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Resource Allocation and Efficiency of the Varietal Testing System

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Introduction

Plant breeding is expensive research. In India, Paroda (1992) listed 19 All India Coordinated Crop Improvement Projects (AICCIPs) for important crops or groups of crops. They had a budget of 178m Rupees and employed over 1,750 scientists at 380 centres. A large proportion of the money allocated to crop improvement is devoted to varietal testing to establish Value for Cultivation and Use (VCU), and the areas in which new cultivars will be recommended.

Many genotypes are evaluated in the multilocational varietal testing system but only a few of them eventually become successful varieties. During the selection process, the breeder aims to:

- select genotypes that will improve performance to the greatest extent, and
- maximise the probability that a good genotype entered in the trial will be selected.

The two criteria related to these objectives are genetic gain and acceptance probabilities (Talbot, 1996).

- The *genetic gain* measures the average deviation in performance of genotypes that are finally selected from all those that entered in the trial. Gain is a function of the proportion of genotypes selected at each stage in the trial and the accuracy of trials.
- The *acceptance probability* is the probability that a good genotype of known improved performance relative to the standard set for acceptance will be selected. The acceptance probability is influenced by the accuracy of the trials as well as, for any genotype, the size of the difference between its true performance and the acceptance standards.

In the case of official trials, acceptance probabilities deal with risks to the breeder of having a good entry rejected. The genetic gain is concerned with benefits to the society. High genetic gain can be associated with high selection pressures, but increases the risk that a good entry will be rejected.

We consider the selection pressures employed in the AICCIPs, their relevance to farmers, and the impact of the selection strategy on the ability to select for specific adaptation.

Issues concerning the location of test sites and trial management were considered in the preceding chapter. Other aspects of trial design are considered here.. All of the AICCIP trials involve multi-stage testing over three years, and the number of testing sites and trial designs can vary across the years. This allocation of resources to each stage of testing is an important factor in determining trial efficiency but the topic has been much neglected.

In this chapter we ask the following questions:

- Does the selection strategy employed result in efficient resource allocation across the years of multilocational trials?
- Does the selection strategy lead to avoidable delays in release and popularisation?
- Does the selection strategy employed risk rejecting good genotypes?
- How relevant to farmers are the criteria used to promote entries from one trial stage to the next?
- How well do the trials allow the selection of specifically-adapted varieties?

Efficiency of Resource Allocation

Features of resource allocation across trial stages

In multi-stage selection the most efficient strategy is to devote equal resources to each stage of testing (Finney, 1958; Curnow, 1961). This demands that a constant proportion of entries are promoted at each trial stage and the declining number of survivors is compensated by increasing intensity of assessment. Hence, one possible strategy is to halve the number of entries in each testing stage, whilst doubling the land devoted to each entry by increasing one or more of: replicate number; plot size; or site number.

As a first component of this study on resource allocation, the survival of entries in all trials across years was analysed for several AICCIPs. Any entry included in the analysis had to have a possibility of surviving for at least three years. To ensure this, some trials and entries have to be excluded from the analysis (see 'Methods used' below). In most crops, the trials system eliminated the highest proportion of the entries after the first year of testing (Fig. 3.1). After the first year of testing, about 60% of the entries in rice and groundnut, and about 75% of the entries in sorghum and wheat, are eliminated from the trials. Talbot (1996) estimated the average potential gains in trials systems with varying levels of precision and selection rates. He observed that after the first year of testing as many as 60% of the poorer genotypes could be rejected without noticeable reduction in average gain. However, this is on the upper limits of an optimal selection strategy, and there is a noticeable reduction in percentage average gain from rejecting as many as 80% of genotypes after one year of trials. He presented a rough guide to optimal selection which is to discard the same proportion at every stage as proposed by Finney (1958). The practice in pearl millet came closest to the optimal selection strategy (Fig. 3.1) with about 50% of the entries being rejected each year, but in many of the crops selection pressures are too high in the first year.

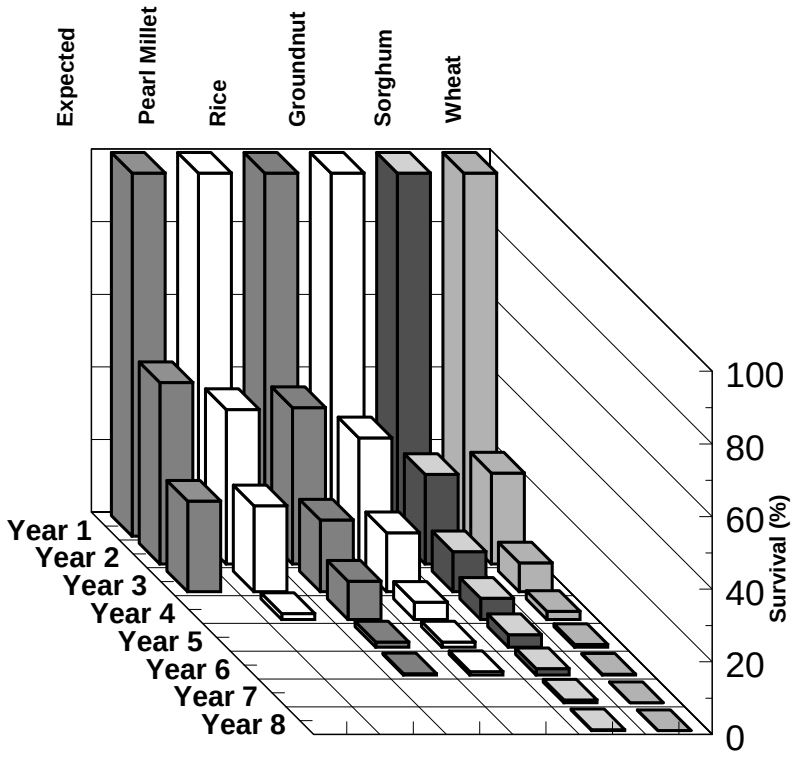

Fig. 3.1 **Survival of entries over years of testing in five crops in AICCIP trials compared to the expected ideal**

