Agricultural University; SDA = State Department of Agriculture; KVK = *Krishi Vigyan Kendra*; NGO = Non-government Organisation.

Such examples of the lack of suitable replacements is a *de facto* criticism of the breeding and testing system which is considered in the next section.

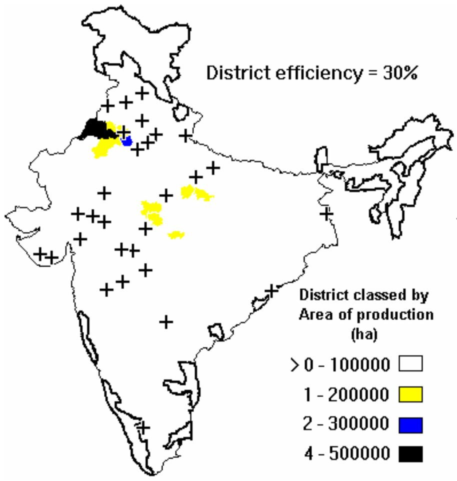
3. Do Multilocational Trials Target Low-resource Farmers?

3.1 *Do the Trials Represent the Important Areas of Production?*

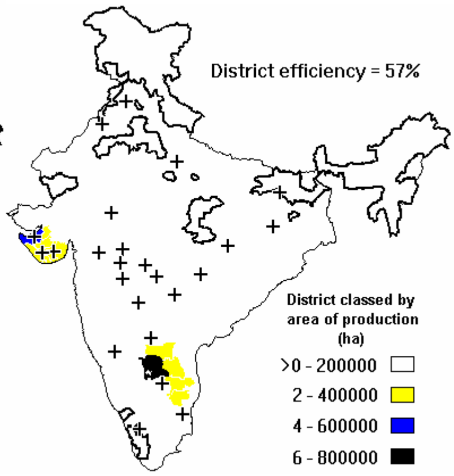
The trials will best predict the agricultural performance of new varieties if the trial sites are congruent with the area of cultivation of the crop. Ideally the allocation of test sites must match distribution of the crop by area and amount of production, and how well this is achieved was examined for a sample of AICCIP breeding trials.

We used breeding trial data in the AICCIP annual reports: 1991 to 1993 for rice, pearl millet, sorghum and groundnut, and 1990 to 1992 for chickpea. The trial sites in the AICCIP reports for selected trials were classified by district, state and zone. For all crops except groundnut, the mean values for 1989 and 1990 for area and production at the district, state and zone levels derived from data published by Government of India (1992). For groundnut, only data for 1988 were available. These data were satisfactory since yearly fluctuations in area of production are too small to seriously influence the outcome of the analyses.

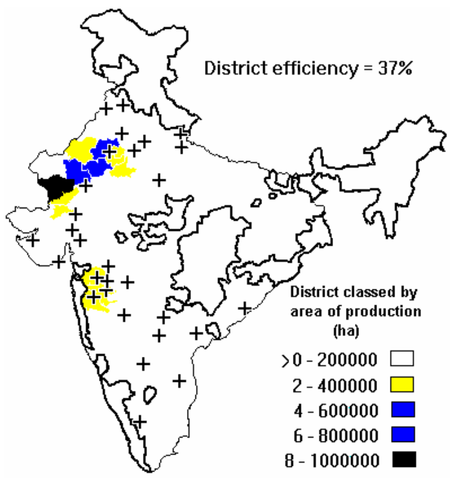
Efficiencies of site allocation by districts were obtained as a ratio (in per cent) of the total area of the *n* districts with trial sites, to the total area of the *n* districts having the greatest area of production or amount of production. This was done for a sample of advanced trials in different crops. In chickpea, groundnut, pearl millet and sorghum the district efficiency of site allocation by area of production varied from only 30 to 52% (Fig. 5). The low efficiencies were confirmed when all of the trials were pooled across three years in five crops (Table 6). There are large discrepancies in the AICCIP trials between the actual number of test sites and those predicted from optimising trial site location on the basis of area of production or amount 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 for the crop. The discrepancies also occur because the number of test sites is generally too low to achieve an optimal distribution.



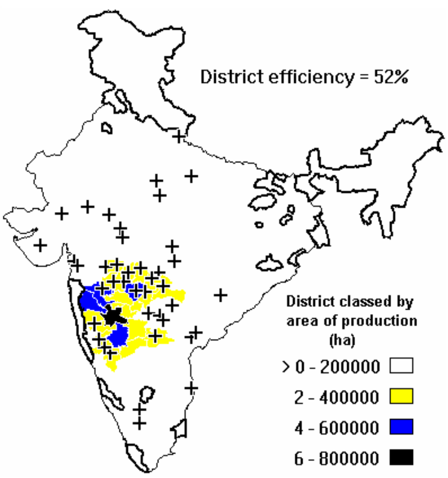
Chickpea - AVT 1990 trial



Groundnut - AVT 1991 trial



Pearl millet - AHT 1991 trial



Sorghum - AHT 1991 trial

Figure 5. Location sites of AICCIP trials for chickpea (1990), groundnut (1991), pearl millet (1991) and sorghum (1991) in relation to area of production by district. Areas within the thicker black lines have no recorded cultivation of the crop.

