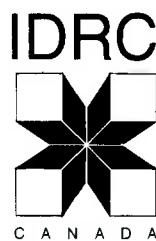


# Participatory plant breeding

*Proceedings of a workshop on participatory plant breeding*  
26-29 July 1995  
Wageningen, The Netherlands

**P. Eyzaguirre and M. Iwanaga, editors**



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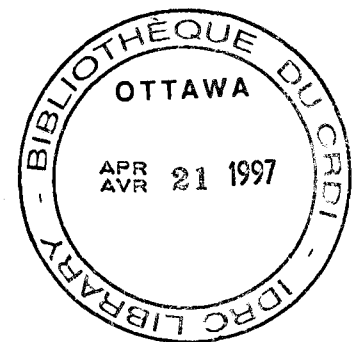
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IPGRI  
Via delle Sette Chiese 142  
00145 Rome  
Italy

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## Foreword

The papers in this volume were originally presented at a workshop on participatory plant breeding which was held in Wageningen, the Netherlands, on 26-29 July 1995. The workshop was convened to crystallize a novel approach that plant breeders, genetic resource conservationists and social scientists were demonstrating with increasing success. That approach is to place knowledge about genetic resources, as well as enhanced germplasm, directly at the disposal of farmers for them to use and develop according to their own needs and practices. Experiences indicated that in using this approach, biological and social scientists were learning a great deal about the useful diversity in target crops and farming systems. Farmers were also benefitting from access to greater diversity and from the partnerships they were forming with plant breeders.

The workshop was sponsored by the International Development Research Centre (IDRC), Ottawa, Canada; the International Plant Genetic Resources Institute (IPGRI), Rome, Italy; the Food and Agriculture Organization of the United Nations (FAO), Rome, Italy; and the Centre for Genetic Resources, which is part of the Centre for Plant Breeding and Reproduction Research (CPRO), the Netherlands. The workshop brought together 24 participants and included technical and social scientists from several Centres (CIAT, CIP, ICRISAT, ICARDA, IPGRI, IRRI) of the Consultative Group on International Agricultural Research (CGIAR), representatives from FAO and staff from donor organizations and European government agencies. The methodology of the workshop was to review experiences by presenting and discussing case studies, followed by working groups on the major themes which arose from the discussions. Seventeen presentations were made by participants, followed by deliberations in three working groups which were set up to explore: (a) institutionalizing and legitimizing the participatory approach in which farmers and crop breeders work in partnership; (b) participatory and decentralization breeding for productivity and biodiversity, stressing the contribution farmers make in managing crop diversity; and (c) the state of the art in participatory breeding in a global context. The workshop aimed to take stock and see if, indeed, a new approach was in the making which merits the attention of the wider research and development community. Our conclusion was "yes" and we hope that these proceedings stimulate further research and practice in decentralized, participatory plant breeding. A summary of these proceedings was published in October 1995 by IPGRI as No. 3 in its Issues in Genetic Resources series.

## Acknowledgements

We express our thanks to Joachim Voss and his staff at IDRC who helped bring the participants and their experiences together. FAO's contribution was invaluable in demonstrating the potential significance of these experiences for plant genetic resources policy. A special thanks is due to the host institution, the Centre for Genetic Resources, the Netherlands, who welcomed us to Wageningen. Dr Jaap Hardon, the Director, ensured that the meeting was not only challenging and productive, but also friendly and, as the Dutch say, "gezellig". Thanks are due to our editor, Linda Sears, assisted by Judith Thompson in the production of this volume, and to Patrizia Tazza for her inspired cover art.

## The Global Context: Breeding and Crop Genetic Diversity

### Introduction

#### *Jaap Hardon*

CPRO-DLO-CGN, 6700 AA Wageningen, The Netherlands

The Wageningen Workshop on Participatory Breeding, organized jointly by IDRC, FAO, IPGRI and the Dutch Genebank (CGN/CPRO-DLO), brought together 24 technical and social scientists from various Consultative Group on International Agricultural Research (CGIAR) centres, some national institutions and donor organizations, all of whom were actively participating with farmers in breeding plants for less favourable environments. The methodology of the workshop was to review experiences by presenting and discussing case studies, followed by working groups on the major themes that arose out of the case studies. The objective was to gain a better understanding of ways in which farmers could be incorporated into the processes of selection and breeding, and how farmers and farming communities could achieve more direct benefits from institutional research in their own crop improvement systems.

The following themes were assigned to the working groups:

- **Working group 1.** Institutionalizing and legitimizing participatory breeding approaches
- **Working group 2.** Participatory and decentralized breeding for productivity and diversity
- **Working group 3.** State of the art in participatory breeding approaches.

The workshop brought together plant breeders and social scientists in an intensive dialogue. Many proposals were made but many problems remain. It is hoped that this workshop made a contribution to the further evolution of participatory plant breeding, and will widen interest at the institutional level in accepting the challenge of the approach.

### Discussions

#### *Problem definition*

Institutional breeding appears to have failed to adequately meet the needs and requirements of 'difficult' environments. This stems largely from the fact that plant breeding is mainly directed at increasing yield in more favourable environments. While broad adaptability is a major objective, there are many more marginal environments in which improved varieties do not express their increased yield potential or do not satisfy other user requirements. In the more extreme environments, genotype x environment interaction starts to play a major role. It involves adaptation to both the physical environment (climate, soil, abiotic/biotic stresses) and the socioeconomic environment (economic status, user concerns, consumer preferences, markets, etc.). This suggests the need for more decentralized breeding approaches. This approach is not, however, necessarily limited to the less



favourable environments. In favourable environments social inequality may also affect user requirements.

A central issue is how best to meet users' concerns. This calls for better information on user needs and demand-driven systems of breeding. These requirements are met in full by traditional seed systems employing and managing landraces. However such systems are under considerable stress in many regions. Genetic resources are often limited and unsecured, while indigenous knowledge and social institutions are being eroded in many parts of the world. Factors contributing to such erosion include political instability, wars and escalating relief aid programmes. It is within these contexts that breeding may have to consider new approaches that do not avoid but rather employ genotype by environment interaction in its widest sense.

The challenge in the choice of breeding approach is not limited to marginal environments. The farmers in better-endowed environments may benefit from more participation in the breeding process, for some of the same reasons as in marginal environments, especially from a choice between a wider range of cultivars, and faster dissemination of products from breeding programmes. Many of the environments that appear to have lost a lot of diversity may particularly benefit from more diversity (i.e. more cultivars of diverse origin), for example for greater stability under pest and disease attack.

#### **Rationale for participatory plant breeding**

The term participatory plant breeding (PPB) is used here in its widest context, ranging from decentralized breeding controlled by plant breeders to various degrees of farmer involvement in the breeding process. This was done to avoid a continuous need to qualify statements. The fundamental differences between the two forms of breeding were clarified and considered as a continuum from breeder-controlled to farmer-controlled systems of breeding and selection.

## Participatory breeding and IDRC's biodiversity programme

*Joachim Voss*

International Development Research Centre, Ottawa ON K1G 3H9, Canada

### **Introduction: The sustainable use of biodiversity**

IDRC's Biodiversity Programme supports research on the sustainable use of genetic resources, which balances productive use with socially equitable access to and conservation of these resources. While recognizing that there is some overlap, we separate genetic resources into those that are found in the wild and those that have been domesticated, since the patterns of use, transformation and conservation differ significantly. In both cases the key research question we ask is: What are the social, technological and economic conditions that are necessary for increasing the productivity of genetic resources without eroding the biodiversity on which our future options and indeed our long-term survival depends? This leads us into two cross-cutting issues. The first is property rights (both material and intellectual) and their interrelationship with equity and sustainability. The second is research for the development of new products and processes in order to add greater value to biological resources and hence to improve the standard of living of the people who rely upon them.

It is frequently assumed that giving value to genetic resources through their transformation into useful and profitable products will automatically lead to the conservation of biodiversity (Juma 1989). Conceptually, the main problem with this assumption is that it confuses the conservation of the narrow range of immediately economically useful traits with the conservation of overall diversity. Even within economically useful species, this assumption also requires empirical validation and analysis of the conditions under which it does and does not hold. It is especially questionable in the case of open-access resources, such as medicinal plants or rattan collected from the wild where, under some conditions, increased economic value may lead to overexploitation to the point of extinction<sup>1</sup>. In agricultural systems, the main difference seems to be that in traditional, low external input subsistence agriculture, manipulating and increasing diversity is an important farmer strategy for reducing yield losses from diseases and climatic uncertainty (Voss 1992). Highly specialized, market-oriented agriculture attempts to compensate for the loss of natural stabilizers through increased human control of the environment via irrigation, fertilizers and chemical plant protection.

For domesticated biodiversity, it is axiomatic that these species, and the varieties within them, have a value, even if that value is purely ornamental. However, the archeology of domestication demonstrates vividly that domestication has been an ongoing dynamic process of selection and rejection in order to improve useful qualities and/or adaptation to changing environments. The original domesticated maize, for example, was less than 2 cm in length and fell out of use thousands of years ago. In every major crop, countless varieties have come and gone over the centuries of domestication. Farmers have always adopted what is most valuable and rejected or neglected that which has become less valuable. What has changed is not this

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<sup>1</sup> Both the medicinal plant networks supported by IDRC in Asia, Africa and Latin America, and the Bamboo and Rattan Network (INBAR) have made this issue a major concern of their socioeconomic research.

process, but rather a number of factors that are putting pressure on the process, directly or indirectly:

- changes in the nature of value, from use value to exchange value to value as a commodity
- the nature of farming itself, toward ever more mechanization and market orientation
- the methods and tools of plant improvement, toward ever greater sophistication in identifying and manipulating the genes for particular desirable traits.

#### **The intensification of agriculture: biodiversity and productivity**

The changes noted above started well before the Green Revolution, dating back to the beginnings of urbanization and accelerated by the Industrial Revolution. Indeed, agricultural intensification leading to surplus production was a necessary condition for the occurrence of the specialization in nonagricultural professions that is characteristic of urban life. Urban markets, in their turn, influenced farmer strategies as trader and consumer preferences became factored into farmer strategies for obtaining the best possible market return. Thus, even in crops that were not amenable to Green Revolution technologies, such as common beans, a very few phenotypes typically dominate in the urban markets. Some interesting work by Willem Jansen *et al.* (1994) suggests that even in apparently rigid markets, consumers may well be more flexible in their preferences than trader intermediaries.

The Green Revolution provides the most dramatic case for illustrating the general trend of the relationship between productivity, technology and biodiversity in the recent past. Science and technology were systematically applied to the goal of raising yields in rice and wheat in order to meet the challenge of feeding a rapidly growing global population. The technologies developed to increase the productivity of the world's major food grains combined with high external-input agriculture and commercial pressures favoured a very narrow range of the most productive, input-responsive, new varieties of rice and wheat. Although this was very successful in staving off widespread famine in India, it had the consequence of greatly reducing the tremendous diversity found within and between the landraces developed as a result of centuries of farmer breeding and selection (Frankel 1970).

Consequently, one of the research challenges IDRC has identified is to better understand these causes of genetic erosion, the extent to which it is occurring<sup>2</sup>, its ecological and societal implications, and to question the "inevitability" of this direction of agricultural development.

Notwithstanding its success in rapidly increasing food production in the short to medium term, the Green Revolution illustrates that technology (in this case new varieties) is not neutral when it comes to the conservation of diversity *in situ*. Technology, however, is an outcome of human inventiveness and is a tool for meeting socially defined objectives. Given the increasing awareness of the importance of conserving biodiversity *in situ*, we ask how technology and society need to evolve to meet this challenge. The key research questions we have identified for plant breeding are:

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<sup>2</sup> Although there are many anthropological studies which report a substantial decline in the number of varieties of many crops being grown by farmers, including some NGO studies supported by IDRC, it is difficult to find scientific studies which document the impact of this at the genetic level.

1. Is it technically possible to obtain sustainable yield increases using breeding strategies which would increase productivity while maintaining or increasing cultivated diversity? What levels of increase can be attained this way compared with conventional approaches? How would the potential to do this and the methods vary according to outcrossing, self-pollinating and clonally propagated crops?
2. Could a participatory approach, working with farmers to improve the productivity of their landraces and to combine indigenous with scientific knowledge, produce such a result? Under what conditions? Could productivity be increased with sufficient speed to keep up with population growth?
3. If it is technically feasible, what kind of incentives and institutional changes would be required for it to work and be implemented? What are the key institutions, including regulatory systems, that would need to be modified?

### **Complex agro-ecosystems, diversity and participatory breeding**

IDRC has tended to concentrate its research support on complex smallholder farming systems which are typically found in less favoured areas, such as desert and forest margins, hilly and mountainous areas and fragile coastal areas. We have done so for a combination of reasons. These are the areas at greatest risk of environmental degradation because of their ecological fragility. A disproportionate number of the world's rural poor live in marginal areas where they have often been pushed by complex combinations of civil strife and global forces that have led to increasing appropriation of the lands best suited to mechanization and have dramatically widened the gulf between rich and poor. Although they are not suited to large-scale mechanized industrial agriculture, with proper management many of these areas can be highly productive. The research challenges, however, are complex and typically require a high level of community participation for the research to be effective. The sustainability of agriculture in many of the most favoured areas also depends critically on what happens in these more marginal areas because of their role in regulating water supply and climate. Finally, these are also the areas where much of the world's agricultural biodiversity has been developed and conserved.

While it is necessary to understand the fundamental reasons for genetic erosion in the more favoured areas, it is also important to conduct research to identify how, why, where and by which farmers diversity is being conserved in these complex smallholder systems. In this way formal institutions could learn from and reinforce such conservation efforts, rather than inadvertently undermining them as they attempt to increase the productivity of these systems. In these areas, selecting for diversity has been an important farmer strategy for reducing the risk of total crop failure and/or for taking advantage of a myriad of ecological niches. This is also where centralized breeding approaches have had very limited or no success.

In large part, participatory breeding, combined with decentralized selection under high stress conditions, has arisen as a breeding strategy to attempt to improve the performance of formal breeding for difficult environments. The paper by Ceccarelli *et al.* in this volume, for example, clearly shows the existence of a "crossover effect", meaning that varieties selected under good conditions generally are not the best performing under marginal conditions and vice versa. It also mirrors farmers' strategies for dealing with heterogeneous environments by emphasizing the potentials of genotype  $\times$  environment interactions, rather than seeing this as an impediment in the way of the classical "one size fits all" breeding approach.

Participatory breeding, combined with decentralized selection, has at least two advantages. It allows the individual farmers to (1) meet their needs for a diversified portfolio of varieties in order to manage risk, and (2) satisfy different end uses. Also, it allows a diverse set of farmers to meet individual needs which are themselves diverse because of differences in wealth and agronomic conditions on their farms.

### **Favourable agro-ecosystems, participatory breeding and diversity**

Are participatory approaches and breeding strategies based on the improvement of diverse populations only appropriate for stressful or heterogeneous environments? To some extent, these are two separate questions since one needs to disentangle participation and diversity. Since participation is an approach toward more closely attuning breeder and farmer objectives, it is logical that participatory breeding approaches will only reinforce agricultural biodiversity where the maintenance and use of such diversity is an integral part of farmers' production strategies.

The paper by Kornegay *et al.* shows clearly that participatory approaches in a highly market-oriented context are very effective at identifying varieties that will be adopted by farmers; but, the farmers' selection criteria include a very narrow set of market-oriented characteristics. They consequently chose only a few varieties for which they judged there would be a good demand and a higher price.

Therefore, if productive diversity is considered to be a breeding objective for market-oriented conditions as well, farmer participation by itself is not enough. It would need to be combined with more upstream approaches. The first would be a technical breeding challenge to maximize the range of underlying genetic diversity within the acceptable range of performance standards and phenotypic market characteristics such as colour, taste and milling quality. The new biotechnologies would seem to have considerable promise for doing this. The second would be to tackle the issues of consumer preference and market incentives directly. This would require both market research and advocacy with the goal of making diversity (of content rather than of brand names) a consumer preference. This second approach would complement the former in that it would give breeders more options for increasing productivity. The third requirement would be for research and development into food technologies which would be capable of transforming less homogeneous inputs into a variety of processed foods.

A breeding approach toward more productive diversity in favourable areas would likely have the further benefit of providing more stable, longer-lasting disease resistance. Current approaches which emphasize the development of a few high-yielding varieties have created a self-perpetuating breeding treadmill. Placed under tremendous selective pressure by the widespread adoption of resistant varieties, pathogens tend to evolve rapidly and the resistance of the new varieties to them typically breaks down after a few seasons. One might argue that this serves commercial seed company interests very well, as it keeps farmers coming back for seed of the latest disease-resistant variety; however, it is less appropriate when sustainability becomes an important objective, nor does it correspond well with the objectives of the poorer farmers who typically produce their own seed.

Trygve Berg shows in his paper that as Green Revolution technology reaches its limits, or begins to break down because of as yet poorly understood long-term ecological shortcomings, farmers spontaneously begin to experiment in an attempt to overcome these problems. This creates a new opportunity for breeders and social scientists to improve the efficiency of such experimentation and to increase the range of available options by working directly with such farmer experimenters. As

cautioned above, the end result would likely only be more diversity if this is an explicit goal in the experimentation.

### **Institutional and policy issues for participatory breeding**

Scientific breeding approaches based on diversity are not new. As early as 1919 Harlan and Martini advocated the use of mixtures, and an early CGIAR strategy meeting in 1976 at CIMMYT similarly had a presentation arguing for such an approach (Neeley *et al.* 1976). Nonetheless, the dominant breeding paradigm of this century, both in university teaching and in practice, has clearly been toward the development of single high-yielding varieties based on the IR8 prototype for rice. One might speculate that this is due to a conjuncture of forces, including the close connection between the breeding profession and the seed industry as well as cultural fashions and values favouring purity and uniformity (such as the vogue for Wonder bread).

A key question then becomes: What would it take to create a paradigm shift in the breeding profession, such that students would be taught alternative approaches and professional breeders would have incentives and rewards for releasing a diversity of material at earlier stages in the breeding cycle and improving the performance of populations? What changes would have to be made to varietal release policies to allow this to happen? What would happen to the concept of intellectual property rights, including both breeders' and farmers'/indigenous peoples' rights under such a scenario? If participation is based on mutual respect and shared knowledge and experience, would there not need to be mutual recognition for the contribution of both farmers and breeders for improvements that are made using this approach?

More fundamentally, given the diversity and range of sophistication of the farmer's knowledge and practices, and of farmers themselves, how best can the formal and informal systems mesh and mutually reinforce each other? There will not be a single simple solution to this question. It will vary by crop, ecology and society. Still, one might generalize that for each set of conditions, the required research involves clearly identifying the comparative advantages of both farmers and breeders and identifying both the most appropriate informal institutions and farmers according to the research and development objectives.

Doing this kind of research is far from straightforward and would require close collaboration between breeders and social scientists. In less specialized agrarian societies, the institutions responsible for fulfilling the functions related to seed selection and conservation are frequently enmeshed in a web of ritual or religious significance and may be completely overlooked by someone looking for specialized institutions. Furthermore, the identification of key informal institutions and appropriate farmers risks falling into a static analysis. Institutions evolve and people learn. Traditional institutions adapt to new purposes and interested farmers' capacities to select and breed grow as part of the participatory process of working together with breeders. One of the main research challenges is to figure out how to institutionalize such processes of experimentation and learning in order to render them more effective, dynamic and self-perpetuating.

### **Acknowledgements**

The author thanks Miguel Holle and Louise Sperling for their insightful comments on an earlier draft of this paper.

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## Farmers' contribution to maintaining genetic diversity in crops, and its role within the total genetic resources system

*Pablo Eyzaguirre and Masa Iwanaga*

International Plant Genetic Resources Institute, Rome, Italy

In this paper we concentrate on the contribution that decentralized crop breeding by farmers can make to maintaining and maximizing the genetic diversity within total crop gene pools. This leads us to focus on two aspects of the problem. One is the possible sources of genetic variation and how those sources can be maintained. The second is concerned with the range of users of both the existing genetic diversity and the crop germplasm that is maintained. We then link the sources of genetic diversity and the ways in which they are maintained to the users of resources. This link between the sources of genetic diversity, the systems for maintaining that diversity, and the users lies at the heart of both the challenge and the potential that decentralized farmer-based breeding offers for conserving the maximum amount of genetic diversity in crops.

### The sources of genetic diversity in crops: a system perspective

The total genetic diversity in a crop gene pool is the result of:

- natural processes unaided by humans (wild relatives of crops)
- crop evolution, selection and adaptation in farming systems in highly variable and often marginal environments
- formal breeding to create new genetic combinations according to predetermined criteria.

Another important feature of genetic diversity within traditional farming systems is that it allows for geneflow between crops and their wild relatives. One way of conceptualizing the geneflow within a crop gene pool is as a plant genetic resources (PGR) system with interactions and flows between the three sources of genetic variation. Each of the three sources of diversity—wild relatives, landrace and formal breeding—is characterized by the increasing degree of human control over the process of exchange of genes, and by the reduction of complex environmental factors in the selection process. Wild relatives and landraces still account for the bulk of genetic diversity within a crop gene pool. Formal breeding reagggregates existing genetic variation from these two sources. While new techniques employed in mutation breeding programmes and some engineered genes (e.g. those with enhanced herbicide resistance) may actually introduce new variations, isozyme and molecular data on the amounts of diversity in wild relatives, landraces and modern cultivars indicate that wild relatives and landraces remain the main sources of genetic diversity in crop gene pools (Miller and Tanksley 1990). Conserving these sources is therefore crucial to the future of crops. Our existing system of genetic resource conservation and use, however, may need to be redirected in order to maintain this diversity.

The flow of genetic variation within this existing PGR system is largely unidirectional, from wild relatives and landraces to the formal centralized breeding programmes (Fig. 1). In fact, some centralized breeding strategies seem to be characterized by the view that "landraces have outlived their usefulness in agricultural production, and where improved varieties attuned to local conditions are available, landraces should give way to them. Their role is to serve as sources of genetic materials for plant improvement" (Frankel and Soule 1981).



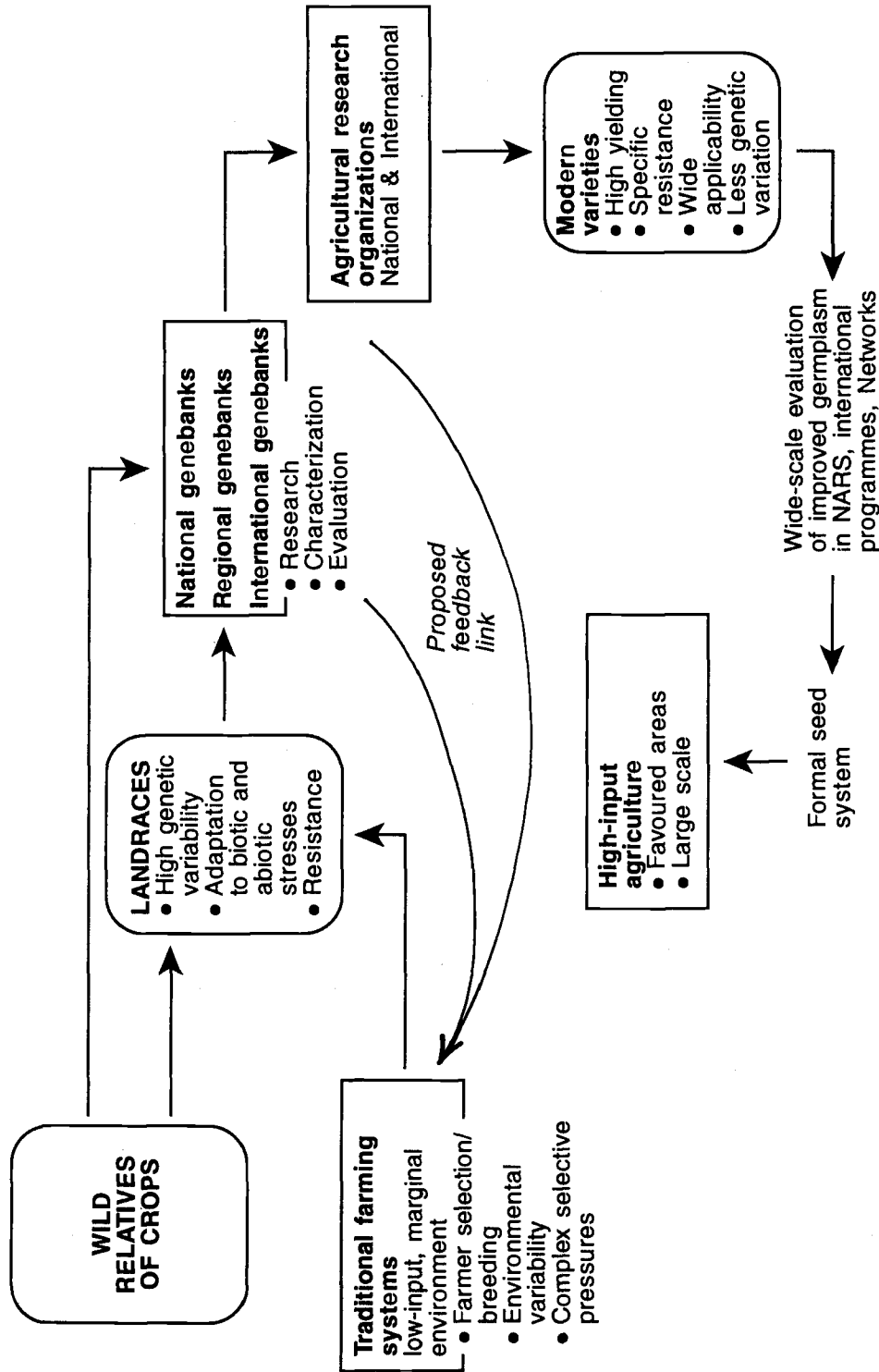


Fig. 1. Sources of genetic variation and the maintenance and use of genetic diversity: a view of the existing system.

There are two reasons why treating traditional low-input farming systems as relics and landraces as raw material for centralized crop breeding may not work. First, by treating landraces as outmoded and as raw material for formal breeding, we are not providing any positive feedback into the farming systems that generate that genetic diversity. By not strengthening farmer-managed crop evolution in complex, heterogeneous agricultural environments, we are weakening one of the crucial sources of genetic variation. As the farming systems in marginal environments are replaced, these traditional "cauldrons" of genetic diversity will no longer generate new combinations, leaving only what the formal breeding and genetic resources conservation institutions have been able to collect and maintain. While we have few, if any, studies on the population biology of crop gene pools to be able to say with any degree of accuracy how much of the total genetic diversity that exists in farmers' fields or in the wild has been captured and safely stored in genebanks, it would be safe to say that there is some loss of genetic diversity as germplasm moves from agricultural environments into genebanks.

Even the more successful and well-managed genebanks are finding that their holdings are increasingly dominated by advanced cultivars with landraces poorly represented and inadequately documented (Evenson and Gollin 1995). In the final analysis, we may be losing significant portions of the crop gene pool by not feeding back into the sources of genetic variation in crops, namely, farmers and their interactions with complex environmental pressures.

A second reason why traditional farming systems and landraces should not be seen as relics is that formal centralized breeding may not be able to provide alternatives that are appropriate and economic for low-input agriculture in less favoured environments, where approximately "100 million people in Latin America, 280 million in Africa, and over 990 million in Asia raise food under difficult conditions at yields little changed since mid-century" (Wolf 1986). There are combinations of technical and economic factors that limit what formal centralized breeding can contribute to germplasm improvement for traditional farming systems in marginal areas.

While it may be technically possible for formal centralized breeding to produce varieties for heterogeneous and marginal environments, it is not cost-effective. Formal breeding often requires large economic returns through wide-scale adoption of the improved cultivars produced by breeders. As a result, formal breeding programmes have logically focused on wide adaptability across as large an area as possible. Those varieties that are widely adapted for one criterion—resistance, yield, etc.—depend upon uniform agronomic conditions and inputs to realize their potential (Fig. 2). The socioeconomic and biophysical environments of resource-poor farmers do not allow them to avail themselves of these new cultivars. Furthermore, the high degree of genotype  $\times$  environment interactions make it difficult for formal breeders to identify cultivars suitable for traditional farming systems characterized by high variability in social, economic, edaphic and biological conditions (Eyzaguirre 1992). These economic and technical factors also help to explain why small-scale farmers continue to rely on landraces even when improved modern cultivars are readily available (Brush 1992).

The less favoured agricultural environments were bypassed by more formal breeding efforts, and rural poverty in those areas remains largely unaffected by many of the scientific developments leading to new agricultural technologies and practices. Economies of scale in formal breeding programmes lead logically to a focus on favourable agro-environments or areas where the environment can be more easily controlled by human agency, such as irrigated areas and greenhouses. From the

genetic resources conservation standpoint, the economic value and impact of the new varieties which were produced certainly justifies continued support and expansion of genebanks. However, from the total genetic diversity perspective only part of the genetic resources were being addressed and conserved. Key sources of genetic diversity were being ignored and are now subject to genetic erosion.

### **Traditional farming systems and genetic diversity**

Small farmers in marginal areas live with great variability in their environment; they lack the economic and institutional resources to transform their environments to suit the requirements of modern cultivars. Their strategies rely on diversity at all levels; cropping in mixed stands, making maximum use of micro-environments and niches, combining crop agriculture with gathering, wage labour, animal husbandry or craft manufacture are all hallmarks of the diversified and still precarious survival and production strategies of resource-poor farmers. In the crops they plant, they select for those criteria that allow for greatest resistance across several competing characteristics: straw versus grain, hardiness/rusticity versus yield, cultural preferences in flavour and appearance over total calories.

There are now substantial data and evidence that farmers maintain and select among their landraces, and that this can be considered traditional breeding or management of diversity (Richards 1994; Weltzien 1995; Riley 1996). As a result of these studies we can identify two particularly important components of farmer strategies for maintaining and managing this variation. First is the agromorphological diversity which is largely in response to use and preferences, e.g. colours, flavours, plant architecture and crop types. Second is the diversity in terms of a crop's adaptive characteristics. Examples are adaptation to microenvironments, environmental stresses or biological hazards such as pests. In genetic terms, this adaptation is often not based on single characters but is multilocus with complex inheritance or co-adapted gene complexes. Breeding this type of diversity is something that farmers do well.

Trying to breed elite varieties that fit these competing objectives and micro-environments is vexing if not impossible for formal breeders to achieve (Simmonds 1991). These, however, are the characteristics that resource-poor farmers want and which fit their particular environments. Not surprisingly, landraces of sorghum, wheat, cassava, beans and sweet potato all fit these holistic criteria of hardiness, multipurpose and cultural preferences. When comparing landraces with improved cultivars based on farmer's criteria within their specific environments, it is not altogether surprising that the traditional cultivars are often good performers when compared with the costs and yields of the improved varieties (Prain *et al.* 1992; Sperling *et al.* 1993). Both as sources of livelihood and as sources of genetic diversity and variation, low-input farming systems merit attention. Development actions that enhance the productivity of the system should not eliminate or bypass them.

### **Support for traditional farming systems and the maintenance of genetic diversity**

We need to conserve not only the genes themselves but also the farming systems and agro-ecosystems that produce and maintain genetic diversity. This requires some positive feedback in the germplasm improvement and conservation system directed to traditional farming systems which use and maintain landraces. Those inputs need to be in a form that farmers can use as part of their own system with its particular practices of selection, breeding and management of crops. In this way they can

continue to use and develop genetic diversity in crops as an integral part of their own social and economic development. Some of the case studies at the farming system level have begun to demonstrate the benefit of farmer-managed diversity in genetic resources and to illustrate that it can be an integral part of agricultural development (Loevinsohn and Sperling 1995; Riley 1996).

Cases where new and interesting germplasm and diversity is fed back into traditional farming systems are far too rare. The current unidirectional flow of genetic resources into formal centralized breeding of elite varieties with high yields and specific resistance offers little that is useful to small-scale farmers who are engaged in maximizing genetic diversity and who maintain landraces. When new germplasm is introduced into their system, the genetic diversity that is in this way made available to farmers may be considerably less than what was already available in their traditional varieties. Thus, for poorer farmers on marginal lands, it reduces their options to cope with variable environmental conditions and to exploit niches and micro-environments in their farming systems. Reducing the range of options for survival and development within these agrarian systems is at the same time reducing the potential contributions from this source of new and complex genetic variation.

The fact that technological innovation and agricultural development have not made a big impact in marginal areas does not mean that these farming systems will remain unaffected and viable. Nor does it mean that their traditional sources of genetic diversity in crops are secure. Neglect is not enough. As long as livelihoods and well-being are precarious because farming in marginal environments can barely produce enough crops to support survival, then farmers will seek other options. Poverty increases resource degradation, including loss of biodiversity; they will face difficult choices to conserve or consume natural resources in order to survive. In many cases farmers and entire communities will leave the areas of high crop genetic diversity to work as labourers in the more favoured regions or in urban areas. Cases in the Andes and in the East African highlands indicate that depopulation can also be a cause of resource degradation and loss of biodiversity (Tiffen *et al.* 1994; Zimmerer 1991).

The formal system for plant improvement and conservation of genetic resources can undertake actions to support traditional agriculture in marginal areas and thus arrest the genetic erosion that the disappearance of these farming systems entails. The continued and successful use of landraces will limit genetic erosion, but this can only be an ethical and viable strategy if it is linked to the social and economic development of the poor farming communities that continue to use them. Improving the social and economic value of traditional cultivars through germplasm enhancement and landrace improvement is a promising development that decentralized breeding approaches provide. Decentralized here refers to the efforts of formal breeders to work with farmers in the improvement of their genetic resources within their diverse environments and social conditions. A goal is to make landraces more competitive with elite varieties and more productive to the farmers who grow them<sup>3</sup>.

### **Bringing farmers into the genetic resources conservation system**

In general, the formal genebank subsystem cannot hope to maintain all the variation present in traditional cultivars. Specifically, a genebank is not the most effective way of maintaining specific adaptive gene complexes, i.e. the particular combination of characteristics that constitutes adaptation, for use in individual farming systems.

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<sup>3</sup> Some innovative actions are already underway through the Community Biodiversity Development and Conservation Programme.

While formal breeders may prefer to continue working mainly with elite lines where genetic expression is more easily understood, they may be missing opportunities for breakthroughs by crossing cultivars adapted to widely different environments (Frankel and Soule 1981; Pistorius 1995).

The key to maintaining the sources of diversity in farming systems while providing development options that support the continuity of those systems is to work directly with the genetic resources that farmers value and conserve. The genetic resource conservation sector will have to be more than the receiver and keeper of germplasm that farmers identify and provide. It will have to make genetic resources available to farmers as inputs into their own selection and breeding system. This implies changes in the flow of germplasm and in the institutional relationships within the existing system of genetic resources conservation and use.

The creation of protected areas and reserves is a key way to conserve the genetic resources of the wild relatives of crops which are sources of new variation under natural conditions. Genebanks are the principal and most efficient way to conserve genetic resources for use in formal breeding programmes. The third source of genetic variation, the traditional farming system, is seldom included as part of the total system of conservation of agricultural biodiversity. On-farm development and enrichment of crop genetic resources is an appropriate way to support those farming systems which continue to create, maintain and use genetic diversity (Altieri and Merrick 1987).

One way to enrich crop genetic resources for low-input farming systems is to provide farmers with more genetic diversity in the form of landrace germplasm from a wider range of sources. This germplasm will have gone through the research, characterization, and evaluation process in a national or regional genebank. Genebanks could place greater emphasis on characterizing and storing landrace germplasm, where it can be made available to plant breeders. The germplasm can also be returned to farming communities, enhanced by the documentation and understanding of its genetic composition and expression. Farmers will have available to them enhanced germplasm of the type they have traditionally selected and bred. They would also have access to such germplasm from a wider range of habitats outside those which they occupy. By making a wider range of enhanced germplasm available, there is greater potential to improve yields and farm incomes within those variable and marginal environments where landraces are comparatively most productive.

### **Making greater use of genetic diversity through decentralized breeding**

The current PGR system ends in the provision of improved varieties for high-input agriculture in favoured areas. The low-input farming system remains primarily a source of genetic resources, a source which is increasingly precarious given the growing gap between the more-favoured and less-favoured agricultural regions. Decentralized breeding in support of traditional farming systems offers the opportunity to narrow the gap in human welfare between the favoured and marginal areas without sacrificing the genetic diversity in crops in return for increased farm incomes.

Where research attention has been focused on the farming systems that maintain crop landraces in marginal areas, scientists have realized that the decisions and genetic resource management practices of farmers merit support. Where decentralized breeding approaches have been started in Western Asia and the Near East (Ceccarelli 1993; Ceccarelli *et al.* 1994), Central Africa (Sperling *et al.* 1993; Voss 1992) and West Africa (Jusu 1995), farmers have quickly gained the respect of formal

breeders and become partners. In return, breeders have gained legitimacy with farmers as a result of the better understanding they gained on the criteria, conditions and "the architecture of the cultivar" that is appropriate for marginal areas with high environmental variability. This encouraging trend toward decentralized breeding makes farmers full partners in crop-improvement efforts because of the interesting genetic resources they maintain and manage. This partnership in crop improvement has important implications for the inclusion of farmers as full partners in plant genetic resource conservation as well.

In general terms, there is a need to make greater use of plant genetic diversity in plant breeding. This is important in overcoming limits on productivity, in reducing chemical inputs in the more favoured areas, and in developing crop varieties for the marginal areas. A corollary of increasing the use of diversity in plant breeding is a decentralization of plant breeding activities as well as the increased participation of farmers in those activities (Cooper *et al.* 1994). Giving greater importance to the role of farmers in a decentralized breeding strategy has been recognized as an important component of an effective multilateral system for plant genetic resources conservation and use. The multilateral system is designed to foster international cooperation in the use of genetic resources to promote agricultural development. Broadening of plant breeding strategies is essential for reconciling the two primary objectives of the evolving multilateral system for PGR, namely, conservation and use, and would also ensure that benefits reach those farmers (Cooper *et al.* 1994).

From the perspective of the global system for PGR conservation, decentralized breeding by farmers is not only an issue of equity and the development of appropriate biological technologies for marginal areas. Farmer-based breeding is an important strategy for the maintenance and use of genetic diversity in agriculture as part of the emerging multilateral PGR system. The key points of action in this regard are:

- making a wider range of genetic material available to farmers, directly as well as through the use of a broader genetic base in formal breeding
- breaking the link between plant breeding, agricultural development and genetic erosion
- developing plant varieties suitable for resource-poor farmers in marginal areas; creating incentives for *in situ* conservation of PGR (Cooper *et al.* 1994).

### **Increasing access and changing the flow in the PGR system**

In our diagram of the genetic resources conservation and use system (Fig. 1) we propose a direct feedback in the middle of the cycle to link the germplasm in genebanks to the traditional farming systems that generate and maintain landraces. This feedback can improve the productivity of farmers' production systems, thus ensuring the continuity of this important source of new variation in genetic diversity. The three ovals in the diagram represent the three sources of genetic variation in a crop genepool: wild relatives, landraces, new cultivars and varieties produced in formal breeding programmes. The squares denote the institutionalized processes that use, maintain or transform genetic resources: traditional farming systems in marginal areas, genebanks, breeding and seed production within agricultural research institutions.