Survival rates explain the reduction in resources in terms of the number of test entries surviving at different stages of testing (Fig. 3.1). However, they do not describe the resources allocated to each entry at each testing stage. To do this the area of land devoted to each entry at each stage needs to be calculated. The total area devoted to an entry is a function of the number of test sites, the number of replications at each site and the plot size. We examined this in pearl millet and groundnut for a number of trials where the resource allocation to the entries in an initial trial was studied over three years. The reduction in the number of entries at the early stages was never completely compensated for by increases in the land devoted to testing the surviving entries and resource allocation across the trial stages was very uneven in both crops (Figs. 3.2 and 3.3). In pearl millet, resource allocation in the second and third years was much less than in the first year for all trials examined. The resources allocated to the hybrids trials, in comparison to populations trials, decreased as the testing progressed. In groundnut, although there was a progressive increase in plot size for each entry, resource allocation was very skewed in favour of the earlier years. This was because survival of entries into the third year was very low (Fig. 3.1). Indeed, in many trials very few (1 or 2) or no entries were tested in the third year, despite the considerable investment in resources in the earlier years.

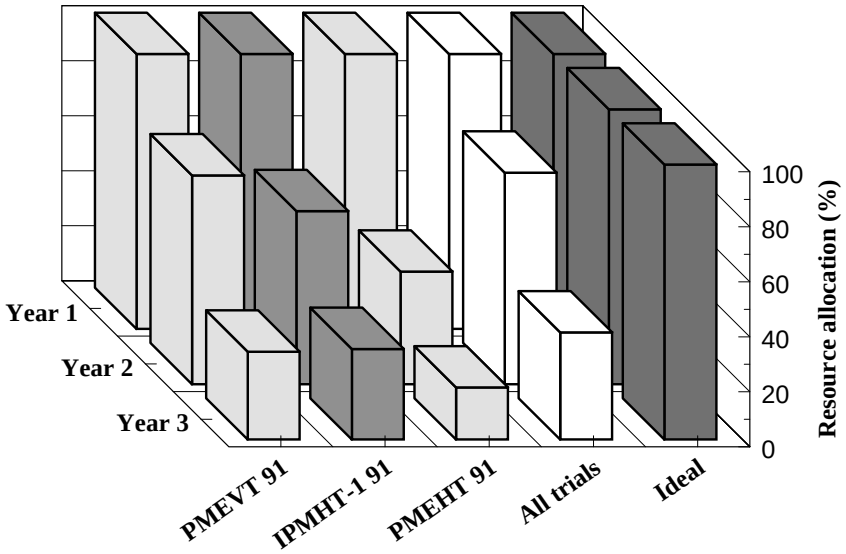

Fig. 3.2 **Resource allocation over three years (1991-1993) in a pearl millet (PM) early varietal trial (PMEVT), a hybrids trial (commencing with IPMHT-1) and an early hybrids trial (PMEHT). The resources allocated to the second and third year of testing is expressed as a percentage of the resources devoted to testing the entries in the first year. The ideal resource allocation of equal resources over all years is also shown.**

The only attempt to equalise resource allocation over the years of testing of entries in the AICCIP trials is by slight increases of plot sizes in, for example, wheat, rice, groundnut and pearl millet in the advanced stages. However, the way in which such increases in allocation are constrained when a two tier, rather than a three tier system of testing is used (Fig 6.2). In most crops (wheat, rice, pearl millet and sorghum) a two tier system of testing is used. There is an IVT (Initial Varietal Trial) in the first year of testing, and an AVT (Advanced Varietal Trial) where entries in the second and third years of testing are in the same trial. In such crops, there is no possibility of increasing the number of testing sites for third year entries over second year entries, and increasing either replicate number or plot size for third year entries when they are being tested alongside second year entries would lead to an unusual experimental design. In some crops, such as chickpea and groundnut, a three tier system of testing is followed. There is an IVT in the first year, and entries in the second (AVT-I) and third years (AVT-II) are tested in separate trials with a

progressive increase in plot size. In the first year of testing no zonation is practised and the number of locations is much greater than in the second and third years (see Annex 1 for a description of the zones and Chapter 2 for further discussions). Zonal trials are conducted in the second and third years in which the small number of locations, and the number of replications usually remain unchanged. Resource allocation is substantially higher in the early stages of testing in comparison to the final stages (Fig. 3.3).