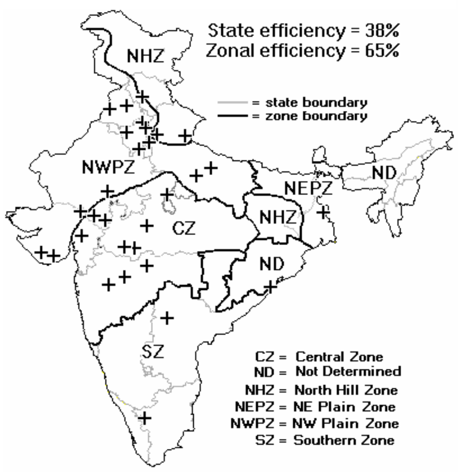
India is a vast country with many different agro-climatic zones. The Planning Commission has identified 15 agro-climatic regions, 14 in the mainland and one in the islands of Bay of Bengal and the Arabian Sea (Khanna, 1989). The National Bureau of Soil Survey and Land Use Planning, divided the country into 54 agro-ecological zones on the basis of "fairly-uniform, climatic land form (soil) conditions" (Sehgal *et al.* 1989). Subsequently, the Bureau published a map with 21 zones (Sehgal *et al*. 1990) in which zonal boundaries were adjusted to district boundaries. In the National Agricultural Research Project (NARP) of the ICAR, launched in 1979, 131 (Fig. 6) agro-ecological zones were defined (Ghosh, 1991). In each agro-ecological zone a zonal research station was established to conduct location-specific research.

Table 6. **Average efficiency of trials allocation by districts in the AICCIPs for five crops, across all trials and three years for each crop**		
	District Efficiency (% of optimised)	
Crop	Area	Prod.
Rice	43	36
Pearl millet	34	42
Sorghum	44	42
Groundnut	51	47
Chickpea	29	26

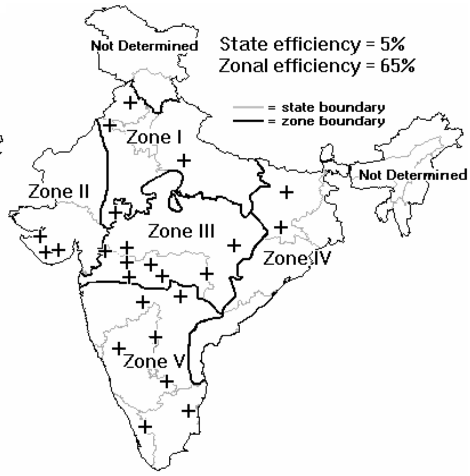
Figure 6 Agro-climatic zonal map of India of the National Agricultural Research Project (NARP)

3.2 *Do the Trials Represent the Agro-ecological Zones?*

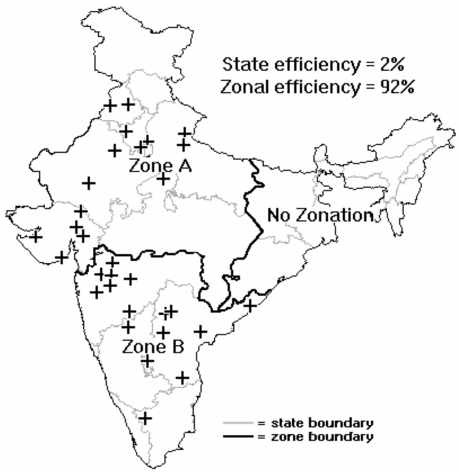
However, each AICCIP has created a different zonation system for the multilocational varietal trials (Fig. 7). The zones are much larger than those in the NARP because there are so few of them (Table 7), so in effect each AICCIP zone covers a wide diversity of agro-ecological conditions. The number of zones used in the AICCIPs is less than the lowest number of zones used in any system, the 14 mainland zones of the Planning Commission. We used the Planning Commission zones to examine the location of trial sites. In many zones that are important for the crop there are no trial sites, and sometimes there are sites in zones where the crop is not grown (Table 8). 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 efficiency is zero, there being no correlation between site location and the importance of the zone for the crop. In chickpea the efficiency was only 22%. Sorghum had a very high efficiency of 97%. Nonetheless, even where trial zones selected do correspond closely with zones identified by the Planning Commission this means little in practice because Sorghum AICCIP does not employ any zonation when assessing the performance of varieties or recommending where they should be released.