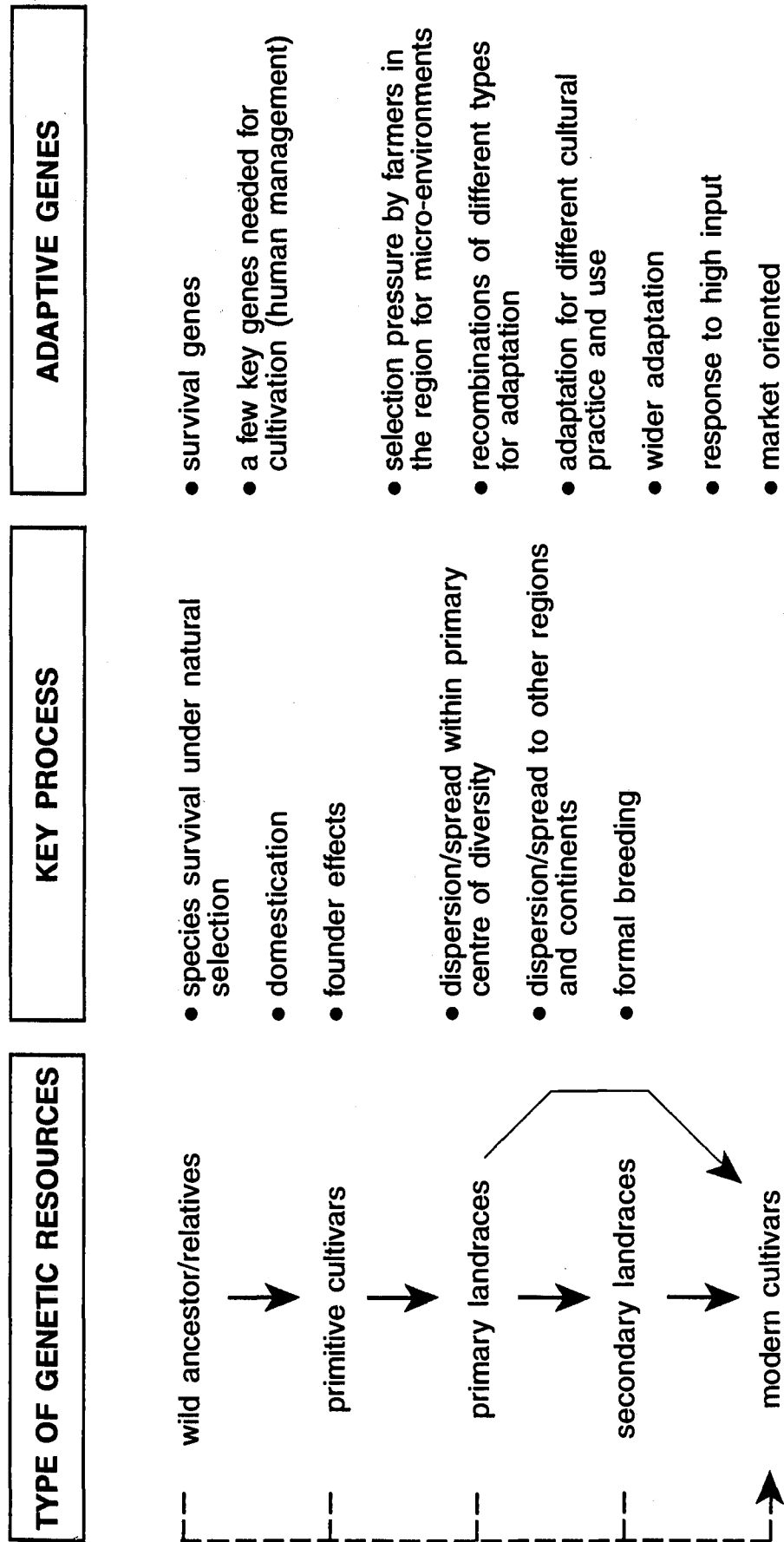


Fig. 2. Origin and process of adaptation.

In effect, the redirected PGR system we envision is one that is open to farmers. It makes PGR directly available to them in a form that is enhanced and documented through the work of plant genetic resource programmes, but not necessarily as products of a national breeding programme. Plant genetic resources programmes which have heretofore regarded breeders as the primary direct users of the genetic resources they maintain will increasingly look to farming communities which maintain landraces as direct users as well as contributors of plant genetic resources held in genebanks.

The genebank, while a central component of a plant genetic resource programme, will need to be complemented by community-based genebanks as well as by on-farm conservation. The scientific, technical and institutional requirements of these new approaches are now under investigation and some are being implemented (IPGRI/FAO 1995). Genebanks will need to be reinforced in their efforts to provide a more direct service to farmers for evaluation and characterization of their genetic resources and to encourage their participation in crop improvement exercises and their use of resultant germplasm. These research and characterization functions within genebanks, functions which have been weak in the past, will need to be strengthened in order to make a wider range of genetic diversity available to a broader set of users.

In the long run, the partnership between farmers and genetic resources programmes can stimulate the work of formal breeders as they find ways to use a greater amount of diversity in their own breeding programmes, and as they address the complex inheritance and plant architecture that traditional farming systems value. For genetic resources research and conservation, the link to communities that maintain diversity will allow the PGR system to conserve a wider range of genetic diversity. It will also be incumbent upon the PGR system to foster increasing exchanges between communities that conserve biodiversity with the goal of increasing the total genetic diversity that farmers can use and develop for their continuing welfare. This link between conservation and use offers the best prospect for maintaining the key sources of genetic diversity in crops.

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## Variety improvement in the informal sector: aspects of a new strategy

*Hubertus Franzen<sup>1</sup>, P. Ay<sup>2</sup>, F. Begemann<sup>3</sup>, J.A. Wadsack<sup>2</sup> and H. Rudat<sup>2</sup>*

<sup>1</sup> Council for Tropical and Subtropical Agricultural Research, 53119 Bonn, Germany

<sup>2</sup> German Agency for Technical Cooperation, Eschborn, 65726 Germany

<sup>3</sup> Centre for Agricultural Documentation and Information, Information Centre for Genetic Resources, Bonn, 53177 Germany

### Background

Improved seed is of basic importance in agriculture. For the farmer, high-quality seed plays a central role in all efforts to raise yield per unit area and achieve a higher income. Furthermore, seed is the key to optimum use of natural resources and, according to its provenance and the breeding goal, seed determines the requirements for inputs such as pesticides, fertilizer and agricultural technology.

Accordingly, to improve agricultural yields, the scientists working in national and international agricultural research mainly concentrate on the breeding of new high-yielding varieties. During the so-called Green Revolution, using this strategy, the yield levels of food staples such as wheat, rice and maize were improved relatively quickly and successfully when mineral fertilizer and plant protection measures were applied, and soil fertility was maintained. Apart from yield, factors such as resistance to diseases and pests, as well as quality aspects, became additional breeding goals. However, despite many years of research and trials, and partly owing to the absence of appropriate infrastructures, the spread of the new varieties in the developing countries often lagged well behind expectations and set objectives. Time and again it was found that the farmers<sup>4</sup> in different regions preferred to use local varieties despite the improvements achieved at the research stations. It took some time until it was realized that the reasons were clearly economic and resulted from consumer preferences. The foregoing clearly shows that there is an urgent need to develop additional approaches capable, on the one hand, of strengthening seed production in the smallholder/informal sector and, on the other hand, of ensuring closer connection between the use and conservation of plant genetic resources.

Kenya and India are good examples of the results which can be achieved through conventional breeding of improved maize, rice and wheat varieties. However, although both countries are largely self-sufficient in the production of food staples, food security has not basically improved because of the dualistic agricultural structure in these countries. In most developing countries, there are furthermore no viable concepts or breeding strategies capable of meeting the extensive requirements of smallholder farming systems, of strengthening seed production in the informal smallholder sector and of creating a link between the use and conservation of plant genetic resources.

To enable the structures urgently needed for the successful development and establishment of a national seed sector, new concepts which should be based on traditional local seed marketing will have to be developed. This raises the fundamental question of how the informal sector can be promoted and put in a position to take over functions which the state generally can only carry out

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<sup>4</sup> The terms "farmer" and "smallholder" refer to farmers/smallholders of both genders.

inadequately or not at all. In this discussion, it will be necessary to consider both measures for promotion of the national agricultural research institutions (NARS), research projects and extension services with a view to the development of instruments and participative methods of sector analysis and the setting up of services for the informal sector as well as the sustained inclusion in sector planning of nongovernmental organizations (NGOs) and farmers.

### **Introduction**

In the developing countries, breeding of improved varieties generally takes place in two ways: on the one hand, via programmes developed by international or national agricultural research centres or private industry in cooperation with *ex situ* genebanks (institutional/formal sector) and, on the other hand, where this is possible in accordance with the prevailing legal, economic and organizational framework conditions, through the local selection of traditional varieties at farm or village level (informal sector). Generally, both sectors operate side by side with little or no contact.

In many developing countries, especially in Africa, the smallholders produce, in the traditional cropping systems, their own seed by saving part of the harvest for sowing the next crop. In this way, the seed is handed down from generation to generation and the resulting varietal diversity in shape, colour, plant growth and yield, and also in taste of the processed product, corresponds to the farmers' and consumers' requirements which have developed through cultural practice and traditional cropping techniques. The system in which the farmers produce their own seed also covers trade in and a market for seed. This basically closed system of seed production opens up through the exchange of seed with neighbours and the regional trade in agricultural produce. Examples from Africa relating to the introduction of maize, cassava, cocoyams and various types of legumes are proof—*inter alia* through the speed with which the introduced plants spread over the continent—of the efficiency of this informal network even in past epochs when trade between African countries was still relatively undeveloped. Through the centuries, the genetic make-up of traditional varieties or ecotypes has thus undergone considerable change through spontaneous hybridization, mutation, selection and trade.

### **Context**

#### **Seed sector**

Scientific plant breeding mainly became possible through the discovery of Mendel's laws. In addition, increased trade in seed since the beginning of the 19th century led to significant changes in the seed sector in industrialized countries. In modern agricultural systems, the traditional varieties of principal crops have been replaced by improved high-yielding varieties produced by specialized breeding enterprises. These enterprises were able to develop as a result of the introduction of breeding incentives which guaranteed breeders an adequate remuneration for their intellectual efforts. Plant variety protection and the regulation of the seed market are central elements of this system.

Basic and applied research at university or state research institutes have played a decisive role in the development of new high-yielding varieties. Additional research capacity was built up by the private breeding enterprises. The fact that transnational groups are meanwhile making headway on the seed market is mainly

attributable to the development and potential of biotechnology. However, it is also typical for this new development that the modern techniques are mainly being used for a few food crops which are of particular importance worldwide. The impact this development will have on the seed sector is impossible to foresee at the moment.

In many parts of the developing countries, modern varieties are only successful to a limited extent despite the results of the Green Revolution. In contrast to the industrialized countries, many developing countries do not have either a state-promoted seed sector or a system of multiplication and breeding enterprises operating according to private enterprise principles. For most food crops, the informal seed multiplication and plant breeding sector consequently plays a considerably greater role than the formal one. This applies in particular to the so-called underutilized crops. Experts have estimated that 80-100% of the production of planting material takes place in the informal sector in the developing countries (Delouche 1982). Overall it is estimated that modern sorghum and millet varieties, account for about 6% of the cropping acreage (IFPRI 1991). In Thailand, about 6% of the cropping acreage was down to modern varieties in the mid-1980s (Groosman *et al.* 1991). According to recent literature, high-yielding varieties account for approximately 60% of the rice and 8% of the maize cropping acreage in Thailand (Kush 1995; Groosman *et al.* 1991). As for Africa—with the exception of Kenya, Zambia and Zimbabwe which have built up an efficient seed sector for maize—the African family farm generally saves seed from the harvest and uses it for sowing the next crop.

The fact that modern seed production and distribution systems have failed to gain ground in many developing countries despite considerable efforts by national and international organizations is due to complex institutional, socioeconomic and ecological correlations which to date have not been investigated sufficiently by the specialists in natural science and sociology disciplines.

### **Breeding strategies**

For the main food plants of the tropics, modern breeding strategies have in the past concentrated too much on increasing yield potential through fertilization, crop protection and the development of resistance characters. Despite undeniable breeding results, acceptance by the farmers posed a problem when these varieties were introduced on the smallholdings. Partly, taste and colour of the processed product did not correspond to the requirements of the consumers. Partly, the varieties were not adapted to the cropping systems of the smallholders, their storage methods, the biological and abiological stress factors involved, etc., or the breeding strategies had failed to take into account secondary forms of use such as animal feed, roofing, etc. It must also be noted that the modern breeding and marketing strategies frequently lead to the use of only a few varieties which in turn results in great genetic uniformity. Often, a mixture of different varieties will be used on the same farm in order to reduce the cropping risk. The farmer may, for instance, simultaneously grow varieties resistant to drought and others which will produce particularly high yields under humid conditions. Although this may result in lower overall yield levels than would be achieved with each individual variety under optimum conditions, this strategy will as a rule prevent the disaster of total crop failure.

The yield differences between local and high-yielding varieties were often smaller than expected when they were tested under on-farm conditions (CIMMYT 1987). Local varieties often had the advantage of being better adapted to local

conditions. This included better resistance to disease and higher levels of drought and pest tolerance. The high yield levels of the new varieties could often only be achieved with the corresponding inputs; without mineral fertilizer, pest control and adequate amounts of water, yields often lagged behind those of the local varieties and represented a risk to the farmer. Decisions in favour of specific varieties were also based on their behaviour in mixed crops. Thus cassava, which produces considerable shade, was not planted on fields with many different products. On the other hand, preference was given to shade-producing plants in less complex crop mixtures because they kept down the weeds.

In short, the breeding goals aimed at in the production of high-yielding varieties do not correspond to the requirements of the smallholders. The smallholder's main concern is to achieve stable yields and grow a number of different varieties which are adapted to marginal and climatically varying site conditions, and are suitable for mixed cropping systems. The modern varieties, on the other hand, in order to achieve their yield potential, have to adapt to high rates of fertilizer application, to single-crop systems and to a situation where high demands are made on disease resistance. As early as 1982, Delouche realized that the northern and southern breeding goals were incompatible and urged that the existing inadequate breeding concepts should be corrected and more importance and greater value be attached to the smallholders' traditional practices, selection criteria, quality controls and development and exchange systems. In future, in view of the lack of data, especially on traditional varieties, landraces and seed-production systems, particularly for underutilized crops, it will be most important to take into account the traditional practices of the smallholders in the development of seed-multiplication programs. Decentralized multiplication systems, which are based on the smallholders' varieties and take more account of local conditions, would appear to be most suitable as a first step towards the development of varieties adapted to the low-input farming systems of the smallholders. The adaptability of the traditional seed multiplication systems can best be illustrated by the example of the soy bean in Java which is permanently grown by the smallholders despite its poor storing properties under the local climatic conditions.

Accordingly, varieties which can be considered suitable for the smallholder must meet a number of criteria, the most important one being yield stability under varying climatic conditions. This means that in order to achieve constant high yield levels the variety must be adapted to the length of the rainy period, to both water shortage and an excess of water, to site-specific soil fertility, to the photoperiod concerned and to diseases. In the past, these local criteria have not been adequately taken into account in the breeding programmes. Overall, the diversity of the farming systems, types of land use and cropping conditions make it necessary for crop plants of great genetic diversity to be permanently available to enable a dynamic adaptation process to take place. Obviously in a lot of cases the genetic diversity is endangered or even lost. There is an urgent need to conserve and to protect the remaining diversity and to use it meaningfully.

## **Traditional plant breeding**

### ***Dynamics of traditional systems***

In the past, as a result of the approach that traditional local varieties must *per se* always be inferior to newly bred varieties, both the number of local varieties and their different qualities were underestimated. Even today, dynamic developments and the active role of the smallholders in plant breeding and in the spread of new

varieties is generally still underestimated. Furthermore, our knowledge of the smallholders' criteria is still inadequate as far as variety selection, seed selection, quality traits and the organizational pattern of seed exchange in traditional agricultural societies are concerned.

This lack of knowledge can be illustrated by a few simple facts. In Africa, a number of plants which were introduced from other continents have meanwhile become "traditional" plants. This includes cassava, maize, bananas, beans, potatoes, cacao and sisal. The spread of these species over the entire continent into the optimum cultivation areas generally took place outside the official promotion schemes. How it actually happened and how it was organized is still largely unknown even today. What is definitely known, however, is that the smallholders are continually experimenting and that there is a dynamic flow of information among them. In everyday life it hardly matters whether the existing know-how was handed down, whether it came from the agricultural administration or even from a hostile neighbouring village (Séhoueto 1994).

Field studies have shown that new varieties can spread very rapidly. However, it is often impossible to identify the new varieties once they have been adapted to the local conditions and modified by the farmers.

### ***Seed multiplication and plant breeding***

Plant breeding may be done in a professional way by the smallholders, i.e. with technical knowledge, and/or the varieties may have become adapted by natural selection through the influence of the environment and the cropping system.

From a number of field research projects in West Africa and South America it is known that only very few farmers are able to do their own plant breeding (Cromwell *et al.* 1993; de la Rive Box, pers. comm. 1995). In Oyo State in Nigeria, for example, it was reported that a farmer had collected approximately 20 different cassava varieties from the surrounding area and planted them in his field to watch and compare them. He also carried out trials with cassava plants raised from seeds. These observations are confirmed by reports from South America (de la Rive Box, pers. comm. 1995). Similar breeding and selection experiments are also reported for maize, sorghum and rice. Breeding activities of this kind are absolutely comparable to the work at the research stations, the difference being that they are as a rule considerably less systematic and that the results are less predictable and planned than the experiments carried out at the research stations owing to the limited possibilities of the individual farmers. Just as in the scientific field, the development of the farmer's know-how is a rapid, conscious and sometimes even instinctive process of experiments, variations and selections aiming to find answers to arising questions. This know-how is distributed unequally and, in the traditional societies, is determined less by the individual's age and generation than by his or her personal talent, past experience and the desired characteristics of the crop (Séhoueto 1994).

### ***Adaptation through natural selection***

Most of the varieties actually develop as a result of the plants' adaptation to different requirements determined both by the environment and the personal conditions of the farmers. This means that most of the farmers take a more or less active part in the further development of traditional and new varieties. The cultivation of the plants is affected by extremely variable ecological and

socioeconomic conditions. Recommended sowing dates, for example, will not be adhered to if other important work needs to be done or if a worker is ill or unavailable for other reasons. In addition, the amount of rainfall, the temperature and the quality of the soil will lead to the local adaptation of the varieties through natural selection. Since plants whose traits correspond best to the specific environment concerned have a better chance of survival, the seed for the next crop will contain a larger proportion of these traits than the seed used for the first sowing.

For certain products, a division of work has developed. Some of the farmers have, for instance, specialized in the production of seed. In this way, a market for maize seed has developed in northern Tanzania which offers several local varieties and variety mixtures with new varieties constantly being added. Sometimes when there is a shortage of improved seed, the maize sold for food purposes is also used as seed. Thus in the past few years when hybrid maize seed was sold, the harvest from these varieties was frequently used again as seed. This resulted in a mixture of many different characters. There are, however, also examples of successful cultivation of hybrid maize in Africa, for example in Kenya. Success depends to a large extent on the existence of the corresponding infrastructure (transport, extension services, marketing, etc.). The cultivation of hybrid maize should therefore only be promoted where the necessary infrastructure can be set up and maintained.

#### ***Environment, cultural practices and variety adaptation***

The conditions under which seed is used, the characteristics of the different products and the site-specific conditions considerably affect the multiplication of seed as well as natural selection.

In the case of plants that are propagated vegetatively, such as cassava, potatoes, yams and sweet potatoes, the variety traits are generally maintained much longer than in the case of species which cross easily. Differences between plants are often due to varying environmental conditions. What seems to be a different variety may be the same variety which has developed site-specific traits in a different location. This applies to some bean varieties which will develop into bushes or climbers according to varying photoperiodic and sunlight conditions. Differences in planting dates, temperature and soil quality also affect the plants' growth behaviour. In many African countries, the soils differ even within small areas in moisture content, acidity and available plant nutrients.

The behaviour and growth of plants can also be influenced considerably through the cropping techniques used. For planting cassava, for instance, stem cuttings are used. If the cuttings are planted vertically, a small number of roots, generally one or two, will develop. In Cameroon, in the vicinity of Yaounde, the stem cuttings are covered completely and develop numerous shoots and several small root tubers. Because of the great number of shoots, more leaves can be harvested and used as vegetables. As a result of the different cropping techniques employed, the same variety thus acquires a different appearance which is further influenced by the harvesting of the leaves. When individual stems are removed to harvest the leaves—to continue with the same example—pairs of stems will grow giving the plant a round, bushy appearance.

### **Loss of plant genetic resources**

The multiplication and use of seed differs considerably and ranges from on-farm production to the purchase of seed in the market. Even in the traditional seed-supply systems, the purchase of seed in the market can lead to homogenization of the varieties over large areas.

A good example of homogenization of this kind and reduction in varietal diversity is the production of seed by smallholders in Nigeria. In the humid forest areas in southern Nigeria it is very difficult for the farmers to produce and conserve seed for the next season. The main problems are damage through insect pests and fungus infections. Methods to conserve the seed include mixing it with leaves poisonous to insects or drying and storing it over the open fire. Drying over the open fire in particular has the disadvantage of reducing the germination capacity of the seed. However, with the spread of maize cultivation in the north of the country, a fundamental change took place. The maize bought for food purposes on the markets in the south was found to have a particularly high germination capacity since drying problems do not exist in the north of Nigeria and insects do not pose a great problem either. More and more smallholders began to use the maize from the north not only as food but also as seed. As a result, dozens of local varieties disappeared within a few years.

In all efforts to improve production by importing high-yielding varieties or crossing them to local ones, it must therefore also be taken into account that the large-scale introduction of new varieties into smallholder cropping systems can lead to a rapid loss of valuable traditional varieties. Public and private organizations have attached too little importance to these correlations in the past. Proposals to halt the loss of plant genetic resources point mainly towards the development of varieties with varying genetic background and an improvement of the infrastructure necessary for the conservation and evaluation of plant genetic resources. The improvement of the seed sector should as far as possible be accompanied by the development of efficient systems of resource conservation. Possible approaches might include the conservation of genetic diversity *in situ*, the development of community genebanks and urgently necessary improvements in the coordination of *in situ* and *ex situ* conservation.

## **Approaches to sector development**

### **Breeding and seed production - formal approaches**

In contrast to the industrialized countries, the seed industry in most developing countries is still in its infancy. Apart from national efforts, organized seed production and supply are generally promoted by international organizations (van Amstel and van Gastel 1985) or foreign seed companies which have mainly gone in for the production of hybrid seed of species such as vegetables, hybrid sorghum and soy beans promising high profit margins. In most countries, market demand is therefore generally limited to certain species and efforts to satisfy them and consequently focus on these. The production of seed for high-class products is interesting for national companies as well; it can be expected to continue to increase, but will be limited to a specific market segment. For the growing of vegetables in house gardens, the sale of high-quality seed has evidently gained ground: women in Guinea-Bissau, for instance, buy imported seed for their vegetable production from Dakar; in northern Tanzania, the women buy imported seed from Dar-es-Salaam or Nairobi, or via dealers with far-reaching connections.



Foreign private-sector companies, particularly international corporations, can probably be largely ignored as far as the supply of seed for most of the food crops is concerned, even in the long term. In this area, the public sector will have to take a decisive development initiative and act as a catalyst. The fact that many countries are beginning to privatize much of the public research sector may pose a problem (Engels, pers. comm. 1995).

Kenya and India are good examples of the results which can be achieved by means of improved maize, rice and wheat varieties. However, these results are not only attributable to the breeding achievements, but also to the establishment of official quality controls and marketing channels. In addition to seed, there are consequently further factors of production which are crucial to success and the question remains as to how to set up far-reaching, self-supporting service systems meeting the requirements of the smallholders. Kenya and India have been building up a seed industry since the 1950s with Kenya concentrating on the systematic development of hybrid maize seed production. For the Kenya Seed Company, hybrid seed is still the most important line of production.

Both Kenya and India have become self-sufficient in the production of the basic food crops and in both cases this has been achieved partly through the building up of a seed sector. However, owing to the dualistic structure of agriculture, this has not improved food security in these countries. Higher priority will therefore have to be given to food security in national research in future.

The nonachievement of food security in these countries clearly shows that a completely new role should be assigned to the informal sector in the field of seed production. However, this will require considerable efforts by the public sector and the NGOs at the beginning because of the low purchasing power of the customers and the small profit margins likely to be realized. There are, furthermore, very few countries where the prospects of decentralized seed-multiplication systems have been investigated to an adequate extent. Hardly any data are currently available on either the main demand factors or the possibility of agricultural cooperatives, farmers' organizations and NGOs actively participating in the establishment of decentralized seed production and supply systems. However, it is clear that it will be impossible to draw up blueprints for the promotion of the informal sector in this area, although the systematic development of instruments and methods for the analysis of the informal sector in the field of seed production by smallholders is entirely possible.

### ***Informal approaches***

As already explained, the informal sector has so far rarely been systematically analyzed. The individual reports, analyses and anecdotal accounts found in the relevant literature mainly describe the low level of development of the national seed systems. In the existing literature, reports are also found on projects which have been concerned with on-farm seed production on an individual basis. In addition, activities of considerable importance are being undertaken by NGOs in a number of developing countries. Examples in point are the setting up of community seed banks to safeguard against natural disasters and the implementation of general development programmes on the basis of farmers' initiatives. Technical cooperation approaches have lately been focusing on small-scale seed production and the promotion of the informal sector. Research projects concerned with the systematic study of various aspects of the informal sector have only recently (beginning of 1995) been started by the Centre for Genetic Resources

at Wageningen, *inter alia* in three African countries, the aim being appropriately to link the state services to the informal seed sector. There is, nevertheless, an urgent need for further research work especially on the development of methods and concepts for the promotion of the informal sector. In developing the informal sector, importance should also be attached to the exchange of information and experience between the formal and informal sectors and to issues concerning the conservation of plant genetic resources. In all probability, the promotion of the informal sector will become a matter of such strategic importance within the overall promotion of national agriculture that as far as Africa is concerned it will develop into one of the central tasks in development cooperation in the medium term. In this context, the local communities and NGOs will play a major role. National agricultural research in cooperation with NGOs and small farmers should take an active part in the proposed analysis and development of the informal sector to enable strategies for sector promotion to be developed in the long term.

In view of the dual agricultural structure in many developing countries and the one-sided concentration on high yields as a primary breeding goal (also in breeding for resistance), the responsibility of the public/formal sector for the promotion of a seed-multiplication programme for food crops which is geared to the requirements and structure of the informal sector cannot be emphasized sufficiently. It will be mainly up to the formal sector to investigate possible ways of setting up a decentralized seed supply system under special consideration of a high degree of genetic diversity maintenance and with the active cooperation of the NGOs. To this end, an exact analysis is required of in which areas of sector development the anticipated profits are likely to permit the sustainable development of an efficient private-sector industry and in which areas the long-term involvement of the state will be necessary. It is entirely conceivable and would be desirable to incorporate approaches and developments of this kind into regional rural development projects and programmes.

### ***Conclusions for international agricultural research***

As already explained, the family smallholdings generally obtain their seed via the informal sector. Although the importance of the informal sector is confirmed by the available data, concepts for its promotion have hardly been developed to date. The high proportion of traditional varieties grown by the farmers is visible proof of the inefficiency of the institutional plant breeding system. This is attributable both to the low level of acceptance of new varieties (adaptation to local cropping conditions, requirements of the farmers) and to the fact that the public sector lacks the necessary specialists for the development and marketing of the products while the private sector is not sufficiently developed to carry out these tasks. These deficits are also causing projects for the transfer of new techniques for the production of seed and planting stock to fail unless they cover the entire sectoral scope of tasks (Wolpers, pers. comm. 1995).

The findings of international agricultural research in the field of plant breeding are unlikely to be applied in practice on a sustained basis until access is gained to the informal sector via national agricultural research (NARS). Strategies for sector promotion will have to be accompanied by measures for the conservation of plant genetic resources. Activities aimed at promoting the informal sector should be based on the results of systematic studies focusing on the further development of existing systems. For these reasons, it will be extremely important to study the multiplication strategies of the small farms so that measures in the form of

decentralized seed multiplication, community initiatives, etc. can be implemented in accordance with the findings.

The study of the local systems should also cover dynamic changes, document the diversity of the systems, identify the preconditions for changes and precisely analyze the demand for seed. On the basis of the findings it will also be possible to develop measures for the conservation of plant genetic resources. At the same time, the local institutions should be strengthened in the area of development of instruments and methods for the analysis of the informal sector in order to enable successful concepts to be developed and transferred to farm level. This should also promote contacts and information exchange between the formal and informal sectors. The development of new strategies to build up efficient seed supply systems—especially in cooperation with NGOs—should be regarded as a priority area of development cooperation and should be promoted accordingly.

### ***Conclusions for international development cooperation***

Improved varieties are of basic importance in any efforts to increase the productivity of smallholder farming systems. Modern plant breeding strategies have evidently not completely done justice to these expectations so far. Furthermore, the possibilities which have meanwhile become available to the breeder through modern biotechnological processes will not have an impact at farm level until the new varieties correspond to the extensive requirements of the smallholders. The ongoing discussion regarding the structures needed for the development and spread of biotechnological processes/products in the developing countries studied clearly shows that the public sector currently still has to play a decisive role in the promotion of the seed sector (Wolpers, pers. comm., 1995). To enable the overall structures necessary for the successful development and use of the existing breeding potential to be set up in a country, extensive concepts have to be developed which should be based on decentralized seed multiplication systems. This would lower the high costs of central seed multiplication systems (IFPRI 1991), would enable more account to be taken of local requirements and would permit use to be made of the innovative capabilities of the informal sector in respect of the breeding and conservation of plant genetic resources. New seed multiplication concepts aimed at strengthening seed production by smallholders and village communities should consequently be based on the traditional local seed-multiplication systems. These concepts should in particular aim to promote national institutions with a view to the development of instruments, methods and interdisciplinary analyses in order to enable sustainable sector concepts to be elaborated. The past three decades have shown that there is an urgent need to formulate new, unconventional development approaches for the plant breeding, seed multiplication and seed marketing sectors. To this end, the countries of the north and those of the south should cooperate closely.

### ***Action required***

For the second Green Revolution considered essential for Africa to reduce the food deficit which is reaching threatening dimensions in that part of the world, **new research paradigms** will definitely be required (Chambers 1993). In contrast to the first such revolution, this second one should promote decentralization, take more account in research and development of the diversity and complexity of the farming systems and give priority to the identification of a wider range of crops and to the

principles and practices of the smallholders (Chambers 1993). In view of recent developments at the CGIAR (Consultative Group on International Agricultural Research) in the direction of cooperation with the national partners, and the growing need to identify development paths for the agriculture of the tropics and subtropics which pursue new methods of participative agricultural research, it will be necessary—especially in the plant breeding and seed sectors—to develop completely new project concepts calling for joint efforts by farmers, NGOs, NARS, donor agencies and technical cooperation.

In this context, it will be of prime importance **to analyze the production and distribution of seed through local systems** using the knowledge of scientists from the south. In addition, **studies should be carried out concerning specific aspects of seed multiplication and use** in order to increase knowledge in this field and to enable the priorities in seed multiplication and distribution to be geared more closely to the actual requirements of the farmers. The goals pursued to date in variety breeding should be compared with the results of the studies already described and adapted accordingly. Subsequently, a comprehensive **analysis of the potential and weaknesses of the existing systems** will prepare the ground for the promotion of special enterprises for the production of seed by farmers under local conditions.

In the plant breeding sector, **individual measures in the form of comprehensive interdisciplinary projects** should initially be planned to test the bases of corresponding sector projects. For selected plant species, particularly for the underutilized crops, **decentralized breeding approaches should be pursued and seed multiplication systems set up** which are based mainly on autochthonous methods of seed multiplication. In this context, it should be mentioned that cooperation between ongoing conservation, breeding and research programmes concerning biological diversity and its utilization will have to be intensified. The International Agricultural Research Centres (IARCs) should be actively involved in the corresponding measures. During the analysis phase of the projects and measures to be planned, **the national market should be studied** and, depending on the anticipated commercial benefits, the seed multiplication systems should be planned to operate in the form of either private-sector or public-sector enterprises. These analyses should also cover **the processing and use of, as well as trade in the products concerned**. **National agricultural research should develop participative methods for the analysis of the informal sector** and apply its findings in practice in close cooperation with NGOs and farmers. **The project concept should cover both the underutilized crops and the principal food staples of the region concerned**. Efforts should be made to set up an intensive external monitoring and evaluation system during the actual implementation of the project.

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## Farmers Managing Crop Diversity

### The compatibility of grassroots breeding and modern farming

*Trygve Berg*

NORAGRIC, N-1432, As, Norway

#### Abstract

Grassroots breeding is most often found as a component of vanishing traditional farming systems. A case from the Philippines is presented where seed selection has reappeared among modern farmers after switching to organic agriculture. While the adoption of organic farming is influenced by NGO movements, the reappearance of seed selection seems to be spontaneous. Certain trends in scientific agricultural research, integrated management of pests and soil fertility, are bringing modern and alternative forms of agriculture closer to each other. Could these trends generate a need also for integrated seed management and participatory methods of plant breeding?

#### The fall and rise of on-farm selection

The introduction of farm technology packages, including high-yielding varieties and chemical fertilizers, has resulted in the decline of traditional seed selection in many areas on all continents. When these technology packages now seem to reach their limits and farmers as well as scientists are looking for new ideas, the on-farm seed selection may reappear and become a component of new post-Green Revolution technologies. A case from the irrigated rice system at the Philippines will be used as an example.

High-yielding varieties were introduced together with other technology components and a clear extension message: "the high-yielding varieties are pure and off-types are impurities". Farmers were advised to rogue off-types if they were saving seeds and to renew their seeds at intervals of a few years in order to maintain varietal purity. A sophisticated seed infrastructure was established in order to maintain varieties unchanged. That meant suppression of the urge to diversify inherent in the nature of the species, and it meant suppression of the curiosity of diversity inherent in the minds of the farmers.

But suppressive regimes are hard to sustain. Sooner or later there will be a rebellion, by individuals first and eventually by mass movements.

When visiting a project at Mindanao in the Philippines in September 1994 I met a farmer named Eulogio Sase Jr. He told about a field of rice which was established in 1985 with seeds of an IRRI variety that he had got from another farmer. He noticed a dark green off-type and marked it with a stick. The water buffalo ate part of it, but he managed to save four panicles. One month later he planted the seeds after soaking them in water for 3 days. Then he planted it in a small plot with a spacing of 40 x 40 cm. That gave profuse tillering, an average of 42 tillers per plant and a harvest of 30 kg. He used it again and harvested 127 bags. Then he started spreading it under the name Bordagol which means "strong". It is now a popular variety. It is claimed to be high-yielding but with a better taste than the IRRI

varieties. In the beginning it was also resistant to the Tungro virus but that resistance was lost in 1989.

I got this story from Mr Sase himself, but it was confirmed by other farmers who grow it. The variety and its origin as a farmer's selection is also known in Philrice (The Philippine Rice Research Institute in Los Banos). According to Mr Sase's experience, off-types start to appear in the second or third generation of new seeds. This has happened also in Bordagol. I met farmers who grow a selection from within Bordagol.

This act of anti-Green Revolution behaviour may have prepared for a change in attitude to off-types and variations within a variety. Farmers who were provided with traditional varieties in connection with an organic farming programme<sup>5</sup> immediately started discussing seed selection. Screening of varieties was the immediate challenge, but varietal heterogeneity was seen by some farmers as an invitation for selection within varieties. And they talked about it with enthusiasm. "Selecting plant types is equally as exciting as panning for gold", one of them said. He was a former gold panner. In 1994, only 2 years after the start of the programme, several farmers already had their own selections, and they wanted more varieties for trials. Generally they preferred heterogeneous varieties because they provide more opportunities for selection. They also discussed merits and shortcomings of the different varieties and thought of making crosses to combine desirable traits from different sources. One farmer had started his own crossbreeding.

Studies of farmer selection normally take researchers to remote or marginal areas where traditional farming systems have survived. This group, however, are modern farmers. They are well educated, some of them in high school. They are used to the high-input system and high-yielding varieties. Most of them said that they had taken over their farms after the Green Revolution and said that they had no personal memory of pre-Green Revolution technologies. But seed selection reappeared.

Do we dare to hypothesise that seed selection may reappear spontaneously anywhere when we no longer manage, or no longer see any reason for keeping up, the pressure that maintains the uniformity of seeds? For areas where the modern seed infrastructure is missing or too expensive, the maintenance of farmer selection of seeds is an obvious necessity. But could it also survive in areas where a sophisticated seed infrastructure is present and functioning? In the case at the Philippines, it happened after a gradual erosion of the benefits of the pure variety, high-input system, but that trend is widespread. In wide areas farmers experience declining soil fertility after many years of fertilizer intensive production (IRRI 1994), and profit margins are also declining (Pingali 1993) bringing many small farmers into problems of debt. The switch to organic farming is usually an attempt to escape from the debt trap. However, science also has to respond to the ecological and economic crisis of the conventional system. Individual researchers are about to depart from established ways of thinking. A new paradigm is being formulated.

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<sup>5</sup> CONSERVE (Community Based Native Seed Research Center) is located in Cotabato, Mindanao, the Philippines. The project works for the conservation and use, including improvement, of traditional rice and maize varieties, and for the promotion of organic farming. It started operations in April 1992. My own visit to the project took place in August 1994.

### **Post-Green Revolution technologies: toward integrated approaches**

The conventional way of thinking—"Overcome soil constraints to fit plant requirements through purchased farm inputs"—is being replaced by a **second paradigm**: "Rely more on biological processes to optimise nutrient cycling, minimise external inputs, and maximise the efficiency of their use" (Sánchez 1994). This is the soil science version of the second paradigm. In plant breeding this means less emphasis on the modification of environment and more emphasis on modification of crops to fit the environment (Ceccarelli 1996).

Once such new ways of thinking are accepted, science has an enormous capacity to make them parts of mainstream approaches. This is evident from the history of integrated pest management. The original movements called for strictly alternative pest management, but as a result we got the more balanced integrated methods, now almost universally accepted.

Technology of integrated management of soil fertility is on the way and will be a welcome successor to the pure reliance on chemical fertilizers as well as to the dogmatic versions of organic farming. Similarly, integrated weed management technologies might come next.

Considering the objectives of the various alternative agriculture movements, Evans (1993:380-81) concludes that "... modern agriculture is already moving in the same directions, to a more sparing, timely and effective use of inputs, to a more integrated approach to pest management; to closer local adaptation; and towards the optimum use of the resources available through more informed and expert management".

But these developments are changing the entire agrosystem to which plant breeding is tailoring our crops. When integrated approaches to management of soil fertility, pests and weeds are coming, integrated seed systems may have to follow suit.

### **Toward an integrated seed system**

Modern plant breeding is associated with a seed system that favours broad adaptation and wide use of a small number of market varieties. It does not tolerate intravarietal diversity. Therefore the system limits the options available for scientific breeding. Typical examples are breeding for disease resistance and for specific adaptation. Such things are often commented upon in theoretical literature, sometimes with resignation since the seed system and its requirements are taken for granted.

In a paper on plant quantitative genetics, Mayo (1990) concluded that multifactorial resistance would be an obvious advantage because of "its slower rate of breakdown and its broader responses". But still this form of resistance "rarely had a place in resistance breeding". With application of genetic engineering he predicted that quantitative methods would be limited even more.

Reviewing the history of boom and bust cycles of pure-line barley varieties in North America, Steffenson (1992) considered the alternative of introducing more genetic diversity. He found it impractical because of the rigid cultivar identity requirements of the malting and brewing industry.

But looking away from cultivar identity requirements by industry and seed certification authorities, there are great potentials in quantitative methods, as shown by Allard (1990). In studies of the disease response of a barley composite cross, he found that the parents of the original population must have had at least 29 different loci for resistance to local races of barley scald (a fungal disease). On the



assumption of only two alleles per locus, they can be combined in  $7 \times 10^{13}$  different ways. The natural sorting and selection of that diversity has kept the population's resistance to this (and other) disease(s) stable, also in "years during which diseases have devastated commercial varieties". Allard concluded that "natural selection is likely to be more successful at this task than are geneticists, genebank personnel and plant breeders".

We may question why plant breeding should continue being subservient to a seed system that blocks the exploitation of this effect in applied plant breeding. The same question may be made about specific adaptation. With the "second paradigm", less emphasis on modification of the growing environment and more emphasis on modification of plants to fit the environment, location-specific adaptation will become more important. This may increase the demand on the genetic resources. Quoting Evans (1993) "The wealth of genetic variation in adaptive responses to soil and climatic conditions conserved in the world's genebanks is little known and less used relative to that in resistance to pests and diseases, but it may yet prove to be the most important genetic resource of all". This links genetic resources to the "second paradigm" of agricultural development.

The world needs different approaches to development. The developmental trends discussed here might not become universal, but may become important. Seeds and Intellectual Property Rights legislation should have sufficient openings for the survival or reappearance of a seed system that allows crop evolution and seed selection to take place at farm level. While grassroots breeding is incompatible with the commercial seed system, it may not be incompatible with modern farming. The trends considered here are likely to create niches for participatory breeding approaches.

### **Methods of participatory plant breeding**

In principle, participatory breeding leaves germplasm enhancement with the scientific sector and devolves selection to the level of the community. For this to succeed, participatory research methods must be adapted to the needs of plant breeding, breeding methods must be modified for the participatory approach, and communities must be organized and motivated for their participation. All of these three preconditions are now sufficiently developed for the wider adoption of participatory methods in plant breeding.

Participatory research methods provide a rapidly evolving framework for fruitful involvement of farmers in technology development. Sperling and others (Sperling *et al.* 1993) have elaborated those methods for application in plant breeding. Ceccarelli and others at the International Center for Agricultural Research in the Dry Areas (ICARDA) have made significant progress in adapting breeding methods for decentralized selection. The organizational platform is also in place: NGOs and community organizations with genetic resources programmes are coming up, and growing, all over the world (Berg 1995).