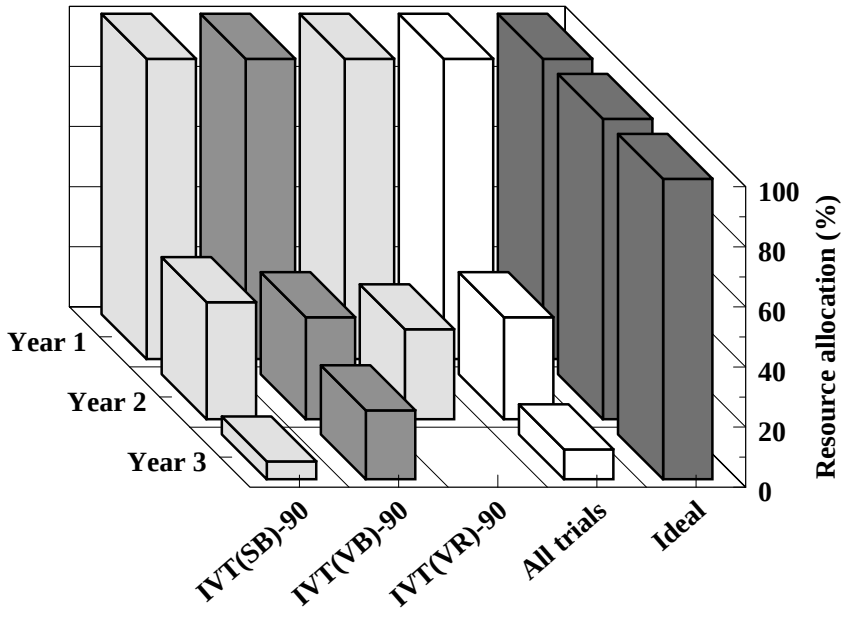

Fig. 3.3 **Resource allocation over three years (1990-1992) in a varietal trial (commencing with IVT) of groundnuts Spanish Bunch (SB), Virginia Bunch (VB) and Virginia Runner (VR). The resources allocated to the second and third year of testing is expressed as a percentage of the resources devoted to testing the entries in the first year. The ideal resource allocation of equal resources over all years is also shown.**

This unequal resource allocation is not the unique property of the Indian testing system. An examination of the trials system in many other countries revealed that there was no increase in plot size or replication number in the advanced years of the trials. The Coordinated Varietal Trials (CVTs) in Nepal, National Performance Trials (NPTs) in Kenya, National Uniformity Yield Trials (NUYTs) in Pakistan, and Comparative Trials (CTs) and Regional Trials (RTs) in Bolivia have a constant plot size and number of replications in all of the years of testing within these stages. However, in the Philippines, the increase in plot size over the two years of Advanced Yield Trials (AYT I to AYT II) in rice is appreciable. In some countries, such as Syria, resource allocation is even more severely skewed in favour of first year entries as a single tier testing system is employed.

Another aspect of resource allocation is the trade-off between number of replications at a site and the number of locations. With multilocational testing, the commitment of large resources to maximising the precision of comparisons among genotypes within individual locations may be wasteful because genotype x environment interaction limits the precision of across-location comparisons. Replication may also be limited by seed supplies. One general conclusion which emerges from several studies (Box 1) is that an increase in the number of replicates is always less beneficial than an equivalent increase in the number of sites or years. Thus, single replicate or two-replicate multi-site trials offer an effective and efficient means of identifying high yielding genotypes, particularly in the early stages of the testing process. Using the argument of Johnson *et al.* (1992) an initial three-replicate AICCIP trial could be replaced, using the same resources, by single-replicate trials in about 50% more sites while allowing the testing of three times as many

entries. On-farm testing could be employed to provide the additional locations. When single or two-replicate, on-farm trials are employed many farmers will have a much earlier exposure to new varieties than when they are tested at a few research stations.

Box 1. A short review of the literature on single replicate multi-site trials

Kempton (1984) discussed the use of unreplicated field trials. He concluded that '*where limited replication of each test line is possible* (e.g., because of limited seed) *it may be preferable to perform unreplicated trials at a number of sites rather than a multi-replicate trial at one site: this will give a broader environmental basis for assessing test lines. … A … strategy is to design and analyse the set of trials as one multi-replicate trial. For example, the trials might be arranged so that each trial represented one replicate of a balanced lattice design.* Kempton was of the opinion that, in the UK 5 two-replicate trials would generally provide a more precise estimate of overall performance than 10 unreplicated trials, but if fewer total replicates were possible, unreplicated trials might be preferred.

Dofing and Francis (1990) working on sorghum in the USA recommended that one replicate trial should be used at as many locations as can be afforded, as long as the cost of an additional location relative to the cost of an additional replication is not excessive. The methodology presented by them allows the researcher to determine the efficiency of one-replicate testing for a programme with any set of location and replication costs.

Johnson *et al*. (1992) looked at the trade-off between replications within a site and additional locations with fewer replications. They examined the situation from the viewpoint of grain sorghum yield trials in west Africa and looked at the type of errors involved in trials:

- Type I - the risk of declaring one entry better than another when there is really no difference;
- Type II - the risk of declaring two entries to be the same when they are really different, and
- Type III - the risk of declaring an entry inferior when it is really superior.

They found that controlling type I errors required many less locations than controlling type II and III errors. If a type III error was to be controlled then the large number of locations required became impracticable. For the error structures pertaining to their study they found that a three-replicate test could be replaced by 42 to 65% additional single-replicate locations and have triple the number of cultivars. This is a remarkably favourable result for the unreplicated trial design. It means that with the same precision, either three times as many varieties can be tested or the same number of varieties can be tested more accurately with much less resources. They conclude that '*single replicate testing requires only rudimentary statistical skills, complements extension activities, and is a viable alternative for rapid, reliable identification of superior cultivars in food production environments where both reliability and speed are critical'*.

Bhatt *et al.* (1984) working in Australia looked at the same problem as Johnson *et al.* (1992) in Africa, but using a more simple statistical analysis. They examined the correlation between randomly selected single replicates at each site with the overall entry means using all of the replicate data. The correlations so obtained varied from +0.88 to +0.98 with a mean over the 16 data sets examined of +0.94. They concluded '*that unreplicated multi-site tests offer breeders an effective and efficient means of identifying high yielding genotypes, particularly early in the breeding programme when seed supplies are limited'*.

Box 2. The use of single or low replicate trials in India

The review in Box 1 refers to trials on several crops in the UK, to sorghum trials in Africa and wheat trials in Australia and the USA. These conclusions can be tailored to the situation in India. The utility of single-replicate multi-site AICCIPs trials needs to be examined so that resources devoted to multi-replication trials at single locations are diverted to allow testing in more sites.