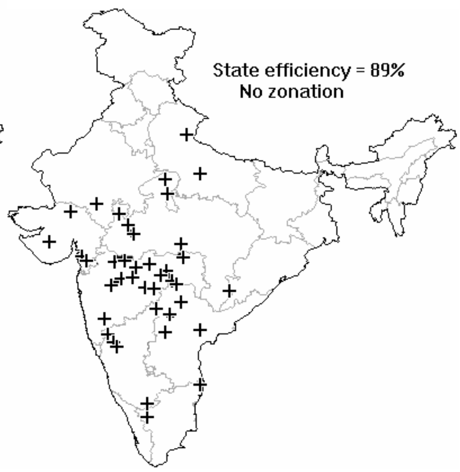
Chickpea - AVT 1990 trial



Groundnut - AVT 1991 trial



Pearl millet - AHT 1991 trial



Sorghum - AHT 1991 trial

Figure 7. Location sites of AICCIP trials for chickpea (1990), groundnut (1991), pearl millet (1991) and sorghum (1991) in relation to crop zonation. Areas within the thicker black lines have no recorded cultivation 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 7) 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.

Table 7. **Summary of 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

Table 8. **Distribution of AICCIP trials in three crops in 14[1] agro-climatic zones of Planning Commission, and the per cent efficiency of trials allocation by zones**

Zone	Chickpea		Pearl millet		Sorghum	
	Sites (No.)	Area (%)	Sites (No.)	Area (%)	Sites (No.)	Area (%)
1	2	0.1	1	0.2	1	0
2	0	0.1	0	0	0	0
3	1	0.4	0	0	0	0
4	1	4.3	0	0.6	0	0.3
5	4	6.7	2	7.2	1	2.0
6	7	5.3	4	7.1	0	0.5
7	0	3.7	0	0	1	1.5
8	5	43.0	7	13.4	4	13.4
9	5	16.1	2	17.7	16	46.9
10	3	4.8	7	7.0	11	28.2
11	1	0.1	2	2.0	2	0.6
12	0	0.1	0	0	0	0.4
13	4	2.2	5	9.2	4	5.7
14	0	13.2	1	38.5	0	0.6
Efficiency (%)[2]	22		0		97	

[1] Zone 15 represents islands in Bay of Bengal and Arabian Sea, and is not included here.
r^2 (A) of actual number of sites and per cent area: 0.22 for chickpea, 0.04 (r value negative) for pearl millet, 0.97 for sorghum.
r^2 (B) of optimised number of sites by area and per cent area: 0.99 for chickpea and pearl millet, and 1.00 for sorghum
[2] Efficiency (%) = (r^2 (A) /r^2 (B))*100.

There is only one economically feasible way of increasing the number of trials in the AICCIPs to an adequate level, and that is by a greater involvement farmers and the extension services of the SAUs and State Departments of Agriculture, in the evaluation of new cultivars (Table 4). For example, the KVKs are widespread throughout India, have established linkages with farmers, and already run adaptive trials on farmers' fields. Testing a broader range of material in varietal trials, instead of adaptive trials, uses more efficiently their existing infrastructure, and strengthens linkages between research and extension.

3.3 *Do the Multilocational Trials Represent the Inputs Applied in Farmers' Fields?*

There are no published statistics on the fertilisers that farmers apply to particular crops. We therefore indirectly examined the inputs used in trials and used by farmers by comparing the mean yields of the trials with yields on farmers' fields. Trial mean yields are reported in the AICCIP annual reports, and farmers' yields were assessed by the district mean yields in which the trials were conducted. District mean yields are obtained from districtwise area and production data that are collected by the state departments of agriculture and published by the Directorate of Econoimcs and Statistics, Department of Agriculture and Cooperation, Ministry of Agriculture, Government of India, New Delhi in the series: '*Agricultural situation in India'*.

The frequency distributions of the trial means and the district yields were very different (Fig. 8). 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 fertilizer varied from 36 to 90 kg $ha^{-1}N$; 10 to 50 kg $ha^{-1}P_2O_5$; and 0 to 30 kg $ha^{-1}K_2O$ at various reaserch stations in the country. Also insecticides such as Thimet, Furadan, BHC 10% were applied to levels upto 25 kg ha^{-1}. At some stations other insecticides such as Endosulfan, Ziram, Melathion and Carbofuron 3 G were also applied. Contrary to this, rarely, if ever farmers apply fertilizer to pearl millet at this high level; and insecticides are rarely applied by the vast majority of farmers.

- Better physical locations of the research station in a more favourable agro-ecological situation shown by the yield gap between the districts in which the trials are conducted and the All-India mean.

The differences are much too large to be only because of genetic differences. For example, 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. 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 two legumes (groundnut and chickpea) there were small differences, in two out of the three cases studied, between the mean yields of the trials and the districts in which they were located (Fig. 8). This may be because nitrogen levels are less different between research stations and farmers' fields in legumes than in cereals.

Apart from groundnut, mean yields were higher in those districts where the trials were conducted than in the whole of India (Fig. 8). The districts in which research stations are located have higher yields than the all-India average. 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.

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 (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.