Farmers can be involved at various places in the chain of events that leads to the generation of new germplasm for use in agriculture:

- in the final stage of variety testing, or screening of breeders' lines (Maurya *et al.* 1988; Witcombe and Joshi 1995).
- in line selection from bulk populations provided by breeders (Witcombe and Joshi 1995; Ceccarelli *et al.*, this volume).
- in planning and decision of what to cross (i.e. Sperling *et al.* 1993).

The form of involvement may depend on the perspective. Do we involve farmers in plant breeders' business, or do we involve scientists in farmers' business? In the first case, the work might lead to identification of materials that could be candidates for official release as new varieties (Witcombe and Joshi 1995). If, however, the farmer is selecting for her/himself, the materials will be maintained as evolving populations. Such populations could of course be a source of line selection, but that would not be the farmer's intention. They would maintain their materials as landraces and distribute them by diffusion in the community.

Both of these perspectives are warranted and have comparative advantages according to circumstances. Personally I am more fascinated by the second perspective; the independent farmer breeder and her (his) evolving populations. Returning to the case of the farmer who selected the rice variety Bordagol, it may be argued that such cases are rare. And that is true. They are so rare that they are unlikely to appear in the limited areas of experimental fields at research stations. But such cases do occur within the millions of hectares of land which are managed by farmer breeders. Imagine an African family sitting outside the hut shelling groundnuts. Every single seed passes through the hand of one of them. All of a sudden an abnormal seed comes out of the shell. It attracts everybody's attention. It is passed around and, if found interesting, put aside and planted at a special place for observation next season. Dismissing the cadres of seed selectors that are required to detect and screen such spontaneously occurring variation may not be a wise contribution by the modern system.

The reappearance of seed selection in a community where traditional seed selection was not only discontinued but also forgotten is exciting. These farmers have been exposed to science in school. Some of them keep written records of what they are doing. They may go their own ways, but the farther they go, the deeper they involve themselves in the breeding, and the more they will understand of the limitations of their germplasm and their methods. Motivation for scientific involvement can only grow.

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## **Participatory diagnosis as an essential part of participatory breeding: a plant protection perspective**

**Peter Trutmann**

Swiss Centre for International Agriculture (ZIL), Zurich, Switzerland

### **Abstract**

Efficient diagnosis, which incorporates participatory approaches, is argued to be a part of and the basis for effective genetic interventions and participatory breeding strategies for systems broadly considered as traditional. Diagnostic research of plant disease constraints for beans in the Great Lakes Region of Africa is taken to illustrate the point. In these studies, varying levels of farmer participation were used to determine the importance of diseases versus other agronomic constraints, and to understand existing local crop disease management practices as well as farmer perceptions of disease. It was determined that disease control could enhance bean yields by 52-59% over local practices and that six diseases accounted for most of the yield increases, and yet farmers did not recognize individual diseases except as being the effects of fertility or some types of rain. Locally there was a strong selection against varieties susceptible to rain. Farmers placed importance on states of susceptibility that led to illness rather than on treating the illness. Their disease-management strategies were principally prophylactic. It follows that the use of genetic resistance when it consistently reduces disease severity should be compatible with local strategies of disease management. Farmer management strategies rely on the availability of options to change the state of the crop in order to avoid disease. Locally, genetic diversity is effectively used to tailor for a multitude of environmental conditions. Often mixtures exist for different fields and seasons. Depending on the region, local bean mixtures already contain substantial amounts of resistance to at least some local diseases such as anthracnose. The choice of farmers' management options must not be reduced through new genetic interventions. Some fundamental rethinking is required on the appropriate genetic strategies required for plant disease control in the Great Lakes Region to ensure that additional resistance will better control the whole complex of diseases that affect beans without eroding genetic diversity in mixtures. Including farmers in the process of selecting and breeding new varieties is a welcome strategy. It empowers farmers to build on their knowledge and value systems, thereby reducing the chance of genetic erosion.

### **Introduction**

In the 1970s around 50% of the world's population, 40% of agricultural land (Wellhausen 1970) and 70% of the poor (Todaro 1977) depended on systems that can broadly be characterized as traditional. Today these figures have changed. The percentage of developing country populations living in urban centres has increased from 24.7% in 1970 to 37.1% in 1990 (Abdulai and Rieder 1995). It is a great concern that subsistence systems, which today exist principally in less favoured and heterogeneous environments, have mostly been bypassed by the Green and post-Green Revolutions. In contrast, major production increases have been achieved in the more agriculturally favoured areas, especially in irrigated areas. Spectacular production increases through genetic improvement and high inputs in the favoured areas prevented famines and in some cases produced food surpluses for export.

Many of the present strategies for commodity improvement of the centres belonging to the Consultative Group on International Agricultural Research (CGIAR) stem from successes achieved in the favoured and more climatically uniform areas. However, the successes driven principally by germplasm-displacement strategies using high-yielding, high-input varieties have resulted also in problems. Some of these have been caused by severe genetic erosion. Many authorities are now promoting research for favoured areas at the expense of that for the less favoured regions where traditional agricultural systems still predominate. Considering that a large proportion of the human population still depends on traditional genetically diverse agricultural systems and that urban populations often stem from poor rural areas, it would be a mistake to neglect traditional agricultural systems. A better approach would be to re-examine the value of previous approaches used to provide technologies for these often heterogeneous environments in order to develop more sustainable and more farmer-centred strategies. New concepts are now emerging to devise better ways to improve local agricultural systems in heterogeneous environments.

In this paper the role of interdisciplinary, participatory diagnostic approaches will be considered as an integrated part of genetic improvement in traditional systems.

#### **Case study: diagnostic approaches in setting plant protection priorities**

An estimated 11 million people in the Great Lakes Region of Africa (Rwanda, Burundi and the Kivu region of Zaire) depend on *Phaseolus vulgaris* L., known as common bean, as their principal source of protein. The region has one of the highest population densities in Africa. Beans were brought from the Americas to Africa originally by Europeans in the 16th and 17th centuries and introduced to the region probably hundreds of years ago through African or Arab traders. Today East Africa and the Great Lakes Region are regarded as a secondary centre of diversity for beans. Even the earliest European records in the region describe at least 60 different seed types and colours in Burundi (Meyer 1916). Research in the region on the crop was begun in the 1940s.

In 1983 the Centro Internacional de Agricultura Tropical (CIAT) was invited to initiate a programme to improve the productivity of beans in the region together with existing national programmes of Burundi, Rwanda and Zaire and was supported by the Swiss Development Cooperation (SDC). It became clear at an early stage that little was known about the bean production systems in the region. From 1984 onwards diagnostic research was conducted through anthropology, agronomy, nutrition, plant protection and breeding. Diagnostic breeding work initially concentrated on better understanding the population dynamics in mixtures. From that it became clear that farmers practised strong selection pressures to maintain the composition of mixtures. Greater knowledge and appreciation of the local systems led to the now much recognized participatory selection and breeding initiatives (Sperling 1992).

#### **Approaches**

Initial diagnostic on-farm trials were designed to determine which major agronomic factors were most limiting in various regions. Previous data were qualitative and station oriented. Participation of farmers in these on-farm trials was limited to the agronomic management of plots which were an integrated part of farmers' own bean fields, delineated only with pegs to distinguish treatments (Trutmann and

Graf 1993). The trials were managed as part of a normal bean crop by farmers. Farmers were also present at evaluation and on-farm discussions.

Farmer disease perception studies were conducted in Rwanda and the Kivu region of Zaire (Trutmann *et al.* 1995). Firstly, farmers were consulted on their perception of major production constraints. Thereafter farmers were surveyed about their knowledge of individual bean diseases and pests using available material and photographs. Subsequently, a 2-month structured group study was conducted of farmer perception and management of diseases in six villages within the Kivu region of Zaire. In each village, groups of six people locally regarded as good farmers (three men and three women) participated in repeated structured group discussions.

Farmer plant protection management studies were conducted using initial farmer surveys and later the farmer study group in Kivu. These data were augmented by various individual experimental findings (Trutmann *et al.* 1993). In addition, two nonparticipatory studies were conducted to better understand the dynamics of mixture and disease management by introducing disease-resistant varieties into local mixtures (Pyndji and Trutmann 1992; Trutmann and Pyndji 1994).

## **Findings and implications**

### ***Selection and breeding practices of farmers***

Selection of site-specific mixtures in newly settled areas commences by farmers selecting germplasm generally adapted to the numerous specific on-farm environments and soil conditions. At this early stage many farmers sow any seed they can obtain. At harvest seed of the survivors is collected. The process is continued until a satisfactory mixture is obtained. The varietal mixtures for various fields are often kept separately. In established areas the formal surveys indicated a more conservative selection process (Voss, pers comm. 1995). Here farmers fine tune mixtures to include individual preferences for seed colour, seed size, taste, etc. A selection was observed for and against various seed colours and against seed blemished around the hilum (a common indication of seedborne pathogen infection). Consequently, it may be worthwhile to use different germplasm-based improvement strategies in various areas depending on the stage farmers have fine-tuned their mixtures. The greatest potential to introduce large amounts of new genetic material into the system is clearly in areas where farmers are still in the initial stages of adapting bean germplasm to their specific environments.

### ***Identification and setting of breeding strategies***

#### **Biological constraints**

On-farm, multi-seasonal diagnostic trials whose agronomic portion was managed by farmers determined that diseases are a major constraint to bean production in the region (Trutmann and Graf 1993). Eliminating major disease and pest constraints increased yield almost 52-59% and 17-32% respectively. Extrapolations to the national level in Rwanda suggested that annual bean yield losses were of the order of 220 000 t for diseases and 90 000 t for insects. Together, such increases could feed an additional 4.6 million people assuming consumption of 60 kg beans per person per year. Overall, angular leaf spot, anthracnose, phoma blight, floury

leaf spot, rust and root rots disease severity were associated with most of the yield losses. It follows that management of these diseases must be a high priority. Genetically, this would suggest that incorporating various types of resistance, depending on region, would be most valuable to farmers. However, the issue is more complex.

### Perceptions

When we consider how farmers perceive diseases, further considerations become important. Farmers in the Great Lakes Region perceive certain forms of rain as the cause of diseases which cause soft rot on plant tissue (Trutmann *et al.* 1995). Similar, but not the same, farmer perceptions have been reported in Central America (Bentley 1991). Other diseases such as angular leaf spot and bean common mosaic virus are associated by farmers with fertility or variety traits; differences in opinion exist between farmers.

Farmers' perception of plant disease is linked to attitudes on human illness. They concentrate on the prior state of health and often employ prophylactic rather than curative disease management practices. For example, too vigorous leaf production of certain varieties is disliked because it causes humidity problems that cause rotting beneath the canopy and such plants often do not produce much seed; they "burn" themselves out. Action is taken based on the state of plant health. In climbing-bean areas, farmers remove leaves of too-vigorous (leafy) plants. However, a variety disliked for its predisposition to rain in fertile soils might be chosen for more infertile soil where it may grow less vigorously. Similarly, farmers select against varietal traits associated with susceptibility to rain.

Principally, it was concluded that:

1. Farmer variety selection practices could be made more efficient if farmers were empowered with better knowledge of individual diseases.
2. Farmers' disease management is based on prophylactic measures. Consequently it is likely that similarly based interventions rather than curative measures are more compatible with local practices. Genetic improvement with the right genes used with the right intervention strategy is one clear compatible option.
3. Our studies were closely interlinked with other sources of diagnostic information. This indicated that the overwhelming majority of farmers consciously preferred using variety mixtures over single varieties.

As mentioned earlier, farmers strongly select against rain-susceptible material. Highly site-specific mixtures exist to cope with the multitude of conditions in mountainous areas. If on-farm germplasm specificity and variability is to be retained and improved it will be at best inefficient to provide germplasm for these specific environments without participatory approaches. Farmers are likely to be able to find the best use for new germplasm—an argument to involve farmers in the breeding and selection process as early as possible

### Management of genetic resources

Farmers' disease management practices are integrated with other plant protection measures (Trutmann *et al.* 1993). It is clear that farmer bean disease management is dependent on the availability of management options. Flexible use of management options is critical to farmer plant protection strategy. Management of genetic variability is one tool used by farmers to manage plant diseases and numerous

other crop protection factors. One important strategy, for example, has been the maintenance of appropriate mixtures for specific conditions. It follows that breeding strategies for these systems must not reduce the existing farmer management options.

Farmers were unable to provide much information on the resistance in their mixtures to specific diseases. Consequently, participatory diagnostic knowledge was supplemented with studies to better characterize local variety mixtures and to provide guidelines for appropriate genetic intervention strategies for genetically diverse crops such as beans in the Great Lakes Region. Firstly, a mixture incorporating equal quantities of 20 local mixtures collected in two regions was exposed to the local pathotypes of *Colletotrichum lindemuthianum*, the causal agent of bean anthracnose (Trutmann *et al.* 1993). There are great methodological problems in investigating varietal mixtures. We know that bean mixtures are highly variable (Adams and Martin 1988), no seed being genetically identical. Without uniform seed, standard replicated trial designs are not possible. For this reason we determined resistance of seed types using controls with uniform standard susceptible varieties to determine the evenness of inoculation pressure. A sizable proportion (35%) of seed types in local mixtures were resistant to anthracnose. The proportion that these resistant seed types occupied in the mixture was region dependent. In regions favourable for anthracnose, resistant seed types occupied 25% of mixtures. In lower-lying climates less conducive to anthracnose, they made up only 16% of the mixtures. Despite this, it was clear from on-farm diagnostic trials that in regions favourable for anthracnose, the disease remained one of the most important constraints in local mixtures. One explanation for this phenomenon is that a balance is established in mixtures between resistance to various diseases to optimize multiple disease control. The resulting overall level of control may be suboptimal for individual diseases, but may provide the most effective management of multiple diseases. It is evident that more research is required to provide better insights.

In practical terms we are left with a dilemma. Anthracnose was identified as a priority disease in diagnostic trials. A logical response for germplasm improvement was to place incorporation of resistance to anthracnose into germplasm high on the regional research agenda. Yet, if varietal mixtures already contain significant amounts of resistance and if mixtures optimize the proportion of resistance genes to manage multiple (not individual) diseases, what contribution are present breeding strategies really providing? It is very evident that we require better information on the way single and multiple diseases are managed within highly genetically variable plant populations of the Great Lakes Region.

A start has been made to understand the dynamics of adding a resistant variety to local mixtures to manage angular leaf spot disease and to increase yield. On-station trials indicate that where angular leaf spot is the predominant problem, significant reductions in angular leaf spot severity are obtained by adding a resistant variety to 25% of a local mixture. A protection of 'susceptible' local varieties, known as 'the mixture effect', was also observed (Pyndji and Trutmann 1992). Yield increases comparable to using 100% pure resistant variety were obtained in such cases due to yield increases above the expected from purely additive interactions (Trutmann and Pyndji 1994). We concluded that substantial benefits for angular leaf spot control could be achieved through displacement of only 25% of local mixtures with resistant varieties.

The question became more complicated in multilocational trials where angular leaf spot severity was reduced and yield increased only proportional to the



promotion of resistant variety occupied in the mixture. There were no mixture and yield enhancement effects (Trutmann and Pyndji 1994). The reasons for the results are still unclear. Possibilities include the interaction with other important diseases which negated benefits obtained from angular leaf spot control and/or inoculation of angular leaf spot from nearby plots in which case the protective effects on susceptible mixture components are lost (Wolfe 1985). The size of the proportions of resistant varieties required in mixtures to manage a disease need to be considered, because genetic erosion increases with the proportion of the variety required for disease control. Multiple disease control could cause substantial genetic erosion unless well managed. Presumably, participatory approaches as outlined by (Sperling *et al.* 1994) would minimize the dangers of large-scale displacement of local germplasm.

### Conclusions

It is evident that our understanding of disease management in local bean mixtures is still in its infancy. Although some information is available on the farmer level, many questions which have bearing on disease management using genetic improvement strategies remain unclear. The subject of combining participatory methods with backstopping research is an exciting area for national and international scientists. Clearly, diagnosis is a continuing process in these still poorly understood systems. They are complex, and technological improvement is dependent on the joint knowledge and efforts of both farmers and scientists. In the end, the effectiveness of breeding efforts depends on the quality of genes offered to farmers by breeders and on the strategies used to incorporate the genes into local systems. Accurate diagnosis will remain a key.

### Dedication

This paper is dedicated to Epiphanie Mukaremera and Gaspar Gasana, both of whom I worked with closely and respected highly. They were reported killed in the genocide in 1994. *A part of me has also died with you.*

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## Results, methods and institutional issues in participatory selection: The case of beans in Rwanda

*Louise Sperling*

New Delhi 110 057, India

### Abstract

The paper presents results of a 5-year programme (1988-93) on participatory selection of beans (*Phaseolus vulgaris* L.) in Rwanda. It looks at the technical and social challenges of integrating farmers into on-station selection as well as issues in setting up a country-wide programme on decentralized selection in community plots. Choice of farmers, trial design and evaluation procedure can affect the technical findings but also influence the potential to institutionalize participatory selection procedures on a broad scale. Some of the trade-offs between a research-focused versus a development-focused participatory selection programme are highlighted. Finally, the paper discusses participatory selection in light of the recent and wide-scale civil disruptions in Rwanda. Farmer-centred methods are being used to evaluate possible varietal and genetic erosion, and participatory selection has been proposed as a major means for reintroducing landrace material to Rwandan communities.

### Introduction: Beans and bean expertise in Rwanda

Beans (*Phaseolus vulgaris* L.) are pivotal to the Rwandan household. Eaten twice daily—with pods, green seeds, leaves and grains all variously thrown into the cooking pot—beans provide 65% of the protein and 32% of the caloric intake (MINIPLAN 1988). Beans are the 'meat' and to some extent the 'bread' of the Rwandan countryside.

The centrality of beans for nutrition is matched by their key role in agriculture. Grown by 95% of farmers, in all major regions of the country (from 1000 to 2200 m), beans are sown two and sometimes three seasons a year. A third remarkable aspect lies in their genetic diversity, with Rwanda providing one of the most varied and vibrant bean varietal pools in the world. At least 550 local varieties are found countrywide, with important and unique types having evolved from both the MesoAmerican and Andean gene pools (Scheidegger in CIAT 1993, S. Beebe, pers. comm. 1995). Households manage varietal mixtures of up to 30 components (Lamb and Hardman 1985; Voss 1992), altering blends according to different soil conditions, crop associations and seasons. Such mixture use encourages production stability as well as utilization of the country's highly diverse production niches.

Yet, while most Rwandan farmers need and directly grow beans, have been exposed to very diverse materials and manage complex mixes, they were for many years at the fringes of the research system. The selection sequence of the Institut des Sciences Agronomiques du Rwanda (ISAR), paralleling western models, sought farmer feedback at the very last stages, in on-farm trials, if at all. Further, farmers were offered but 2-5 options; the tip of a selection funnel originally numbering some 200 entries. Follow-up surveys in 1988 showed that ISAR had some laudable bean successes, but short of what could be expected in a country where a Rwanda farmer on her own may test 75-100 varieties in a lifetime (Sperling 1992).

In was in the spirit of improving performance for highly heterogeneous production environments that ISAR and International Center for Tropical Agriculture (CIAT) researchers took the first steps toward a participatory selection programme in 1988. Two key questions shaped inquiry. Was there 'untapped potential'?—that is, could farmers absorb and productively use a much greater range of cultivars than that currently delivered by the formal research system? Second, could breeders and farmers, working together, achieve important gains: could they target more environments, faster and more productively?

## Overview of the participatory selection programme

### **Phase I: 1988-90**

The results of the first phase of research have been reported elsewhere (Sperling 1992; Sperling *et al.* 1993). In brief, from 1988 to 1990 the experiment centred on participatory, on-station screening. Local experts in Rwanda, drawn from the pool of older women, evaluated 15 cultivars in on-station trials for two to four seasons before normal on-farm testing. On-station evaluations revealed that experts select bush beans along two general axes, preference and performance criteria, with many of the attributes not easily anticipated in a formal breeding framework. On-farm results demonstrated farmers' ability to target cultivars from station fields to their home plots. Farmer bush bean selections outperformed their own mixtures with average production increases of up to 38%; breeder selections in the same region on average showed negative or insignificant production increases. In addition, the diversity of cultivars desired by farmers was considerably greater than that normally on offer: the number adopted over the 2-year experimental period, 21, matched the total number of varieties released by the national programme in the previous 25 years (Sperling 1992; Sperling *et al.* 1993).

The first phase of the participatory selection, although collaborative, remains very much research-oriented. The major conclusions are summarized in Box 1.

#### **Box 1. Participatory selection with Rwanda bean farmers: Technical results Phase I, 1988-90**

- Communities recognize differing expertise in varietal selection. These go beyond the frequently cited divisions of gender and age. Some women are known for astutely distinguishing among varieties for particular farming contexts.
- Farmers' varietal criteria overlap with breeder concerns but also contain 'composite' traits. These composites, which represent combinations of features, help determine actual performance on-farm and are hard for formal breeders to anticipate.
- Farmers can target from station to on-farm plots, both meeting their own agronomic and socioeconomic criteria and achieving production gains.
- Farmers are ready to use a wide diversity/number of cultivars.

**Phase II: 1990-93**

In 1990, CIAT and ISAR expanded the farmer participation experiment, exploring specific themes in several directions.

**The format**

On-station, researchers wondered whether farmers could be brought in a stage earlier, 5-7 seasons before normal on-farm testing. This also implied that farmers would be screening many more lines. Was there a limit on what farmers could handle?

For the 3 years, farmers viewed a trial normally containing about 80 lines. To minimize risk, the CIAT pathologist screened this trial earlier than usual and eliminated the most disease-susceptible entries (to anthracnose, aschochyta, bean common mosaic virus and rust). So, in fact, farmers screened what researchers felt was the "largest possible reduced risk pool", some 79, 41 and 43 lines in 1990, 1991 and 1992 respectively. Bringing farmers in this early amounts to what might be termed 'prototype screening' and in any such premature collaboration, researchers should make special efforts to anticipate risks which farmers cannot.

In terms of broadening the programme on-farm, the concerns of Phase II focused on how to encourage communities to select their own expert representatives and how to evolve much of the on-farm testing to where it belongs, in the communities themselves. The move toward devolution was a healthy mixture of empowerment and economics. Communities should have the right to select their own delegates to screen on-station. Communities should also control how those 20 or 25 chosen varieties are subsequently tested in rural areas. In practical terms, such a selection programme can only be widely decentralized, targeting germplasm for many different areas, if communities bear the brunt of the local-level costs (Sperling and Berkowitz 1994).

From March 1990 onwards, women experts coming to the station represented the interests of three types of *ad hoc* local groups: farmers' research groups backed by nongovernmental organizations (NGOs) for specific development projects, self-organized and independent groups of 'research-oriented farmers', and several groups of farmers united by geographic proximity in an administrative unit known as a commune.<sup>6</sup> The cultivars women selected were then managed in various types of community plots, the NGO probably serving several hundred farmers, the commune units potentially reaching up to 6000 households. (Hence total potential population reached was 27 000 households or about 135 000 persons). Thirty to fifty farmers were normally invited to review each community plot. One or two of the selected varieties were to be given to each evaluator at harvest, eventually to be tested in their home plots the following seasons.

It is important to note the protests among scientists about the concept of Phase II, which some saw as being at the border of biological research and moving toward extension. The participatory programme came under yearly review from the Great Lakes Regional Bean Network Oversight Committee, an interdisciplinary group representing national institutes of Burundi and Zaire and Rwanda. Here, the feeling was that research itself would be needed to determine the "hows" of the programme's

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<sup>6</sup> In other contexts, such as Zaire, the participatory experiment was carried out with well-organized farmer cooperatives. Unfortunately, Rwanda has a limited tradition of farmer cooperatives or any grass-roots organizations which might lobby for farmers interests or organize collective ventures on a large scale, for example, credit or marketing.

institutionalization, not only for Rwanda, but for a range of African national partners. Partially to address the concerns of rigour, the programme was eventually set up as an experiment in which the normal breeding sequence served as the control and the participatory programme as the treatment. The two schema were eventually to be compared along such parameters as number of acceptable varieties identified and adoption rates. Table 1 outlines the framework (Scheidegger, fieldnotes).

**Table 1. Research experiment to compare two varietal selection frameworks**

Season*	Classic procedure (ISAR)	Decentralized selection with farmer participation
1989A	Triage trial	
1990A	Comparative trial	
1990B	Comparative trial	Selection on-station by expert farmers: 20 varieties
1991A	Multilocation 1	Community selection plot; 50 farmers per community
1991B	Multilocation 1	Farmer designed and managed trials ca. 150 (no researcher intervention). Independent evaluation by farmers.
1992A	Multilocation 2	Follow-up of 150 trials to identify which to test in controlled plot
1992B	Multilocation 2	WAIT
1993A	On-farm trials	
1993B	On-farm trials	
	Release of varieties	
1994 A& B	Researcher-managed trials to compare the varieties chosen for diffusion with the 4 most frequently multiplied by farmers; 4 replicates, 1 trial in 6 communities in Southern Rwanda	
1995A	Adoption study of 6 communes	

\* A denotes the season covering the period from September through January. For example, 1989A extended from September 1988 through January 1989. B denotes the season covering the period February through July (Source: Scheidegger, fieldnotes).

### Select results, Phase II

From the initial screenings, it was clear not only that different farming communities wanted to test a number of varieties, but that they had diverse needs and preferences. For instance, some farming areas were moving principally toward climbing bean varieties, others focusing on what they felt would be "poor soil performers." Table 2 suggests the span for trial evaluations near the end of 1992: only 5 of 19 bush bean entries were chosen across all farmer groups. Communities represented in the on-station screening were located within about a 50-km radius, and gradients in soil fertility were perhaps their most important differentiating variable.

Table 2. Farmer selection\* of bush beans from community plots in Rwanda, December 1992 to January 1993

Variety	Sites				
	Sahera	Rutsatira	Gikongoro	Save	Muganza
RWR 756	X	X	X	X	X
RWR 1058	X	X		X	X
RWR 1115	X	X	X	X	X
RWR 785	X		X	X	X
RWR 779	X	X	X	X	
RWR 911	X	X	X	X	X
RWR 1134	X				
XAN 162	X	X	X	X	X
G484	X	X	X	X	X
RWR 719	X	X	X		X
MLB 49-89A	X			X	
URUGEZI		X	X	X	X
SCAM 80		X		X	
CM/5					
RWR 14			X		
RWR 802			X	X	X
RWR 853			X		
RWR 1056			X		
MLB 40 89A			X		X
RWR 1059				X	

\* Shading highlights varieties chosen by all farmer groups.

The participatory experiment had proposed that varieties selected by communities, and later widely adopted, should be brought back into the formal system and baptized as farmer-breeder varieties. Subsequent seed multiplication and distribution would have to be decentralized to meet diverse regional needs.

Perhaps the most important insights during Phase II lay with institutional concerns. Turning over both the choice of on-station representatives to communities as well as subsequent community plot testing does not always mean that community needs are served. This certainly rang true in Rwanda where relationships even at the neighbourhood or "hill" level are marked by hierarchy and where women fall near the bottom of the heap no matter what the class or ethnic group. "Women have no race" goes one proverb, indicating that their power derives from their relationships to significant male others, brother, father, whatever the case may be.

In practical terms, the power structures and particularly male hierarchies, distorted the expansion of the experiment at several key points. In the selection of farmer representatives to screen on-station trials, researchers had the sense that some of the so-called community-selected experts were neither very informed nor very representative of community interests. For instance, one community was represented by the government agronomist's sister and the sector head's wife. The male authorities in charge linked power with knowledge, and imputed male knowledge to their female sidekicks. If **he** was an important official, **she** must be a farmer expert.

There was also concern that key figures in charge sometimes fell short on their obligations to community participants at the very last stage. The community plot was laid, evaluations completed, but seed of selected varieties was never distributed. So in theory, the data were in, but the seeds never got out to home plots. The advantages of

working through administrative structures are many: these units exist countrywide, in all agro-ecological zones and potentially canvassing all farmers. They have the land and could incorporate a mandate of decentralized selection. The philosophy of such units, however, is sometimes governed by 'control' rather than 'service'. Given their substantial strengths, researchers hoped they could be reshaped to collaborate more fully.

The experiment did thrive when women themselves had some control and when the community saw itself as a true community. The women's cooperative, supported by a Belgian NGO, was well organized and very serious about the research. Five experts were sent to station, varieties chosen were subsequently tested on designated group members' plots, and the cooperative as a whole agreed what to multiply, what to discard and what to test further. Over a tonne of seed was multiplied before other communities had started to budge.

Participatory breeding programmes are often viewed by scientists as technical experiments (e.g. Do farmers have expertise? Can they effectively screen segregating populations?), yet some of the greatest challenges may lie in identifying appropriate institutional forms. Within the Consultative Group for International Agricultural Research (CGIAR), institution building has principally been focused on national institutions, for instance, helping National Agricultural Research Systems (NARS) become more client-oriented (Merrill-Sands *et al.* 1991). However, equal if not greater challenges may rest at the community level: how to identify or help create organizational bodies which represent the full range of farmer interests and which can serve as ongoing research partners to a welcoming formal sector. Incipient work on the effectiveness of working with local farmer groups (Ashby *et al.* 1995) and larger farmer organizations (Merrill-Sands *et al.* 1996) is pathbreaking. However, it remains marginalized and detached from the hard core science concerns within the CGIAR. Box 2 summarizes some of the initial findings of Phase II.

While it may be a conceptual leap, cost-effective breeding hinges on identifying legitimate and representative local partners, and in some cases, expanding the local power base. In the longer term, local partners, and particularly solidly organized local groups, should create a demand-pull on research, reshaping the larger pool of varieties on offer and selecting from this the most promising options for localized experiments (Ashby and Sperling 1995). Expressed in popular form, one might think of the research station as an inventory warehouse: the goods are on offer to whet clients' interests/needs, with customers selecting only what is relevant. Future stocks, even prototype models, might be developed together with clients, and certainly with clients' needs in mind.

### **Methods: technical and institutional concerns**

The shift from a focus on exploring technical expertise to one of experimenting with institutional options was accompanied by a changing methodological emphasis.



**Box 2. Participatory selection with Rwandan bean farmers: Institutional concerns  
Phase II, 1990-93**

- Differences in varietal preferences among even closely spaced farming communities suggest that participatory selection has to be coupled early with decentralized seed multiplication programmes.
- Scaling up of a participatory selection programme implies that formal sector research must partner with organized groups of farmers, rather than individuals, to share the costs and responsibilities of widespread varietal research.
- Working through community institutions does not guarantee that community needs are served. Local power structures—for example, male hierarchies—can distort the fundamental premises of a "participatory" programme. The challenge is to identify local organizations which represent the range of farmer interests and which can serve as research partners.
- Working with farmer groups demands that methods be developed which "feedforward" information to communities as well as feedback insights to the formal sector. There may be important methodological trade-offs between community R&D and formal sector R&D approaches.

***On-station procedures***

In terms of technical concerns, great care was taken to find out how to make the on-station trials 'transparent' to farmers, that is, to assure there were no hidden biases. Although seed colour and shape of trial entries might be similar to local varieties, it was explained that farmers were evaluating varieties new to the region. Any use of manure was signalled, as was any other management practice which might enhance yields. For one season, researchers planted varieties in a box format, 3 × 3 m, rather than sowing in two lines, so that farmers could better see a clump of the variety, walk around it and more easily exchange comments among themselves. Farmers said they appreciated the effort, but it made no difference; they were used to testing varieties in small, odd patches.

Another experiment tried to examine validity of farmer evaluations in the face of a single replicate assessment. Eight varieties of bush and climbing beans (total 16), which had been chosen by women farmers the preceding year from ISAR's trial, were grown with and without 30 t/ha of farmyard manure. While farmers normally evaluate a single replicate, during 1991, a select group scanned six. Repeatability of farmer scores was high for clearly good or bad yielders, while scores were not fully consistent over replications for intermediate varieties. It was observed that farmers differentiate parts of higher and lower soil fertility within an experimental plot and then estimate yield for both parts separately. This way of looking at experimental plots, if less objective, may be more refined than the experimental procedure of determining total plot yield and, under highly diverse soil conditions, could result in a fairer judgement of varieties. Farmers also stated that there were no visible differences among replications; that is, there was no relation between fertilization and crop development. This qualitative assessment was in full agreement with statistical analysis of yield data (Scheidegger in CIAT 1991).

During the initial phase of the programme, there was also a strong focus on direct feedback. Scientists wanted to learn first hand how farmers evaluate: by which

criteria, the ranges of acceptability within criteria, as well as the trade-offs among varietal features. The evaluation format was comprehensive: farmers scored each variety and assessed its positive and negative traits. Interviewing was often one on one, scientist (or technician) to farmer.

As the experiment evolved, exposing farmers to a greater range of germplasm and moving toward a community (versus individual) focus, so too methods had to be retooled. From the scientist point of view, in-depth evaluation of 80 entries was no longer logistically possible, nor perhaps necessary. The evaluation format aimed for efficient procedures which encouraged sharing among farmers and gave feedback (or feedforward) out to communities rather than channeling it back primarily to research offices. Farmer groups, each region sending 3-5 representatives, were given two sets of coloured ribbons to indicate varieties they wanted to test in future community plots and those they felt should be eliminated. They marked as many entries as desired, negatively and positively. After the tagging, plenary field discussions focused on the varieties most often signalled, the outliers (those with one ribbon) and any variety which particularly captured farmer interest. While one might argue that ribbons confounded results, that is, farmers visualizing others' choices might be unduly influenced, farmer representatives, eager to ferret out the most suitable varieties for their own home areas, perceived no problem. On the contrary, they enjoyed exchanging ideas and reflecting on intergroup differences. They found the final tallies particularly exciting. Ribbons allowed them not only to reflect on their own choices, but to immediately synthesize the results of five group selections. Such synthesis, usually confined to office corridors, was visually striking and illuminating. During the second phase of on-station evaluation, feedforward came at the expense of detailed feedback, with more cursory identification also the consequence of greatly enlarging the options on offer.

### ***On-farm procedures***

On-farm procedures also followed a course from intensive to more extensive monitoring. Farmers designed and managed their individual home trials during Phase I, but researchers asked for a local check and were on hand to weigh and sometimes help harvest experimental plots. For the research community, qualitative and quantitative information was critical for assessing whether farmer selections from on-station trials had actually performed. Farmers, of course, often carry checks in their heads and do not need a scale to show if the variety is a winner.

During the second stage, tested paradigms within communities were determined by participants themselves and in part reflected the group's orientation toward its members. The farmers' research group, technically assisted by an NGO, decentralized testing and evaluated together. A core group, designated as the research contingent, divided up the station-selected varieties and tested them on individual plots: group evaluation was then completed by means of a walking tour (PAMU 1993). The group subsequently multiplied and diffused the most promising entries. The Rwandan Program received a written report on the farmer evaluation, by which time the varieties had already been launched on their way among other community members.

The experiment within the administrative units (communes) was conducted in a very different and more standard manner. The agronomist took control, station researchers drew up a standardized protocol (varieties sown in lines, at given densities) and some local farmers were invited to evaluate the plot and select varieties for home use. One advantage was that more farmers were exposed to a greater range of cultivars than in the previous model. Such a top-down research posture at the

community level is not atypical of many local grassroots groups, who may have some trained technicians (trained under standard models). Owing to their greater involvement in commune evaluations, researchers received feedback more quickly, but the progress toward adaptive testing on individual plots and further diffusion was significantly slower.

The different methods and designs used through the experiment represented trade-offs for the various actors involved. Researchers were initially disappointed by the level of farmer expertise proffered when communities themselves controlled participant selection. Perhaps with greater experience, the power structures would have better signalled exceptional skills within the global group 'women'. Some scientists also lamented the decline in detailed feedback as farmers screened a larger pool of germplasm and as some subsequent community designs and evaluations ignored 'researcher language' altogether, for example, no yield data. The move toward community-oriented models, however, brought important gains to local participating groups. Ribbon evaluations were more transparent; more farmers directly benefited on farm, and, in the best cases, farmers identified and distributed productive varieties with unusual speed. As institutionalization of the approach hinges on community participation, standard research models will have to reorient toward communities' own research and development (R&D) concerns.<sup>7</sup> Box 2 summarizes select institutional issues of the second phase of research.

### **Emerging research models**

Perhaps the most important technical lesson of the 5-year experiment is that farmers use a wider range of criteria than breeders do for selecting varieties: observed yield is important, but so is, for instance, a variety's compatibility for growing with bananas. Furthermore, the criteria farmers use and their relative importance vary by region. If given access to appropriate germplasm, farmers have the edge in targeting for their varied local circumstances.

Institutionally, it has also become clear that farmers can organize themselves to test quite a wide range of germplasm on-farm, although the different organizational structures and protocols used will influence which and how many households can be reached and even the number of germplasm entries potentially accommodated. Research on possible arrangements for community testing needs to be carried much further.

The results of the experimental programme suggest that the standard breeding models may not be using the talents of each partner, breeder and farmer to best advantage, particularly in areas marked by marginal, heterogeneous environments. Breeders may not be the best candidates to select for the diversity of needs/preferences nor for the difficult 'composite' traits. Breeders' unique expertise lies in their capacity to generate new genetic variability. Farmers do cross and select, but at an extremely slow rate; scientific breeding accelerates the process. Breeders might also concentrate on those constraints/opportunities which are invisible to farmers: e.g. certain pathogens and diseases. In turn, the finishing of the product, targeting the variety to a particular production system, can and should be left to farmers. To pursue this goal, farmers would need access to a wide range of germplasm (Box 3).

<sup>7</sup> For instance, facing similar challenges in India, the KRIBHCO project is recommending that "farmer-acceptability" data, versus the standard yield trials, be considered as sufficient evidence for varietal release (J. Witcombe, pers. comm. 1995).

### Box 3. Conceptualizing a new division of breeding labour

#### *Breeders*

- Create new genetic variability
- Make accessible a wide range of germplasm (local and exotic)
- Screen large amounts of material for minimum criteria
- Screen for key stresses 'invisible' to farmers

#### *Farmers*

- Target for agronomic conditions (performance)
- Target for socioeconomic circumstances (preference)

Rethinking the division of labour for the breeding process probably also demands that the scientific community rethink how they evaluate the relative success or failure of the growing number of participatory breeding trials. In Rwanda, initial stages were marked by an exclusive focus on production or impact achievements. Our conceptual framework sought to compare the standard and experimental programmes in terms of "end-result" variables: for instance, number of acceptable varieties identified, number of disease-resistant varieties identified, rates of adoption of the two sets of material adoption. Varietal diversity of the ISAR-released compared with farmer-selected material mainly became evident as an evaluation variable when it became clear that farmers wanted many and varied cultivars. However, aside from giving farmers access to a wider range of options on-station, the experiment was not shaped to specifically enhance genetic diversity on-farm. Much more could have been done to promote genetic diversity had the participatory programme been conceived with this primary goal in mind.

As the experiment evolved, community capacity to serve as research partners lunged to the forefront as a process to strengthen. The technical findings alone (e.g. farmers can expertly target varieties) could not deliver adapted varieties to local groups. Enhancing community control and research skills therefore became a central issue in enhancing the efficiency of breeding. Within such a perspective, empowering communities becomes a functional necessity for achieving cost-efficient research programmes. Box 4 suggests parameters along which we might start to evaluate our participatory breeding trials, according to each programme's specific focus.

Broadly, at least three perspectives presently guide such participatory experiments: some practitioners focus on production achievements, some on the enhancement of genetic diversity, and still others on the shifting of control (of germplasm and the breeding process itself) to communities and other grassroots organizations. A successful participatory breeding programme should probably show positive indicators in all three categories. Relative emphasis will vary greatly according to the primary objective of the programme.

**Box 4. Participatory breeding programmes: potential evaluation criteria****Functional perspectives (orientation: products)***Production/Impact Enhancement*

- No. of farmer-acceptable varieties
- No. of disease-resistant varieties
- Absolute production gains
- Rates of adoption

*Genetic Diversity*

- Genetic profile of released varieties
- Incidence of landrace parents

**Control/empowerment perspectives (orientation: process)***Degree to which:*

- farmer skills are enhanced to more effectively cross/select themselves
- farmers gain fuller access to wide pool of germplasm
- farmers control local testing
- farmers are involved in decisions of varietal release

**After the genocide: Varietal assessments and reintroductions**

The escalation of the Rwandan civil war in April 1994 resulted in the death of about 1 million persons and the displacement another 2 million. Agriculture, the main occupation of upwards of 90% of the population, was acutely affected as civil disruptions peaked in the midst of the normal February-June growing season. Harvest losses overall during this period have been estimated as high as 60% (Dr Iyamemye, pers. comm.).

The aid community, particularly NGOs and various United Nations agencies, responded swiftly and on a wide scale to the agricultural crisis. During the subsequent growing season, September 1994-January 1995, large amounts of seed of key crops were distributed: 6970 tonnes of bean, 1707 t of maize, and 7230 kg of vegetable seed (MINAGRI/UNREO/PNUD/FAO 1994).