- If genotypes have not been tested in appropriate environments in India, as is the case for entries in the international nurseries from IRRI to CIMMYT, there is a greater need for testing over several environments. This multi-site testing can only be done if unreplicated trials are employed. If such international nurseries are tested in only a limited number of environments, as must be done if replicated trials are employed, material may be selected that is acceptable in the few test environments but performs extremely poorly in other, perhaps more relevant, environments.
- The more diverse the target environments the greater the need for multi-site testing. If only one or two test environments are employed, the complete range of environments that can be encountered in farmers' fields is poorly represented. It is therefore difficult or impossible to identify material with specific adaptation to particular extreme environments. If only a few sites are employed it is also not possible to identify material with wider adaptation with any reliability.
- Multi-site testing at the nursery stage provides an opportunity of selecting material for contrasting environments - perhaps environments for which the international nursery was not even intended.
- As well as at the nursery stage, the use of unreplicated trials at the IVT stage can increase the number of locations above the low average number presently employed within a zone in the AICCIP trials that ranges from an average of 4 sites for groundnut and chickpea to 15 sites in pearl millet (Virk *et al.*, 1996a,b; Table 1.4). This will provide a reasonable number of test sites within agro-ecological zones.

Box 3. Statistical and practical considerations

- Increasing the present low number of test sites within any agro-ecological zone at IVT stage of trials may not be logistically difficult. The zonal AICCIP IVTs in rice and wheat, are conducted on an average of 7 sites in any agro-ecological zone.
- Increasing the number of sites significantly beyond the number of sites presently used presents a greater difficulty. Perhaps it would mean testing at sites other than those in the government network. However, an obvious solution is to move the trials to farmers' fields, where the added benefit of farmer participation in trial evaluation can be gained.
- A common objection to the use of single-replicate trials is the risk that planting errors will go undetected, resulting in increased error. However, several techniques can be used to reduce such risks. These include the use of:
  - Repeated check cultivars (unlike test entries, there is no limitation on seed of checks).
  - The recording of obvious phenotypic characters that are stable across locations.
  - The use of a correlation analysis to examine the relationship of phenotypic values for highly heritable traits, such as plant height and flowering time, against the overall across-location trial mean. If the data from an individual site has an anomalously low correlation with the across-site mean the data from that site can be discarded.
  - The risk that an experiment can fail due to vagaries in the weather is not greater than when multi-replication trials are conducted. In the multiple-replication trials the loss of an experiment at any site is more important as it comprises a greater proportions of the trials.
  - The use of unreplicated trials does not preclude the use of replicated trials. It is a simple matter to analyse the data from a multi-site trial where some trials are replicated and others are not. For example, overall across-site genotype means can be determined across the replicated and unreplicated trials. The value of single- and multi-replicate trials in predicting the overall genotype means can be determined using the methods employed by Bhatt *et al*. (1984): the effect is compared of taking at random either single-replicate trials or single replicates from the replicated trials.

Summary of conclusions on resource allocation

The topic of resource allocation has been little discussed in the literature, so it is not surprising that little attention has been paid to it and uneven resource allocations are found. Resource allocation in the AICCIP trials differs dramatically from the optimum. It also differs greatly from the optimum in all other developing countries we have studied. To obtain a more equal allocation of resources to the different trial stages in the AICCIPs, without increasing resource requirements, there is a need to reduce resources for the first year of testing and increase them in the second and third years. This can be achieved by using single-replicate multi-site designs (Boxes 1 to 3) in the first year, by increasing the number of trial sites in the second and third years, and adopting a three tier-system in all crops. Of the three factors: number of locations, number of replications and plot size, that can contribute to an increase resource allocation, increasing the number of test sites is the most effective strategy. More sites can be obtained by involving farmers in varietal testing, rather than increasing the number of research stations.

Prolonged Testing and Delays in Variety Release

Losses in potential benefits are substantial if the release of a good new variety is delayed. Systematic delays in release mean that farmers always have access to poorer varieties than could be the case. Delays caused by the official testing system means that society, which can not rapidly get

the benefits of improved genotypes, bears the cost. Individual breeding programmes also suffer, but if all varieties are affected equally by delays the burden is shared equally.

There ought to be a balance between the too hasty release of inappropriate cultivars and avoidable delays in the testing system. Avoiding such delays would make a significant contribution to the efficiency of the national varietal testing system. Usually a successful variety is released after 3 or 4 years of testing in trials. Beyond this limit, retention of any entry in the trials will be an inefficient use of resources and will represent an opportunity cost if the variety is eventually released. However, entries are retained longer than the minimum requirement of three years: up to 6 years for rice and groundnut, and 8 years for sorghum and wheat (Virk *et al.,* 1996a,b). In wheat, entry PBW 226 was tested over an 8-year period in four different zones for periods varying from 1 to 4 years, in the northern plain zone 1985-1987, in the north-western plain zone 1988-1990, and 1992, in the north-eastern plain zone 1990-1992, and in the peninsular zone in 1990. It was tested and released in the northern plain zone and then re-entered for testing in the north-western plain zone. Wheat entry HS 223 was tested for a period of 7 years in the same zone but in different trials. Entries HD 2329 and Raj 3077 were also tested for a total of 7 years in different zones. The practice in pearl millet came closest to the optimal selection strategy (Fig. 3.1).

Prolonged testing and delays in varietal releases have also been found to exist in other countries. In Nepal, entries are tested for too long not only in the advanced stages but also in the early stages of the trials system. Although a three year testing procedure is the standard in India and several other countries, there is a great variation in the minimum testing period before a variety can be proposed for release. In Nepal, a variety is tested at least for a period of 5 years (one year in IET, 2 years in CT, and 2 years in FFT). In Bolivia, the minimum period is 2 years of external validation trials for varieties imported into the country. However, it can be much longer (up to 9 years): first entries are tested for 1 or 2 years in Preliminary trials, then for 2 to 3 years in Comparative Trials, followed by 2 to 3 years of testing in Regional Trials. In Pakistan, after the regional or zonal trial, a variety is tested for two years in the national trials and simultaneously for registration even if it is to be released in a region or province. Depending on the country, the testing period thus varies from 3-9 years. Further delays occur from bureaucratic delays in convening the series of committee meetings through which a variety has to pass. There is also a considerable gap (e.g., 4-6 years in India) between the release of a variety and commercial seed production (Vyas, 1995; Chapter 7).