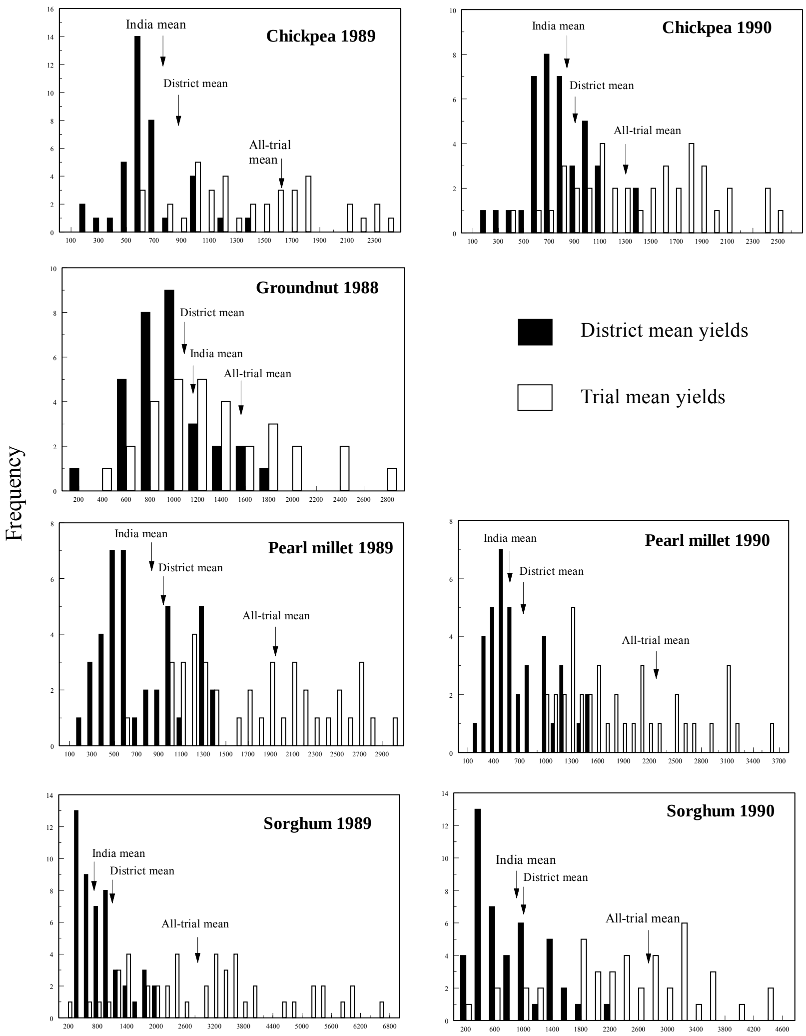


Figure 8 Frequency distribution of AICCIP trial mean yields for four crops and the mean yields of districts where the trials were conducted

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.

However, in the AICCIPs the bias towards, high-input farming systems, so well illustrated in Fig. 8, causes large genotype x environment interactions between the research station trials and low-resource farmers' fields. 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. To avoid this, trials should not be rejected because they have a low mean yield. Nor should they be rejected for having a high coefficient of variation unless there is no statistically significant differences between the entries (Table 4). The most effective way of catering for the needs of low-resource 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.*1995).

The AICCIPs are rooted in a Government of India 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 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, e.g., Maurya *et al.* (1988), and Sperling *et al.* (1993). These results are powerful arguments for unpacking the package (Table 4). 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. Farmers are reluctant to try new cultivars when they are told that they require additional inputs that they cannot purchase or cannot risk applying.

3.4 *Do the Multilocational Trials Permit Specific Adaptation?*

Early maturing genotypes are adapted to drought-prone environments since they escape terminal drought stress. In the post rainy season they mature in a short time span that can be supported by residual soil moisture. Lateness provides adaptation to environments with longer growing seasons. However, extremely early- and late-maturing entries, that are likely to have highly specific adaptation, rarely perform well in multilocational trials. The relationship between grain yield and flowering time of entries in several important breeding trials was examined (Figs. 9, 10). Because extremely early and late entries were rarely the highest-yielding entries, a strong selection pressure for high yield will result in strong stabilising selection for flowering time. Such strong selection pressures for yield are exerted at the final stage of AICCIP breeding trials. Where separate trials were conducted, as in the case of sorghum, for early, medium and late maturity groups, entries with extreme flowering time may survive.

Nonetheless, there is direct evidence that some released cultivars are acceptable to low-resource farmers (Joshi and Witcombe, 1995). However, most resulted from partially decentralised breeding, since they were released only for specific regions of India. There is also indirect evidence from trials such as the scientist-managed, pearl millet multilocational trials analysed by Witcombe (1989). He found that the breeders' practice of selecting on mean performance across locations always selected cultivars that yielded more than average in those environments, although it did not always identify the best cultivar for the environment. Hence, this was only a weak demonstration of specific adaptation to marginal environments. In this study, analyses of cereal (rice, wheat, pearl millet and sorghum) and legume (groundnut and chickpea) crops tested in multilocational trials in India confirmed this result.