The CGIAR has responded along lines of its own advantage, assessing the state of varietal and genetic erosion and developing strategies to restock germplasm in national research sites as well as on farmers' fields. A Seeds of Hope<sup>8</sup> initiative is now multiplying collections of local material, breeding lines and improved lines

<sup>8</sup> The Seeds of Hope Initiative is a joint rehabilitation initiative of the CGIAR. Formalized in September 1995, many African NARS have contributed germplasm, field space and advice to the initiative: those of Burundi, Ethiopia, Kenya, Malawi, Tanzania, Uganda, Zaire, Zimbabwe and, more recently, Rwanda. In addition, some seven of the International Agricultural Research Centers (IARCs) are strongly involved in the Rwandan Agricultural reconstruction:

- International Center for Tropical Agriculture (CIAT)
- International Maize and Wheat Improvement Center (CIMMYT)
- International Potato Center (CIP and its network PRAPACE)
- International Center for Research in Agroforestry (ICRAF)
- International Institute of Tropical Agriculture (IITA)
- International Livestock Research Institute (ILRI)
- International Plant Genetic Resources Institute (IPGRI)

appreciated by farmers for possible reintroduction. For beans alone, 170 landraces have been obtained through national and international genebanks. The first nationwide surveys, conducted through a range of NGOs (CARE, World Vision, Swiss Disaster Relief, Catholic Relief Services and Médecins sans Frontières) has suggested that varietal loss has been less than anticipated: 45% of the seed sown during the first post-event season came from farmers' own stocks (Sperling 1995a). In August/September 1995, surveys will further examine this issue of varietal loss for the most vulnerable areas, those which experienced large-scale population movements.

Methodologically, in reference to farmer participatory selection, two interesting developments can be signalled.

First, Seeds of Hope is looking at the complementarity and differences between farmer varietal assessments and molecular genetic assessments. Farmer assessments tend to be site specific and indicate the degree to which farmers can access desired varieties (that is, varieties which have useful traits which are available in useful combinations). Molecular assessments (using RFLP) suggest the presence/absence of genetic characters nationwide and map regional variations at community (versus farm) levels. Both programmes aim to determine the genetic and varietal needs of Rwandan farmers and to guide the rebuilding of genetic collections at ISAR (Sperling 1995b; S. Beebe, pers. comm. 1995).

Second, farmer participatory selection is being proffered as a major method of reintroducing germplasm at the community level, should varietal restocking be necessary (World Vision, J. Hooper, pers. comm. 1995). As provenance data on the 170 landraces need to be sharpened, the proposals suggest that entries roughly be sorted by high, medium and low-altitude adaptation and then be moved to community plots for further targeting. In the Rwandan context, farmer participatory selection thus becomes a chosen strategy for research and development initiatives but also for emergency aid and rehabilitation efforts. Let farmers help get the germplasm to where it can best be used.

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## Farmer participatory approaches for varietal breeding and selection and linkages to the formal seed sector

John Witcombe<sup>1</sup> and Arun Joshi<sup>2</sup>

<sup>1</sup> Centre for Arid Zone Studies, University of Wales, Bangor, Gwynedd LL57 2UW, UK

<sup>2</sup> Krishak Bharati Cooperative Indo British Rainfed Farming Project (KRIBP), Dahod, Gujarat, 389151, India

### Abstract

There are many farmer participatory approaches, employing differing degrees of farmer participation, for the breeding or identification of improved crop cultivars. These can be usefully categorized into farmer participatory varietal selection (PVS) and farmer participatory plant breeding (PPB) since they define two contrasting approaches. It is efficient to try PVS first since it is less resource-consuming than PPB. PPB can follow from the successful participatory identification of cultivars, or be used where PVS is not possible or has failed. In the Crops Programme of the Krishak Bharati Cooperative Indo British Rainfed Farming Project (KRIBP), a PVS research programme has identified both released and nonreleased cultivars that are preferred by resource-poor farmers. Released material is of value in participatory research because, although centralized breeding limits specific adaptation, it does produce some genotypes adapted to low-yielding environments. Participatory research should be designed to produce outputs that also fit in with conventional varietal release and seed supply. The benefit-cost ratio of participatory research is improved by taking advantage of economies of scale provided by large-scale seed multiplication.

### Introduction

Participatory varietal selection (PVS) involves the selection by farmers of nonsegregating, characterized products from plant breeding programmes. Such material includes released cultivars, varieties in advanced stages of testing and advanced nonsegregating lines. In contrast, participatory plant breeding involves farmers selecting genotypes from genetically variable, segregating material. The difference between PVS and PPB may not appear to be great at first sight. However, PPB requires more resources than PVS, and PVS identifies material that can be adopted more rapidly by the formal seed sector. The contrasting impacts of PVS and PPB on biodiversity have been discussed by Witcombe and Joshi (1995).

Most of the published work on participatory research for varietal breeding and selection can best be defined as participatory varietal selection, since farmers were given near-finished or finished products to test in their fields (e.g. Maurya *et al.* 1988; Sperling *et al.* 1993; Joshi and Witcombe 1995). There are few examples in the literature of participatory plant breeding. Sthapit *et al.* (1995) have carried out PPB with farmers in Nepal to select chilling-tolerant rice from F<sub>5</sub> bulk families. In collaboration with S.N. Goyal, of Gujarat Agricultural University, the authors have created a broadly based maize composite for participatory plant breeding in India. The first selection by farmers is being carried out in Gujarat in the *kharif* (rainy season) 1995, and the strategy of this approach is outlined in this paper.



### **Participatory varietal selection**

Participatory varietal selection to identify preferred cultivars has three phases: identifying farmers' needs, searching for suitable material to test with farmers and experimentation on farmers' fields. Once identified, seed of farmer-preferred cultivars needs to be rapidly and cost-effectively supplied to farmers.

#### ***Identification of farmers' needs in crop cultivars***

Prior identification of farmers' needs in crop cultivars reduces the possibility that farmers will be given obviously unacceptable varieties to test. Various methods can be used, separately or in combination, to identify these needs. These methods include participatory rural appraisal (PRA), the examination of the crops in farmers' fields at or near maturity, or the preselection of varieties by farmers from trials of many entries grown on a research station or on-farm. If resources permit, local germplasm should be collected and grown in a trial with recommended cultivars as a control. This can provide information that a PRA may not reveal because:

- the extent of diversity can be evaluated in the trial
- the degree of agreement between the names given to landraces by farmers and their phenotypes can be determined
- the performance of recommended cultivars can be compared with that of local germplasm.

#### ***Search process using released material and advanced lines***

After the requirements have been identified, a search is carried out to identify suitable cultivars for testing with farmers. The cultivars may be national, state or regional releases, both recent and old, and may also be 'prerelease' material at an advanced stage of testing. Results have shown that suitable cultivars for resource-poor farmers exist among the released cultivars but they have not been exposed to farmers. If released cultivars are identified, then the large-scale provision of seed to farmers is easier than for advanced lines.

#### **The suitability of released cultivars for resource-poor farmers**

It is assumed that centralized breeding has produced cultivars adapted to low-yielding environments, even though centralized breeding may be less efficient than decentralized breeding in this respect. Therefore, among the released cultivars it is probable that there are ones that will be preferred by farmers over those they are currently growing. There is direct evidence that released cultivars are acceptable to resource-poor farmers (see below), and indirect evidence that this is the case from the analysis of scientist-managed trials. In analysis of pearl millet multilocal trials, the breeders' practice of selecting on mean performance across locations sometimes did not identify the best cultivar for low-yielding environments, but always selected cultivars having above-average performance in those environments (Witcombe 1989). Unpublished analyses (Virk and Witcombe) for several cereal and legume crops tested in multilocal trials in India confirmed this result. However, the multilocal trials also provide evidence that decentralized selection may be more efficient in breeding for specific adaptation. For flowering time, an important trait for specific adaptation, there is strong stabilizing selection in multilocal trials. Extremely early and late entries likely to have highly specific adaptation rarely perform well. Moreover, in these trials, the range of

genotypes is limited because breeders are aware that they are breeding for success in multilocational trials where cultivars with extreme specific adaptation are unlikely to succeed. In contrast, decentralized breeding and selection encourage the testing of a greater range of genetic material. Decentralized breeding also permits the inclusion of much lower-yielding environments. Such environments do not occur in well-managed multilocational trials, or the data from them are deliberately excluded on the grounds that they are too low yielding.

#### **Lack of exposure of new cultivars to farmers**

Another key assumption in the PVS of released cultivars is that cultivar replacement rates are lower than optimal because farmers have never seen a range of new cultivars. Hence, all that is needed is for farmers to be given seed of the existing cultivars that are suitable for the project area, but have not been released and are unavailable in the area. Such cultivars can be introduced from other states for a participatory varietal selection programme; in most crops in India, cultivars can be found that have only been released and widely grown in a single state.

There is much evidence that most of the cultivars grown by farmers are old and that only a few of the released cultivars are widely grown. For example, in rice in India the average age of cultivars, for which there is a demand for breeder seed, is 11 years, and the average of cultivars in certified seed production ranges from 12 to 17 years in the three states of the KRIBP project, Gujarat, MP and Rajasthan (Witcombe *et al.*, unpublished). The two most popular cultivars in the whole of India are IR36 (released in 1981) and Rasi (released in 1977) and they are grown in a large proportion of the area under rice cultivation. However, there is a good choice of cultivars in rice as there have been a total of 525 releases, 88 of them in the period 1988 to 1993 inclusive. In India, cultivars of most crops are, on average, older than those in rice. The average age of the cultivars for which seed producers demand breeder seed is 13 years in chickpea, 15 years in groundnut, 16 years in sorghum, and 17 years in maize (Witcombe *et al.*, unpublished).

#### **Advantages of PVS in uptake of research results**

Choosing from among released cultivars has the advantage that any nongovernmental organization (NGO) or governmental organization (GO) can, in principle, readily procure seeds in sufficient quantities for testing with farmers. If they are identified as being farmer acceptable it should be possible to provide large quantities of seed to the farmers with little delay, much easier than in the case of prerelease or breeder's lines. However, to enlarge the basket of choices and exploit recent outputs from plant breeding research, prerelease cultivars were also included in the search process and a number were identified as being suitable for testing with farmers (Table 1). Some of these prerelease cultivars would be defined by others as advanced material, e.g. Maurya *et al.* (1988).

#### **Experimentation for PVS**

Various testing and evaluation systems can be employed that can vary greatly with the extent of farmer participation (Table 2). Many on farm trials are conducted almost entirely by researchers on farmers' fields, so there is little or no involvement of farmers. At the other extreme, very limited inputs can be provided by outsiders, such as scientists and development workers, by giving farmers a range of cultivars

to try without outside intervention. Outsider inputs in evaluating the material can also be minimized by asking farmers in informal discussions which of the cultivars they like the most, or by merely waiting for demand for seed from farmers. On the basis of such discussions or demand, an NGO, a seed company or a GO can make decisions on what seeds to provide to farmers. Informal research with minimal outsider inputs can be highly cost-effective, and is recommended for NGOs with limited resources that wish to provide seed of farmer-acceptable improved cultivars.

**Table 1. Cultivars identified by participatory varietal selection in the KRIBP project and performance of recommended cultivars**

Crop	Performance of recommended cultivars	Cultivars tested <sup>1</sup>		Cultivars identified	Release location	Release year
		Rel.	Pre-rel.			
Rice	All recommended cultivars tried failed in farmers' fields.	9	7	Kalinga III Sathi-34-36	Orissa Gujarat	1983 1955
Maize (white)	Recommended cultivar not distinguished from local by farmers.	3	3	Shweta	U.P.	1980
Chick-pea	One of the recommended cultivars, Dahod yellow, is the local cultivar. Other failed.	4	1	ICCV 2 ICCV 10 ICCV 88202	A.P. SZ <sup>2</sup> Not rel.	1989 1992 -
Black gram	Recommended cultivar T-9 was less preferred. Others not tested as very old.	2	2	TPU-4 IU8-6	National Not rel.	1992 -

<sup>1</sup> Rel.=released cultivar and Pre-rel. = pre-released cultivar

<sup>2</sup> SZ = Southern Zone comprising A.P., southern M.P. and Tamil Nadu

In KRIBP, the varietal trials were carried out by farmers in Farmer Managed Participatory Research (FAMPAR) trials. The trials were divided into introductory and adaptive trials; small quantities of seed were given to farmers in the introductory trials, but, to avoid overestimating acceptability, seed was sold at commercial rates in the adaptive trials (Joshi and Witcombe 1995). In the introductory trials, each participating farmer was randomly assigned a single variety and grew it alongside the local variety in the same field. Farmers were asked to mark the plots and not to change the management of the crop in any way. Sufficient seed was provided for plot sizes that were much larger than that used in advanced on-station trials, but were not too large to create undue risk for the farmers.

In the introductory trials, data were collected by means of Focus Group Discussions (FGDs) before and after harvest, on all aspects of the crop including

taste, market value, threshing characteristics and storability. Evaluation was facilitated by the participating farmers visiting each other's plots in 'farm walks'. All the cultivars could then be compared in the discussions, and it permitted the assessment of the reactions to each cultivar of all of the farmers who participated in the farm walks. In some cases, questionnaires were completed for individual households to assess the reactions of household members to the variety.

**Table 2. Methods of participatory plant varietal selection with varying degrees of farmer participation**

Methods of farmer participation (in increasing order)	Evaluation	Typical institution involved
On-farm trials, researcher-managed; replicated design	Yield data	Research
On-farm-trials, farmer-managed with scientist's supervision; several entries per farmer; replicated design	Yield data	Research
Farmer-managed trials, replication across farmers, one cultivar per farmer	Yield data; farmers' perceptions	Research; extension; NGO
Farmer-managed trials; replication across farmers; one cultivar per farmer	Farmers' perceptions	NGO; extension; research
Farmer-managed trials; no formal design	Informal, anecdotal	NGO with limited resources; extension

### Results obtained from participatory varietal selection in KRIBP

The research has been applied to a number of crops (Table 1), and an example of this participatory research is summarized for the case of upland rice. In 1993, introductory trials of rice were planned with 25 participating farmers in each of six villages. Successful trials were conducted by 128 farmers. In each village, five cultivars were grown and every cultivar was replicated across three to five farmers. The cultivars were Kalinga III, Sathi-34-36, Jaldi Dhan-1, Jaldi Dhan-3 and GR-3.

The farmers' perceptions of Kalinga III, the most preferred cultivar, were evaluated in the six villages. For yield, there was perfect agreement amongst the farmers that Kalinga III was higher yielding in all villages in MP and Gujarat, and most farmers thought it higher yielding in Rajasthan. In all villages, Kalinga III was perceived to be earlier than the local. The reaction of farmers to Kalinga III in focused group discussions showed a high degree of concurrence for perception of quality traits. Nearly all groups perceived Kalinga III as having thin husks and grains that remained unbroken on dehulling. The farmers' preference for Kalinga

III has been confirmed in subsequent seasons by sales, at unsubsidized rates, of large quantities of Kalinga III.

Using similar techniques to the example above, we have identified in the KRIBP project three cultivars of chickpea, two of rice, one of maize and two of black gram that are markedly preferred by farmers (Table 1). This has been achieved in only 3 years.

One of the most important results is that recommended cultivars are rarely, if ever, preferred. This is almost certainly because their true recommendation domain is for areas where farmers grow crops in highly fertile soils where water is not limiting. For example, the recommended upland rice cultivar in Gujarat, GR-3, was the least preferred cultivar in the trials described above. Instead, all of the preferred cultivars, apart from one cultivar of rice (Sathi-34-36) and a national release in black gram, are introductions from outside of the three states in which the project area is situated. This indicates that the recommendation domains of released cultivars are too limited. Unfortunately, there is no mechanism of ensuring that once a cultivar is popular in one state of India it is extensively tested in other states. An argument commonly used against the need to do this is that the material has already been tested in coordinated project trials. However, every case needs to be examined in detail. Often the number of locations in which an entry has been tested in any particular state will have been very small, and sometimes the trials in a state that included the entry in question failed or were rejected because the trial had excessive experimental error.

### **Participatory plant breeding**

Participatory plant breeding is a logical extension of participatory varietal selection. If it is desirable to involve farmers in selection of cultivars then there is no need to wait until there are finished products. Farmers can be involved in selecting among segregating material. However, the first recourse should be to PVS since PPB is more resource-consuming. PPB has to be used when PVS has been tried and failed, or when the search process has failed to identify any suitable candidate cultivars.

The methods used in participatory plant breeding are poorly documented, since there are no reports in the literature of a completed participatory plant breeding programme. Sthapit *et al.* (1995) have used  $F_5$  bulk families as the starting point for their participatory breeding programme. These were derived from seed harvested from  $F_4$  families that were grown in land rented from a farmer. The breeding scheme is at the  $F_7$  stage in the monsoon season of 1995, and it is intended to monitor progress in the farmers' fields until a finished product is produced.

In a collaborative programme with the Gujarat Agricultural University, a participatory breeding programme has been initiated for white-grained maize in the KRIBP development project. In the past, at least as far as India is concerned, efforts on breeding white-grained maize have been largely, or entirely, dependent on the progeny of crosses between white-grained parents. However, since most maize breeding programmes have concentrated on yellow-grained maize, the diversity and yielding ability of yellow maize parents is higher. It is, therefore, desirable that yellow-grained parents should be used when breeding white-grained maize. Using white and yellow maize as parents in the breeding of white maize is possible because grain colour is a highly heritable trait, and because of the Xenia effect the genotype of the pollen parent can be seen on the individual grains of a cob. Hence, it is easy to produce a pure white-grained population from a yellow  $\times$  white cross. Not only can superior yellow maize cultivars be used as parents, but the crosses are

between genetically unrelated cultivars of yellow and white maize. The main features of this programme are the use of :

- a broad-based composite based on both yellow- and white-grained parents
- locally adapted parental material
- selection in farmers' fields to remove genotype  $\times$  environment interaction between the research station and the farmers' fields and to carry out selection on multiple traits of interest to farmers
- replication of the programme across farmers.

The fourth random mating generation of the composite, created from six farmer-acceptable open-pollinated cultivars, is being grown and mass selected by farmers in Gujarat in *kharif* 1995.

#### ***Possible breeding methods with self- and open-pollinated crops***

A range of participatory plant breeding methods is possible with predominantly self-pollinating crops, and they have been ordered by degree of farmer participation in Table 3. The methods vary according to which generations are grown by farmers, and by the extent of researcher participation. The method with the greatest farmer participation and the greatest number of generations requires little breeder input during the selection stages. However, participatory plant breeding is not intended to make plant breeders redundant, and in all of the methods the plant breeder is the facilitator of the research. Only the plant breeder can make the crosses between the parents and have the essential understanding of the underlying genetics in the segregating generations. Moreover, only the plant breeder has the knowledge of the official release system, and cultivar release is still a very desirable endproduct to make the results of the participatory research more widely available.

For predominantly open-pollinating crops, plant breeders can create composites in isolation and give the third or fourth random mating to farmers for mass selection. Large plots of the composite have to be grown by the farmer, or small plots need to be isolated from other plots of the same crop by time of flowering or by space between the plots. Because of these constraints, it is difficult to carry out the breeding scheme in many locations. Mass selection can be done by farmers with or without an off-season generation controlled by the plant breeder. The off-season can be used to breed for wider adaptation by plant breeders recombining selections from different farmers. Although it is likely to reduce the progress made by selection over the best farmer's selection, it avoids the risk of continuing a population from a poor selection by one farmer, or from a population where outcrossing with crops in surrounding fields happened to be higher than expected.

Greater plant breeder input is possible by employing any method of progeny testing. Plant breeders can produce progeny before giving material to farmers, and can produce progeny between generations of farmer selection. In the most extremely breeder-oriented system, the farmers grow progeny trials of full-sib or  $S_1$  families, and the breeder recombines from remnant seed the farmer-preferred progeny.

**Table 3. Methods of participatory plant breeding in predominantly self-pollinating crops**

<b>Methods of farmer participation (in increasing order)</b>	<b>Site specificity</b>
Early generation ( $F_2$ ) in farmers' fields; all other generations and procedures with plant breeder	Single location
Best advanced lines at $F_7$ or $F_8$ given to farmers for testing; closest method to participatory varietal selection since farmers given nearly-finished product	Easy to use across locations
From $F_3$ onwards farmers and plant breeders work together to select and identify the best material. Farmers are the selectors. Plant breeders facilitate the process by giving advice on which characters are heritable, and on selection methods. Pre-release multiplication can take place in parallel to the participatory plant breeding. Release proposal prepared by plant breeder.	Possible to run selection procedures in more than one location.
Breeder gives $F_3$ or $F_4$ material to farmers. All selection and advancement of generations left to farmers. At $F_7$ to $F_8$ or later, stage breeders monitor diversity in farmers' fields. They identify, by phenotypic appearance and farmers' perceptions, best material to enter in conventional trials and pre-release multiplication.	Extremely easy to run selection schemes in many locations.

**Participatory approaches and seed supply**

PPB and PVS are usually conducted with farmers situated in a small geographical area. Nonetheless, the cultivars that are selected or bred will have a recommendation domain larger than the area in which the research was conducted, for the area of research will always be a small part of a larger agro-ecological zone. If the research outputs are not to be limited to farmer-to-farmer spread, then the economies of scale of the more formal seed sector need to be exploited. The benefit-cost ratio of the research can be maximized by exploiting a more efficient method than farmer-to-farmer spread or community-based seed production.

In KRIBP, a separate seed unit has been created within the project to use the results of the participatory research. Suitable cultivars, once identified, can be placed under commercial production by the seed unit. In any development project where seed supply of improved cultivars is an important component, it is essential to have linkages with public or private sector seed producers that can produce and supply the seed of identified cultivars. Such linkages should be considered during project formulation.

KRIBP has also started building an informal network of NGOs to share the information from the participatory research, and a number of requests for seed have been accommodated.

An important factor in the wider dissemination of the results of participatory research is whether the identified cultivars are released in the area in question. Usually, a cultivar needs to be released before it can be recommended by the extension services and its seed multiplication undertaken by public-sector seed agencies. Unfortunately, in most developing countries the release procedure is

time-consuming and requires data that a participatory approach cannot normally supply. For participatory approaches to be more cost-effective, data on farmer perceptions and on demand for seed also need to be considered as legitimate by varietal release committees, rather than the almost total reliance presently placed on yield data from scientist-managed yield trials.

For participatory breeding, in both Nepal and India, steps are taken to bring the results of the research into the formal system. In Nepal, a 'parallel' breeding programme to the participatory research has been done to produce material for the national trials (Sthapit *et al.* 1995). In India, the collaboration for participatory maize breeding between a development project and a State Agricultural University (SAU), which works within the state system for varietal testing and release, ensures the entry of a successful product of PPB into the formal system. The SAU benefits from the linkages the development project has with farmers, which can be too expensive for a research station scientist to establish, and the development project gains the support of the SAU research programme.

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## **The role of local plant genetic resource management in participatory breeding**

***Esbern Friis-Hansen***

Centre for Development Research, Gammel Kongevej 5, DK1610K, Copenhagen, Denmark

## **The relevance of local plant genetic resource management institutions for participatory plant breeding**

### ***Need for a new paradigm for agricultural research***

It is today widely recognized that a very large number of food producers, between a quarter and a third of the world's population, will not in a foreseeable future have access to the inputs (mechanization, irrigation, improved seed, fertilizer and pesticides) required to benefit from the conventional agricultural technology, characterized by high input/high output. In parts of the world, the proportion of the population with access to agricultural inputs for food production is declining, e.g. impact of structural adjustment programmes in Sub-Saharan Africa.

Meanwhile the traditional farming systems are not able to cope with the production demands of the increasing population. There is growing evidence that pressure of production results in irreversible mining of natural resources, which further undermines the capacity of traditional farming systems.

Conventional agricultural research is based on modification of the environment to ensure that crops and animals get optimal growing conditions, and modification of crops and animals enables full utilization of the improved growing environment. Realizing that this agricultural paradigm is inadequate, the international and national agricultural research systems have painfully and slowly begun searching for an agricultural research paradigm. This emerging paradigm is based on optimizing yields under given environmental conditions, without large inputs of agrochemicals, mechanized implements and irrigation (CGIAR 1994). Instead, further genetic modification of important crops to widen their environmental tolerances, improvement of soil and water management techniques and clever use of integrated pest management and weed management may improve yields and food security (Bie 1994).

### ***Implications of adopting a new paradigm for agricultural research for participatory plant breeding approaches***

Optimizing yields under given environmental conditions is a radical departure from the conventional aim of plant breeding to optimize potential yields. This has at least three major implications for the goals and methodologies of plant breeding:

1. Plant breeding needs to be **participatory** in order to understand what the given environmental conditions imply for farmers with different access to resources.
2. Plant breeding needs to **optimize the performance of varieties under low or no external-input conditions**, as a very large proportion of the target farmers will not be using high volumes of external inputs in the foreseeable future.

3. The environmental conditions of crop growth depend upon crop husbandry practices (which relate to farmers' access to resources) and moreover vary between agro-ecological areas. To optimize varieties to this range of environmental conditions, **the number of varieties of each crop needed to be developed by plant breeding, released, multiplied and distributed to farmers needs to be greatly increased.**

### ***Participatory plant breeding and local plant genetic resource management***

Local plant genetic resource management institutions include: norms and traditions for selection, treatment, exchange, planting, cultivation and end-use of local germplasm. Rural people's knowledge<sup>9</sup> of local plant genetic resource management is not adequately recognized as an important resource. While conservation and scientific use of genetic diversity is the subject of worldwide interest, the cultural institutions creating it are hardly studied. The formal plant genetic resource institutions, e.g. conservation and plant breeding, generally do not recognize rural people's knowledge of plant genetic resources as a useful resource, and cooperation between the formal and informal institutions is limited. However, rural people's knowledge has gained recognition at the international level, e.g. in the preamble of the Convention on Biological Diversity and in Chapter 14 (Agriculture and Rural Development) and Chapter 15 (Conservation of Biological Resources) of Agenda 21.

The capacity for local plant genetic resource management varies greatly between different geographical locations. Three factors strongly influence the capacity for plant genetic resource management at a given geographical location: the existence and integrity of cultural diversity, access to genetic diversity and exposure to agricultural modernization. The capacity for plant genetic resource management moreover varies considerably within communities, depending on the coexistence of different ethnic groups, degree of social differentiation, gender relations and different age groups.

The structural reasons for why a very large segment of small-scale farmers in developing countries have been unable to reap the benefits of scientific plant breeding are well understood today. Widespread poverty is preventing many farmers from performing the agronomic practices required to take full advantage of improved seeds. Diversity of crops and crop species is continuously used by farmers to ensure household food security and to optimize the productivity under the given, often seriously resource-constrained, conditions of farming. While principles of local plant genetic resource management are well adapted to low external-input agriculture, the productivity of crop production is increasingly inadequate to ensure household food security and an acceptable level of social reproduction.

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<sup>9</sup> Rural people's knowledge has been defined as "cultural knowledge, producing and reproducing mutual understanding and identity among the members of a farming community, where local technical knowledge, skills and capacities are inextricably linked to nontechnical ones, e.g. cultural, ecological and sociological factors" (Scoones and Thompson 1994). Rural people's knowledge is a broader definition than the production-oriented definitions of "Indigenous Technical Knowledge" (IDS 1979) and "Indigenous Agricultural Knowledge" (de Boef *et al.* 1993). Rural people's knowledge has the advantage of leaving out the confusing term "indigenous", which means of local origin when referring to knowledge, and suppressed or colonized when referring to people.

A major argument for the centralized nature of scientific plant breeding is its high cost in terms of manpower and capital. With the increased calls for decentralizing scientific plant breeding, local plant genetic resource management may have a major comparative advantage because of its low capital cost. Decentralization of scientific plant breeding, moreover, implies greater location-specific adaptation of modern varieties. In this aspect local plant genetic resource management has a strong comparative advantage, as farmers are in the best situation to understand the nature of local conditions of farming. The potential of using local plant genetic resource management institutions as partners in decentralized participatory plant breeding approaches is therefore high. Local plant genetic resource management requires assistance from the formal sector to become more productive in two ways: extension of improving methods of seed selection, and access to enhanced germplasm.

Farmers select on the basis of phenotypic characteristics (characters which are easy to observe) and not on genotype characteristics used by scientific plant breeding. This method of plant breeding is only efficient in breeding for characteristics with high inheritability (Berg *et al.* 1991). Further, improving farmers' ability to select for increased yield requires transfer of knowledge of scientific methods of seed selection from plant breeders to farming communities.

*Ex situ* collections have in recent years been used as the basis for reintroduction of plant genetic resources as a strategy to counter the effects of serious genetic erosion following droughts, wars or other major destructive events. Such links between genebanks and farmers could possibly be extended to give farmers access on a regular basis to germplasm lost due to the general process of genetic erosion.

### **Analysis of local plant genetic resource management in Mkulula village, Iringa district, Tanzania**

#### ***Introduction to crop production in Mkulula village***

Mkulula village is situated in Ismani Division, some 3 hours drive on a poor quality dirt road from Iringa town, situated in the Southern Highlands of Tanzania, 500 km from the capital Dar es Salaam. The area is today characterized as semi-arid, with annual rainfall in the village of 431 mm (6-year average). The distribution of rainfall is highly variable from year to year as well as within the agricultural season.

The recent history of agricultural development in Ismani Division is highly dynamic. Only 50 years ago the area was densely covered with natural forest and cultivation has since then gradually expanded into the area from the neighbouring highland areas. Major clearing of forest took place in the 1950s and 1960s, where a slash and burn type of agriculture was practised, with maize, sorghum and millet as the major crops. Maize was further consolidated as the main crop in the 1970s, in connection with the forceful resettlement of the population into nuclear villages. By the mid-1980s, deforestation was widespread, soil fertility low and rainfall no longer able to sustain maize. Sorghum gradually became the main crop. The present cropping pattern is shown in Table 1.

The average harvest level was 2 t per household (Table 2). Many of the poor households do not harvest sufficient food for subsistence. The low level of harvest is a reflection of very low yields (Table 3). There are no clear relationships

between social stratification and yield level, and the correlation between social group and size of harvest is related to the size of cultivated area.

**Table 1. Cropping pattern in Mkulula village (hectares per household)<sup>1</sup>1993/94**

Crop	Poor <sup>2</sup>	Average	Better off	Mean
Maize	0.45	1.09	0.61	0.72
Sorghum	1.74	1.05	2.23	1.67
Sunflower	0.24	0.53	0.85	0.54
Cotton	0.0	0.04	0.08	0.04
Groundnuts	0.04	0.08	0.04	0.05
Other	0.04	0.0	0.12	0.05
Total	2.51	2.79	3.93	3.07

<sup>1</sup> All data on farming in Mkulula village are based on fieldwork carried out in 1994 and 1995 by the author. A detailed analysis of the farming system can be found in Friis-Hansen, forthcoming.

<sup>2</sup> The three categories of farmers are based on a wealth ranking using the farmers' own criteria for differentiating between the three groups.

**Table 2. Average harvest (kg) per household in Mkulula village, 1993/94**

Crop	Poor	Average	Better off	Mean
Maize	225	396	414	345
Sorghum	774	1314	1755	1280
Sunflower	210	285	503	333
Cotton	0	7	63	23
Groundnuts	14	21	14	17
Other	0	5	6	4
Total	1223	2028	2755	2002

**Table 3. Yield per household (kg/ha) in Mkulula village, 1993/94**

Crop	Poor	Average	Better off	Mean
Maize	506	363	682	517
Sorghum	445	1248	788	827
Sunflower	864	541	583	663
Cotton	0	173	778	317
Groundnuts	346	259	173	259

### **Local management in a social and cultural context**

#### **Ethnicity and culture**

In societies where ethnic groups play an important role at the community level, management of local plant genetic resources in food and agriculture (PGRFA) is commonly closely integrated with the culture.

Table 4 shows a marked difference in the use of sorghum varieties between ethnic groups in Mkulula village. The Gogo and Sangala tribes migrated to the village from traditional sorghum-growing areas, while the Bena and Hehe tribes have a strong preference for maize. The Masai were traditionally pure pastoralists and have only recently taken up cultivation of crops on a large scale.

**Table 4. Sorghum varieties cultivated in 1994/95 season in Mkulula village by ethnic groups**

Variety	Ethnic group				
	Hehe	Bena	Gogo	Masai	Sangala
Serena	x	x	x	x	x
Tegemeo			x		x
PN3	x	x	x	x	x
Sandala			x	x	
Sanyagi	x	x	x	x	x
Kilezilzi					x
Lugugu			x		x
Nyangobwi	x	x	x		
Madzi			x		
Hembahemba			x		
Kasao			x		
Mihondunu			x		
Total	4	4	11	4	6

#### **Wealth and social status**

Evidence indicates that different social groups of farmers use different seed varieties. Crop varieties are adapted to optimize the performance when cultivated under resource constraints. Resource-poor farmers, who do not own a team of oxen and a plough, have to wait until the better-off farmers have finished ploughing their fields to rent an ox team (payment is the weeding of a similar area, a labour task which is 6 times greater). Initial data from Ikuvala and Mkulula villages indicate that farmers who do not own an ox team use a higher proportion of early maturing varieties than the better-off farmers.

Farmers who are relatively better off, compared with the community in which they live, often manage a higher than average number of varieties and can afford to take the risk of experimenting with new germplasm. Only the relatively better-off farmers in Usangu Plains cultivate a low-yielding but particularly good-tasting landrace called *Shingua ya mwali*, which can be translated as "the neck of a virgin girl in the pre-marrying age".

## Gender

There are clear gender differences in local PGRFA management. Women play a dominant role in managing PGRFA, as their responsibilities include reproduction as well as production. Women are local seed selectors for the range of end-use criteria relating to the household food requirements, e.g palatability, taste, colour, smell, cooking time, etc. Women's focus on the household economy provides a balance to market-oriented pressures that emphasize high yield and uniformity.

In many households, women manage components of the farming system containing high levels of biodiversity, such as home gardens, and make extensive use of gathered species and tree products. Since women prepare the family meals, this influences the variety of crops which they select for the home garden. Often, this is used as an experimental plot, where women tend local and other species as they try them out and adapt them for use. Home gardens also serve as a refuge for less common species and varieties.

To the extent that a division of labour exists, where women are responsible for food crops and men responsible for cash crops, the task of managing PGRFA commonly follows similar gender division. In the study villages women are responsible for local PGRFA management for cowpea, beans, finger millet and sweet potato.

## Treatment and storage of seed

A range of local treatment and storage techniques exists for seeds of agricultural crops. The treatment and storage of seed often, but not always, differ from storage of the harvested crop. Scientific information on the quality of local seed storage is insufficient to draw general conclusions. Judging from general descriptions and anecdotal evidence, local seed storage is serving its purpose without any major problems. This impression is supported by a recent scientific study of the quality of seed saved by farmers in Ghana, Malawi and Tanzania, which show a high level of viability (>70%) for maize, cowpeas, groundnut and soya; beans were more variable (Wright *et al.* 1995). No studies have been done on vigour (a measure of how well the plants become established in the field), which would give a truer indication of the efficiency of seed storage. Neither are there any studies of the quality of local seed storage in connection with poor harvests, e.g. following a drought.

In Mkulula and Ikuvala, seed of maize, sorghum and finger millet are selected from the household storage post-harvest. A major advantage of this selection practice is that pests and diseases will have become evident in storage by the time of selection, enabling a selection pressure for good storing properties.

## Local PGRFA management and the crop cycle

### Local seed selection

A literature review from 1989 concludes that the existence of farmer experiments, innovations and adaptive practices is now commonly accepted (Richards 1989). Mass selection is the basic method for selection used in local plant genetic resource management. The farmer selects seed from his/her own field, either before or after harvest. Selection is based on direct assessment of either the whole plant or the economic part of it, according to the objective of the farmer. Observed variation is caused by the combined influence of environment and genetics, also termed G×E interaction.

The strength of local selection is its ability to adapt varieties to the specific cultural, economic and social requirements of farming communities. Local selection criteria used by farmers may be divided into four groups: adaptation to specific local agro-ecological environments; adaptation to specific household preferences; adaptation to resource-constrained farm management conditions, and development of horizontal resistance to pathogens.

#### Seed multiplication and exchange

The basic principles of local PGRFA management are applied by the majority of farmers in developing countries. However, there are always some farmers within a given community who have better-than-average skills for managing PGRFA, which gives rise to specialization with the community.

Retention is the dominant source of seed of frequently used landraces, while new or less frequently used varieties are exchanged among neighbours, within the community or even within regions. For crops such as beans, the seeds of which are easily stored and whose varieties are distinct, the market may play a greater role as a source of seed for landraces. Seed exchange may also be an important source of seed for landraces in situations of rehabilitation following poor harvest. An Impact Assessment of emergency assistance in the form of seed, following the devastating drought in Southern Africa in 1991/92, revealed that farmers' local seed exchanges are remarkably resilient and are an efficient mechanism for revitalizing diversity of local varieties (Friis-Hansen and Rohrback 1993).

Table 5 shows that seeds are frequently exchanged among farmers and that the exchange takes place within all three social groups. One farmer in Mkulula (outside the sample) is known to produce good-quality seed, and he gave seed to more than 50 farmers in the village in exchange for grain.

**Table 5. Community seed exchange in Mkulula village**

	Better-off	Average	Poor
% of farmers giving seed to others	75%	69%	62%
Average number of varieties given to others	5.8	7.9	4.4

#### Characteristics of indigenous landraces

Farmers select for specific end-uses such as palatability as porridge (maize, sorghum), palatability in cooked form (bean, cowpea, rice), brewing quality (maize, sorghum, fingermillet), cooking time (beans, cowpea) and period in which the plant yields edible leaves (beans, cowpea, sweet potato, cassava).

Farmers in Ikuvala village, for example, prefer a local creeping variety of cowpea, simply called *kunde ya kinyeti*, from which the women can harvest green leaves used as *mchicha*, relish to supplement *ugali*, for a 12-week period, as opposed to the improved erect bush type which only provides leaves for a 2-week period. Leaves of local cowpea are likely to be the first available food in a given season, and play an important role as a food bridge to resource-poor households in which the harvested dry grain possibly has been eaten.





Selection for optimal performance when cultivated in environmental microniches within the farmers' fields includes local adaptation to flat versus sloped fields, dry versus swampy fields, clay/loam versus sandy soil.

Farmers' use of sorghum in Mkulula village provides an example of local specific adaptation to microniches (Table 7).

Selection for high fodder yield is reflected in most landraces. All the local sorghum varieties are thus tall and provide an important supply of supplementary fodder for the livestock. The quality of nongrain yield is moreover important; for example, the stem of local varieties of sorghum and sunflower is commonly used as building material.

**Table 7. Examples of local specific adaptation of sorghum varieties in Mkulula village**

<b>Nature of local microniche</b>	<b>Sorghum varieties adapted to local specific microniche</b>
Fields continuously cultivated for several years	Serena, PN3, Sandala, Tegemeo and Sanyagi
Fields cultivated for less than 2 years	Madzi, Hembahemba, Lugugu and Kasao
Loamy clay soils	PN3, Tegemeo, Sandala, Sanyagi and Msabe
Sandy soils	Serena, Madzi, Lugugu and Kasao

Selection for drought stress adaptation is the result of farmers' selection over time of the varieties surviving the irregular and low rainfall patterns.

The plant trait of drought stress tolerance is complex and composed of four mechanisms: scope, avoidance, dehydration tolerance and tolerance. Scope is a mechanism which allows the crop to complete the drought-sensitive growth stages during periods of adequate moisture. Avoidance is the ability to endure drought by maintaining high water potentials of the plant through higher levels of water absorption due to a better distribution and larger root system, and reducing the water loss by avoidance control. Dehydration tolerance is the ability to withstand membrane degradation and protein denaturation through the cellular level activity of osmotic adjustment. Tolerance is the ability to survive an eternal stress due to dehydration tolerance or avoidance mechanisms.

Earliness to maturity is a highly valued characteristic which provides a much required flexibility in the cropping season. Earliness to maturity enables farmers to plant and subsequently harvest early, as well as plant late and still harvest a mature crop. The disadvantage is that earliness to maturity is inversely related to yield, and farmers compromise by selecting for a range of different times to maturity.

Horizontal resistance to pathogens (disease, insects, fungi and virus) is a common characteristic of landraces. It consists of a complex of mechanisms which provide a degree of protection against attack of, e.g. a given disease on a plant, and if the disease has been established, a degree of protection against the disease spreading to the entire plant population of the field. The basis of horizontal resistance to pathogens is that landraces are genetically heterogeneous populations. The heterogeneity of the plant populations is maintained by farmers selecting small samples of seed from several different heads within a given field. The fact that the

disease loose smuts on sorghum is managed at a low and economically insignificant level in Mkulula is an example of horizontal resistance to a disease.