Promotion Criteria and Their Relevance to Farmers

Consequences of stringent promotion criteria

Incorrect choices of poor genotypes and the discarding of good genotypes are inevitable in any trials system—the best that can be hoped for, is that a subset of genotypes will be selected which represent an improvement over established genotypes. When the minimum acceptance standards for promoting entries are high, fewer entries are expected to be included in the selected group (Talbot, 1996). The smaller selected group means that the acceptance probability, the probability that a good genotype of known improved performance relative to the standard set for acceptance, is reduced. Also, as the precision of the trials reduces, the critical differences, or standard error of differences increase, along with the probability of rejecting good genotypes. The acceptance probability is also influenced by the size of the difference, for any genotype, between its true performance and the acceptance standards. We have seen that stringent selection pressures result in an uneven resource allocation across stages of testing, and it also results in a greater probability of rejection of acceptable entries.

Too stringent a selection for yield prevents the release of cultivars that have a small yield advantage with some other highly desirable trait. In several countries, such as India, there is a requirement for an entry to yield 10% more than the best check. However, in CPs in India that require entries simply to be better than the trial mean, entries that failed to yield more than 10% of the best check have been released and are now cultivated on millions of hectares. An excellent

example is the released pearl millet 'MP 124' (ICTP 8203) that yielded much less than 10% more than the best check and actually failed, by a very small margin, to meet the requirement of yielding more than the trial mean. A small yield advantage proved to be no barrier to its adoption, as its extreme earliness and large grain size is much liked by farmers, and it is now widely grown in Andhra Pradesh, Karnataka and Maharashtra.

A yield advantage of 10% over the best check before a variety can be released is a very demanding selection criterion. The average annual genetic gains in yield are reported to be only 1% per annum (Byerlee and Heisey, 1990) and these have been found to be comparable with the yield gains under farmers' field conditions (Byerlee *et al.*, 1986). One of the greatest annual genetic gains reported during the 'green revolution' period of introduction of semi-dwarf wheats rice varieties during 1960s and 1970s was 2% per annum. The yield gains in Mexico (Evans, 1981), and Australia and the UK (Godden and Brennan, 1987) are comparable to the 2% yield gains in India and Pakistan achieved during the green revolution period. This means that we can expect several years to lapse, before a new entry can beat the best check by 10% margin. Moreover, the need for a variety to yield 10% more than the best check (Table 1.7) means that, in practice, many varieties that are in reality superior to than the best check will be rejected. There is also a high probability, because of the imprecision of trials, that an entry that is genetically 10% better than the best check will not only fail to yield 10% more than it, but will yield less than it.

Talbot (1996) simulated the risk of good genotypes being rejected from a population of genotypes whose yields are normally distributed and range 5% either side of the population mean. He assumed that there were two years of trials with all genotypes being sown in each trial. Taking an example of 10 locations over two years he obtained critical differences of 7%. The chance that the fifth best genotype out of 100 will be ranked in trials below the top third is 30%. The risk that it will be ranked in the lowest third is 7%. The degree of risk is associated with the accuracy of trials. When they are less accurate, the risk of wrongly selecting poor genotypes and discarding the good genotypes increases.

Table 3.1 Promotion criteria 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	They must appear within the same statistical group as the top-ranking entry in the trial
Pearl millet	Either the yield must be greater than the trial mean yield combined with a downy mildew score of less than 10% or the yield must be 10% above that of the best check.
Sorghum	Yield > 10% than the best check
Groundnut	Yield > 10% than the best check
Chickpea	Appear within the same statistical group as the top-ranking entry in the trial. Yield must be higher than the best check on the basis of zonal data.

The relevance of promotion criteria to farmers

Farmer-relevant traits, other than high yield, are rarely considered while promoting an entry in AICCIP trials (Table 3.1). Promotion and release are largely dependent on a comparison of the yield of new entries with checks or trial means. Attention is paid to collecting data on other important traits but are little used in promotion and release decisions. However, examples can be found of selection for other traits in addition to yield. In pearl millet, a variety must have a specified level of downy mildew resistance. In maize, a variety must not be more than 1.5 days later to 75% silking than the average of the checks. This is negative selection, whereby material inferior for specific traits is rejected, rather than positive selection for farmer-important traits. Such negative selection is carried out in many national systems. For example, in Kenya, an entry must have disease resistance and a better agronomic score in addition to improved yield. In Zimbabwe, sorghum and pearl millet entries should have higher yield and mature early or at the same time as the check.

Murty (1992) while retaining the yield criterion of 10% better than the best check suggested that where such a yield advantage is not apparent, a new variety can be identified for release if it is superior in at least one character of considerable economic significance. However, such criteria can usually only be taken fully into account when considering a variety for release i.e., after it has completed three years in the trials. This is because traits, other than yield, have been ignored at the earlier stages of promotion - initial to advanced trial, or promotion to a second year of testing in an advanced trial. Hence, in practice, varieties with superior disease or pest resistance, earliness, fodder yield or grain quality can only be promoted if they have a yield advantage in the first two years of testing.

Many traits are difficult to record in the traditional trials system, and it is certainly not possible to record all important economic traits in any trial. Trait evaluation is limited mainly to those that are easy to measure in the field. A few easily-recorded traits may also be measured in the laboratory at the post-harvest stage. The assessment of many traits, such as cooking quality, taste, value-added qualities such as higher market acceptability, and storability, is usually delayed until the variety is released. They are used to describe a variety rather than as target traits in the breeding of new varieties.