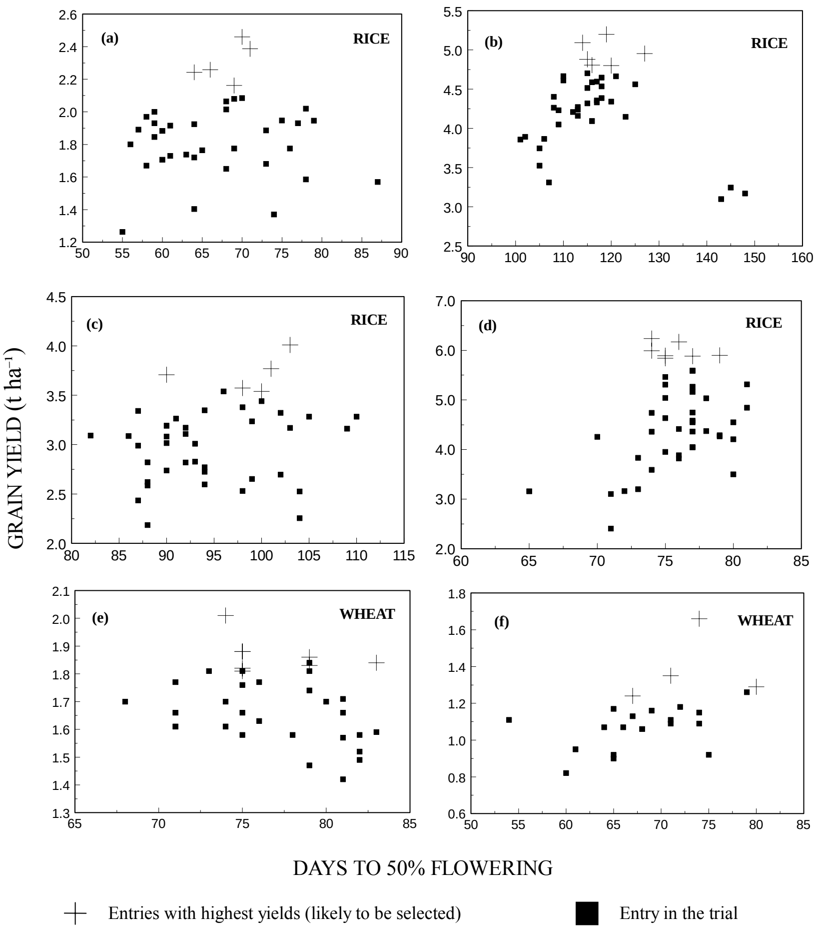


Figure 9 The grain yield and time of flowering of entries tested in some AICCIP trials (a) Rice upland IVT-VE (DS) 1993, (b) Rice-lowland IVT (SHW) Zone 1 1993, (c) Rice-upland IVT-VE (transplanted) 1992, (e) Wheat-rainfed IVT (timely sown) NEPZ and (f) Wheat-rainfed IVT (timely sown) CZ 1991.

We cannot assume that centralised breeding employing multilocational trials is an efficient way of producing cultivars adapted to marginal environments (Simmonds, 1984). Although the multilocational trials studied provided no evidence against selecting for broad adaptation when breeding for marginal environments, the range of genotypes tested in these trials and the number of lower-yielding environments was limited. Specific adaptation to high- and low-yielding environments should be found if trials have:

- highly diverse material. However, the range of genetic material in the trials is decided by breeders. The data presented in Figs. 9 and 10 show that breeders are likely to quickly discover that entries with extreme flowering times fail to be released. Hence, it is likely that they will stop entering such genotypes into the multilocational trials.

- very diverse environments. However, the range of low-yielding environments in the multilocational trials is limited because the trials are well-managed, or because scientists deliberately exclude data from low-yielding environments.

-

Decentralised breeding encourages the use of specifically adapted material and very low-yielding environments (Table 4). Several other steps can be taken (Table 4) to improve the chances of entries with specific adaptation surviving in trials, by creating trials for:

- early, mid-late and late-maturing genotypes;
- target regions and specific situations;
- genotypes with specific traits such as high fodder yield;
- adaptation to low-input environments, by using lower levels of inputs more similar to those used by farmers.