### ***Dynamics of plant genetic resource management***

As a response to the 1991/92 drought in Southern Africa, Concern, an Irish NGO, distributed 40 t of an improved sorghum variety (PN3) in Ismani Division. The NGO had no particular knowledge about the PN3 variety and has not supplied any additional sorghum seed to farmers since 1992. PN3 was developed by ICRISAT using elements of participatory plant breeding. The variety is based on a landrace collected in West Africa, it was evaluated and developed by ICRISAT in India and was further developed by ICRISAT's Southern African station in Zimbabwe, involving on-farm trials and socioeconomic studies. As a consequence of the involvement of farmers in the breeding process, PN3 satisfies the primary objectives of farmers:

- it is short season with yields similar to those of the long-season varieties cultivated in Mkulula
- it is white and farmers are highly content with its palatability for food as well as local beer
- it is easy to process.

The introduction of PN3 has had dramatic effects on the cultivation of sorghum in Mkulula village. It was cultivated on a small scale in 1992/93, and was highly appreciated by farmers. PN3 covered almost half of the sorghum area in 1993/94 season. Preliminary data from a survey carried out in November 1995 indicate that PN3 now covers 90% of the sorghum area in fields of farmers from the Bena and Hehe tribe, who now only cultivate one local variety for food security reasons. The Sagala and Gogo people still cultivate the full range of 11 sorghum varieties, but these are now confined to 25% of the sorghum area, with PN3 dominating the remaining 75%.

While this can be seen as a great success for ICRISAT's plant breeding efforts, the long-term impact of this new variety on the availability of local landraces of sorghum is unclear. If most of the local sorghum varieties are abandoned within the next few years, the community will be highly vulnerable if the PN3 variety falls victim to a disease or pest.

### **Conclusion**

Participatory plant breeding can benefit greatly by linking local plant genetic resource management institutions. While participatory plant breeding goes a long way in meeting the requirements of resource-poor farmers, it is not adequate on its own as a strategy for crop development. The release of well-adapted varieties, developed in cooperation with farmers, may result in serious genetic erosion, similar to the release of conventional modern varieties, if distributed without complementary action.

Our understanding of the dynamics of local plant genetic resource management systems is inadequate and further research is needed with regard to the effectiveness of farmers' methods of seed selection, treatment and storage.

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## Innovation in the organization of participatory plant breeding

**Jacqueline A. Ashby Teresa Gracia, María del Pilar Guerrero Carlos Arturo Quirós, José Ignacio Roa and Jorge Alonso Beltrán**

Hillsides AgroEcosystem Programme, IPRA Project, CIAT, Cali, Colombia

### Introduction

Farmer participation in formal plant breeding spans a very broad set of activities along a continuum ranging from the involvement of farmers in helping plant breeders to develop the plant ideotype, to decision-making about the release of varieties and seed production. The development of the plant ideotype with farmers can be accomplished by involving farmers in a dialogue about desirable plant characteristics, their presence and absence in known landraces, and the kinds of traits farmers would like to introduce. Farmer involvement in the early stages of a plant breeding programme involves eliciting farmers' criteria for ranking alternative materials or contrasting plant characteristics in order of preference, and then searching for parents which offer some of the desired traits. Then farmers can take part in active selection among the progeny. Active farmer participation in evaluating segregating populations is still unusual, but involving farmers in the evaluation of advanced lines, whether in breeders' nurseries on-station, or in multilocational varietal trials on-farm, is increasingly recognized as a useful way to generate timely feedback to breeding programmes about the potential acceptability of new materials.

At what point in the continuum of these activities decision-making about the selection (and deselection) of materials is best delegated to farmers is still a major question. However, as farmer participation in the later stages of varietal selection tends to coincide with seed multiplication of the most promising materials, it can be very advantageous for farmers to take over responsibility for adaptive varietal testing, multiplication of the locally adapted materials and dissemination of seed. Experience with this approach shows that new varieties selected with farmer participation methods are better adapted locally than those recommended by researchers working on their own, and that significant widespread adoption and impact can be achieved by varieties selected together with farmers (Sperling *et al.* 1993; Worede and Mekbib 1993).

Many social science methods and techniques which can be used to implement farmer participation in varietal evaluation and selection are well known (Ashby 1990). The implications of farmer participation, especially in the early stages of selection (e.g. before the  $F_4$  or  $F_5$  generation), for plant breeding methods are less well understood, but there are a growing number of practical experiences with the approach which lend themselves to systematic assessment of the relative advantages of different methods. The implications of participatory plant breeding for institutional development, and the question of what types of institutional arrangements would be likely to support and promote its application have, however, received little attention to date. It is well understood that participatory breeding requires a significant degree of decentralization of the breeding effort (Ashby and Sperling 1994), but the organizational implications for national breeding programmes, for example, of this type of decentralization have yet to be identified.

One approach to decentralizing participatory breeding could be the establishment of community-based organizations of experimenting farmers (i.e. farmers who do varietal testing on their own initiative and are known to introduce and select material). There are an increasing number of experiences involving organizing groups of farmers to participate in adaptive technology testing. This strategy is in part a response to concerns about how to reduce the costs of involving farmers in research when this makes heavy demands on the time of salaried professionals (researchers or extensionists). It also addresses the need to 'scale up' farmer participation in research and seed production so that technology testing can be carried out in numerous, diverse microenvironments without incurring excessive expenses and compromising the quality of participation (Ashby 1990; Okali *et al.* 1994; Bebbington *et al.* 1994).

Many questions can be raised about the viability of institutionalizing a role for farmers in formal plant breeding programmes, and the constraints such efforts are likely to face. Could this local capacity, if linked effectively to research agencies, share the costs and expand the coverage of decentralized breeding, while ensuring that this is relevant to local farmers? Can a farmer-managed, community-based, varietal-testing service linked to local seed production, and perhaps to community seed banks, be institutionalized to support farmer participation in decentralized breeding? How can a few specialized plant breeders working with advanced breeding techniques in a national and international crop improvement effort be effectively linked to a multiplicity of community-based nuclei where decentralized varietal screening, selection and seed multiplication might take place? Is this feasible without increasing the transaction costs to an unwieldy extent? Little systematic work has been done on the costs of creating organizations at the community level to fill this function, nor has there been much empirical assessment of the extent to which such organizations can increase coverage in a way which is self-sustaining (Axinn 1994).

This paper reports on an effort to provide empirical data on some of these issues from action research carried out in 1990-94 by the IPRA project of the International Center for Tropical Agriculture (CIAT) with support from the W.K. Kellogg Foundation. The project aims to assess the potential for institutionalizing a community-based capacity for involving farmers in carrying out adaptive research in which the community carries out a diagnosis and sets priorities for experimentation. Many of the communities where this pilot study is being conducted have prioritized experimentation with crop varieties in an effort to diversify their production systems. In some cases, the varietal testing carried out by community-based committees of farmers has evolved into the establishment of small-scale seed-production enterprises. This paper reports some of the results obtained from this experience with committees of experimenting farmers, the effects of scaling-up this approach to achieve broad coverage and its cost.

The paper is organized as follows. The following section describes, in summary form, the procedures used for forming farmer committees and their activities. The results referred to above are presented in relation to the evolution of the farmers' committees over the 4-year period 1990-94. The paper ends by pointing out issues that these raise for future application of this approach to decentralized, participatory breeding.

## Description of the CIAL methodology

### **Project strategy**

The project's strategy is to implement participatory research methods for adaptive technology testing, by forming committees of farmers based in rural communities to carry out technology testing together with public sector agricultural research and extension agencies, and intermediate organizations (NGOs and farmer cooperatives). Development of training courses and materials used for training farmers and staff of public sector and intermediate organizations for this purpose is part of this strategy.

The purpose of the farmers' research committees (Comités de Investigación Agropecuaria Local or CIAL) is to mobilize local leadership among farmers to take responsibility for experimenting with technologies not known in their community. In this way, the project aims to create 'demand-pull' by clients of public sector and intermediate organizations on agricultural research and extension, by diversifying the type of technologies available and increasing the number and rate of flow of technologies to resource-poor farmers, thereby improving adoption, farm incomes and welfare.

### **Pilot area**

The project was initiated in a pilot area in Cauca Department, in southern Colombia. Cauca is one of the poorest, lowest-wage departments in the country. The pilot area is characterized by hilly terrain, poor infrastructure of roads and markets and small farms averaging 5 ha in size (average cultivated area is less than 3 ha). All farms engage in a mix of commercial and subsistence production. This is a marginal coffee-production area, with infertile acid soils, often badly eroded. Most farmers cultivate coffee, together with cassava as a cash crop; some maize and climbing beans are grown traditionally for subsistence. Livestock are scarce (only 13% of farms have any cattle), although the typical farm may have as much as 40 to 60% of area in degraded pasture or secondary bushy growth, a feature of the fallow-rotation system commonly practised.

Literacy is quite common (heads of household have an average of 3 years of primary school), as is typical of rural Colombia. However, among the mixed mestizo and Indian population, the ability to speak, read or write in Spanish is less widespread. Women and children participate in all aspects of farm labour except for heavy physical work, such as land preparation or harvesting cassava. However, as income level rises, women's work is increasingly concentrated around the household and its tree garden and vegetable plot, while young children attend school.

### **Formation of CIALs**

The project began the formation of CIALs in five communities (*veredas*) in 1990; the number increased to 18 communities in late 1991, to 32 in 1992/93 and then to 55 communities by 1994. A further 30 CIALs, which were formed in Bolivia, Ecuador, Peru and Honduras by international trainees in the method, brought the total to 85 so far. This paper reports information obtained from monitoring the 48 CIALs formed between 1990 and mid-1994 in the pilot area in Colombia; these CIALs cover an area of approximately 1605 km<sup>2</sup>, involving an estimated 50 000 families,

and direct contact with over 4000 farmers, of whom 220 participated in training as members of the CIAL or research committees.

Each CIAL is formed with four farmers elected at a community meeting, which meets regularly during the first training cycle (or experimental period, usually equivalent to a cropping season of about 6 months). The first training cycle involves up to ten training visits by a paraprofessional farmer (who has had at least one year of prior experience in CIAL). Over the next cycle or cropping season these visits are progressively reduced in number, as the CIAL gains experience and carries out experiments with increasing autonomy. The paraprofessional is backed up by an agronomist who provides input to statistical design of CIAL experiments and the analysis of data taken by the CIAL members. At present in the project area, the 48 CIALs are attended by three paraprofessionals, backed up principally by one trainer-agronomist. The organizing principles and the types of trials conducted with the CIALs are discussed in more detail in an earlier paper on this approach (Ashby *et al.* 1995).

The procedure currently used for formation of a new CIAL is as follows.

1. On-farm research and extension staff of the host institution receive training in the CIAL methodology and select communities, or respond to requests from communities to form a CIAL. The host institution may be the state agency or an NGO or farmer cooperative.
2. The host institution calls a community meeting in which farmers make a group analysis of what it means to experiment with new agricultural practices, of local experience with experimentation and its results, and of the purpose of a local research committee.
3. If the community decides to establish a CIAL, it elects a four-member committee of farmers recognized locally as experimenters, with leadership qualities defined together with the community, before the election.
4. The CIAL conducts a diagnosis in one or more community meetings at which a topic for the CIAL experiment (e.g. a crop, cultural practice, fertilizer use) is prioritized.
5. In a planning meeting with their host institution's agronomist, the CIAL defines the objective of their experiment; the treatments and the check; criteria for site selection; timing; inputs; data needed to draw conclusions from the trial; responsibilities for different tasks. In the first training cycle, a paraprofessional farmer visits the CIAL on a regular basis, as these tasks are implemented.
6. Once the experiment is planned, the CIAL carries out the activities involved, from planting to harvest, managing the community's CIAL fund. This is a collective rotating fund, in which each CIAL has a share. In Colombia the CIAL fund amounts to less than 50% of the value of a head of livestock in the pilot area (US\$500 per CIAL).
7. Once the experiment has been harvested, the CIAL meets with the agronomist to draw conclusions from the data they have taken on their experiment and plans the community meeting at which the CIAL will present its results.
8. The community meets to hear an oral report by the CIAL of its activities, results and financial status. If appropriate, the diagnosis is repeated to orient the CIAL's activities for the next season. If the CIAL decides to continue the same experiment into a second cycle, the experimental approach taught to the CIALs involves starting with a small-sized plot (*parcela de prueba*) which may have several treatments (e.g. varieties or fertilizer treatments or planting

distances). The more promising treatments selected by farmer evaluation enter larger plots (*parcela de comprobación*); in the next planting season two or three selected treatments progress to production plots (*lote de producción*). The options farmers consider desirable are then planted on what is considered locally a commercial-scale plot, so that management requirements can be realistically assessed.

9. In the second and subsequent cycles of experimentation two or three monitoring visits are conducted by the paraprofessional farmer to verify that plot selection by the CIAL is appropriate for the trial's objective, that treatments are labelled and harvested accurately, and that the motivation of the CIAL is strong.

### **Results of the CIAL method**

This section of the paper reviews the results obtained during 1990-94 from the organization of 48 CIALs or farmers' research committees in the pilot area in Cauca, Colombia. The four organizing principles discussed above were drawn on to create the step-wise procedure for the formation of CIALs described earlier.

### ***Devolution of responsibility for adaptive testing***

One of the most important questions for the project is "What types of responsibility for location-specific technology testing can be successfully taken on by experimenting farmers organized in a CIAL?"

The procedure for forming CIALs was developed in a pilot phase from 1990 to 1991 in which five farmers' research committees were established and trained in techniques for participatory diagnosis; planning and establishing replicated on-farm trials; participatory evaluation of technology; analysis and interpretation of results; budget analysis of the total cost of the trial and of the individual treatments. Planning and presenting a short oral report on the results to the five CIALs, which met as a group, and to each community was part of the process. After the first training cycle (or cropping season), the agronomists in the IPRA project team began to gradually hand over each operation in the process to the farmers. Monitoring visits by a sociologist were made regularly to assess how well the farmers were able to manage each operation, and to detect when follow-up training was required.

On the basis of this experience, training materials in the form of 12 CIAL handbooks were prepared using discussions with the farmers involved, who helped to prepare the text and illustrations (see Appendix 1).

At the end of 1991, the second phase of formation of CIALs was initiated. The project used the training materials to teach a course with NGOs in the pilot area, to prepare agronomists on their staff to establish CIALs. As a result of the course, a further 13 CIALs were established using the training handbooks. Monitoring by the project of this second phase now covered 18 CIALs, and included revision of the training handbooks as these were used in practice by the NGO trainees and their CIALs. Based on this experience, the training handbooks were finalized, and in 1992 the project began to teach a regular course on the CIAL method to NGO trainees (who are university students doing a 6-month agricultural extension practicum in the rural areas with the NGO), state extension agents and local community leaders.

In a third phase a further 28 CIALs were formed in response to requests from communities and farmer associations. In 1993 trainees in the course on the CIAL method included three farmers who were members of CIALs formed in the second



phase. These farmer-paraprofessionals were contracted (one by an NGO, one by a farmer cooperative, one by the project) to form the CIALs in the third phase.

The 43 CIALs formed after the first five in the pilot phase have therefore been established successively by trainees coming fresh to the methodology. This has allowed the project to evaluate the training requirements for setting up new CIALs, the rate at which CIALs can be progressively "detached" from their trainer, and the rate at which they can take over the responsibility for carrying out experiments in the absence of a trainer.

Table 1 shows the rate of increase in activities carried out by CIALs independently of institutional support in the form of training by the agronomist or paraprofessional farmer. The data on the first cycle show how the number of training visits required has gone down from 17 needed to develop the method and the training materials in Phase I to 10 training visits in Phase III. Training sessions follow the activities outlined in Table 2. In practice, the number of training visits has been reduced, because some activities listed in Table 2 such as obtaining inputs, and repeated activities like observation or evaluation of the experiment, can be carried out independently by the farmers even during the first training cycle.

The newest CIALs formed in Phase III are operating by cycle 2 with an average of 4 visits for training and support (Table 1). The 5 pilot CIALs formed in Phase I have continued to increase their autonomy: by the last cycle, pilot CIALs were operating with only two support visits (one for planning the experiment; one for analysis of results) by the paraprofessional farmer.

**Table 1. Rate of increase in independence of CIALs from institutional support, 1991-94.**

Formation phase	No. of CIALs	Mean number of visits per training cycle				
		Cycle 1	Cycle 2	Cycle 3	Cycle 4	Cycle 5
I (Pilot)	5	17	10	4	2	2
II	13	12	7	3	3	-
III	30	10	4	4	3	-

Table 2 summarizes conclusions on the type of institutional support required by a fully trained CIAL in the form of training and monitoring visits to carry out a crop-related on-farm experiment. Our experience demonstrates that farmers' committees working on their own confidently and accurately record results for separate treatments without confusing these when they are interested in the results. When in the planning meeting, farmers have defined data they want to take, in measurement units that make sense to them; they are able to analyze these data to compare treatments, to assess germination rates and crop development. For example, height of maize plants was evaluated as: too low (dogs can reach and steal cobs); medium (will withstand wind and resist lodging, which is desired); too tall (susceptible to lodging). Yield data are commonly processed by farmers in terms of yield per unit of seed, because they do not customarily use measures of area, although experimental plots are measured and staked out.

Monitoring of the 48 CIALs showed that of the 15 activities detailed in Table 2, a fully trained CIAL (with two cycles of experience) required training support in four activities at most. In Phases I and II, two of these required the presence of a trained agronomist: planning, including the statistical design and analysis of results. Two visits by a paraprofessional were identified as desirable: to check that

plot selection is consistent with the experimental objectives and to ensure that data at mid-term or harvest evaluation are taken accurately. Monitoring visits routinely involve a visit by a paraprofessional to the community, diagnosis and community report meetings. By Phase III the paraprofessional farmers were beginning to take over responsibility for support of planning the CIAL trials, and the analysis of results, by bringing the plans and later the results to a meeting for this purpose with one of the host institutions' agronomists.

**Table 2. Activities carried out by a CIAL in a crop-related experiment, and institutional support required**

Type of activity	No.	Training and assistance by		Monitoring by paraprofessional farmer
		Agronomist	Paraprofessional	
Group diagnosis	1	-	-	(1)*
Planning	1	1	-	-
Plot selection	1	-	1	-
Land preparation	1	-	-	-
Obtain inputs	1	-	-	-
Establish experiment	2	-	-	-
Check germination	2	-	-	-
Crop management	variable	-	-	-
Mid-term evaluation	2	-	1	-
Harvest evaluation	1	-	-	-
Analysis of results	1	1	-	-
Community report	2	-	-	1
Total	15	2	2	2

Most of the CIALs' research questions can be addressed by single-factor experiments (e.g. 6-10 varieties superimposed on local cultural practices; or 3-4 fertilizer or pest-control treatments). This makes support of trial planning and analysis feasible for paraprofessional farmers, together with a check of the design and interpretation provided by an agronomist. (In practice, training was required as much to reinforce skills of trainee agronomists to design and analyze on-farm trials, as to teach these skills to farmers).

The research agenda defined by the CIALs is evolving from principally germplasm-based strategies (the search for new crops and varieties) at the beginning, to an interest in cultural practices once a viable new crop or locally adapted varieties have been selected by their experiments. Most recent experience shows that the paraprofessional farmers can support CIALs in the design of a two-factor experiment: planting density  $\times$  fertilizer dosage is one example of a design set up by a CIAL without the intervention of an agronomist.

In conclusion, the project's experience demonstrates that the training of farmer research committees can be accomplished in two cycles (i.e. during two experiments), and that the fully trained CIAL can take over responsibility for the majority of the activities required for farmers to implement on-farm experiments.

Experience in 1993/94, in Phase III, indicates that paraprofessional farmers (with two cycles of experience as a CIAL member) can provide almost all of the

training and monitoring support required for formation and maintenance of the CIALs' experimentation in the form of simple on-farm trials. This is permitting the agronomists involved in the project to delegate the planning and analysis needed to routinely support fully trained CIALs, as well as the process of CIAL formation.

The next issue of importance is the quality of the research carried out by CIALs operating with this degree of autonomy.

### ***Quality of research conducted by CIALs***

Evaluating the quality of farmers' research is related to the issues discussed earlier, of the usefulness to farmers of the scientific method as compared with folk experimentation. The project's strategy is to combine both approaches: a formal experiment is planned and established, but if farmers decide to make changes in treatments or alter the experiment along the way in the style of folk experimentation, then the only requirement is that this is a decision made in committee by the CIAL, together with any other collaborating farmers.

CIAL experiments have been established with a minimum of three replications (farmers), and on occasions are also replicated within each site, if an agronomist judged this to be advisable. Trials have been established on land belonging to members of the CIAL, on communal land, or on land belonging to other farmers, and have included rental or sharecropping arrangements common in the community in question. Site selection is a decision made by the CIAL, with a follow-up visit to check that the proposed sites are consistent with the experimental objectives identified in the planning activity.

Consequently, the trials are carried out with a variety of collaborative arrangements, involving on occasions a group of community members (who, for example, donate labour for the trial) or an individual who sharecrops (contributes land or labour and gets a share of the harvest). Observation and evaluation of the progress of the trials may involve several experimenting farmers, identified by the CIAL committee members as knowledgeable experts in the topic chosen in the community's diagnostic meeting, who then take part in planning and implementing the replications. There exists, therefore, scope for farmers to intervene and to combine folk experimentation with the formal experimental design.

The project has monitored the quality of CIAL's research with respect to three criteria:

1. Is the experiment interpretable by farmers and also statistically analyzable?
2. Were farmers still satisfied that they could draw useful conclusions from the experiment, even if statistically unanalyzable?
3. Did farmers conclude that they could not draw useful information from the experiment?

The evaluation asks, therefore, if farmers perceive the experiments as useful for generating information, and as well, do the experiments have the potential to communicate with formal research and extension systems.

Table 3 presents the results of this evaluation. Of the 273 trial plots managed by CIALs during 1991-94, the plots (replicates) that could be used for statistical analysis averaged 75%. In Phase I, 91% were judged useful by farmers of which 84% were statistically analyzable. However, in Phase II, only 62% were statistically analyzable, although farmers still judged 89% to be interpretable for their purposes. The reasons for this drop in percentage statistically analyzable were detected in the self-evaluation exercise conducted with each CIAL. In Phase II, CIALs were linked

to trainee extension agents who were managing the supply of inputs for the CIAL experiments together with those for their NGO's credit programme. The credit programme was plagued by delays in obtaining the funds for purchasing inputs given in kind to participating farmers, which resulted in delayed planting and subsequent loss of trial plots from the CIAL experiments. The CIALs requested that they manage the petty cash fund for purchasing experimental inputs, and once this was put into operation, the capacity of the CIALs to implement their trials in a timely fashion improved significantly. In Phase III, the number of plots lost to analysis owing to late planting decreased to three (managed by one CIAL); the remainder were lost because of other factors.

In sum, the average success rate by farmers' criteria is 90%, or by statistical criteria is 75%, in terms of carrying out trials judged locally useful for knowledge generation.

**Table 3. Quality of on farm trials conducted by farmers' Committees (CIAL), January 1991-August 1994**

Formation phase	No. of plots	Percentage of plots		
		SA and IF*	SU and IF	Lost to analysis
I (Pilot)	42	84	7	9
II	85	62	27	11
III	146	78	12	10
Total	273	75	15	10

\* SA = statistically analyzable; SU = statistically unanalyzable; IF = interpretable by farmers.

### ***Reasons why devolution succeeds or fails***

Why is this degree of responsibility and accuracy in conducting adaptive trials achieved by resource-poor farmers who are very busy people, struggling to cope with running their own plots and farms? This is especially puzzling in view of the huge resources devoted in the past to training and equipping teams of on-farm (or farming system) researchers for whom obtaining farmer collaboration or participation in formal experiments was a major source of frustration (Lightfoot and Barker 1988). Analysis of the success and failure of CIALs over the period 1991-94, during which time five CIALs have become inactive (representing 11% of the total number formed) suggests that there are several determinants of the degree to which a CIAL makes a commitment to running its experiments with a minimum of institutional support.

First, the CIAL's training must successfully impart the principle that the committee's objective is to experiment, to generate knowledge and to disprove or discredit unreliable recommendations. If this objective is not clear, the CIAL members experience loss of purpose if an experiment shows that local practice is in fact the best available alternative to the innovation being tested.

Our experience shows truly impressive persistence of some CIALs in the face of several experiments which did not identify a promising innovation compared with local practice. In this respect, contact among CIALs is an important ingredient of success; one CIAL benefits from the others' experimentation and is motivated by it.

The following example illustrates how CIALs work together. In 1991, Loma Corta prioritized field peas in their community diagnosis, with the objective of

finding a short-season crop, easy to cultivate and with a stable price, useful for consumption as well as for sale and easy to market. Field peas were a completely new crop in the CIAL experiments. This region is considered marginal for field peas and so the crop is not recommended officially. Loma Corta planted a varietal trial with four varieties obtained from an experiment station in another department by the paraprofessional. In another experiment Loma Corta compared three systems of support for field peas: posts with string, the technical recommendation; bamboo stakes collected from the local groves; bamboo stakes with one-third of the amount of string recommended. CIAL Loma Corta discarded the technical recommendation with posts and string (this costs \$5 for the string and the other systems use only local materials, or 60% less string with the bamboo stake/string support). Their budget analysis showed that the local support systems require more labour but less cash outlay.

At the annual meeting of CIALs (the Encuentro CIAL), CIAL Betania learned about the results of Loma Corta with peas, then in its second cycle (*parcela de comprobación*). As a result CIAL Betania planted the two varieties and the support system selected by CIAL Loma Corta.

CIAL Esperanza, a colder-climate community, repeated the varietal trial with the two varieties selected by CIAL Loma Corta to see if they were adapted, with two planting systems (line planting and *cajuela* i.e. their traditional system of planting holes). After determining that line planting was preferred, because of the higher plant density obtained in a small plot close to the home garden, CIAL Esperanza planted a second experiment to test the two support systems with bamboo stakes.

Loma Corta lost one year (two cycles) waiting for an agronomist who had promised to obtain more field pea varieties which never materialized. Notwithstanding this demoralizing experience, Loma Corta then went back to experimenting with the two varieties, after observing the progress CIAL Betania was making with peas.

CIAL Betania, having learned from Loma Corta that the support system of bamboo stakes with string was preferred, had selected one variety (Piquinegra) which had the best commercial quality and which the women selected for its large size. They planted a production plot and began to sell the produce. They decided to sell part fresh and another part as seed (worth 120% more than the fresh peas) to other farmers in Betania and in the region.

On the basis of Betania's experience, Loma Corta planted Piquinegra with the bamboo stakes and string, and went immediately to production plot and seed multiplication. Esperanza, having tested variety, planting system and support to its satisfaction, scaled up to production plot and seed multiplication, buying seed from Betania. Now field peas are beginning to appear in monocrop and in association with other crops in farmers' fields, after Betania took its seed for distribution to the Encuentro CIAL.

It is obviously useful for a CIAL to include one literate member who can read the CIAL handbooks aloud to the other members and who can keep records and tally accounts, because this facilitates the management process. However, written records have proved important mainly to the host institution which is collating data from several CIALs. Nonliterate farmers recall complicated varietal code names, the layout of treatments and the differences among treatments with amazing facility if they perceive the information as important and useful to them. Our experience suggests that literacy may not be a prerequisite for farmers to carry out the CIAL's adaptive research responsibilities, but it does mean that support by the

paraprofessional may have to be more intensive over an extended period. Nor does functional illiteracy prevent farmers from exchanging results with each other, since the oral tradition is strong in these communities.

More critical to success is identification in the group diagnosis of a problem or question for the CIAL's experiment which the farmers concerned want to answer and which is of interest to the community. This is why the monitoring visits at diagnosis and report time are important: to ensure that the committee feels accountable to its community and, at the same time, gets encouragement from the interest shown in its results. The sense of community service and responsibility to the group welfare created and reinforced in these meetings is possibly the single most important determinant of successful completion of the experiment by a CIAL. Monitoring shows that conflict in the community and/or conflict in the CIAL is, conversely, most likely to result in an inactive CIAL. For this reason, the approach includes use of a technique for periodic evaluation by the CIAL of how its members feel about each other and their relationship to their community, which can be used by the committee with or without the paraprofessional's presence.

Another motivating factor is that managing a CIAL and experiments which command the respect of 'outsiders' has proved to be a useful tool for 'pulling in' the attention and resources of institutions external to the community. One CIAL has, for example, successfully negotiated a grant of land for a communal farm from the state land reform agency, on the strength of demonstrated management capacity and teamwork; others have attracted marketing arrangements with middlemen who previously would not journey to a distant village, but are now attracted by the quality and quantity of produce resulting from experimentation; yet others have persuaded the NGOs to introduce results of CIAL experiments into their credit programmes. The motivation to run an experiment autonomously is as much related to its organizational function as an interface with external organizations as its usefulness as a method of knowledge generation.

### ***Impact of CIAL trials***

The results reported so far show that the 48 CIALs in the pilot area have, with a decreasing amount of institutional support, carried out a large and increasing number of on-farm trials which farmers consider useful for knowledge generation and which are, to a very large extent, statistically analyzable. This section examines the impact of these trials.

A rapid appraisal of the CIALs' impact showed that in 75% of the participating communities there was a perceived benefit from their CIAL in the form of new seed, new cultural practices or information about which recommendations to follow. For example, one community asked its research committee to compare the state agency's recommendation to cover the ground under fruit bushes with black plastic, and a local practice for controlling nematodes. The CIAL experiment shows to date, at least, that the local practice is more effective under farmer management. Of those CIALs with no perceived benefit, all but two were formed in Phase III and are therefore newcomers with less likelihood of impact so far.

State institutions in the pilot area set research and extension priorities on the basis of area devoted to different crops in the municipality. Thus, in the pilot area, the priorities are cassava, pastures, sugar cane and coffee. Small farmers participating in CIAL diagnostic meetings had different priorities, as shown by the crops selected for CIAL experiments listed in Table 4. It is apparent that the communities identified a much more diverse research agenda than the institutions.

For example, not one community prioritized cassava in their group diagnosis, although over 4000 farmers have participated in community meetings for this purpose. Diversity in the CIAL agenda reflects farmers' objectives to identify alternatives to traditional cash crops (coffee and cassava) and to increase their food sufficiency by growing staples such as potatoes, beans (a substitute for meat in the rural diet) and maize (used for feeding chickens, an important source of locally produced protein and an important ingredient of traditional staple dishes). Even though these staples are produced in Cauca, the department imports these from other parts of the country to meet its food requirements (SAG 1989), so the local food self-sufficiency agenda reflects a regional problem.

**Table 4. Experiments of Local Agricultural Research Committees**

Topic	Number of experiments*		
	Phase I	Phase II	Phase III
Peas and related cultural practices	1	3	5
Potato	6	5	3
Maize and related practices	7	8	7
Peanut	1	3	4
Fruits and related fertilizer dosages; pest control	3	6	11
Beans	6	4	0
Snap beans	0	1	1
Tomato	1	1	1
Soya bean	1	2	1
Vegetables	4	7	6
Chicken feed mixes	1	1	0
Forage grasses	1	1	1
Cover crops (green manure)	0	0	1
Guinea pigs	0	0	1
Total	32	42	43

\* Sums to less than the number of CIALs because not all CIALs are establishing new experiments.

At present, the CIALs are having some success in exerting demand pull and improving the diversity of technologies on offer via state and NGO programmes. For example, in the NGO credit and technical assistance programmes, maize and peas were introduced as a result of CIAL's experiments and beans were given more importance. The municipal credit and technical assistance agencies (UMATA) also began to respond to farmers' priorities, especially once some of the CIALs started producing seed of varieties they had selected in their trials, which the UMATA recommended and distributed to other farmers. One UMATA recently began to use the CIAL's results for formulating recommendations to farmers participating in its credit programme. Another responded to a CIAL's request for help in identifying peanut varieties for testing, by obtaining a selection of new varieties from ICRISAT through the national agricultural research agency.

An important development was the evolution of some of the CIALs, which had successfully selected new locally adapted crop varieties, into small-seed production enterprises delivering seed of these and local varieties to farmers in the area. To date six CIALs have begun to produce seed, for which they receive additional

training in simple seed production, processing and quality-control techniques. This seed can be sold with state approval, when visits from the national agency responsible for seed certification are made, under the category of "farmer-improved seed."

Table 5 shows the amount of seed produced by the six CIAL seed enterprises. The CIAL seed is distributed locally in the village stores and weekend markets. An estimated 281 ha of maize, 3064 ha of beans and 3.5 ha of field peas (an entirely new crop introduced by CIAL experimentation into the pilot area) have been planted with CIAL seed. More than 10 000 farmers have purchased CIAL seed, which over one planting season is estimated to have produced grain to a gross value of over US\$2 million. Based on the yield differential between locally available varieties and those selected by the CIALs for seed production, this production represents an additional US\$765 000 of gross income to local farmers from maize and beans, and a newly introduced income source worth over US\$8000 to date from peas. On a per capita basis, this represents an increment worth about one month of wage income in one planting season to the farmers who purchased CIAL seed.

**Table 5. Seed production by six CIALs and its estimated impact over one planting season**

	Crop			Total
	Beans	Maize	Peas	
No. CIALs	2	2	2	6
Total seed production (kg)	147 080	8430	136	155 646
Estim. area planted (ha)	3064	281	7	3352
Estim. prodn. (t)	3064	1124	3.5	4192
Farm gate price (US\$/t)	683	488	2439	-
Gross value (US\$000)	2093	549	8	2650
Increment in prodn. (%)	30	25	100	-
Value of increment (US\$000)	628	137	8	773

The seed enterprises also generate employment since they must hire additional labour to plant, harvest, sort, clean and pack the seed in 1-5 kg sacks, also made locally by women. The bean seed enterprises have for example generated an average of 20 000 labour-days of employment locally over five seasons, worth an estimated US\$ 85 000 at current wage rates over the 5 years of operation.

This impact has been achieved by six CIALs formed early in the project. There is no guarantee, of course, that the newer CIALs will repeat this experience by identifying new practices or germplasm with comparable impact. The six CIALs which have developed into seed enterprises may have already captured the best opportunity and the windfall profits from participatory breeding and seed production. The impact of the newer CIALs may be more difficult to realize, especially, as Table 4 indicates, as their research agenda is shifting emphasis from grains to perishables. On the other hand, the recent introduction of field peas, via CIAL experimentation, suggests that there could be scope for a significant increase in impact from CIAL experimentation with high-value crops.



***An example of how CIALs can increase genetic diversity by selecting and multiplying seed through their adaptive testing***

A central objective of local farmers in the pilot area, as expressed in the CIALs' research agenda, is to diversify their cropping systems. New crops and new varieties are therefore given high priority in the topics selected for local experimentation. Thirty CIALs have conducted varietal trials evaluating, in all, 47 local landraces, 50 farmer-introduced landraces obtained from outside the area and 259 exotic materials. Farmer experimentation with landraces continues to be a feature of their varietal testing as several CIALs are concerned with rescue; they multiply seed of their local germplasm and maintain a diversified portfolio of genetic materials in their fields.

Maize varieties have been progressively selected by different CIALs which share their results by visiting each other. CIAL Pescador did a varietal trial with seven materials in spring 1991 and identified MB258, MB254 and MB251 as locally adapted lines with desirable grain types. A hundred kilometers away to the south CIAL El Diviso continued in fall 1991, with additional materials. In fall 1991, CIAL San Bosco at a lower altitude and further north, also took up the maize selection. After four seasons of selection, in 1993 the CIALs identified MB254, MB251, MB258, SWAN 8027, CIMCALI-SA 2 (amarillo) and a regional variety as locally adapted, and began multiplying all six as "farmer-improved seed".

ICA (the Colombian national research programme) decided to release MB251 and MB258 in 1993, after conducting 29 trials in the Colombian coffee region over 6 years. The varieties were released with 80 t of certified seed. Farmers in the CIAL communities have not obtained any ICA-certified seed of the new varieties, which are not yet available locally in the government seed distribution agencies or commercial outlets. But they are already harvesting these varieties, using seed from their community's seed enterprise.

The selection of maize varieties is an example of how the CIALs complement the breeding efforts of formal research programmes by pulling technology into the resource-poor farm community, which ensures that farmers benefit from a rapid introduction of locally adapted technology.

Among the benefits these small farmers obtained in addition to earlier access to the improved varieties is that the San Bosco CIAL's research showed that the new varieties could be grown on soils found close to the village. To grow maize previously, farmers had to walk for several days into the outlying hills to find less-exhausted soils, and so they usually had to sharecrop this land. Now they not only keep all the maize harvest in the community instead of sharecropping it, but they save time previously spent journeying to distant plots. Experimentation by the CIAL with organic fertilizer is encouraging farmers to improve plots around the village with chicken manure now that these plots can be used to grow the improved maize.

***Scaling-up and the costs of the CIAL programme***

The results presented to this point show that a fully trained CIAL can take responsibility for executing most of the activities involved in the management of the kinds of adaptive research trials required for the research agenda identified in the 48 participating communities. The experimental results have been useful for knowledge generation, and more specifically have contributed to increasing the diversity of technology tested, as well as improving the rate of flow of technologies

to the participating communities, with sizeable monetary benefits in the specific case of CIAL seed purchasers.

One of the most important questions this research aimed to address was to what extent this type of farmer participation in research could be scaled up to achieve broad coverage, and at what cost. Before participatory research became fashionable, critics often queried whether this approach was an expensive luxury, attractive on a case-by-case basis and when supported by highly skilled professionals, but not affordable for working with large numbers of farmers (Farrington and Martin 1988).

In this section we present information on the potential of the CIAL method to increase the efficiency of salaried personnel working in on-farm adaptive research and extension, by decreasing the amount of time required for them to carry out on-farm trials. We also examine the operating costs of the CIAL corporation, a second-order organization formed by the CIALs in Cauca, to provide some insights into the feasibility and costs of creating self-sustaining CIALs.

One way of assessing the potential of the CIAL method to increase the efficiency of public-sector or NGO programmes carrying out adaptive research is to compare the amount of time required to conduct an on-farm trial with and without a CIAL. Table 6 presents estimates of the labour-days required and cost of labour for an on-farm trial run by an extension agent, an on-farm trial run by a new CIAL in the first cycle of training, and by a fully trained CIAL. The analysis is based on the activities in Table 1, for which we estimate that an extension agent would require 8 labour-days for a trial with up to three replicates (sites). A new CIAL requires an average of 10 training visits by the paraprofessional farmer plus one labour-day of extension agent input to do the same job. A fully trained CIAL can carry out a trial with 4 labour-days of support training from the paraprofessional and a fraction of the input from the extensionist, conservatively costed here at one day. Estimates of the different labour costs show that even training a new CIAL to carry out an on-farm trial is less costly than running a trial with a salaried professional, given the pay differentials for the pilot area. More important, devolving an on-farm trial to a fully trained CIAL costs 60% less in labour costs than running a trial using an extension agent.

**Table 6. Comparison of labour requirements of an on-farm managed by CIAL and by extension**

<b>Trial management</b>	<b>Days required* (n)</b>	<b>Total cost of salaried labour**</b>
By extension research	8	62
New CIAL (Cycle 1)	11	46
Fully trained CIAL	5	23

\* Excludes crop management after trial establishment which is variable depending on the crop; and initial diagnosis.

\*\* Paraprofessional farmer's time costed at minimum wage; extension agent costed at 2 x minimum wage; agronomist time costed at average salary current in the pilot area.

One of the implications of this figure is that adaptive research programmes could potentially reduce their labour costs for on-farm testing significantly (by up to 60%) by working with CIALs. Alternatively, a given amount of professional labour can be expected to at least double its coverage, that is to increase the number of on-farm trials and farmer groups attended, by working with CIALs.

Important variables which affect the efficiency and coverage of adaptive research are the variability of micro-agroecological regimes, the density of the population and the type of terrain which affect the amount of time required for site visits. Before going on to examine the current operating costs of the CIAL corporation, the sociogeographical context in which coverage obtained by the existing CIALs has been developed needs to be described.

Today, in early 1995, there exist a total of 55 CIALs scattered in nine municipios in the Department of Cauca in Southern Colombia, which together compose an area of 6648 km<sup>2</sup>, with an average population density of 40 persons/km<sup>2</sup>. The communities of small farmers participating in the project represent an area of influence of approximately 1605 km<sup>2</sup> in which the population is concentrated at a much higher density: farm-level surveys show an average of 132 persons/km<sup>2</sup>, when the extensive cattle and forest holdings are not included. Communities are characterized by a land use of 0.25 ha of cropland *per capita*, a figure comparable to estimates for Bolivia (0.33 ha), Ecuador (0.25 ha) or Peru (0.17 ha) (Pachico *et al.* 1994).