If due consideration is to be given to the farmer-relevant traits when establishing promotion criteria, selection must be made using multiple-trait selection indices. For example, high fodder yield is an important trait for resource-poor farmers growing cereal crops (Jansen *et al.,* 1989). For many crops, high fodder yield needs to be a part of such a selection index, or specific trials need to be created for dual purpose varieties that are grown for both fodder and grain. However, for some crops in the AICCIPs, fodder yield is not even measured. Grain quality is also crucially important. In a study in India, farmers preferred the Kalinga III variety of rice, in part, because of the high market value of its grain (Joshi and Witcombe, 1995). Market value is important for resource-poor farming households who have to enter into a cash economy to survive, usually by working as migratory labourers. In such households, selling a staple crop for cash is a common transaction, so the total value of the yield is often more important than the yield itself.

The adoption of farmer participation in varietal evaluation would it allow many farmer-relevant parameters to be assessed, including taste, cooking quality, threshability and storability (Mauryra *et al.,* 1988; Sperling *et al*., 1993; Joshi *et al*., 1996; and Witcombe and Joshi, 1995,1996) rather than the small number of traits that can be cost-effectively measured in breeder's trials. 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 variety - none of these traits are assessed in multilocational yield trials (Joshi and Witcombe, 1995). Such trade-off between traits cannot be evaluated in a non-participatory trials. In chickpea, the way farmers trade-off early maturity against yield was evaluated in farmer participatory trials (Witcombe and Joshi, 1996).

Multilocational Trials and 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. However, extremely early-maturing entries, that are likely to have highly specific adaptation to the drought prone environments of many resource-poor farmers, rarely perform well in multilocational trials. The relationship between grain yield and flowering time of entries in several important breeding trials was examined (Figs. 3.4 and 3.5). Because extremely early entries were rarely the highest-yielding entries, a strong selection pressure for high yield will result in either strong stabilising selection for flowering time, e.g. in rice (Fig. 3.4) and pearl millet (Fig. 3.5) or directional selection for lateness, e.g. in chickpea and groundnut (Fig. 3.5). Such strong selection pressures for yield are exerted in AICCIP breeding trials, particularly at the final stage when varieties are selected for release. Where separate trials were conducted, for early, medium and late maturity groups, as in the case of sorghum, entries with extreme flowering time may survive.