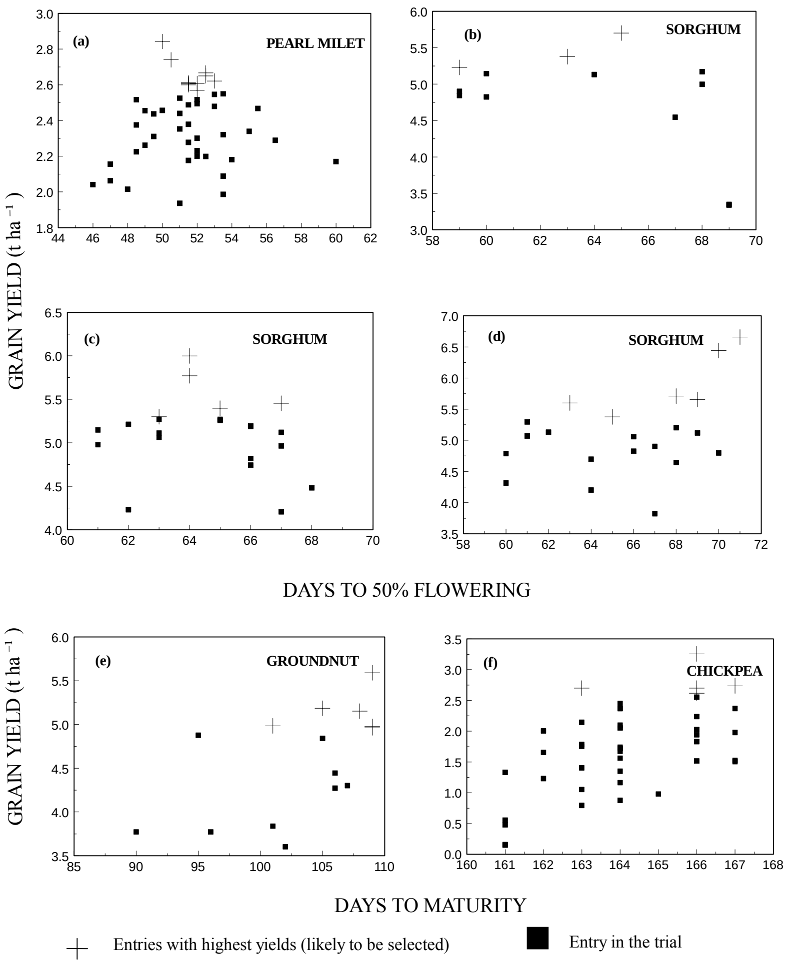


Figure 10 The grain yield and time to flowring of entries in some AICCIP trials (a) Pearl millet IHT-I 1994, (b) Sorghum IHT-I (early) kharif 1993, (c) Sorghum IHT-II (mid late) *kharif* 1993, (d) Sorghum IHT-III (late) *kharif* 1993, and the grain yield and days to maturity in (e) Groundnut IVT rabi zone-VI 1992, (f) Chickpea IET, NHZ 1992-93

3.5 *Are Farmer-relevant Traits Considered?*

Farmer-relevant traits are rarely considered while promoting an entry (Table 9) in AICCIP trials. The promotion procedure essentially involves comparing the yield of new entries with checks or trial means. Similar procedures are followed when varieties are considered for release. Limited attention is paid to other important traits, although examples can be found. In pearl millet, a variety must have high grain yield and a certain level of downy mildew resistance. In maize, apart from a high grain yield a variety must not be more than 1.5 days later to 75% silking than the average of the checks. However, these are negative selections, whereby inferior material for specific traits is rejected. There is no positive selection for farmer-important traits. For example, although high fodder yield is an important trait for low-resource farmers in cereal crops (Jansen, *et al.* 1989), cultivars will only be promoted if they satisfy the criterion for grain yield. If promotion criteria are to give due importance to farmer-relevant traits, selections must be made based on multiple-trait selection indices. High fodder yield needs to be part of such a selection index, or specific trials need to be created for dual-purpose types, that are grown for both fodder and grain.

Table 9. **Use of yield as a promotion criterion in six All India Coordinated Crop Improvement Projects**

Crop	Criterion to promote an entry
Rice	Significant yield advantage over check and zonal mean yield
Wheat	Within the same statistical group as the top-ranking entry in the trial
Pearl Millet	More than the trial mean yield and downy mildew score less than 10% of susceptible check
Sorghum	More than 10% higher yield than the best check
Groundnut	More than 10% higher yield than the best check
Chickpea	Within the same statistical group as the top-ranking entry in the trial. Yield higher than the best check on the basis of zonal data.

Murty (1992) while recommending criteria for varietal identification suggested that a variety could have at least 10% yield advantage over the most recently released variety used as a standard check. Where such a yield advantage is not apparent, he suggested that the variety can be selected if superior for at least one character of considerable economic significance. However, such criteria cannot usually only be taken fully into account when considering a variety for release because traits other than yield have mostly already been ignored at earlier stages of promotion, i.e., from an Initial Evaluation Trial to an Advanced Varietal Trial, or promotion to a second year of testing in an advanced trial. Hence, in practice, varieties with significantly superior disease or pest resistance, earliness, fodder yield or grain quality are not promoted unless they have a yield advantage.

Farmer participation in varietal evaluation should be adopted (Table 4) because it allows all of the important farmer-relevant parameters to be assessed, e.g., taste, cooking quality, market value, threshability and storability, rather than the limited set of characteristics measured in plant breeders' trials (Mauryra *et al.* 1988; Sperling *et al*. 1993; Joshi *et al*. 1995; Witcombe and Joshi, 1995a, b). For example, farmers all agreed that the preferred rice variety, Kalinga III, had thin husks, grains that do not break on dehulling, and grain that would fetch a higher market price than the local (Joshi and Witcombe, 1995). In chickpea, market price, and the way farmers traded off early maturity against yield could be evaluated (Witcombe and Joshi, 1995a). None of these traits would be evaluated or considered in a conventional non-participatory trial.

Unfortunately, data from participatory trials do not command the scientific respectabilty of data from replicated multilocational trials. Participatory data need to be more widely accepted, particularly in the submission of release documents, and participatory methods incorporated as as essential component in more breeding programmes (Table 4).