Since 1991, the CIALs in the project area have decided to meet on an annual basis to exchange results. In this 1- or 2-day meeting, financed by raising money in their communities for transportation and lodging, CIALs give oral reports on their experiments, exchange seed, swap notes about their host institutions and formulate recommendations on how to improve their performance on goals they themselves establish in each meeting. This experience prompted the election of a central coordinating committee (*junta*) in 1993, and then in 1994, led to the CIAL's decision to incorporate legally at the recommendation of the *junta*. Donations were obtained which enabled the CIAL corporation to establish an investment fund, from which the corporation can draw up to 70% of the interest (the remainder going back into the capital) for operating expenses. This put the CIALs on a self-sustaining financial basis. In addition the paraprofessionals have begun to give courses to the municipal extension services (UMATAs), which have contracted them to form small numbers of pilot CIALs elsewhere, paying up to 50% of their salary, and so generating additional income for the corporation. The following data on costs are taken from the CIAL corporation's annual operating budget, itself derived from the project's data on the costs of running the CIALs in 1994.

There are very few published data on the costs of doing adaptive research with groups of farmers with which to compare the figures in Table 7. These show the total operating cost per CIAL, i.e. per community per year at US\$502, and an annual per capita cost ranging from \$125 if we only consider the 220 farmers who are committee members; to under \$1 based on the total population in the area of influence; to \$6.5 per capita if we assume that only a third of the population in the CIAL's communities actually receive any contact with their CIAL's adaptive testing. Based on the estimated number of purchasers of CIAL seed, the cost *per capita* would be approximately \$3. The total annual operating budget of the CIAL corporation currently amounts to the equivalent of about two agronomist salaries at national programme rates. These figures compare favourably with costs cited by Nimlos and Savage (1991) of \$36 per capita and \$2664 per community annually for an extension programme using village-level paraprofessionals in Ecuador. Also in Ecuador, Romanoff (1993 cited in Bebbington *et al.* 1994) reports the cost of forming groups of 10-30 members using farmer-to-farmer training mechanisms at around \$3000. However, these groups were farmer associations for processing and marketing cassava, much larger and more complex than the CIALs.

**Table 7. Annual operating costs of the CIAL corporation for 55 CIALs**

<b>Annual costs</b>	<b>US\$000</b>
<b>Cost per CIAL</b>	
Personnel costs *	290
Cost of experiments **	90
Other operational costs ***	122
Total	502
<b>Cost per capita</b>	
Total population (50,000)	0.55
CIAL communities (12,900)	2.1
33% of CIAL communities (4260)	6.5
Seed purchasers (10,500)	2.6
CIAL committee members (220)	125.5

\* Includes agronomist (0.33), farmer coordinator (1.0), paraprofessionals (2.0).

\*\* Average of costs per CIAL charged against CIAL funds in 1994.

\*\* Average of transportation, supplies, and capital depreciation on four motorcycles.

With respect to coverage, figures cited by Schwartz (1994:11-12) range from 100 to 300 farmers per extension agent (private sector) to 3000 per extension agent (public sector) from case studies in Nigeria, Kenya and Thailand. Comparable figures for the CIAL corporation can be estimated at between 66 (direct contact with committee members) to around 3000 (population of the CIALs' communities or seed purchasers for example) per salaried paraprofessional/agronomist. However, since the CIALs do not at this time have a complete extension function, but a partial research/extension function, facilitating the adaptation of technology, this comparison is not completely equivalent.

One reason why the cost of forming and running CIALs is relatively so low may be that the procedures for creating these groups were formalized fairly early on in the process, into training materials that were written together with farmers and are easily used by farmers. Use of these materials means that paraprofessionals with practical experience in the procedures, who represent very low-cost labour, can form and run CIALs with minimal external support. Experience in Bolivia, for example, suggests that the CIAL handbooks can be used readily to form and run CIALs by extensionists without prior training in the method (Soria, pers. comm. 1995).

Nonetheless, the cost data presented here should not be viewed as conclusive, to the extent that further testing of the approach without the intervention of the originators (the IPRA project team) is underway, and will permit assessment of how robust and replicable the method is in different environments, with variant cost structures.

### **Equity**

An issue related to assessing the effectiveness of the CIAL method for broadening the coverage of adaptive research is the question of how equitable is the distribution of benefits. The project has yet to conduct a comprehensive analysis to address this question but survey data are available on a subpopulation of 11 communities which provide some insight. As discussed earlier, selection of CIAL members is predicated on the assumption that experimenting farmers are likely to be relatively better-off members of the rural community. Moreover, the CIALs are not designed to involve a large population in research; the committee mobilizes a

capacity to test technology within the community, on the basis of a limited participation in conducting the actual research. Therefore, distribution of knowledge about a CIAL's activities, rather than participation in it, is a more important test of the extent and nature of the coverage achieved.

A comparison of three social strata differentiated on an index of well-being (Ravnborg 1994) shows that of the 64 farmers actively participating in 11 CIALs, 39% come from the upper stratum compared with 22% who come from the lowest stratum (Chi square  $P = 0.046$ ). Among the very poor, only 8% participate in CIALs compared with 17% of the upper stratum. However, the community population is essentially one of small farmers and in this subsample there is no significant difference in farm size between those who participate in the committees (average farm size is 4.4 ha) and those who do not (average farm size 3.5; probability of  $t = 0.1484$ ). Knowledge of the CIALs is more evenly distributed: 52% of the population surveyed knows of the CIALs, and there is no significant difference between the proportion of very poor people (49%) and the remaining two better-off strata (53%) who have this knowledge (Chi square  $P = 0.491$ ).

The key issue is to what extent special-interest groups in the community are able to get their priorities onto the agenda defined in the community diagnosis which decides the problems on which the CIALs do research. Monitoring by the project has detected the marked tendency for few women to attend these meetings, and those who do attend often propose research problems which are not prioritized. In order to address this need, the project established a separate fund for communities to set up a women's CIAL if a group of 10 or more women requested to do so. However, only two women's groups formed CIALs and four others added women to the committees. Women still represent only 7% of committee members. The main reason for this appears to be the difficulty women have in devoting time to regular meetings that take them out of the home. For special-interest groups like women, or the semilandless labouring poor, the research committee may not be an appropriate instrument for addressing their special research agenda. Several options have yet to be explored: for example, separate diagnosis with special-interest groups to identify priorities which then are included as treatments in trials carried out by CIAL members. This raises the question, however, of the degree of motivation of CIAL members to carry out trials on topics of secondary importance to them, and the more powerful members of the community. Another option is to have special-interest groups evaluate the trials so that their criteria for what is a desirable innovation are included in the analysis and recommendations drawn from CIALs' research. It may be, however, that increasing the equity of coverage by adaptive research has to be achieved by targeting the very poor, with the 'slack' research/extension capacity of intermediary organizations created by devolving part of the research agenda to CIALs. These issues are topics for further empirical research, now starting in the project.

### **Implications for institutionalizing participatory plant breeding**

Forming and monitoring the evolution of the CIALs is an ongoing experiment to assess the feasibility and the implications of devolving the responsibilities for implementing farmer participation in agricultural research. The CIALs were formed to investigate to what extent the methods for participatory diagnosis and problem definition, planning and evaluation, and ultimately monitoring of adaptive technology testing could be handed over to community-level organizations, to generate 'demand-pull' on formal research and extension systems, and to improve the access of resource-poor farmers to an adaptive technology-testing service, at a

reasonable cost. Many of the communities have prioritized varietal selection in their choice of a topic for their CIAL's experiment and several have evolved from varietal testing to establish seed-production enterprises.

Our experience so far suggests that it is possible to institutionalize responsibility for varietal testing with farmers, that it is not unrealistic to expect hard data from farmer-managed varietal trials, and that this demonstration of farmers' capability wins respect for farmers, which is catalyzing a gradual reorientation of bureaucratic institutions' priorities. Results show that current costs and coverage compare quite favourably with some state or private-sector systems, although the basis for comparison is very limited. A favourable cost structure is clearly related to the demonstrated effectiveness of paraprofessionals for scaling up, and for achieving devolution.

Devolution to the CIALs has, as a matter of strategy, stretched the line of communication between plant breeders and farmers in the CIALs. Most of the CIALs' activities take place in the absence of outsiders and although the opportunity exists for feedback to research institutions to be mobilized, when for example, agronomists interact with CIALs over the planning and analysis of their experiments, this function has been downplayed during the preoccupation of the research team with analysis of the organizational process of the CIALs. For example, the peanut varieties obtained through communication from the CIAL to the local extension service, the UMATA, then to the national research programme and thence to ICRISAT is an instance of the stretch of this line of communication which does not as yet have a formalized channel for feedforward from the microlevel testing of the CIAL back to the plant breeders. Moreover, there may be a danger of poor linkages affecting the scale and quality of feedback to research as devolution and delegation to farmers increases, nullifying the benefits over the long run of gains in coverage or cost effectiveness (see for example Collinson 1986). Methods for systematizing and interpreting a wealth of location-specific, decentralized varietal testing have to be developed, and the institutional mechanisms for ensuring efficient and timely feedforward of this type of information have to be provided. Another question is to what extent the CIAL experimentation will maintain its current identification with the method of controlled comparison, or will there be a return to folk experimentation in the CIAL corporation, now that it is a self-financing entity and has no need to legitimize the use of funds by adherence to the scientific method?

In fact the CIALs have not evolved with an emphasis on making farmers' knowledge more accessible to outsiders, although some theorists consider this to be the key challenge for participatory research for agriculture (see for example Scoones and Thompson 1994). Instead, the overriding focus has been on constructing management capacity and skill formation which strengthens farmers' own ability to make demands on the institutions which, so far, have failed to provide the service performed by the CIALs. It could be that the CIALs thereby function as just one more channel for village-level elites to express their demand, although the leadership that consolidates around providing a community-based service tends to be leadership by virtue of performance (Shah 1994:251-2) rather than exclusively traditional. This issue requires further investigation, and the extent to which the CIALs generate benefits that disseminate to a cross-section of the community has to be examined.

The project is entering a new phase with an international training programme and monitoring of new CIALs, which are disseminating in widely contrasting sociocultural environments as distant as Brazil and Honduras. Many questions

remain about the long-term viability of the CIALs as an approach to institutionalizing farmer participation in formal plant breeding programmes. But there are already some signals — like the CIALs (rechristened CALITS) in Peru which organized as a group to campaign for support for their seed-production efforts from their regional state experiment station — that formal plant breeding programmes may enter a new era in reaching resource-poor farmers in marginal environments, through experimentation with this type of institutional innovation.

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## Appendix 1. Project training materials

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### **CIAT handbooks**

- IPRA, CIAT, El Ensayo (The Experiment\*), Cartilla No. 1 1993, 43 pages.
- IPRA, CIAT, Los Comités de Investigación Agropecuaria Local (Local Agricultural Research Committees\*), Cartilla No. 2 1993, 35 pages.
- IPRA, CIAT, El Diagnóstico (The Diagnosis\*), Cartilla No. 3 1993, 29 pages.
- IPRA, CIAT, El Objetivo del Ensayo (The Objective of the Experiment\*), Cartilla No. 4 1993, 27 pages.
- IPRA, CIAT, La Planeación del Ensayo (Planning the Experiment\*), Cartilla No. 5 1993, 44 pages.
- IPRA, CIAT, La Evaluación del Ensayo (Evaluating the Experiment\*), Cartilla No. 6 1993, 41 pages.
- IPRA, CIAT, Cosas que pueden pasar (Things that can go Wrong\*), Cartilla No. 7 1993, 43 pages.
- IPRA, CIAT, Compartimos los resultados de nuestro ensayo (Let's share the results of our Experiment\*), Cartilla No. 8 1993, 25 pages.
- IPRA, CIAT, Un caso real (A Real-Life Case Study\*), Cartilla No. 9 1993, 37 pages.
- IPRA, CIAT, Cómo manejar los gastos del ensayo (How to manage costs of the Experiment), Cartilla No. 10, in press.
- IPRA, CIAT, Las experiencias también cuentan (We Learn from our Experiences), Cartilla No. 11, in press.
- IPRA, CIAT, Sabiendo a tiempo si vamos bien (Let's find out if we're doing things right), Cartilla No. 12, in press.

\* English translations (without illustrations) are available.





## Farmers and Crop Breeders as Partners

### International breeding programmes and resource-poor farmers: Crop improvement in difficult environments

*Salvatore Ceccarelli, S. Grando and R.H. Booth*

The International Center for Agricultural Research in the Dry Areas (ICARDA), Aleppo (Syria)

#### Summary

Farmers in stressful environments have not benefited from the spectacular yield increases obtained by formal (or institutional) breeding programmes in environments which are naturally favourable or can be made favourable profitably by using inputs. After an analysis of the main characteristics and assumptions of formal breeding programmes, the paper identifies in Genotype by Environment (GE) interaction one of the main reasons for the failure of formal breeding to serve small, resource-poor farmers. Formal breeding has frequently adopted a negative interpretation of GE interaction. This has implied selection for broad adaptation, and consequently replacement of landraces with input-responsive cultivars ill-adapted to low-input and stress conditions. By contrast, a positive interpretation of GE interaction implies the exploitation of specific adaptation by direct selection in the target environment. This requires the use of different breeding methodologies, use of locally adapted germplasm and farmers' participation in selection to take full advantage of their knowledge of the crop and the environment. Farmers' participation in selection under their own environmental and agronomic conditions also will speed up the transfer and adoption of new varieties without the involvement of complex, bureaucratic and often inefficient mechanisms of variety release, seed certification and production. These mechanisms, like the breeding methodologies and philosophies of formal breeding programmes, also introduced from industrialized countries, are not used by most resource-poor farmers as their main seed supply. Most of the seed used by these farmers is either produced on the farm, acquired from neighbours or purchased from local markets. These informal sources of seed must be fully understood and exploited if resource-poor farmers have to benefit from plant breeding.

#### Introduction

Formal, or institutional, breeding has been highly efficient in improving yield levels of several crops. However, its efficiency has remained largely confined to favourable environments, or to environments which could be made favourable by adding fertilizer and irrigation, and by chemical control of weeds, pests and diseases.

Resource-poor farmers, who practise approximately 60% of global agriculture, and produce 15-20% of the world food (Francis 1986) have not known the benefit of the Green Revolution. Some 1.4 billion people are dependent on agriculture practised in stressful environments (Pimbert 1994).

Typical characteristics of formal breeding programmes in several crops are:

- they generally produce genetically uniform cultivars (pure-lines, clones, hybrids)
- they are largely conducted either in good environments or in well-managed experiment stations where growing conditions are optimum or near-optimum
- in most grain crops selection is almost exclusively for grain yield and disease resistance
- they promote cultivars which can be grown over large areas (widely adapted in a geographical sense)
- they do not involve the clients (the farmers) in any of the steps which will eventually lead to new cultivars, except perhaps in the final field testing of a few promising lines.

Assumptions of formal breeding programmes are that:

- selection must be conducted under good growing conditions where heritability is higher, and therefore response to selection is also higher
- yield increases can only be obtained through replacement of locally adapted landraces (Brush 1991) which are low yielding and disease susceptible
- breeders know better than farmers the characteristics of a successful cultivar
- when farmers do not adopt improved cultivars it is because of ineffective extension and/or inefficient or insufficient seed production capabilities; the hypothesis that the breeder might have bred the wrong varieties is rarely considered.

Because of the success that breeding has had in good environments, these characteristics and these assumptions are not questioned even when the objective is to improve yield and yield stability for poor farmers in stressful environments. The implicit assumption is that what has worked well in favourable conditions must also be appropriate for unfavourable conditions, and very little attention has been given to developing new breeding strategies for less favourable environments.

In the last few years there has been mounting evidence that these assumptions are not valid, and that the special problems of marginal environments and their farming systems must be addressed in different ways.

In this paper we address the question of why the improvement of crop production in stressful environments has remained such an elusive objective in spite of major national and international research investments. The emphasis will be on crop breeding, because it has historically received the higher allocation of resources in research and development at both national and international level. However, the conceptual framework applies equally well to other disciplines.

### **Agricultural diversity in unfavourable environments**

Throughout this paper unfavourable environments are defined as those where crop yields are commonly low due to the concomitant effects of several abiotic and biotic stresses. The semi-arid areas of Syria, where barley-livestock is the predominant farming system, are a good example of such environments (Fig. 1, zone C) where not only low annual rainfall, but also rainfall distribution, low winter temperatures, high temperatures and hot winds from anthesis to grain filling are important abiotic stresses. The frequency, timing, intensity and duration of each of these stresses, as well as their specific combinations, vary from year to year. However, low yields of barley are common, crop failures occur one year out of ten, and yields of 3.0 t/ha or more are expected less than 15% of the time. By contrast, in relatively favourable

environments (Fig. 1, zone B) yields of 1 t/ha or less have a frequency of about 10%, and yields above 2.5 t/ha occur more than 40% of the time.

Because of the probability of low yields and crop failures in unfavourable environments, the use of inputs such as fertilizers, pesticides and weed control is uneconomical and risky for resource-poor farmers. Therefore, the adoption of improved agronomic practices has been limited, and one economic solution to increase crop yields in unfavourable environments can be through breeding.

Many of the environments where improved technologies in general, and improved cultivars in particular, have had little or marginal impact have some characteristics in common with those described for the semi-arid areas of Syria. These are the unpredictability and variability of climatic conditions, and the consequent high probability of crop failures which discourages the use of inputs.

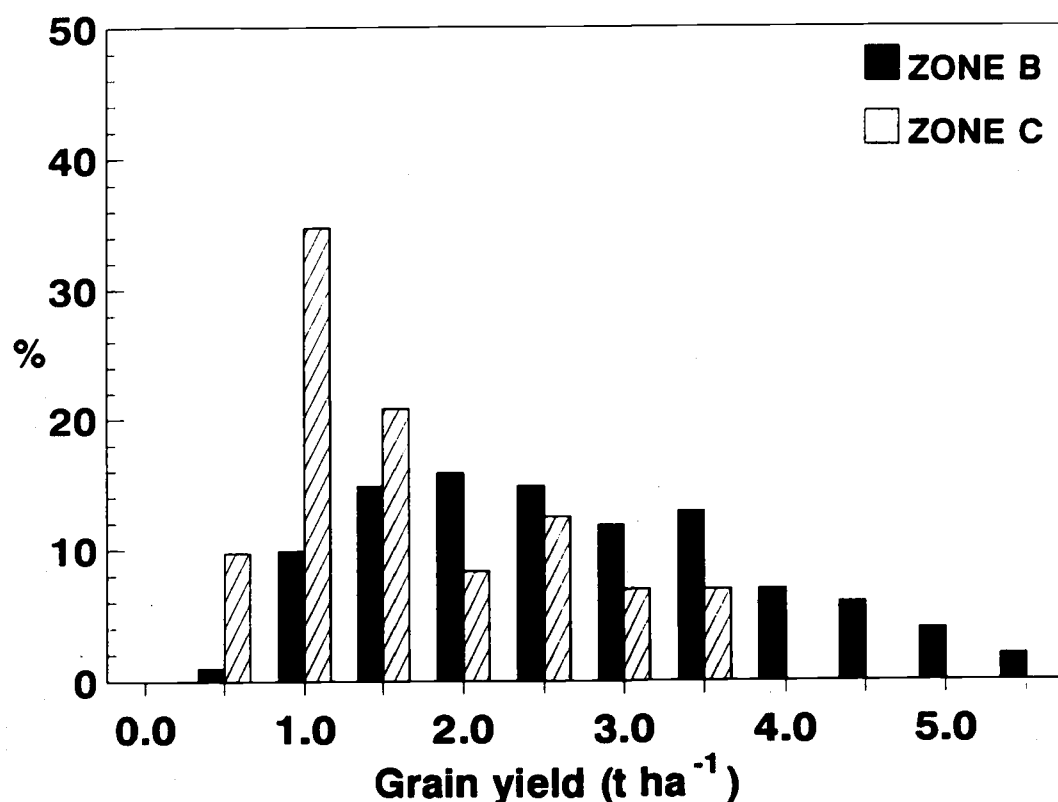


Fig. 1. Frequency distribution of barley yields in unfavourable (Zone C = less than 250-300 mm annual rainfall) and moderately favourable (Zone B = 300-350 mm annual rainfall) environments in Syria between 1983 and 1994.

Resource-poor farmers in many regions of the world practising agriculture in these or similar situations have adopted a strategy based on both intraspecific and interspecific diversity (Martin and Adams 1987). Different crops are grown in the same field at the same time (intraspecific diversity), and the cultivars of the different crops are frequently genetically heterogeneous (interspecific diversity). A second level of interspecific diversity is obtained by growing, at the same time and in the same field, different cultivars of the same crops (Haugerud and Collinson 1990). The type of diversity which prevails in different areas depends on both climatic and

socioeconomic conditions and farmers' response to these. In central Africa and central America both intra- and interspecific diversity are exploited at the same time. In other areas, interspecific diversity represented by one heterogeneous cultivar is predominant. In the dry areas of West Asia and North Africa, for example, barley is often the only feasible rainfed crop, and the cultivars which are grown at present, and which have been grown for centuries, are genetically heterogeneous (Ceccarelli *et al.* 1987; Weltzien and Fischbeck 1990).

This diversity, typical of resource-poor farming, is in marked contrast to the uniformity pursued by formal breeding and production practices in most crops grown in favourable environments, and is one of the causes for a different mechanism of seed supply. While in high-input agriculture (served by formal breeding) the seed market is the main source of seed supply, particularly for grain crops, in resource-poor agriculture the seed is usually produced on the farm, after some form of selection done by the farmer, or it is purchased from neighbouring farmers (Almekinders *et al.* 1994). Formal breeding thus not only tries to replace diversity with uniformity, but also tries to reach farmers with the seed of new cultivars through mechanisms and institutions which are not familiar, are not efficient and often are not trusted by resource-poor farmers.

#### **Genotype by environment interaction**

Genotype  $\times$  environment (GE) interaction is almost unanimously considered to be among the major factors limiting response to selection and, in general, the efficiency of breeding programmes. GE interaction becomes important when the rank of genotypes changes in different environments. This change in rank has been defined as a crossover GE interaction (Baker 1988).

GE interactions in general, and GE interactions of a crossover type in particular, are considered to have a negative impact on the success of breeding programmes, because breeders tend to search for a few widely adapted cultivars. While this is probably the best strategy in the case of breeding programmes targeted at favourable environments, it has been suggested (Ceccarelli 1989; Hildebrand 1990; Simmonds 1991; Stroup *et al.* 1993; Ceccarelli 1994) that, in the case of less favourable environments, breeders may need to look at GE interactions in a different way.

The hypothesis of this paper is that GE interactions of the crossover type are among the major causes of the failure of formal breeding programmes to serve resource-poor farmers. Therefore, the question of how frequently these interactions occur is important.

Examples of GE interactions of the crossover type can be found in the literature in a range of crops and environments, and for various stresses: Breese (1969) in cocksfoot, Arboleda-Rivera and Compton (1974), Muruli and Paulsen (1981), Hildebrand (1984), Loffler *et al.* (1986) and Lafitte and Edmeades (1994) in maize, Simmonds (1984) in sugarcane, Lawn (1988) in chickpea, Ceccarelli (1989) and Ceccarelli and Grando (1991) in barley, Blum and Pnuel (1990) in wheat, Virk and Mangat (1991) in pearl millet, Shannon and Francois (1978) in muskmelon in relation to salt tolerance.

A typical example of GE interaction of a crossover type in barley is given in Table 1. The highest yielding genotypes in the lowest yielding site had an average yield in the highest yielding site which was not significantly different from the population mean. Similarly, the highest yielding genotypes in the highest yielding site had an average yield in the lowest yielding site which was not significantly different from the population mean. Therefore, selection in high yielding sites, such as well-managed experiment stations, does not allow the identification of the best

genotypes for poorer conditions, and promotes genotypes which are not superior in stressful conditions.

**Table 1. Average grain yield of the 5% highest yielding barley genotypes in the lowest yielding (L) and highest yielding (H) sites, on the lowest and highest yielding sites, compared with the population means. Data are the means of 10 cropping seasons (1985/86-1993/94).**

Genotype	Average grain yield (kg/ha) in:	
	Low-yielding sites	High-yielding sites
L sites	1613	3938
H sites	1110	5030
Population mean	1041	3974

A similar picture emerges from the few published data on genetic correlation between yield measured in high and low yielding conditions (Atlin and Frey 1989, 1990; Ud-Din *et al.* 1992; Ceccarelli *et al.* 1992; Cooper and DeLacy 1994).

In general, when different genotypes of a given crop are evaluated in a sufficiently wide range of environments, GE interactions of a crossover type (Fig. 2) seem to be very common. This indicates that, as a general phenomenon, genotypes selected under optimum growing conditions do not perform well under poor growing conditions, and vice versa. This is hardly surprising as physiologists have long recognized, with specific reference to drought, that high yield in favourable conditions and high yield in unfavourable conditions are associated with different physiological mechanisms and different phenologies (Hsiao 1982; Blum 1993).

The range of environments in Figure 2, and their associated yield levels, may represent either variation over time within one given geographical area, or variation over space (different geographical areas within or across countries). We assume that the yield levels below the crossover point are fairly representative of variation over time within a given geographical area. In areas of this type, the probability of climatic events that will determine yields above the crossover point are possible but rare (as shown in Fig. 1).

The implications of a crossover GE interaction have been discussed by Hildebrand (1990), Stroup *et al.* (1993), Simmonds (1991) and Ceccarelli (1994). Formal breeding has taken a negative attitude towards GE interaction, and because selection is frequently conducted only in high yielding conditions, has been unable to serve farmers in environments which are at the other side of the crossover point (Fig. 3). Figures 2 and 3 indicate that breeding for environments below the crossover point must be based on direct selection in the target environments because the best genotypes for these environments can only be identified if selection is done in unfavourable environments.

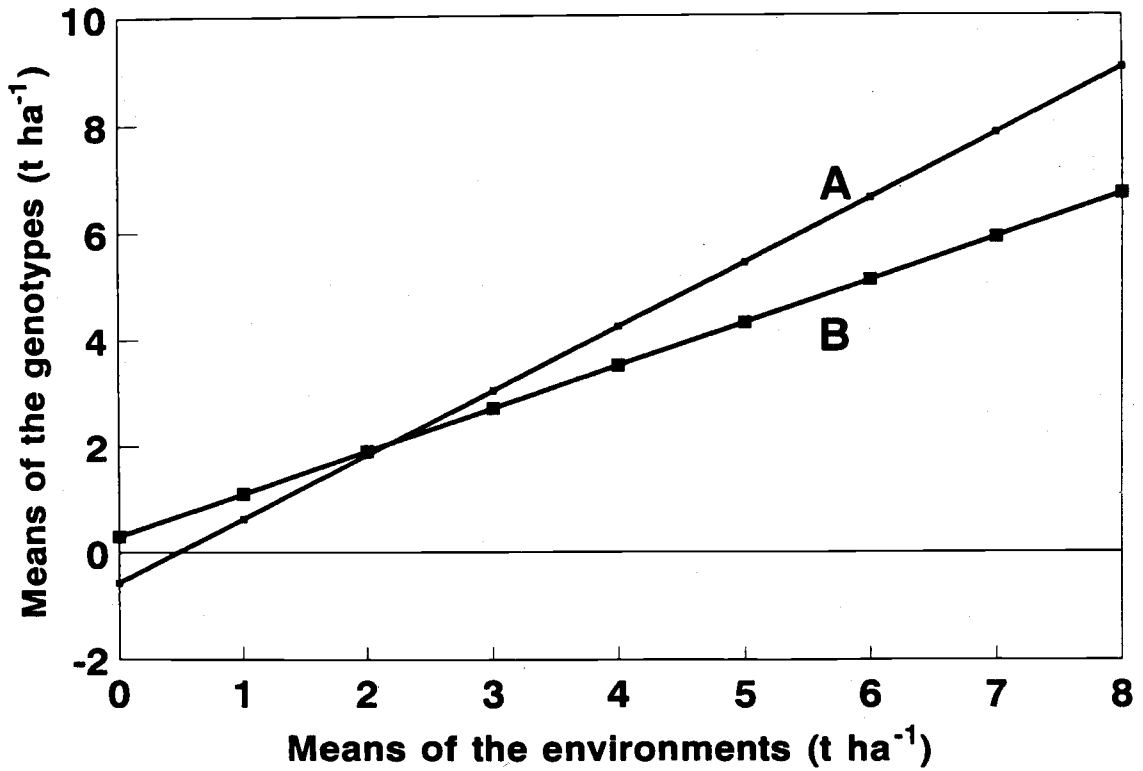


Fig. 2. Crossover type of G x E interaction: A and B are typical genotypes selected in high-yielding and low-yielding environments, respectively.

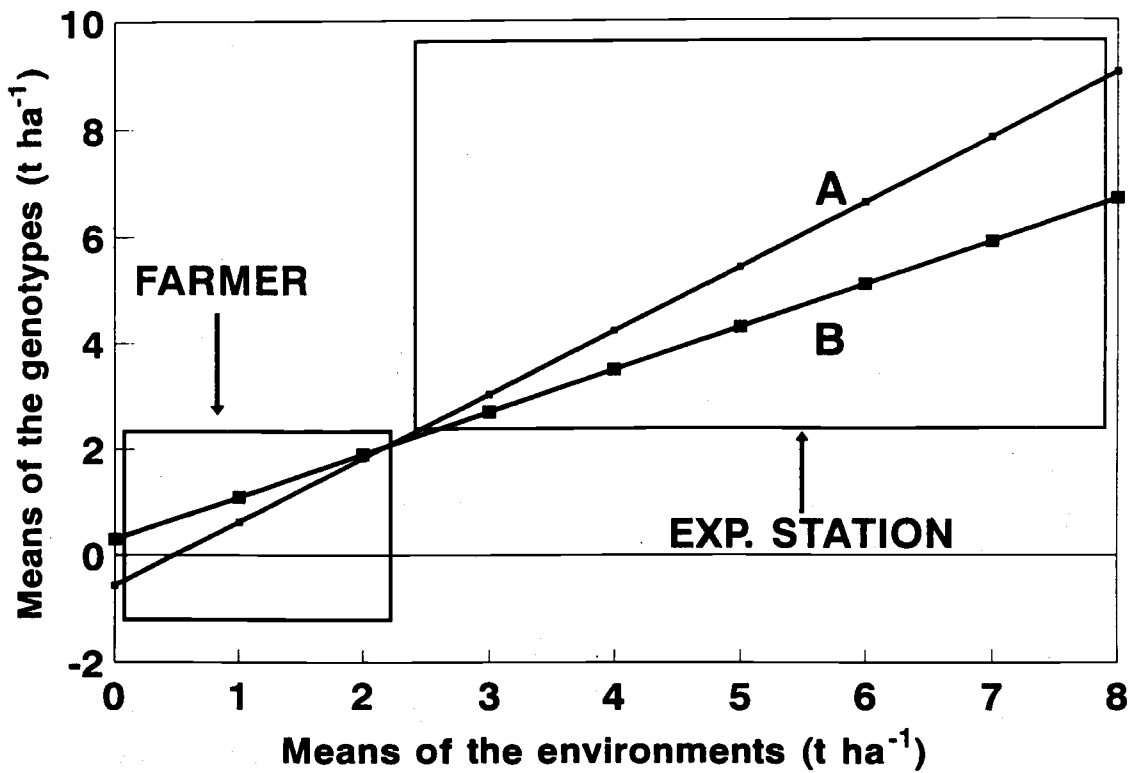


Fig. 3. Hypothetical GE interaction of crossover type between experiment stations and farmers' fields.

### Selection in unfavourable environments

Breeding for unfavourable environments based on selection (not merely testing) in the target environments is undoubtedly more complex than selection for favourable environments largely because of the year-to-year variation. Procedures and methodologies developed for favourable environments need to be modified. The methodology for barley enhancement at ICARDA is as follows.

1. Breeding material (including parental material and segregating populations) is evaluated in the target environments using farmers' agronomic practices, including rotations. In the driest site (long-term average rainfall of 233 mm) this means no use of fertilizers, pesticides and weed control. Farmers' fields are inspected over one or two cropping seasons earlier and those where the farmer's crop is sufficiently uniform are selected as experiment sites. Concurrently, the material is evaluated at the main experiment station (long-term average rainfall of 373 mm) with a level of inputs commonly used in moderately favourable areas. In all the experiment sites the material is evaluated strictly under rainfed conditions.
2. Experimental designs have evolved from the randomized block design to the lattice design (introduced in 1984), to  $\alpha$ -lattice design (introduced in 1993). This has progressively improved our control of environmental variability.
3. Segregating populations are evaluated as bulks for 3 years taking advantage of the large year-to-year variation in total rainfall, rainfall distribution and temperature patterns. Each year, bulks yielding less than the check are discarded. Individual plant selection is done only within the selected bulks.
4. Selection is done for high grain yield at each of the experiment sites, regardless of the performance in other experiment sites. This promotes breeding material with specific adaptation.
5. In addition to grain yield, traits used as selection criteria are: plant height, tillering, straw softness and disease resistance in the two driest sites; earliness, lodging and disease resistance in the wettest sites.

Using this methodology for barley breeding at ICARDA, direct selection in unfavourable environments revealed that locally adapted landraces could be a useful source of breeding material that would have been missed had the evaluation taken place only in high-yielding environments. In Table 2 the term landraces refers to pure-lines isolated by pure-line selection from Syrian landraces. The data of Table 2 suggest that repeated cycles of selection in a given type of environment will reduce the frequency of lines specifically adapted to other environments. This explains why testing lines in marginal environments, after a number of cycles of selection in near-optimum environments, has led many breeders to believe that the expected gains with breeding for marginal environments are small. Not only do landraces have, as a group, a higher average yield under stress than non-landraces, but there is considerable variation within landraces, and landraces with the lowest yield under stress always yielded much more than the lowest yielding non-landraces in the same group (Table 2).

The presence of useful diversity within landraces has been documented in many crops. The diversity within barley landraces collected in Syria and Jordan has been documented by Ceccarelli *et al.* (1987), van Leur *et al.* (1989), Weltzien (1988 1989), Weltzien and Fischbeck (1990) and Ceccarelli *et al.* (1995). More recent evidence of this diversity is given in Table 3 for four populations collected along the Euphrates river (Fig. 4). The first three populations (collected in sites 21, 22 and 23) are black-seeded, while the population collected in site 24 is white-seeded. The black-seeded



populations gave, in general, lower yields both at Breda (290 mm rainfall) and Tel Hadya (373 mm rainfall) but were taller than the white-seeded population in the driest site. Plant height is very important to farmers because it determines whether the crop can be harvested by combine or has to be hand-harvested, which is much more expensive. These data explain why farmers in the driest areas of Syria grow mainly the black-seeded barley landrace. For all the five traits evaluated there was a large diversity within each population, as shown by the range. The highest yielding lines gave a much higher yield than the improved cultivars Harmal and Rihane-03, and were comparable with Arta, the best improved landrace. Within site 24 there were lines outyielding significantly Arta at Tel Hadya.

**Table 2. Grain yield (kg/ha) under stress (YS) and grain yield under no stress (YNS) of barley breeding lines classified according to the germplasm type**

Set <sup>a</sup>	Germplasm type	N <sup>b</sup>	YS <sup>c</sup>		YNS <sup>d</sup>	
			Yield	Range	Yield	Range
1	Non-landraces	155	488	0-893	3901	2310-4981
	Landraces <sup>e</sup>	77	788	486-1076	3413	2398-4610
2	Non-landraces	207	589	197-1101	5400	3558-6962
	Landraces	43	734	468-954	4435	2883-5728
3	Non-landraces	296	634	0-1119	2687	1241-3893
	Landraces	83	802	414-1203	2513	1829-3738
4	Non-landraces	165	525	196-852	3631	1339-4862
	Landraces	76	764	567-990	3275	1378-4309

<sup>a</sup> Group of lines tested in the same locations and years.

<sup>b</sup> Number of lines.

<sup>c</sup> Average yield in low-yielding sites.

<sup>d</sup> Average yield in high-yielding sites.

<sup>e</sup> Pure lines selected from landraces.

The exploitation of the diversity within barley landraces, an ongoing activity in the barley breeding programme at ICARDA during the last 10 years, has been a powerful means to improve barley yields in marginal environments and in areas where the landraces are the predominant cultivars. Arta, a recently released barley variety, is perhaps the best example of the usefulness of the diversity within landraces. Arta is a white-seeded pureline derived from one head collected in 1981 in a farmers' field at Um-Zeitoun, near Sweida, about 100 km east of Damascus, in the Haurani plateau. It has outyielded the landrace from which it was selected, as well as the black-seeded landrace (Arabi Aswad) in many trials and in many locations in Syria (Table 4).

These data provide a strong indication that it is indeed possible to make progress with selection under unfavourable conditions, and that a large amount of potential improvement in unfavourable environments is missed by breeding programmes using only selection in favourable conditions and neglecting the locally adapted germplasm.

**Table 3. Variability between and within populations collected in four sites along the Euphrates river in Syria for grain yield in Breda (290 mm rainfall) and Tel Hadya (373 mm), for days from emergence to heading, for growth habit (1= erect, 5= prostrate) and for plant height in Breda. In parentheses the number of lines per collection site.**

Collecting sites	Grain yield (kg/ha)		Heading	Growth habit	Plant height (cm)
	Breda	Tel Hadya			
Site 21 (n = 86)					
means±s.e.	1289±24	2903±34	111±0.2	3.3±.07	45±0.4
min	891	2207	105	2.0	30
max	1837	3695	114	5.0	54
Site 22 (n = 79)					
means±s.e.	1311±21	2870±26	110±0.2	3.2±.07	47±0.5
min	706	2207	106	2	39
max	1754	3497	114	5	56
Site 23 (n = 70)					
means±s.e.	1296±23	2846±51	110±0.2	3.2±.06	43±0.6
min	832	1553	107	2.3	28
max	1837	3725	115	4.3	55
Site 24 (n = 64)					
means±s.e.	1385±25	3566±54	110±0.2	3.2±.06	34±0.6
min	884	1774	105	1.9	25
max	1823	4491	113	4.3	50
Checks <sup>a</sup>					
Arta	1814	3773	114	3.6	32
Zanbaka	1139	2457	112	4.1	50
Harmal	1164	3309	106	2.6	45
Rihane-03	1284	3624	114	3.0	49

<sup>a</sup> Arta and Zanbaka are two selections from Syrian landraces; Harmal and Rihane-03 are two modern cultivars

**Table 4. Performance of Arta during four cropping seasons in the on-farm trials<sup>a</sup> in Syria**

Year	No. of sites	Mean yield	Rank	% over		
				A.Abiad	A.Aswad	Best line
1988-89	4	1814	1	+18.6	+10.6	+18.6
1989-90	9	1962	1	+12.3	+5.8	+3.5
1990-91	10	2341	1	+5.0	+18.5	+5.0
1991-92	13	3358	1	+31.6	+10.8	+1.8
1991-92	4 <sup>b</sup>	3263	1	+52.5	-	+33.5

<sup>a</sup> Two or three replications with 32 m<sup>2</sup> plots.

<sup>b</sup> Unreplicated with 1000 m<sup>2</sup> plots.

### **Decentralization: using specific adaptation in international breeding programmes**

International breeding programmes aim to assist national programmes to increase agricultural production by developing superior cultivars. This is traditionally done through very large breeding programmes which develop fixed or semi-fixed lines with an average good performance across many environments (often well-managed experiment stations). The interaction between international and national programmes has been largely a one-way, "top-down" process (Simmonds and Talbot 1992) where international programmes develop germplasm, distribute it as "international nurseries", and national programmes test and eventually release it as varieties. This has commonly excluded the use of locally adapted germplasm, which often performs poorly in favourable conditions such as those of experiment stations, and has encouraged its displacement.

The adoption of a positive interpretation of GE interaction by international breeding programmes has been advocated as a way to address the needs of small resource-poor farmers, who have been bypassed by the Green Revolution (Stroup *et al.* 1993).

To exploit specific adaptation fully and make positive use of GE interactions, an international breeding programme should devolve most of the selection work to national programmes by gradually replacing the traditional international nurseries with earlier generation material. Early distribution of breeding material reduces the danger of useful lines being discarded because of their relatively poor performance at some test sites. This problem is illustrated by 288 barley lines evaluated both in the Maghreb countries (Libya, Tunisia, Algeria, Morocco) and in ICARDA's preliminary yield trials grown at three sites in Syria (ranging from moderately favourable to unfavourable) in 1991/92 (Table 5). In the Maghreb countries visual selection was used, whereas in Syria selection was for yield potential, yield under stress and heading date. In Syria 103 entries were selected and in the Maghreb 154 but only 49 of these were selected in both Syria and the Maghreb. More than half of the lines selected in Syria were discarded in Maghreb, and almost 70% of those selected in Maghreb were discarded in Syria. This gives a measure of the danger of discarding lines potentially useful in other areas in a centralized breeding programme.