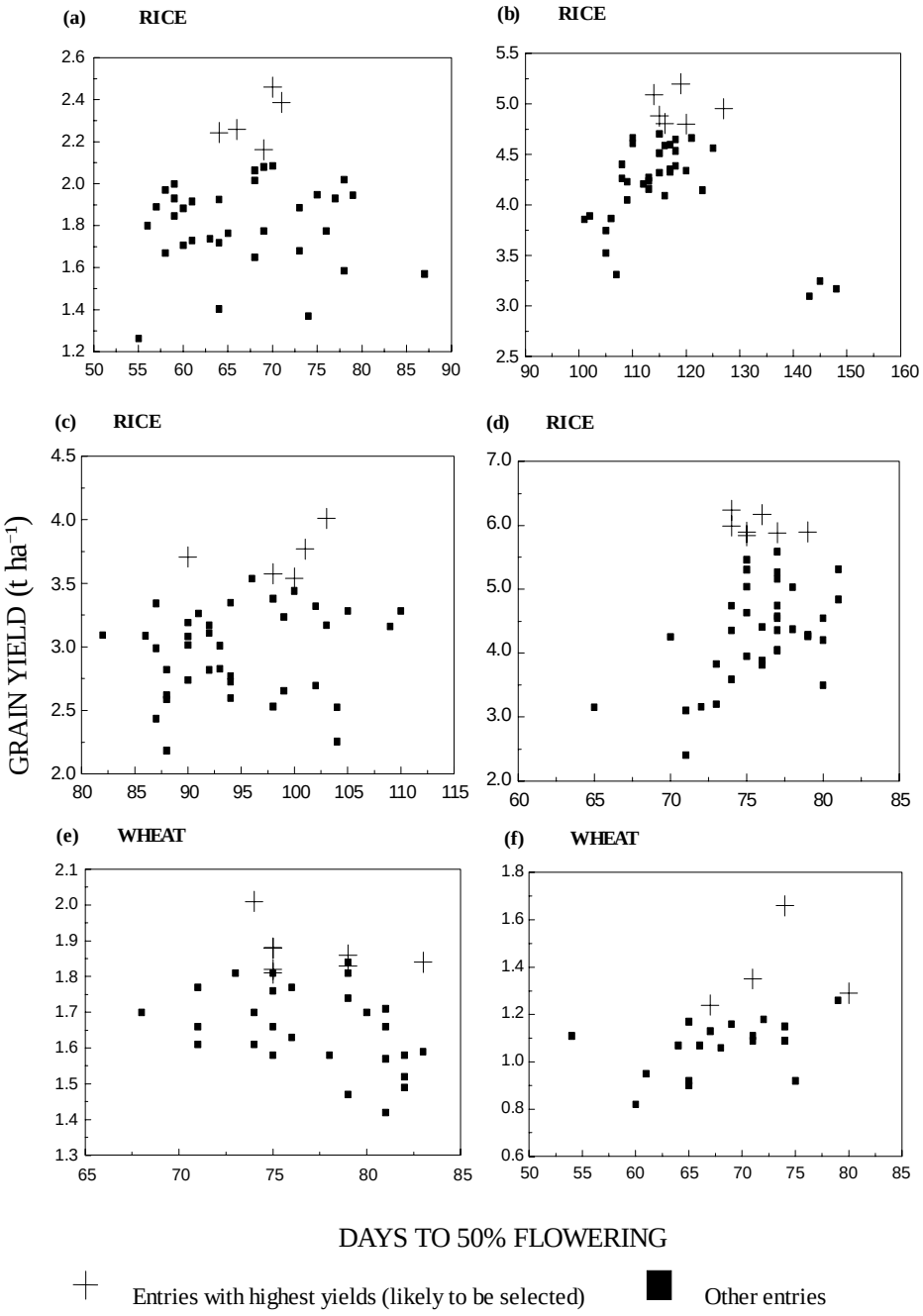

Fig. 3.4 **The grain yield and time of flowering of entries tested in some AICCIP trials (a) Rice upland IVT[‡] -Very Early (Direct Seeded) 1993, (b) Rice-lowland IVT (Shallow water) Zone 1[†] 1993, (c) Rice-upland IVT-Very Early (transplanted) 1992, (e) Wheat-rainfed IVT (timely sown) NEPZ[†] and (f) Wheat-rainfed IVT (timely sown) CZ[†] 1991.**

[†]For explanation of Zone 1, NEPC and CZ see Annex 1

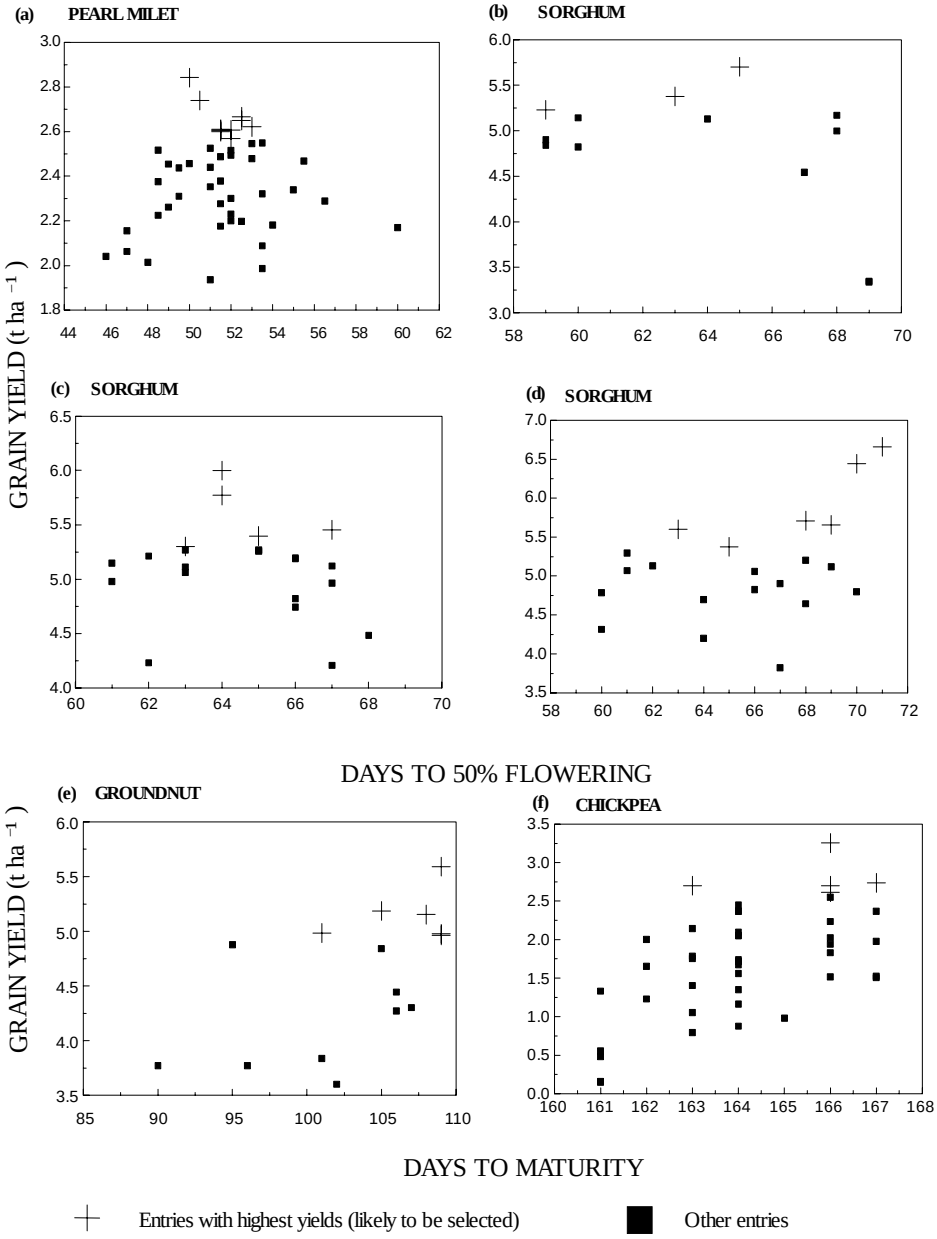

Fig. 3.5 The grain yield and time to flowering of entries in some AICCIP trials (a) Pearl millet IHT-I 1994, (b) Sorghum IHT-I (early) *kharif* 1993, (c) Sorghum IHT-II (mid late) *kharif* 1993, (d) Sorghum IHT-III (late) *kharif* 1993, and the grain yield and days to maturity in (e) Groundnut IVT *rabi* zone-VI 1992, (f) Chickpea IET, NHZ† 1992-93

There is direct evidence that some released cultivars have specific adaptation to marginal environments because they are acceptable to low-resource farmers (Joshi and Witcombe, 1995). Such cultivars often have extreme earliness. They have survived in trials that were 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 resulted in the selection of cultivars that yielded more than average in those environments, although it did not always identify the best cultivar for the

†For explanation of NHZ see Annex 1

environment. Hence, this was only a weak demonstration of specific adaptation to marginal environments. Our study on cereals (rice, wheat, pearl millet and sorghum) and legumes (groundnut and chickpea) tested in multilocational trials in India confirmed this result Virk *et al.*, 1996a,b).