4. Recommendations

4.1 *Increase Farmer Participation in a More Decentralised System*

In the sections above many detailed recommendations have been made concerning the need to make the multilocational trials system more relevant to low-resource farmers. All of these involve greater involvement of farmers and extension workers, and decentralisation of the testing system. They are summarised in Table 4.

4.2 *Better Define Cultivar Recommendation Domains*

The inadequacies of any multilocational testing system that is constrained by testing sites and infrastructure mean that the identification of cultivars for release is imperfect. Once identified for release their recommendation domains are also imperfectly defined. In the present AICCIP system, varieties are released centrally for cultivation in the entire country or for zones consisting of more than one state. State variety release committees release varieties at the state level but the central variety release committee of national level carries out the notification, required under the Seed Act, for certified seed production. In this system, varieties bred in State Agricultural Universities dominate in the states (Fig. 11), and national and out-of-state releases are rarely, if ever, recommended (Jaisani, 1995; Upadhyaya, 1995; and Vyas, 1995). This factor alone greatly limits the choice of improved cultivars that can be provided to farmers.

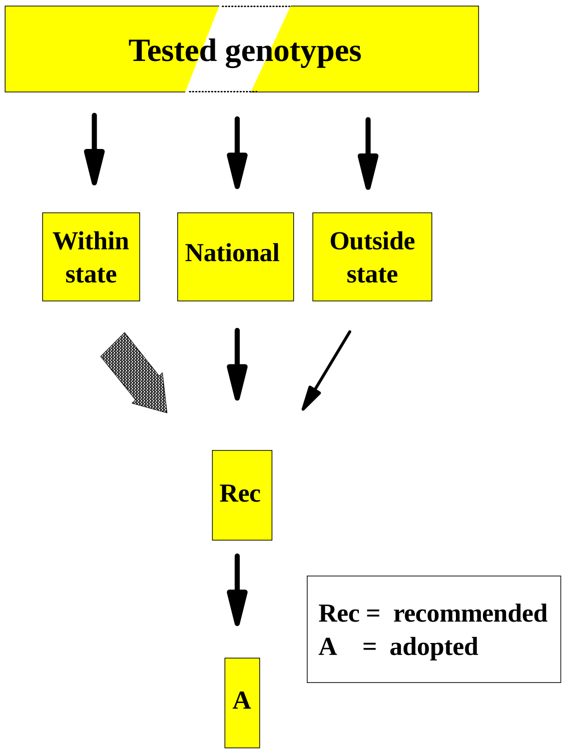


Figure 11 Present system of recommending varieties within any particular state. the width of the boxes indicates the size of the choice, and the thickness of the arrows indicate the relative importance f different sources.

For example, the potential domain of rice cultivar Kalinga III is much greater than its official area of release, Orissa. It was the best performing cultivar in participatory varietal selection trials in Rajasthan, Gujarat and Madhya Pradesh (Joshi and Witcombe, 1995) where it is neither released nor recommended. More than ten years elapsed between the release of Kalinga III and its testing in Rajasthan, Gujarat and western Madhya Pradesh (Joshi and Witcombe, 1995). This was despite the undoubted acceptability of the cultivar as demonstrated by its spread to Bihar and eastern Madhya Pradesh without the support of official release. Clearly, when a cultivar is released and has a significant adoption rate in a state, there should be a mechanism for testing the cultivar in similar agro-ecological zones in other states (Fig. 12). The correct allocation of state-released cultivars to the different zonal and ecosystem trials would be facilitated by extensive prior knowledge of the cultivars. In such a system, the number of entries in the trials would be smaller since they would be restricted to state-released cultivars and nationally released check entries. The lower numbers would allow the use of much larger plots, and makes more possible the incorporation of on-farm testing as an integral part of the zonal trials.