In 1991 ICARDA's barley breeding programme started a gradual process of devolution of selection work to the four Maghreb countries (Ceccarelli *et al.* 1994). When fully implemented, national programmes in north Africa will receive from ICARDA's barley breeding programme only targeted  $F_2$  segregating populations (based on crosses partly designed by national programmes) and yield trials consisting of lines derived from these  $F_2$ 's selected in-country. Selection between  $F_2$  populations will be in the different agroecological environments within each country under conditions as similar to farmers' fields as possible. Lines selected from superior  $F_2$  populations will be advanced at ICARDA and then yield tested in different locations within each country.

Other breeding programmes at ICARDA, such as barley and lentil breeding for the Anatolian plateau in Turkey, lentil breeding for the Indian subcontinent and durum wheat breeding for Morocco, are based on the same philosophy.

However, decentralization to national programmes of the selection component of an international breeding programme will not respond to the needs of resource-poor farmers if it is only a decentralization from one experiment station to another. This can be solved by what may be considered the most extreme decentralization and possibly the most effective way of exploiting specific adaptation, i.e. farmers' participation in selection under their own conditions.

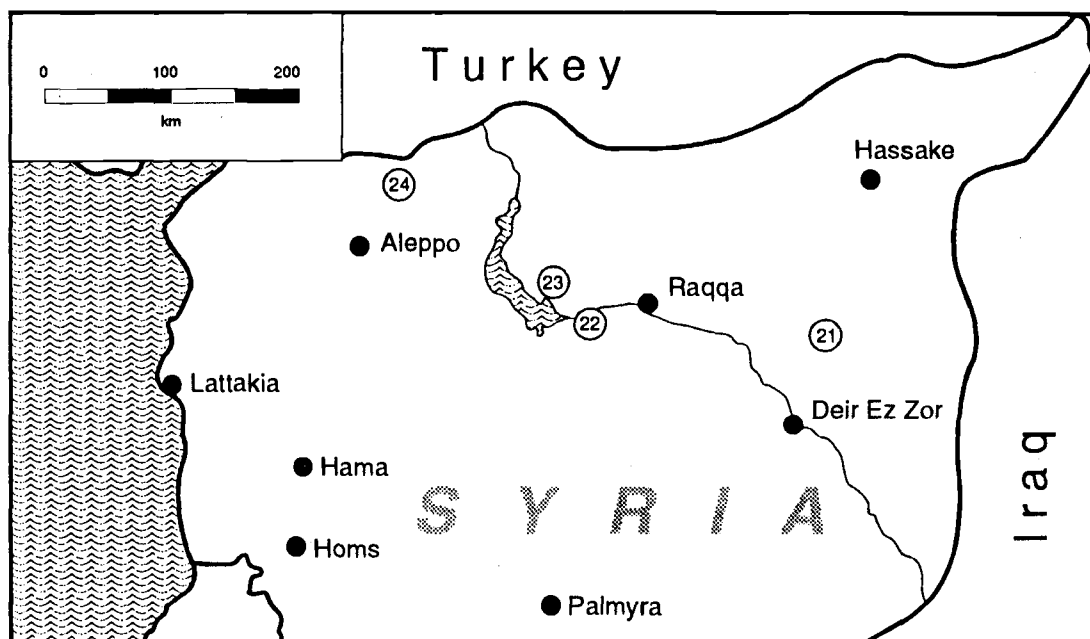


Fig. 4. Locations of the four collection sites of barley landraces in northern Syria used in Table 3.

Table 5. Lines selected in Syria and in Maghreb countries (Libya, Tunisia, Algeria and Morocco) from a common nursery of 288 lines.

Selected in	Selected lines	
	N	% <sup>1</sup>
Syria	103	35.8
Maghreb	154	53.5
Syria and Maghreb	49	17.0
Syria, discarded in Maghreb	54	52.4
Maghreb, discarded in Syria	105	68.2

<sup>1</sup> The first three percentages are calculated on the total number of lines (288) in the nursery, the last two are calculated on the number of lines selected in Syria and Maghreb, respectively.

### Maximizing specific adaptation through farmers' participation

The idea of farmers participating in the development of new technology is not new. It was introduced in 1982 (Rhoades and Booth 1982) as "the farmer-back-to-farmer model", later modified into the "farmer-first-and-last-model" (Chambers and Ghildyal 1985) and more recently discussed by Sperling *et al.* (1993) and Stroup *et al.* (1993). Using Sperling's terminology, "formal breeding programmes" can be described as a sequential and cyclical process in which

- an extremely large amount of genetic variability is continuously created
- this variability is drastically reduced through selection (we have seen that this is often done in conditions which have little in common with those of resource-poor farmers)
- the few lines surviving step 2 are presented to farmers who are asked to verify if the choices made for them are appropriate (Fig. 5A).

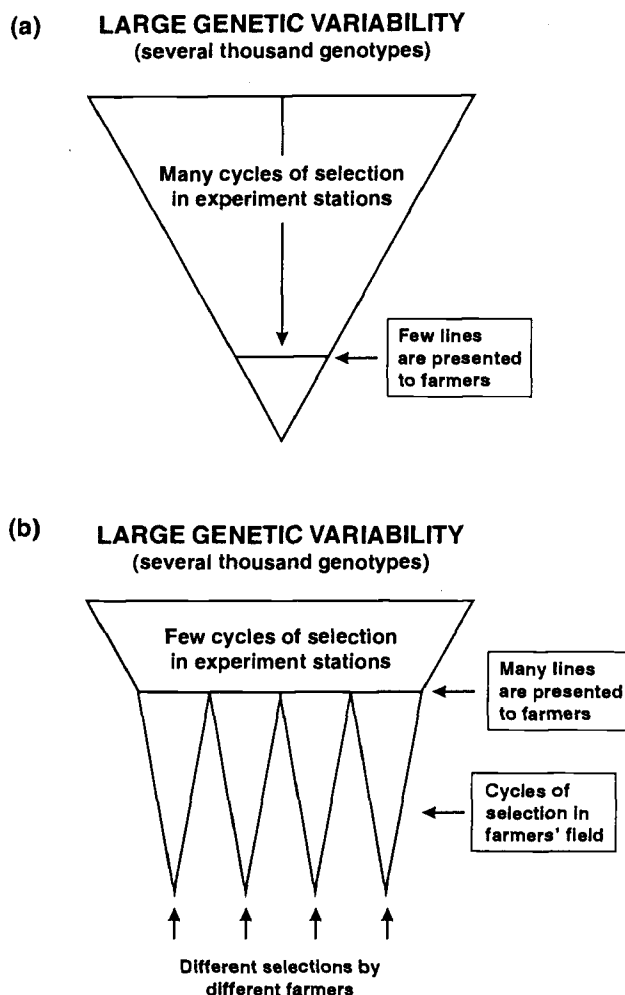


Fig. 5. Schematic representation of formal (A) and participatory (B) breeding programmes: in the first case farmers are passive recipients, in the second they participate in the development of new varieties.

As discussed, the process has been very effective for those farming systems which are sufficiently similar or not too dissimilar from those on experiment stations. It has, however, been used as a model even for target environments very different from those of experiment stations, and it is now acknowledged that the process has been ineffective for unfavourable environments. The reason is likely to be associated with GE interaction. It is also possible that the plant characteristics which are used as selection criteria in a high yielding environment, such as an experiment station, are not those which give the future variety an advantage when grown by a resource-poor farmer. Indeed, there is evidence that when farmers are involved in the selection process, their selection criteria may be very different from those of the breeder (Hardon and de Boef 1993; Sperling *et al.* 1993). There is also evidence that, when breeders and farmers select in the same environment, farmers' selection can be effective (Table 6) implying that farmers possess considerable knowledge which is almost totally neglected in formal plant breeding programmes.

A typical example of different selection criteria between farmers and breeders can be found in crops, such as barley, used as animal feed. Breeders often use grain yield

as the sole selection criterion which usually brings with it high harvest index and lodging resistance. However, in unfavourable environments lodging is often not a problem because of moisture stress, and farmers are interested not only in grain yield, but also in forage yield and in the palatability of both grain and straw.

**Table 6. On-farm performance of varieties of bush bean selected from on-station trials by farmers and of varieties selected by breeders in Rwanda (modified from Sperling *et al.* 1993)**

Year	No. of trials	Trials (%) where new variety outyielded local mixture	Yield increase (%): new var. over local mixture
<i>Farmer selection</i>			
1989A	11	73 ns	3.9 ns
1989B	19	89 **	33.4**
1990A	36	64 ns	12.9 ns
1990B	18	83 **	38.0**
<i>Breeder selection</i>			
1987A	32	34 ns	-8.8 ns
1988A	45	49 ns	-18.9 ns
1988B	15	53 ns	0.7 ns

\*, \*\* Differences significant at  $P < 0.05$  and  $P < 0.01$ , respectively; ns, not significant.

Farmers' participation in the ICARDA barley breeding programme to date has been informal and consisted of discussions during field visits and occasional inspection and selection by farmers of breeding lines. The most significant contribution of this informal participation has been the incorporation by the breeders of plant height under drought and softness of the straw as selection criteria in breeding barley for dry areas. As mentioned earlier, a crop which remains tall, even in very dry years, is important to farmers because it reduces their dependence on costly hand harvesting, while soft straw is considered important in relation to palatability. It is obvious that these two characteristics represent a drastic departure from the typical selection criteria used in breeding high-yielding cereal crops (short plants with stiff straw and high harvest index). It is also obvious that cultivars possessing the two characteristics considered important by farmers in dry areas will not be suited for cultivation in high yielding environments because of their lodging susceptibility, a further indication of the importance of specific adaptation. Lines extracted from Syrian barley landraces show little variation in straw softness but considerable variation, both between and within collection sites, for plant height (Fig. 6). The most promising avenue to improve plant height under drought is offered by the use of the wild progenitor of cultivated barley (*H. vulgare* subsp. *spontaneum*), still widely distributed along the Fertile Crescent where, particularly in the driest areas, it can be easily identified at a distance because of its tallness. Table 7 shows the tallest of 1532 most recently developed breeding lines tested in 1994/95 at a site which received only 222 mm rainfall. While the mean plant height of all the lines was 23.5 cm, the shortest lines were only 12.5 cm tall, and the most widely cultivated landrace (Arabi Aswad) was about 25 cm, some of the lines derived from crosses with *H. spontaneum* were taller than 40 cm. They were also significantly taller than Zanbaka, a pure-line selected from A. Aswad and already grown by some farmers for its plant height.

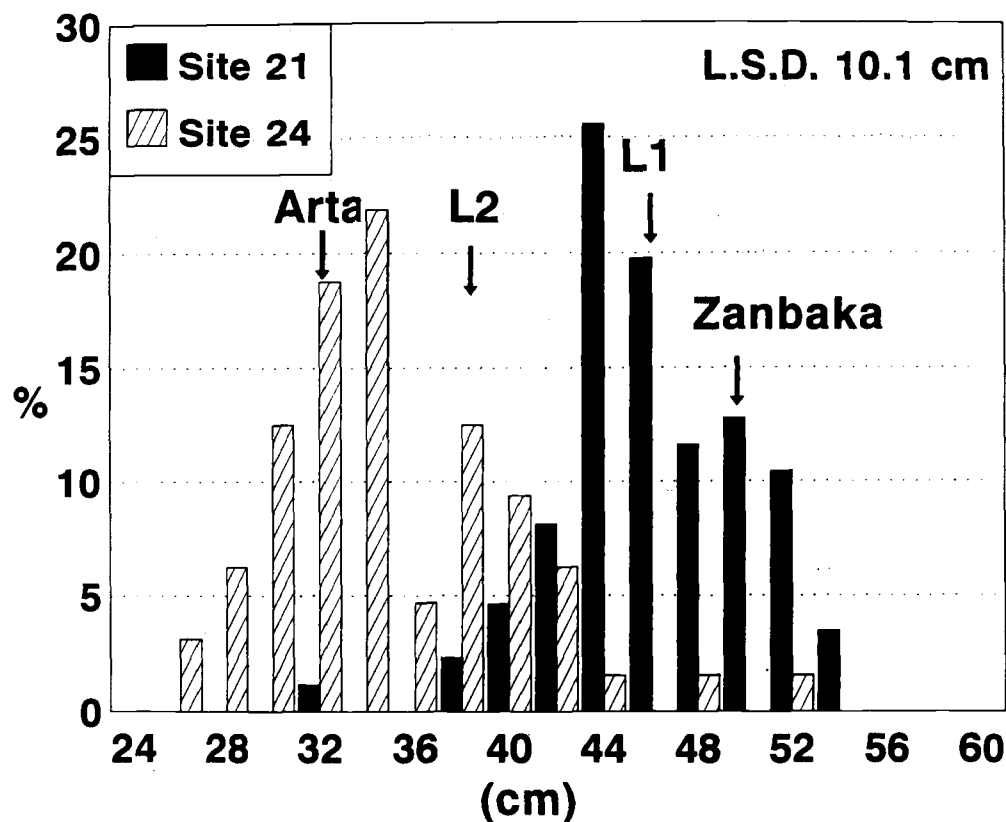


Fig. 6. Frequency distribution of plant height under drought in pure-lines extracted from Syrian barley landraces collected in two sites in northern Syria. Plant height was measured in Breda (290 mm rainfall) in 1994 on 86 lines of site 21 and 64 lines of site 24.

A formal plant breeding programme could combine the concept of a positive use of GE interaction with the utilization of farmers' knowledge by evaluating a wider range of germplasm under farmers' field conditions and in conjunction with farmers (Fig. 5B). In those communities where extension services and conventional seed production systems are not able to reach resource-poor farmers, and farmers traditionally use their own seed from one cropping season to another, this will provide a direct link between formal plant breeding and farmers. The benefit to the farmers will be direct access to improved germplasm. The benefit to all the community will be the maintenance of genetic diversity within a crop because different farmers are likely to select different materials. Eventually, the benefit to formal breeding programmes could be a higher efficiency by using farmers' selection criteria.

Table 7. Plant height at Breda (222 mm rainfall) in 1995 of barley lines derived from crosses with *H. spontaneum*, compared with the barley landrace most common in dry areas (Arabi Aswad) and with a cultivar selected specifically for plant height under drought (Zanbaka).

Cross/Name	Plant height (cm)
<i>H. spontaneum</i> 20-4/Arar 28//WI2291/Bgs	43.5
SLB 45-40/ <i>H. spontaneum</i> 41-1	43.0
Zanbaka/ <i>H. spontaneum</i> 41-2	42.5
Zanbaka/ <i>H. spontaneum</i> 41-2	41.5
Moroc 9-75/Arabi Aswad// <i>H. spontaneum</i> 41-3	41.0
Arabi Aswad	24.8
Zanbaka	26.0
Mean of all breeding lines	23.5
maximum	43.5
minimum	12.5
LSD <sub>.05</sub>	5.6

## Conclusions

Breeding for sustainability has been defined as a process of fitting cultivars to an environment instead of altering the environment (by adding fertilizer, water, pesticides, etc.) to fit cultivars (Coffman and Smith 1991). Also, it has been recognized that the key to increased production with fewer external inputs, a condition which is more self-sustaining and less harmful to the environment, will be through a re-evaluation of the identification and use of selection and testing environments (Bramel-Cox *et al.* 1991).

This paper has shown that for a typical crop of marginal and unpredictable environments such as barley, it is possible to exploit genetic differences for specific adaptation to marginal environments under farmers' conditions and improve yield without additional inputs. Breeding for specific adaptation not only offers a solution to how to improve agricultural production in marginal environments, but also can do so in a sustainable way. This breeding philosophy, based on a positive interpretation of GE interaction, is in contrast with the common belief that the introduction of inputs, such as fertilizer and irrigation, to raise the yield potential is an essential prerequisite for successful breeding work. Breeding for an agronomically improved environment dictates the type of germplasm which will best exploit it, and is based on genetic uniformity, the reverse of the biological diversity requisite for minimizing risk in most natural systems (Wilkes 1989).

The use of high-input selection environments in a market-driven agriculture has been largely responsible for the trend of modern plant breeding toward narrowing the genetic base of our crops accompanied by a trend toward homogeneity: one clone, one pure-line, one hybrid (Simmonds 1983). Uniformity and broad adaptation are very useful attributes to accommodate large-scale centralized seed production (Davis 1990).



Although the merits of genetic uniformity have been questioned in developed countries (Wolfe 1991), it is still very popular in breeding programmes and seed production systems of developing countries at both the national and international level. This is in contrast with the genetic diversity that characterizes agriculture in marginal environments. Genetically heterogeneous landraces are still the backbone of agricultural systems in many developing countries, mainly in marginal environments where their replacement by modern, genetically uniform varieties bred for favourable environments has proved to be a difficult task at the levels of inputs farmers can afford.

Breeding for specific adaptation to unfavourable environments implies a re-evaluation of the role of genetic resources such as landraces, which can play an important role because they possess adaptive features to these environments. This is the first consequence on biodiversity of breeding for specific adaptation.

A second consequence of exploiting specific adaptation on biodiversity is that the number of varieties (not necessarily homogeneous) of a given crop grown at any time will be large. The benefits of maintaining genetic diversity within a crop over large areas have been discussed extensively in the literature in relation to resistance to pests and diseases and do not need further justification. A major constraint of breeding for specific adaptation is the problem of how to distribute many varieties among farmers. However, the distribution of specifically adapted varieties to resource-poor farmers does not have to follow the conventional release/seed production/seed certification schemes used in developed countries. Indeed, there are examples of successful distribution and adoption of varieties through nonmarket methods (Grisley 1993).

In those countries where the same crop is grown in both favourable and marginal conditions, breeding has traditionally given priority to the more favourable areas. At the country level, larger increases of national production can be obtained by increasing production in good environments through the joint effect of improved varieties and improved agronomic practices. However, such a strategy will neglect many small and poor farmers who could represent the majority of the farmers in the country. We believe it is possible to increase agricultural production at the country level and, at the same time, to serve small, resource-poor farmers by recognizing that the two types of environments need separate breeding programmes, with different objectives, methodologies and type of germplasm.

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## Breeding for marginal/drought-prone areas in northeastern Brazil

*Maria J. de O. Zimmermann*

CNPAF/EMBRAPA Cx.P. 179, 74001-970 Goiania, Go., Brazil

### Summary

Northeastern Brazil is the poorest region of the country. Common bean is the favoured staple food and the main protein source for the low-income population. Harvested beans have a predominantly brown seed colour (mulatinho), but mixtures are not unusual. The cultivated varieties/landraces are in many cases unknown. Most farmers are traditional small farmers who usually do not buy their seeds and much variability is kept in each field across a region. Breeding objectives were to obtain genotypes with light brown seed colour (the favoured market type) and resistance/tolerance to drought and a few diseases. Parents were selected according to such characteristics and in each cross (multiparental) at least one local landrace was included. Crosses were planned jointly with CIAT staff and executed at CIAT. Selections were developed in Brazil. The  $F_2$  populations were planted in our central experiment station under controlled drought conditions. From each, 150 plants that showed higher pod set and field resistance to rust were harvested. The  $F_3$  generation was only for seed multiplication.  $F_4$  seeds of each bulked progeny were divided for testing in the region under natural conditions (without irrigation, but still at the experiment station). Three locations without replications but with repeated checks at each of 10 plots were used.

At a main location (Irecê), local farmers and cooperatives were invited, at pod-filling stage and at harvest time, to give their opinions on which would be their selected progenies and why. Plots were harvested from each location, jointly analyzed and the best-yielding plots from the joint analysis, as well as the farmers' choice plots (when not coincident), were selected. Seeds of selected plots ( $F_5$ ), were yield tested in a replicated yield trial in Irecê. At harvest time, from each plot at each replication, plants from a 1-m<sup>2</sup> area were harvested, weighed and analyzed before the farmers got to the field. They were asked to select from each plot the 10 very best single plants and tell us why; then they were asked to select the best plots. In some cases good yielders were refused because of seed colour.

The selected individual plants were seed increased and tested for disease reaction under controlled conditions (inoculations,  $F_6$ ). The most susceptible were discarded. The remaining plots were seed increased again ( $F_7$ ) and tested in a replicated yield trial at the experiment station under controlled drought conditions. The nonsegregating ones that had yield, seed colour and disease reaction which did not differ significantly from other sister lines were mixed and tested in the experiment station under natural conditions ( $F_8$ ) in replicated trials. The 10 very best, according to the farmers, were selected for testing in farmers' fields (10 farmers) in large plots (100 m<sup>2</sup>) with their own practices, no replications and their favourite local variety as check as well as a common check. The four very best (taking into consideration the farmers' opinions and yield data) were selected for final testing in farmers' fields on 1000-m<sup>2</sup> plots. One such line was released for planting in the region with the name Bambui. The procedure took about 6 years, considering testing times and the length of season, from  $F_2$  on.

## Description of the problem

### *The region and the population*

Northeastern Brazil is a large area (nine states) which is the poorest region of the country, with many social problems. The rainfall distribution pattern, outside the coastal area, is bimodal and average annual rainfall is between 250 and 600 mm. It is the semi-arid region of the country. Average *per capita* incomes are very low. It is the area of the country with the highest newborn death rate and highest illiteracy.

Industrialization has not been achieved in that region and the main economical activities are tourism (beaches), saline exploitation and agriculture. In the few areas where water is available, irrigated agriculture, mainly for the production of fruit crops for export to Europe, North America or Southern Brazil, has been very profitable. In the areas where water is scarce, the main agricultural products are sisal, cotton, oil palm and staple food for local consumption.

The main staple foods of the population are cassava and beans (cowpea, *Vigna unguiculata* and common bean, *Phaseolus vulgaris*). Cowpeas are grown mainly in the region called *sertao* which is warmer and drier than the *zona da mata* (about 400 mm rainfall/year), where *P. vulgaris* is concentrated.

The regional preference is for cream-seeded beans (both species), with *P. vulgaris* considered the best and reaching higher market prices. In the region there are many landraces that are cultivated, all of them either of cream-seeded colour or cream background with red mottles and most of them of large seed types. Bean mixtures are also common and the strangest variety names are found there. In many cases the origins of such varieties/cultivars are unknown; they have been in the region for many years or even centuries just through seed exchange by neighbouring farmers. The seed-production system is not organized in most states. Research and extension systems are poor. Their employees are usually located in the capital city and refuse to move to the dry area, owing to the lack of work and living conditions in the countryside.

In that area most farm labour is by hand; sometimes soil is ploughed by machines and other times threshing is also by machines but that is not the general practice, with all other labour being by hand. In most cases, labour is familial (the whole family works in the plot), but in other cases, especially in the case of bean plots, many times it is women's and children's labour only (with some male help for the heavier tasks) because the husband may have another job to help support the family.

The cultivation system is mainly intercropping of bean with cassava, forage palm (some species of cactus that are edible) and when the environment allows, maize. Many times all the species are planted at the same time in the same area, other times there are combinations of one or two of them.

Bean plots are usually small (between 0.5 and 2 ha in general) and no fertilizers, herbicides, insecticides or fungicides are used unless they are remaining from another crop, considered "more important". Beans are grown mainly for family consumption, but in the years when there is a bean shortage, a large social problem occurs due to undernourishment, not only of calories, but also of proteins.

There is one large area in this region, which owing to its particular rainfall pattern and soils, specializes in the production of common bean to supply the demand of local and Sao Paulo markets in the period "between harvests". The people of that area live on the bean crop (*P. vulgaris*) and in the not-infrequent years that the rainfall distribution does not conform to the norm, it means an economic disaster for most growers who lose the crop due to drought and the very conspicuous problem of *Macrophomina phaseoli*, a disease which is triggered by short periods of drought. That area is Irecê, in the State of Bahia. Only there are bean farmers organized in

cooperatives and have access to credit and regular support from the extension service. The problem is that there are not many research results that the extension can use to help the farmers, because of the general weakness of their research programmes and the nature of the problems that the crop has to overcome: in the dry years, drought (resistant cultivars are not easy to obtain, water management requires local research which is insufficient) and *Macrophomina* (a very difficult disease to manage and to obtain resistance to, which leaves inoculum in the soil from one year to the next).

In the more favourable years, rust, angular leaf spot (also a difficult disease which causes large economic damage), *Fusarium* wilt and, lately, bean golden mosaic virus (the worst common bean virus disease and the most difficult to control). To add to this range of problems, local markets are very demanding about grain quality; some slight darkening of the grains or some mixed appearance of the harvest product (even in pure-lines of cream background it happens due to uneven drying of grain) can cause a reduction in market prices and even a refusal of the product.

Bean breeding for such a region has had to combine the seed traits with the agronomic traits and that has proven to be very difficult. A small shade difference, combined with a slightly enlarged seed size, makes a big difference in obtaining a larger price. Many times it looks as if only their strangely named landraces have the right combination of traits, their only problem being their low yield potential and lack of drought resistance.

The objective of the research project was to develop new bean lines that would combine some drought resistance with some tolerance to rust and *macrophomina* with the grain colour and size that are preferred in the northeastern region of Brazil.

### **Research system in Brazil**

The research system in Brazil is composed of EMBRAPA (Brazilian Enterprise for Agricultural Research), which is supported by the federal government, state research institutions and universities. EMBRAPA consists of its headquarters (in Brasilia) and about 40 Research Centres, distributed around the country, with very defined responsibilities.

One EMBRAPA centre is CNPAF (National Research Center for Rice and Beans), located in Goiania, GO, which has responsibility for developing research and coordinating all the research in the country that deals with two crops: rice and beans.

Both crops are grown in all Brazilian states and both are very important agricultural products and staple foods in the country. It is impossible for any research group to deal with such diversity of climates, soils, cultivation systems and regional preferences, if that research group is not well connected with people in the regions. The CNPAF group works for all the country in connection with the state institutions and universities, trying to complement their work, help whenever possible and never compete in order to increase synergies.

For many states, the main work of CNPAF is that of an active germplasm bank for those crops; training, consulting and some breeding and pre-breeding work are done at their request. Other states have a very small research system and budget and they deal with only a few high-priority crops leaving those that are not the main ones for the state economy to EMBRAPA, limiting their action to the final test and recommendation of new varieties or of a few new proven technologies. This is the case of most northeastern states, with a few exceptions. When a full research programme needs to be developed in the region, CNPAF often has to send its personnel to actually do it.

CNPAF is located in the central part of Brazil where the rainfall distribution is unimodal (1200 mm/year, from October to May), with a period of no single drop of rainfall. During that period the temperatures are somewhat lower than in other times of the year (geographic winter) and if irrigation is available, excellent crops can be grown then.

So, at CNPAF it is possible to have a season where bean can be grown and water can be managed to impose stress whenever needed, but since the temperatures are lower than in the regular growing season, the stress will hardly be as high as it would be in natural conditions. CNPAF has a multidisciplinary group of researchers that can provide artificial disease inoculations and evaluations.

Drought-resistance trials and water-stress physiology have always been a subject of attention at CNPAF but it has also been a consensus among researchers that no matter how the trials are grown, there is no good substitute for the local data.

It has always been very difficult to achieve the right commercial grain quality for the types that are preferred in northeastern Brazil. No matter which parameter was taken into consideration (colour, shape, size, uniformity of colour), it seemed that all the improved genotypes that were developed for the region were not ideal for the regional market because people were still able to recognize the local landraces, paid larger prices for them and many times even refused the improved cultivars.

### **Procedures used**

Using bean adaptation data from northeastern Brazil, plus drought and disease resistance data from the National Research Program and from CIAT, a group of multiple crosses (4 to 8 parents) involving at least one of the local landraces in each cross was planned together with CIAT breeders. Some sources of drought and macrophomina resistance, previously identified from the international drought nursery (managed by CIAT) were also included in the crosses (Guimarães and Zimmermann 1987a, b).

The  $F_2$  populations were grown at CNPAF (owing to a seed shortage) and a natural episode of rust was allowed to occur. The populations were planted in June (beginning of the dry season) and they were given two full irrigations in order to establish the crop. After that, water was stopped. A few crosses were heavily infected with rust and were discarded. From the others, the best 150 plants of each cross were individually harvested.

The  $F_3$  generation of the 18 remaining crosses (2700 progenies) was grown under good irrigation conditions (just for seed increase) immediately after harvesting the previous one (same year). The harvested  $F_4$  seeds were divided into four groups: three were used for regional testing of the progenies and one was kept at CNPAF for seed multiplication under irrigated conditions. The three lots of each progeny were grown in the experiment station, in three different locations in the region, without irrigation and, owing to a seed shortage, without replications but with a repeated check at every 10 genotypes. There were two checks repeated throughout the field: a local recommended genotype and the most drought-resistant genotype that had been previously identified from other trials.

The growth of the progenies in the three locations was observed by researchers and by local farmers who were invited to the plots. Farmer visit/selection happened at two points in the plant cycle: pod filling and harvest. (At this stage of the breeding work, when no individual selection for grain colour is to be made, the visit at harvest may not be as useful and may be somewhat confusing for the farmers. It was necessary to reassure them that the strange seed colours they were seeing would not be kept and we did not take into consideration the fact that many of the progenies

showed very mixed colours.) Progenies with high incidence of any disease in the field were discarded. Irecê (the main location in the dry area) showed a high incidence of *Macrophomina*. The healthier progenies from every location, as well as the farmer-selected progenies and the checks, were harvested. Progenies with yields that surpassed the checks in the three locations, and the farmer-selected ones (when not coincident) were kept for continuation. From 2700 original progenies, 376 continued.

The increased seeds from the selected progenies (now  $F_5$ ), were again divided into four groups and yield tested at only the main location, Irecê (experiment station). The test was conducted in four 10 x 10 lattice experiments (the same check genotypes plus a few other local landraces), each experiment with four replications.

The procedure was similar to the one followed the previous season, the farmers being invited to the field twice, first for observation of whole plots and later for selection at harvest time. At harvest, 1 m<sup>2</sup> from each plot was harvested, weighed and analyzed; after the analysis, farmers were asked to select the best 10 individual plants.

Some good-yielder plots were totally discarded because no single good seed type plant was found according to the farmers. The very bad yielding plots were also discarded. From the 376 plots, only 32 remained, from which the 10 best individual plants were taken. The individual plants were immediately seed increased and disease tested for bean common mosaic virus, with controlled inoculations at CNPAF (off-season, 10 seeds for increase and 10 for inoculations). Lines without the I gene, or segregating for it, were discarded. The remaining ones were again seed increased and, in parallel, yield tested with controlled drought at CNPAF. The nonsegregating lines, which had yield and seed colour that did not differ visibly from their sister lines, were mixed and sent for testing in Irecê, in a replicated yield trial, still at the experiment station (complete randomized blocks design, with four replications).

Farmers were again invited to observe the plots at pod-filling and at harvest and they selected the 10 very best according to their evaluation parameters. It was noticed that they were attracted to healthy plants, but their evaluation was based on seed colour and size more than on anything else. A slight difference in seed shape (preference for the more rounded rather than the square ones) was also part of their evaluation. They did not pay much attention to the aspect of somewhat mixed variations in shades of colour if the general aspect was of light colouring and more or less uniform shape and size of seeds. Very light yellowish seeds, very light pinkish and almost-white were acceptable together, but light yellow and slightly brownish were not. Also, yellowish seeds with an orange halo around the hilum were not acceptable even in mixtures with another yellowish seed without halo around the hilum. Bright seeds were also not acceptable in any case even if the other traits were equal to the best lines.

That was new information for us, because we never thought they would be so discerning of such small differences.

Seed of the 10 very best farmer-selected lines was increased and tested in farmers' fields (10 farmers) under their practices, without replications and in larger plots (100 m<sup>2</sup>). The condition was that they used in a neighbouring plot, for comparison, the same genotype that they were using before.

Researchers from CNPAF and from the Bahia State institution followed the whole process and visited the farmers' fields. Each farmer was also interviewed on how they rated the 10 plots and at the end, yield data from each farmer were taken and analyzed together. The four very best plots were selected again for testing in farmer's fields, on 1000-m<sup>2</sup> plots having as controls another plot of the genotype preferred by the farmer and the genotype indicated for the region, when they were not the same. Farmers were interviewed on their opinions about the new genotypes and they



indicated the very best one in their opinion. Yield data were collected from all genotypes. One of them, the line coded SC 9029883, from the cross (BAT 477 × Favinha) × (Carioca × XAN 40) was chosen for recommendation. In parallel to the farmers' field tests, seeds of the four genotypes were increased at CNPAF and after the decision was made, two other off-season seed increases were made of the genotype chosen, which is now recommended for the region with the name Bambui (CNPAF/EMBRAPA 1995).

From the parents, BAT 477 is a drought- and *Macrophomina*-resistant line, identified from the International Drought Nursery (coordinated by CIAT); XAN 40 is a CIAT breeding line; Favinha and Carioca are landraces from Brazil. Favinha is from the northeastern region, very well accepted there. Carioca is from Sao Paulo, but is the genotype that shows the highest degree of yield stability in Brazil.

Even before recommendation, many farmers of the region had seeds of it (which they kept because it was their choice). The new cultivar suffered no criticism for its seed quality, as far as we know.

### Comments on farmers' selection/perception

It was noticed, at the time of farmers' selection, that their opinions at pod-filling stage were not always consistent with their choices made at harvest time. At harvest is when they could see grain quality, the most important market attribute for dry beans.

Every farmer had some sort of different appreciation/preference for some seed types, but for discarding the very bad and choosing the best group, their opinions coincided, and did not always coincide with the researchers' opinions. Yield potential was not their main worry but plants with a very low number of pods were discarded. Plant types that were more erect were preferred to the very prostrate, and healthy pods were also easily spotted. When selecting among the very best group, in order to retain only one genotype, there was generally a large degree of consistency among farmers.

Our impression is that the exercise was not only an interesting experience for the researchers (our group) but also an educational one because it helped us to start to understand which are the really important characteristics for the farmers and what they really prefer in that region.

For the farmers it was also an educational experience because they started to understand the researchers' work and they felt that their opinions were taken into account. For the extension service the experiment was also helpful, because the new variety was known even before they started making the diffusion. The only problem, as many times happens, was for the seed production because requests for those seeds were arriving before the seeds were available.

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## **Breeding rice cultivars suitable for rainfed lowland environments: a farmers participatory approach for eastern India**

**Surapong Sarkarung**

IRRI, Bangkhen, Bangkok 10900, Thailand

### **Introduction**

Rainfed rice including rainfed lowlands (RL) and rainfed uplands accounts for 56% (23 million ha) of the total rice area in India (Maurya *et al.* 1988). The rainfed lowlands, which occupy 14 million ha, are predominantly classified as submergence prone. The majority of these rice areas, however, are found in the eastern part of the country where resource-poor farmers grow old traditional varieties in a high-risk rainfed condition, using low-input management.

In this region, the rainfed lowland rice crops are normally exposed to flashflooding and/or water stagnation. The former is characterized by a sudden rise of natural rainwater in the field in which the crop is subjected to complete submergence for 5-10 days. The stagnant condition refers to water that accumulates in the rice fields and remains deep for a long period during the growing season. Owing to the complex and variable environments, major breeding activities were transferred from IRRI headquarters to major rice areas that are more representative (Sarkarung *et al.* 1995): for submergence prone, Central Rice Research Institute (CRRI) in Cuttack and Narendra Dev University of Agricultural and Technology (NDUAT) in Masodha were chosen to represent the intermediate (0-60 cm) and shallow water depths (0-30 cm), respectively.

The evaluation of rice cultivars was previously carried out on-farm in Eastern India with some level of farmer participation (Maurya *et al.* 1988; Thakur 1995; Joshi and Witcombe 1995). The main objectives were to allow the farmers to select the cultivars of their own choices and to understand their selection criteria. The intention of getting farmers involved in the breeding process appeared appropriate. However, the materials included in those experiments were restricted to a very small number of fixed cultivars of limited genetic diversity.

In our breeding programme, attempts have been made to generate large and diversified sets of breeding materials which can cover different target environments. The parents were assembled from native and improved traditional cultivars that are currently grown by farmers. This paper describes the breeding strategies that may offer farmers a greater choice of materials and provide different alternatives for farmer participation in the breeding process.

### **Diversity of rice varieties in rainfed lowlands of eastern India**

In the RL rice areas of eastern India, native and improved traditional cultivars are still predominantly grown by farmers because they can assure farmers of something to harvest even in the worst years of natural catastrophe such as floods and/or drought. The farmers critically choose varieties well suited to their conditions and normally cultivate two to three varieties of different types in their farms.

The variety Mahsuri, which at one time occupied more than 1 million ha in this region, may serve as a model variety for a breakdown analysis of why farmers prefer to grow this variety. One of its major contributions is the ability to survive and be productive under adverse conditions. Table 1 presents some important traditional cultivars presently grown by farmers in eastern India because they have

traits/characters that are required for that specific condition. For example the variety Begunia, despite its red pericarp, is still grown in the submergence-prone areas because it can survive several cycles of complete submergence in addition to its ability to perform in a no-input management system.

**Table 1. List of major traditional cultivars grown in eastern India**

Cultivar	State	Observation
Khuda	Orissa	long duration
Champrisali	Orissa	long duration
Begunia	Orissa	red grain, wild type, submergence tolerance
Khajara	Orissa	
Madhukar	Uttar Pradesh	medium duration, drought tolerance
Chakia-59	Uttar Pradesh	long duration, lodging resistance
Jalmagna	Uttar Pradesh	long duration, weak stem
Sabita	West Bengal	long duration, submergence tolerance
Amulya	West Bengal	long duration, good in water-logged conditions
Patnai 23	West Bengal	medium duration, very tall, good in P-deficient soils
Safri 17	Madha Pradesh	medium duration, adapted to drought-prone conditions
Cheptigurmatia	Madha Pradesh	medium-long duration, very tall, weak
Rajshree	Bihar	medium duration, drought resistance

### Setting up breeding objectives and priorities

To have a better focus on germplasm development, the RL rice ecosystem is systematically divided into five subecosystems (Sarkarung 1994). However, for practical breeding purposes, the breeding programme is based primarily on developing breeding material that can fit into target environments in submergence- and drought-prone areas. Research related to tolerance of submergence and drought receives top priorities but the breeding objectives are set to meet the major requirements of different environments. For example, in the submergence-prone areas of eastern India, a rice variety needs to have the following traits and characters:

- tolerance to flash flooding, particularly at the seedling stage
- appropriate photoperiod sensitivity
- resistance to diseases (e. g. bacterial blight, false smut)
- resistance to insects (e. g. GLH, gallmidge)
- intermediate height with lodging resistance
- adapted to low fertility conditions but responds to high-input management
- erect flag leaves with panicles well below leaf canopy
- acceptable grain quality.

### **Breeding strategies: farmers participatory approach**

Previous research indicates that the majority of improved rice cultivars developed on-station failed to perform in farmers' conditions; this implies that under the RL conditions the new released cultivars could not compete with the native and traditional cultivars in adverse conditions where water and fertility are uncontrolled. The alternative approach was to evaluate the fixed or nearly fixed cultivars on farmers' fields with farmers' practices and managements. But that could only satisfy part of the problem. An innovative approach to farmers participatory breeding in rice for eastern India has recently been discussed. The principal idea is to get the farmers to share their experiences and their perception on rice varieties suited to the heterogeneity of the rainfed lowland environments. Important steps involved in the germplasm improvement are: characterization of parents, programming crosses, evaluation and selection, yield testing and varietal release.

The abovementioned steps are routinely practised in any traditional breeding programme and they are normally carried out at the research stations. However, in our new approach, we attempt to involve farmers in the breeding process. The question is when and at what stage in the breeding process the farmers should come in, considering the differences in their social and educational backgrounds. The process may involve both medium- and long-term approaches as described below.

### ***Medium-term approach***

#### **A. Using modified bulk and pedigree methods**

1. Characterization of parents
2. Hybridization and generation of  $F_1$  hybrids (20-30 crosses)
3. In each  $F_1$  population, practise single plant selection to form a modified bulk population
4. Evaluation and selection of  $F_2$  (3000-5000 plants/cross, depending upon types of crosses)
5. Continue modified bulk selection in  $F_3$  and  $F_4$
6. Select single plants in  $F_5$  and employ pedigree method in  $F_6$
7. Conduct replicated yield trials.

#### **B. Using anther culture techniques for mass production of doubled haploid lines**

This could be the best alternative approach and may be preferred by farmers since the double haploid (DH) lines are uniform but offer a wide range of phenotypic diversity that farmers can select for their own conditions.

1. Same as in A
2. Same as in A
3. Produce large number of DH populations from  $F_1$  or  $F_2$ , using anther culture techniques
4. Farmers evaluate DHs for adaptation in target environments
5. Assess the performance of DHs
6. Conduct replicated yield trials of the promising DHs.