Despite these results we cannot assume that centralised or partially decentralised varietal testing in AICCIPs employing multilocational trials is an efficient way of producing cultivars adapted to marginal environments. Although the multilocational trials studied provided no evidence that selecting for broad adaptation was a poor strategy when breeding for marginal environments, the range of genotypes tested in these trials and the number of low-yielding trial sites were limited. Specific adaptation to high- and low-yielding environments can only be found in trials that have:

Highly diverse material. However, the range of genetic material in the trials is decided by breeders. The data presented in Figs. 1.10 and 1.11 show that breeders ought to be aware that entries with extreme flowering times fail to be released. Hence, it is likely that breeders avoid breeding and 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 usually grown under well-managed conditions (see Chapter 1.1), or because scientists deliberately exclude data from low-yielding environments.

In contrast, decentralised breeding targeted at a range of more specific environments encourages the testing of a greater range of genetic material. Decentralised breeding also permits the inclusion of much lower-yielding environments.

Several other steps can be taken to improve the chances of entries with specific adaptation surviving in trials, by creating trials for:

- early, mid-late and late-maturing genotypes;
- agro-ecological regions and specific situations;
- genotypes that have specific traits such as high fodder yield, and
- low-input environments, by using lower levels of inputs more typical of those used by farmers.

Conclusions

Plant breeding costs time and effort and all plant breeders strive for cost effectiveness in the allocation of resources. The basic issue is how to reduce the large number of test genotypes to the best few as rapidly and efficiently as possible. How far it is being met in the AICCIPs has been examined. We can now answer the questions posed in the introduction to this chapter:

- Resource allocation is strongly skewed in favour of early stages of testing.
- there is evidence for prolonged delays in releasing material caused by over long testing.
- The promotion criteria are too stringent in many AICCIPs that result in high risks of rejecting good genotypes.
- The promotion criteria heavily rely on yield and many of farmer-relevant traits are not given due consideration.
- The testing in AICCIP trials favours selection for wide-adaptation and poorly targets low-yielding marginal environments and specific agro-ecological situations.
- The ‘basket of choice’ of released varieties to farmers is limited.

In order to allocate resources more evenly over the years of testing and to improve the overall efficiency of the system a number of suggestions have been put forward:

- Approximately the same resources are devoted to each stage of the selection by compensating for the reduction in the number of genotypes over the years of testing with an increase in resources allocated to each entry.
- The trade-off between the number of locations and the number of replications employed at each site is an important consideration in improving the efficiency of resource allocation. It is always beneficial to reduce the number of replications at each site and re-allocate them to an increased number of test sites. This is particularly true at the initial stages of testing.
- The use of the randomised complete block design has been unchanged over the last thirty years of testing. It is time to assess the suitability of alternative designs and methods that can increase cost-benefit ratios. In the UK cereals trials, it has been estimated that replacing complete block with alpha designs produced gains in trial efficiency equivalent to that of an extra replicate. The use of spatial analysis, moving averages and frequent check plots, has shown to produce similar or greater gains (Kempton and Gleeson, 1996; Talbot, 1996).
- More attention needs to be paid to understanding the practical relevance of selection theory in terms of resource allocation, genetic gains, acceptance probabilities and critical differences in decreasing the chances of rejecting good genotypes.
- Greater farmer participation in varietal testing is crucial in increasing the appropriateness of selection strategies. It allows:
  - better targeting of specific environments;
  - a less expensive means of testing varieties than on-station testing research;
  - better evaluation of farmer-relevant traits, and
  - more rapid adoption of improved cultivars.

Methods Used

Survival rate

The survival of entries in all trials across years was analysed to study the pattern in different crops. Any entry included in the analysis had to have a possibility of surviving for at least three years. To ensure this certain trials have to be eliminated in the early and late years of the analysis (Table 3.2).

Table 3.2 The inclusion of trials and entries from six years' of trials for an analysis of the survival of entries

	Trial and entries included			
Year	Initial (IET)	AVT (of two tiers)	AVT-I (of three tiers)	AVT-II (of three tiers)
1	✓	-	-	-
2	✓	2nd year entries	✓	-
3	✓	✓	✓	✓
4	✓	✓	✓	✓
5	-	✓	✓	✓
6	-	3rd year entries	-	✓

✓ = all entries included in the analysis
- = all entries excluded from the analysis

Each new entry in a trial is tested for one year, after which it can be rejected or retained for a further one or more years. The "life expectancy" of an entry will vary according to the severity of selection procedures. The survival of entries over years was calculated for rice (1988-93), wheat (1984-92), pearl millet (1984-93), sorghum (1984-93), groundnut (1984-93) and chickpea (1984-92). Data for this purpose were extracted from the relevant AICCIP reports.

Resource allocation

As an example, we quantified resources allocated in the multistage trials system of AICCIPs for pearl millet and groundnut. For each year of testing, estimates of resources allocated for any trial (T) were obtained. In pearl millet, T was estimated for three trials *i.e.*, Pearl Millet Early Variety Trial (PMEVT), Initial Pearl Millet Hybrids Trial-1

(IPMHT-1), Pearl Millet Early Hybrids Trial (PMEHT) from 1991 to 1993. For groundnut, T was estimated for Initial Variety Trials for Spanish bunch, Virginia bunch and Virginia runner from 1990 to 1992. The amount of resources allocated to any trial in any year was calculated as:

$$T = E \times L \times P \times R$$

where E is the number of entries in the trial for the stage of testing under examination (the number of entries in the second and third year is determined by the number of entries that were promoted from the previous year), L is the number of locations, P is the plot size in square meters, and R is the number of replications in the trial.