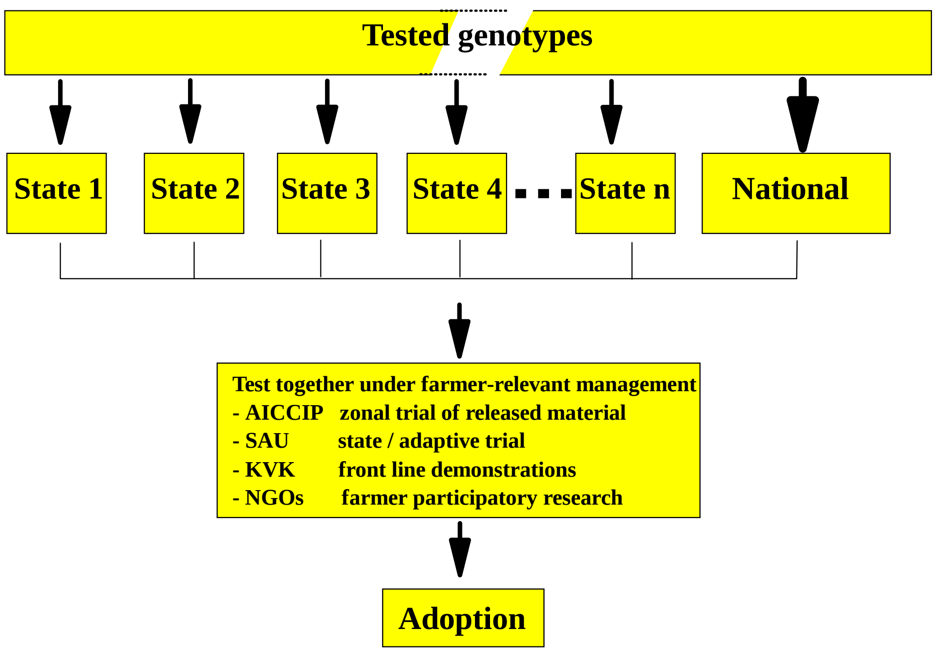


Figure 12 Suggested method that ensures 'freer trade' of state releases between states. The width of the boxes indicates the size of thechoice, and the thickness of the arrows indicates the relative importance of different sources

The case of Kalinga III illustrates the successful use of state-level breeding to release cultivars adapted to specific environments within a state. It also shows that, despite its popularity in Orissa, its popularisation in certain other states has been very slow. If a system of zonal release is not in place, state release systems can delay or prevent the release of 'out-of-state' cultivars, since there is a bias towards the products of the research system within the state.

In contrast to this, there is also the problem of some cultivars being too broadly recommended. The bias towards high-input situations in the multilocational trials means that the recommendation domains for many cultivars are high-potential areas, where soil fertility and water are not limiting, rather than the marginal land cultivated by low-resource farmers. Such cultivars are often recommended for the entire state but they are inappropriate for low-resource, marginal environments within the state.

4.3 *Improve Varietal Popularisation and Research Linkages*

Currently, the AICCIPs depend upon the transfer of technology projects of the ICAR, SAUs and extension network of state departments of agriculture for testing and demonstrating of new varieties, and other technologies on farmers' fields. This system has proved to be ineffective since there is a long time lag between the initial identification of a new variety and its adoption by farmers (Rangarao, 1992). This situation would improve if the scientists who breed new varieties were also responsible for testing them on farmers' fields, and for its adoption. A wider spread of demonstrations is required to represent the environments of low-resource farmers in dryland agriculture. The simplest and most effective method would be Informal Research and Development (IRD) as adopted by the Lumle Agricultural Research Centre (LARC) in Nepal (Joshi *et al*. 1995). In IRD, a large number of packets containing seed of pre-released or advanced generation breeding lines is widely distributed among farmers for them to grow. Follow up surveys can be done to determine adoption rates of the supplied cultivars.

To accelerate the transfer of technology process, the varietal testing and release system needs drastic modifications (Table 5) at various stages of:

- testing the new variety for performance and adaptability in dryland farmers' fields;
- demonstrating the superiority of new variety under farmers' fields conditions;
- upgrading of information literature and distribution of publicity materials about the new variety;
- improving the seed availability and distribution system.

This clearly indicates the need for a greater flow in the number of new varieties that are released, produced and adopted by the farmers. Farmer participatory research should be particularly effective in achieving the desired level of popularisation, and for this reason needs to be institutionalised (Mauryra *et al.* 1988; Sperling *et al*. 1993; Joshi *et al*. 1995; Witcombe and Joshi, 1995a, b).

A number of linkages need to be strengthened to do this (Table 5). The Central and State Variety Release Committees must ensure the dissemination of information about newly released cultivars to the AICCIPs, State Agricultural Universities (SAUs), KVKs, State Departments of Agriculture, and both public and private seed producing agencies. At least the proceedings of these committees should be widely circulated. Preferably, the information should be published in a user friendly format, and computerised databases made accessible. However, information is insufficient on its own. A national seed agency should be given responsibility for multiplying and supplying seed of all released varieties. Such an agency would need to have a strong network with seed producers.

The linkage with Non-government Organisations involved in the seed sector is weak. Seed producers, SAUs, KVKs, and State Departments of Agriculture could take the advantage of better linkages of NGOs with farmers, and undertake farmer participatory research. Moreover, this will help in widening the scope of participatory varietal selection in low-resource environments. The NGOs, in this linkage, will have better access to new cultivars.

At present, many scientists in AICCIPs are isolated from farmers, particular those farmers that are low-resource. There is a need to create a system of varietal testing where scientists participate in on-farm trials conducted under farmer-managed conditions, and where farmer-oriented varietal recommendations are made.

5. Conclusion

We have shown that there is a low adoption ceiling of HYVs in more marginal areas, and the low-resource farmers of those areas are not being properly served by the present Indian system of AICCIPs. Old cultivars continue to occupy large areas because of poor popularisation or non-existence of better alternatives. The multilocational trial system of the AICCIPs is biased towards high-input situations and does not select for specific adaptation to low-input conditions. Modifications in the present varietal testing and release system have been proposed that involve greater participation of farmers and extension workers. The linkages that need improvement in a more participatory system have been specified.

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