**Long-term approach****A. Using population improvement method**

1. Characterization of parents
2. Generate large genepool by intercrossing diverse parents
3. Enhance genetic recombinations by encouraging natural outcrossing (e.g. use of ms lines)
4. Establish base population
5. Extract lines from the base population using pedigree and/or recurrent selection method.

The stage at which farmers should participate in the breeding process should depend on the type of farmer. Some like to practise selection and use different types of cultivars in the same farm. Participation in the breeding process can be as follows.

**Later stages of breeding**

1. Evaluation of the diversified set of breeding lines which include fixed or near-fixed lines and the anther culture derived DH lines in target environments
2. Document farmers' perception of cultivars and traits/characters
3. Organize replicated yield trials of the selected lines by farmers in different key locations
4. Simultaneously multiply the seed of the selected lines in cooperation with farmers
5. Recommendation of cultivars for release is based on topographical niches (shallow: medium season; intermediate/deep: long season).

**Beginning of breeding**

Farmers participating at this stage should have some basic knowledge of genetics and heritability (e. g. maturity, plant height, grain characteristics).

1. Evaluate the segregating populations ( $F_1$  onwards) in target environments
2. Practise basic plant breeding such as single plant selection and/or modified bulk in  $F_1$  and the following generations until the populations/lines become nearly fixed
3. Evaluate the material as lines through observation yield trials with or without replication
4. Follow steps 3 to 5 of **Later stages of breeding**
5. The final products from this programme may be totally from the later stages of breeding because the farmers exert their own selection components very early in the process.

**Strategies for varietal release**

Farmers' perceptions on which rice varieties they prefer to grow in their farms will have an impact of the participatory breeding. This could lead to selection of the materials that really have specific adaptation to different toposequences by deploying cultivars in different water regimes under which farmers have been producing for decades. In participatory breeding, it is unlikely that rice cultivars could be released for every village. An alternative approach is for the farmers to form a cooperative for the community, which may cover several villages and

districts of similar growing conditions. In this way the varieties can be recommended for each ecological niche.

#### **Approach/methodology as a function of the nature of the crop**

The breeding approach for diverse RL environments is largely directed toward understanding the hydrological background of target rice-growing areas. The suitable rice cultivar should have the phenological and agronomic attributes that fit into the duration of the rainfall pattern. Therefore the methodology of development has been directed to the hydrological requirements. This includes breeding objectives, screening, evaluation and selection, plant types, etc.

#### **Social differentiation on approaches to plant breeding**

There would be a great impact on social activities and establishment if farmers participatory breeding becomes an integral part of the breeding programme. These breeding activities would be part of farmers' farming operations in addition to tending their own rice crops. In the process, the participating farmers would learn more about development of cultivars and crop management.

#### **Dissemination of results (knowledge, seeds)**

The participatory breeding approach could be organized to involve farmers in the selected villages/communities of representative rice areas. Meetings and seminars can be informally arranged to have discussion on issues related to breeding, to inform farmers of the progress of the process, to give basic training in agronomy and breeding and to inform them of new findings. This is perhaps the best avenue of disseminating the information and knowledge.

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## Farmer participation in pearl millet breeding for marginal environments

*Eva Weltzien R., M.L. Whitaker and M.M. Anders*

International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, A.P. 502 324, India

### Introduction

One of the goals of the Consultative Group on International Agricultural Research (CGIAR) is to develop strategies and research methods to cope with increasing demand for food production in light of degrading environments. This commitment to integrate growth and poverty alleviation with environmental protection was reinforced by Agenda 21 (CGIAR 1993). A large proportion of the world's poor live in the harsh environments of the arid and semi-arid tropics. It is one of ICRISAT's goals to develop innovative techniques to improve the impact of its research on the nutritional and economic well-being of low-income people in these environments. Developing methods to bring farmers and scientists closer together has been one of the approaches used to achieve research results with more relevance to specific farming communities. Understanding farmers' priorities helps to target research efforts. Giving farmers opportunities to choose, improvise and adapt from a range of choices will create more useful technologies (Farrington and Martin 1988).

New varieties, breeding populations and improved genetic materials are among the major outputs of ICRISAT's research efforts. Farmers' involvement in this process has traditionally been limited to that of a donor of germplasm and of a recipient of a final product. Opportunities for farmer participation in the various stages of this process will be explored in this paper, based on research with pearl millet (*Pennisetum glaucum* [L.] R. Br.) in the state of Rajasthan in northwestern India. This paper describes the interaction between scientists and farmers during individual stages of the breeding cycle of a cross-pollinated crop and summarizes key results obtained to date.

### *Pearl millet in Rajasthan*

Pearl millet is the major cereal crop and staple food of Rajasthan. It is grown annually on 4-6 million ha, predominantly in the drier western part of the state. The area under pearl millet varies greatly from year to year, depending on the yearly rainfall and its distribution. There has been a slight increase in area cultivated with pearl millet over the past 30 years (Jansen 1989). The average productivity of the crop varies greatly from year to year, and rarely exceeds 500 kg/ha. In the western districts of Barmer, Jodhpur and Bikaner, average yield levels frequently are below 100 kg/ha.

Adoption of modern varieties (MV) of pearl millet is low in this state, in contrast to other millet-growing areas in India where both improved open-pollinated varieties and single-cross hybrids are widely used (Jansen 1989). Local varieties of pearl millet from the western part of Rajasthan tend to outperform the standard MVs for grain yield under stress conditions (Weltzien and Witcombe 1989). Pearl millet is normally cropped in mixtures with short-season legumes. Livestock are an important component of the farming system. Crop residues of

pearl millet and legumes are important sources of livestock feed and farmyard manure is the primary fertilizer amendment used by farmers.

### ***The cycle of plant breeding activities***

Breeding new cultivars of any crop involves a series of activities common to all crops. Schnell (1982) defined these major stages as "generation of variability", "selection" and "testing of experimental cultivars". This classification facilitates the analysis of the technical process of variety development, the domain of classical plant breeding research. A successful breeding programme, however, needs two additional stages: the setting of goals or the definition of a target for the breeding programme and an efficient system for varietal release and dissemination. These two stages need to be integrated with the technical variety development process, to allow for feedback between these stages and for a dynamic optimization of the whole breeding cycle.

### **Opportunities and experiences with farmers' participation**

#### ***Defining goals***

Setting goals is usually the first step in developing an effective breeding programme. Appropriateness of goals set determines the effectiveness of a breeding programme to a large extent. The goals have a large influence on the choice of breeding method, composition of the germplasm base and diversity that is required. Formulating goals is crucial to any breeding programme. It is thus surprising that very little research has been reported on methodologies for identifying appropriate goals in breeding programmes. The reasons for this could be historical. Seed improvement, variety development and plant breeding as an enterprise and a research discipline have evolved out of crop improvement in general (Kuckuck 1988; Gäde 1993). Thus the intricate understanding of farmers' production goals, their preferences for certain traits as well as a familiarity with future trends in production conditions formed the basis for genetic crop improvement. With the rapid scientific development in genetics and its application to crop improvement the linkage between genetic, agronomic and farming system improvements has loosened and plant breeders are frequently in a position where appropriate goals are not obviously set. This is particularly the case in marginal environments where farming is frequently subsistence rather than market-oriented, and farmers' strategies for coping with large seasonal variations are not well understood (Matlon 1987).

Pearl millet cultivation in Rajasthan is such a case. We have therefore initiated research with farmers' participation on the following issues relating to the setting of goals for the breeding programme:

- identification of farmers' preferences for individual traits of pearl millet
- identification of major production constraints
- identification of major trends and anticipated changes in the production environment for pearl millet in Rajasthan.

#### **Methods**

In an initial study we used formal, structured, pretested questionnaires to elicit farmers' perceptions of the relative importance of grain versus stover yield (Kelley



*et al.* 1996). The results of this survey were mainly limited by the fact that farmers in marginal areas of pearl millet cultivation had not been exposed to the wide range of variability available among newly released pearl millet cultivars and pre-release advanced experimental cultivars. Farmers could thus not consider the whole range of available variability while expressing their preferences and concerns.

**On-farm trials:** To expose farmers to a wide range of these options we decided to encourage them to grow trials with new cultivars under their normal crop management conditions. We organized the on-farm trials with the support of local nongovernment and government organizations, working with farmers in the target areas (Table 1).

**Table 1. Location and number of on-farm trials organized each year with the support of local organizations**

Year	District	Village	No. of trials	Supporting organization <sup>1</sup>
1991	Ajmer	Kotri	12	SWRC
		Singla	12	SWRC
		Brijpura	12	SWRC
		Nallu	12	SWRC
1992/ 1993	Ajmer	Nunwa	15	IGDP
		Udaipur Khurd	15	SWRC
1994	Jodhpur	Aagolaie	30	DSSWSD and CAZRI
	Bikaner	Kichiyasar	30	Urmul Trust
	Jodhpur	Aagolaie	20	DSSWSD, CAZRI
		Malunga	20	GVVS
	Bikaner	Kichiyasar	20	Urmul Trust
	Churu	Krejada	20	Urmul Trust
	Barmer	Bhadka	20	SURE
Mangla		20	SURE	

<sup>1</sup> SWRC = Social Work and Research Centre; IGDP = Indo-Swiss Integrated Goat Development Project; DSSWSD = Department of Soil Conservation and Watershed Development of the Government of Rajasthan; CAZRI = Central Arid Zone Research Institute; GVVS = Grameen Vikas Vigyan Samiti; SURE = Society for Uplift of Rural Economy.

The on-farm trials were managed by farmers. Each farmer compared one experimental variety with his/her own variety. Farmers obtained assistance for the organization and layout of these trials from village investigators employed in each village. These investigators were trained to understand the trial objectives, the methods for monitoring them and to administer interview schedules to collect background information on key features of the production system. Details of the process we used for selecting target regions, study villages and participating farmers are described in Weltzien *et al.* (1995) and Whitaker *et al.* (1995).

The varieties used for these trials were chosen by the researchers to meet the following criteria:

- to cover a maximum span of variability for the trait time to maturity
- to cover a maximum span for tillering potential and panicle types

- the varieties should have been widely tested for yield, preferably released or near release
- the varieties should preferably be open-pollinated varieties and not single-cross hybrids, permitting farmers to produce their own seed.

We changed some varieties from year to year in response to farmers' evaluations and interests.

**Evaluation of on-farm trials:** Using these trials as the basis for discussions we used several methods to understand farmers' criteria for differentiating between cultivars and farmers' preferences for individual traits and trait complexes:

1. Individual comparisons of experimental varieties with farmers' own variety
2. Group interviews to compare a range of cultivars
3. Farmers' descriptions of an ideal variety.

#### 1. Individual comparisons

Project scientists visited the on-farm trials twice a season to hold discussions with farmers. The first visit took place before flowering to discuss field management and early growth of the experimental variety relative to the farmer's own variety. Prior to harvest plots were visited again to discuss in detail farmers' perceptions of differences between the experimental variety and their own. Individual assessments while viewing the standing crop indicated what characteristics farmers use to distinguish between varieties. For each distinguishing trait farmers were asked to rank the two varieties. Farmers also ranked the varieties over all traits. After harvest, farmers were asked to measure grain and fodder yields and to evaluate grain and fodder quality of the experimental varieties compared with their own.

#### 2. Group assessments

With different groups of 3-6 farmers each, representing farmers participating in the experiments, nonparticipating farmers and women farmers, we conducted group interviews to compare all experimental varieties with each other and with the local variety. Groups toured a cluster of fields to see all three experimental varieties under similar growing conditions. Farmers collected three to four representative plants from each variety to have specimens available during the discussions.

Discussions were structured so that farmers were first encouraged to talk about differences between the local varieties and the experimental varieties. For each trait they mentioned, a picture was drawn on a card. The cards were then used to construct a matrix ranking table. Farmers ranked the three experimental varieties for each of the characteristics they had mentioned. Usually these discussions led to other topics, such as crop management, crop utilization and seed selection.

#### 3. Ideal variety

During the individual and the group assessments farmers were asked to describe the characteristics of an ideal variety, thus ranking and combining the individual traits that they had mentioned before. This was followed by discussions on the reasons for this ranking and the preferred trait combinations.

### Characterization of the cropping system and its main constraints

The expression of individual traits of a crop variety depends not only on the variety's genetic composition but also on the environmental conditions where the variety is grown. Growing conditions have important direct effects on a variety's growth and performance, but more importantly the expression of many productivity-related traits depends on interactions between genetic and environmental factors. These interactions are usually unpredictable. An important part of formulating goals for a breeding programme is thus the identification of key environmental factors and production constraints. This allows the breeder to adapt on-station testing conditions to prevalent target growing conditions.

One complicating element is the time lag between the initial steps of variety development and its possible release and extensive adoption by farmers. This time lag spans normally 5-10 years. During this period production conditions, both economic as well as environmental, can change. The description of target growing conditions thus contains an important predictive element. Discussions with farmers about their management practices, production goals, changes occurring and factors that cause them can be important sources of information for defining target production environments for a breeding programme. We focused our discussions on crop management issues and livestock-crop interactions through individual structured interviews and informal group discussions on specific topics, such as crop rotations, following practices or crop mixtures.

### Results

#### Farmers' preferences for individual traits

Farmers used a wide variety of traits to distinguish between the experimental varieties and their own cultivars. The traits can be classified into three groups: growth and productivity, grain and fodder quality, and adaptation to the environmental conditions and needs. Farmers in the three districts mentioned grain and stover yield during varietal comparisons in about half the cases. Grain yield was consistently mentioned more often. These two traits were the most important for varietal comparisons in all three districts (Table 2).

**Table 2. Percentage of farmers using productivity related traits to distinguish the experimental variety from their own variety, 1992 and 1994 results combined, across all experimental varieties**

Trait	Ajmer 1992	Jodhpur 1992/94	Bikaner 1992/94
No. of farmers surveyed	27	44	49
Grain yield	68	50	65
Stover yield	52	36	53
Earliness	72	48	37
Large panicles	59	34	57
Large grain size	44	40	45
High tillering	20	23	65

The most important difference in farmers' preferences between the higher rainfall district (Ajmer) and the drier western part of Rajasthan was the different attention paid to tillering (Table 2). Tillering is of importance to farmers of western Rajasthan as a component of both grain and fodder yield. They associate better adaptation to low water availability and poor fertility conditions with this trait (Table 3), and consider it as a component of stover quality. Nodal tillers frequently do not mature before harvest and thus contribute to the stover feed quality. Higher tillering varieties commonly have thinner stems, which result in higher intake by the animals, without the need to chop the stover. The local landraces of western Rajasthan tiller profusely from both basal and aerial nodes. They are extremely thin-stemmed with small panicles and very small grain size.

**Table 3. Adaptive traits which farmers in Jodhpur and Bikaner district observed during 3 years of on-farm variety comparisons (bold = mentioned very frequently).**

Trait	Reason
<i>Plant type:</i>	
<b>Early maturity</b>	Associated with low water requirements
<b>High tillering</b> , nodal tillering, many leaves	Associated with high productivity under stress conditions
<b>Tall plant height</b>	Associated with high fodder yield under stress conditions
Large panicle, large grain	
<i>Overall adaptation:</i>	
<b>Good/fast germination</b>	Stand establishment is essential
Low seedling death	
Low water requirements good growth in early drought, dark leaves, less drying, less leaf firing	
Low soil fertility requirements	
<b>Good seed set</b>	Flowering, pollination and early grain development are very sensitive to stress
<b>Reduced bird damage</b> , bristles, glumes	in poor years bird damage causes severe losses, bristles and glumes contribute to nonpreference by birds
Uniformity	
Disease resistance	

The frequency with which earliness was mentioned differed markedly between all three districts. In Ajmer, the district with the highest seasonal rainfall and the longest rainy season (van Oosterom *et al.* 1995), earliness was mentioned most often. This is unexpected, because earliness would seem to be of most benefit in the drier areas of western Rajasthan. However, in Ajmer district the differences in earliness between the experimental varieties and farmers' own varieties were most pronounced. In Ajmer district two of the experimental varieties, HHB 67 and RCB-IC 911, flowered and matured distinctly earlier than the commonly grown cultivars. Farmers in this area had no previous experiences with this degree of earliness, and

perceived it as advantageous in both years of on-farm testing. In 1992, the early maturity of these cultivars gave many farmers the opportunity to plant a post-rainy season crop with the late rains of that year. In contrast, 1993 was a dry year and this earliness was the key to a higher grain yield for many farmers in this district. In both Jodhpur and Bikaner districts the local varieties flower early, thus the difference between local and early experimental cultivars is smaller. Confounding this is the effect of poor soil fertility and other stresses on flowering behaviour. It appears that the flowering of improved cultivars under stress is delayed more than in the local varieties of western Rajasthan (Weltzien, unpublished), thus further reducing the potential differences between the two types of breeding material.

Adaptive traits and adaptation were mentioned by farmers from western Rajasthan (Bikaner and Jodhpur) as criteria for which the varieties differed. Farmers' criteria for assessing adaptation of cultivars fall into two groups: a) plant type or plant architecture and b) specific adaptations to identifiable stress situations. Farmers commonly associate early maturity with low water requirements (Table 3). The relevance of high tillering was already discussed. Tall plant height is at times associated with high fodder yield under stress conditions. Specific adaptations that farmers regularly observed were speed of germination, early growth and other responses to early season drought, the ability to set seed and fill grains, and attributes that contribute to reduced bird damage, which is particularly important under drought conditions (Table 3).

Farmers had specific preferences for grain and stover quality characteristics. In western Rajasthan farmers preferred the thin-stemmed stover of the local varieties, possibly because choppers are generally not available in this region. In western Rajasthan there is a stronger preference for grain quality characteristics of the local varieties. In Ajmer district this preference appeared to have changed, perhaps through the wider availability and adoption of modern varieties (Table 4).

**Table 4. Percentage of farmers preferring their own cultivar for traits contributing to grain and stover quality, as observed during 1992**

Trait	Ajmer	Bikaner	Jodhpur
Number of farmers	19	21	19
Grain size	5	0	0
Grain colour	26	53	95
Cooking quality	11	5	0
Chapati <sup>1</sup> taste	21	74	57
Chapati keeping quality	21	58	67
Overall grain quality	16	74	71
Stover appearance	16	16	43
Chopped quality	32	63	43
Animal preference	11	42	28
Overall stover quality	21	74	33

<sup>1</sup> Local flat bread.

### Traits of an ideal variety

The most frequently mentioned traits of an ideal variety are large panicle size and tillering, with grain yield and earliness lagging not far behind (Table 5). The differences between Ajmer district and western Rajasthan are similar to those obtained from the discussions on trait preferences. High tillering is clearly of much more importance to farmers in western Rajasthan. Similarly, farmers in Bikaner district include low water requirement in their list of traits for an ideal cultivar. These same farmers placed less emphasis on large panicle size and large grain size than did farmers in Jodhpur and Ajmer districts. In all districts at least 50% of the farmers mentioned earliness in their list of ideal traits. Earliness is relative to the length of the growing season in the three districts, and to the crop duration of the prevalent varieties in a district.

**Table 5. Percentage of farmers using a trait to describe an ideal pearl millet variety, based on surveys conducted in 1992 and 1994 in Ajmer, Jodhpur and Bikaner districts.**

Trait	Ajmer 1992	Jodhpur 1992/94	Bikaner 1992/94
Number of farmers	22	32	33
High grain yield	32	56	67
High stover yield	23	28	42
Earliness	55	50	61
Large panicle size	77	75	45
Large grain size	45	34	30
High tillering	27	72	70
Low water needs	0	6	42
Good grain filling	32	9	42

### Evaluations of the on-farm trials by farmer groups

At the end of the season, five groups of farmers in Ajmer district compared the three experimental cultivars, including two groups of nonparticipant men farmers, one group of participant men farmers, one group of nonparticipant women farmers and one group of participant women farmers.

These discussions were held 2-3 weeks prior to harvest, when HHB 67, the earliest-maturing cultivar, had completed grain filling of the main panicle in most locations. Under good fertility conditions it continued to produce tillers, which were later maturing. RCB-IC 911 had completed grain filling in most cases, except under poor fertility conditions. ICMV 155 and their own cultivars had mostly not completed the grain-filling stage, depending on the fertility of the land. Thus most groups used differences in earliness as one of the first criterion to differentiate between the varieties.

Differences in rankings of relative earliness reflected land quality as well as differences in genetic potential. Farmers generally felt that their own cultivars were later than all three experimental cultivars. All groups noted differences in fodder or grain yield among the three cultivars. They expected all three cultivars to yield well relative to their own cultivars in 1992. Relative yield rankings differed across

groups, reflecting the quality of the land where the experimental cultivars were grown as well as the genetic potential of each cultivar.

Most groups noted strong differences in yield component structure between cultivars. The ranking of head size, grain size, plant height and tillering ability was consistent across groups and was congruent with previous on-station comparisons. Perceptions of grain size also seemed related to land quality. Under better conditions RCB-IC 911 produced larger grains. Under poorer conditions the advantage of RCB-IC 911 in grain size disappeared, as it had not yet completed grain filling at the time the discussions were held.

In addition, farmers included quality-related characteristics like fodder and grain quality or water requirements as criteria to differentiate among the three experimental cultivars. They evaluated these qualities visually. Fodder quality for chopped fodder was related to thicker stems, whereas thinner stems were beneficial in direct feeding. Grain quality appeared to be mostly related to large grain size, lighter, yellowish grain colour and sometimes the sweet taste of raw grain.

Water requirements, often considered together with fertility requirements, were judged mostly by considering earliness, tillering and thinness of stems and leaves. Farmers appeared interested in having a cultivar that would give some amount of assured grain yield in a poor year, rather than just fodder. They seemed willing to sacrifice grain yield in a good year.

#### **Production constraints**

As described earlier, adaptation to the climatic and edaphic conditions is a major requirement for success of any new variety in the harsh environments of western Rajasthan. To improve our understanding of the growing conditions for pearl millet in western Rajasthan we held group discussions with farmers in all study villages about the major factors contributing to crop failures and severe yield losses. Crop establishment is often problematic. Pearl millet seeds are small (5-14 g/1000-grain mass) so emergence under adverse conditions (deep planting, crust formation) is difficult. The seedlings are tender and fragile during the first days after emergence. Losses occur because of dry hot winds, sandblasting and heavy rains that fill the furrows in which millet is normally sown. Thus plants are covered with soil. However, in some years emergence conditions are excellent, and yields appear to be reduced by excessively high stands. Farmers are of the opinion that the available tractor-drawn sowing equipment is producing a poorer seed bed than the traditional animal-drawn equipment. It appears that improved sowing equipment, which would allow more precise placement of the seed, could contribute substantially to more reliable stand establishment.

Poor soil fertility is probably the main yield-reducing factor in the western part of Rajasthan. The traditional farming system relied on long fallow periods to restore soil organic matter content and general soil fertility. However, farmers from all over Rajasthan report that during the past 20-30 years a decrease in the duration of fallow periods due to increased population pressure has occurred. Farmers with small landholdings fallow their land only in severe drought years. Farmers in the western part of Rajasthan do not have much experience with mineral fertilizers. However, the notion of its riskiness is widespread. With the decline in fallow periods farmers associate a loss of organic matter and a loss of soil structure. They also consider this to be one of the causes of more severe crust formation.

Farmers in western Rajasthan perceive drought as the main cause for crop failures and yield losses. However, there appears to be a strong interaction with

soil fertility. Comparisons of high- and low-fertility plots over the past 4 years in three districts of Rajasthan lead us to assume that water utilization could be improved greatly in many fields, if a more adequate supply of nutrients were available.

### **Generating variability**

Choosing breeding material, developing the germplasm base for a breeding programme, choosing parents, making crosses and random mating populations are major and crucial activities of every breeding programme. It is generally assumed that breeders have a major comparative advantage over farmers in the choice of germplasm and in carrying out the processes leading to recombination and thus new combinations of traits and gene complexes for quantitative traits. However, a role for farmers in this process could be envisaged for cross-pollinated crops where crossing occurs naturally.

In the villages in western Rajasthan, where none of the experimental varieties satisfied farmers' needs *per se*, the farmers nevertheless used seed harvested from the on-farm trials for their own efforts in seed selection. This seed was most often planted in a mixture with their own variety, mainly to reduce the risk of crop failure from the new seed source. This resulted in intermating of the two groups of material, and farmers observed frequently an increase in variability in their seed stocks. We observed intense discussions among farmers about selection in these more variable seed stocks.

For the breeders it may be worthwhile to consider using population crosses and random matings made in this way by farmers, under farmers' field conditions, with a large population size and selection for the most preferred trait combinations as base material rather than making similar population crosses, often under nonrepresentative off-season conditions, and with severe limitations on the number of plants that can be handled per population cross. Breeders could use farmer-generated population crosses for targeted improvement of specific traits, which farmers can not easily select for on a single-plant basis (e.g. grain yield, stover yield or disease resistance) possibly without having to spend much effort on yield components and adaptive or quality traits.

The role of the breeder in this process would thus become more one of making useful new variability available to enable farmers to generate new population crosses with a good potential for achieving genetic gains for the key traits. For farmer-breeder interactions to be successful at this stage of the breeding cycle, farmers would need to be involved in evaluating a much larger range of material and genetic variability. It would also be beneficial if there were a better understanding of the combining ability of farmers' local cultivars with different sources of germplasm that farmers may want to use. We are presently evaluating farmer-generated seed stocks for their comparative performance and variability.

### **Farmers' participation in selection**

In any breeding programme selection is a key activity which can occur at any of the following stages: in the composition of the base material, in the selection of parents for crossing, in the selection among progenies, in the selection among experimental varieties and in the maintenance of Breeder Seed stocks. Selection among segregating progenies as well as selection during the testing of experimental cultivars requires the balancing between the different traits that vary within the



material. Understanding of the mode of inheritance is beneficial for complex traits, such as grain yield or disease resistance. Selection in all these stages of a breeding programme is normally carried out under experiment station conditions. Visits by farmers to experiment stations are usually limited to the viewing of demonstration plots of a few highly selected advanced varieties. Options for them are thus limited, and feedback from farmers on these displayed options is usually not sought. Possibilities for farmers' participation in selection could be as diverse as the opportunities for selection itself.

### Methods

We have experimented with farmers' participation in the selection among experimental varieties, with the aim of complementing variety evaluation with their opinions, and to confirm previous results on trait preferences and preferences for trait complexes by exposing farmers to a wider range of genotypes.

Groups of farmers—men, women, participants in the on-farm trials and nonparticipants from different villages—were invited to the research station at Jodhpur during 1992, 1993 and 1994. At the beginning of each group visit we discussed the crop management of our trials in detail. Groups of 5-6 farmers were then led through the portion of the trial (usually one replication with 40-60 entries), from which they would make their selections. They were asked to make selections of single rows from this trial which would be beneficial for farmers in their area. Each farmer could make up to 10 selections, by tying numbered labels to the ends of selected rows. After they completed their selections we held discussions on the range of variability they saw and its usefulness as well as on their reasons for making these choices. Farmers were then given the opportunity to select one of the entries in the demonstration for their on-farm trial the following season.

This method could easily be modified to involve farmers in selection among progeny rows or for selection among single plants for mass selection in a population bulk in on-station conditions. Crucial to the success of these efforts is identifying farmers who have a keen interest in seed issues and selection for their own local area and social group. These visits are time-consuming for the farmers and not necessarily of immediate benefit.

We analyzed the selections by grouping the varieties in the trial according to plant type based on time to flowering, tillering behaviour and panicle size, and recording the frequencies with which different farmers and farmer groups selected these types of material. The composition of the trial (Rajasthan Varieties and Population Trial, RVPT) changed from year to year; thus not all groups are represented each year and the genotypes within each group are not always the same.

### Results

As 1992 was a rather wet year with uneven rainfall distribution, short drought spells occurred in the vegetative growth stage and toward harvest. In 1993 the trial was exposed to a severe early season drought and received moderate rainfall for the remainder of the season. In 1994 no periods of drought occurred; growing conditions were excellent for pearl millet. At the time of the farmers' visit to the research station in 1992 the differentiation between early and later maturing genotypes was very clear, whereas in 1993 and 1994 these differences were not so obvious, because the farmers' visits occurred later in the crop cycle.

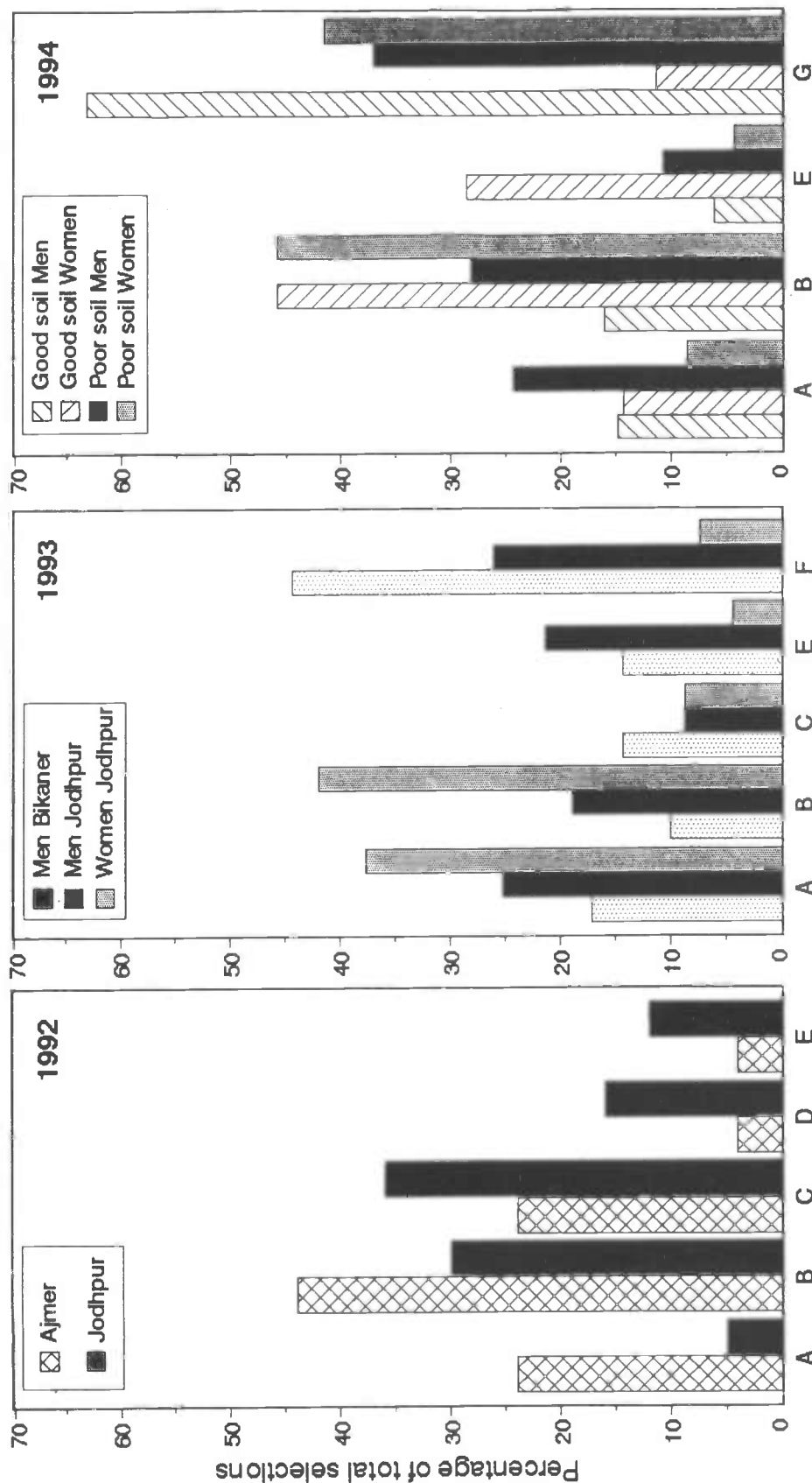


Fig. 1. Selections made by farmers from different districts in Rajasthan among groups of pearl millet varieties differing in plant type, as percentage of total selections made by each group of farmers, made in 1992, 1993 and 1994. A: medium maturity, low tillering, large panicle; B: early maturity, low tillering, large panicle; C: medium maturity, basal tillering, medium panicle; D: extra early maturity, high tillering, small panicle; E: early maturity, high tillering, small panicle; F: early maturity, high tillering, medium panicle; G: early maturity, medium tillering, medium panicle.

Results from 1992 showed that farmers from different pearl millet production areas selected very different types of plants (Fig. 1). Farmers from Jodhpur selected earlier maturing and higher tillering material than farmers from the higher rainfall area in Ajmer district.

In 1993 farmers from Bikaner district selected mostly high-tillering, tall material which were predominantly landrace accessions from another low-rainfall district in Rajasthan, Barmer. From Aagolaie village in Jodhpur district, a group of men and women made separate selections in the trial. Women tended to select material with large panicles and lower tillering more frequently; whereas the men appeared to be divided, with about half of their selections made for large panicle types with high grain yield potential and the other half for higher tillering with better stover yield and quality.

In 1994, men and women from the same village in Jodhpur district (with relatively poor soil conditions) and from a new study village (with better soil conditions) visited the on-station trial. Farmers from the village with poorer soil conditions, who also had experience with some of the cultivars in their own fields, appeared to prefer a new type of material derived from combining high tillering local varieties with large panicle modern varieties. This type was equally preferred by men and women from this village. However, men from the new village with better soil conditions preferred this type of material much more than did women from the same village. These women selected mostly material with large panicles and high grain yield potential.

The follow-up discussions indicated that for women from these villages grain yield, early availability of grain and the ease of harvesting by hand (lower panicle number and lower plant height) were their main considerations for making selections. For the men, stover yield and quality appeared to be a stronger concern.

#### ***Advanced variety testing, variety release and seed dissemination***

It is not uncommon to have some level of farmer involvement in the final stages of variety testing, mostly through researcher-managed on-farm trials, on-farm demonstrations and large-scale minikit testing. Similar types of trials are commonly organized by the extension services to expose a large number of farmers to newly available varieties and other technologies. Generally these trials are managed with the full range of recommended external inputs, which may be atypical of the predominant growing conditions in the target region. Farmers often have little input into the management of these trials. Based on our experience of the usefulness of careful evaluations of on-farm trials with farmers using their criteria, it appears that the biggest drawback of such on-farm trials is that only standard yield data are recorded. Farmers' evaluations of the test genotypes are not sought, and farmers' evaluation criteria are not regularly used, or if so, they do not enter final reporting and play no role in the decision-making process for varietal releases and recommendations (Farrington and Martin 1988). It is our experience that the type of on-farm trials we described in the first section and an attitude toward learning and understanding from the farmer reveal new information which allows a more precise assessment of the overall usefulness of a new genotype, based on the judgement of a large number of farmers. Some methods for discussions with individual farmers and farmer groups were described in the first section of this paper. Similar approaches have been used by Joshi and Witcombe (1995) to identify locally well-adapted cultivars from the often wide range of already released cultivars of different crops. Such participatory evaluation and selection of existing

released varieties has great potential not only for identifying locally acceptable varieties but also for exposing a large number of farmers to new varieties.

In Ajmer district, one of the varieties (RCB-IC 911) included in the on-farm trials yielded better in two very contrasting years, 1992 and 1993. The structure of our studies resulted in a large number of farmers having had visual exposure to this variety and it was widely accepted as being better than other options. In our discussions with individuals and groups there was a strong interest by farmers in obtaining seed for the next season. We indicated that because this variety was an open-pollinated variety, farmers could maintain relatively pure seed stocks in the village. Pamphlets and posters were provided illustrating how fields might be isolated and pure seed selected. Farmers indicated a strong interest in obtaining sufficient quantities of seed to provide the community with its requirements. Farmers indicated a willingness to pay Rs 10/kg for seed of this variety, which is slightly more than the cost for seed of local varieties in this area.

Availability of seed of improved genetic material is often a primary reason for lack of adoption, even if well-adapted, acceptable varieties are available, and released. On the background that farmers had stated a strong interest for seed of RCB-IC 911 the issue of seed availability could be addressed in our study area in Ajmer district. It was agreed that ICRISAT would produce a larger quantity of seed, which would be distributed by the local NGO (SWRC, see Table 1). A total of 2500 kg of RCB-IC 911 seed was supplied to SWRC in May 1994. This seed was made available to 14 villages in the area. Included were villages where earlier work had been conducted as well as villages which had limited or no exposure to RCB-IC 911. All the available seed was sold rapidly and not all the demand for it could be met.

Rainfall in 1994 was excellent and visits to the area indicated that this variety performed well and local seed production by farmers was seriously pursued. ICRISAT will be conducting an early-adoption study in 1995 to determine farmers' perceptions of their 1994 production, and to assess how the seed was produced and stored, and to evaluate its spread in 1995. It will be possible to determine the impact of farmer involvement in variety evaluation and of seed availability on early adoption.

### Conclusions

We have outlined in this paper opportunities for and results from farmer involvement and participation in the main stages of a formal variety development programme. Our results and observations indicate that farmer input into all these stages can be very meaningful and helpful to make such programmes more cost-effective. There is no doubt that appropriate targeting will help to maximize the gains that can be expected from a breeding programme. The use of farmer-generated population crosses may help to increase potential gains from a formal breeding programme by relieving breeders from selecting for adaptive and quality traits, and thus allowing more focus and intensity for selection on disease resistance or productivity-related traits. Planning for farmer-generated population crosses may involve more detailed analyses of the available genetic diversity, and its relationship with adaptation to and productivity under specific growing conditions.

Farmer participation in selection was mainly discussed with respect to their involvement in on-station evaluation of progeny trials, or variety trials. In the system of pearl millet cultivation as it is found in Rajasthan, it is difficult to envisage how a large number of progenies or varieties could be effectively tested by farmers in their own fields. There is, however, no difficulty to foresee farmers'

involvement in the selection among single plants in a population bulk grown in farmers' fields, especially if simple methods for pollination control can be implemented.

It is well established that farmers can evaluate a smaller number of experimental varieties in on-farm trials under their own management (Farrington and Martin 1988). If the active involvement of farmers in the evaluation and ranking of these varieties is sought, the most acceptable varieties can be rapidly identified, and the time span between variety testing, release and seed dissemination shortened dramatically, particularly if farmers have the option to multiply their own seed.

The analyses presented are based on the assumption that a full-fledged formal breeding programme is desirable and its effectiveness could be supported by input and involvement from farmers in and from the target region. The different options for farmer participation described here could be combined in a breeding programme in many different ways, depending on needs and opportunities.

In contrast to the described scenario, there may also be situations in which it is not economical to operate full-scale formal breeding programmes. A thorough understanding of the traditional system of seed selection, production and storage may open avenues for specifically targeted support by breeding research of such a traditional, indigenous seed system (Hardon, this volume; Lenné *et al.* 1995).

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## Monitoring potato and oxalis varieties in mixtures grown on farm family fields in the Titicaca Lake basin, Peru, 1990-95

Roberto Valdivia<sup>1</sup>, E. Huallpa<sup>1</sup>, V. Choquehuanca<sup>1</sup> and M. Holle<sup>2</sup>

<sup>1</sup> Centro de Investigacion para Recursos Naturales y Medio Ambients (CIRNMA), Puno, Peru

<sup>2</sup> Centro Internacional de la Papa (CIP), Lima, Peru

### Introduction

Agriculture in the Titicaca Lake basin is ancestral with traditional strategies under variable climatic conditions. Frost and drought events can occur on any day of the year. At least three highly developed cultures have interacted in the area. Present populations are of quechua and aimara lineage. Land is owned communally and while crop plots are managed by the individual farm family, pastoral lands are communal. Social organization promotes solidarity and reciprocal exchanges including gift giving, bartering and rituals. Group decisions that favour participation are taken periodically on land use and development actions.

The basic rotation starts with potato, and is followed by chenopodium, oxalis tubers, fava beans and barley before a 3 to 10-year fallow period during which land is pastured. Most cash comes from raising sheep, cattle and local cameloids. Cash inputs are restricted to manure and fertilizer for the first-year potato crop and curative animal medicines. Home consumption and seed needs comprise up to 70% of the crop harvested. A nearby rural local market takes up any surplus produced and provides the necessary 'imported' goods such as wheat, oil and rice. At harvest, natural freeze-dry methods for tubers result in products that can be stored for up to 20 years and are essential during drought periods (Holle and Risi 1992). All these conditions favour risk-avoidance strategies such as crop variety mixtures in dispersed plots in order to fulfil multiple objectives at the farm family level.

Descriptions of variety mixtures are scarce and their dynamics have rarely been followed. In 1989, while following seed production in remote communes, we observed flower colours that belonged to native and improved potato varieties. The question arose of how varieties are acquired and maintained. Work done in nearby Cusco reported that farmers handled up to 30 phenotypes for home and market objectives. Isozyme analysis confirmed this many genotypes (Quiros *et al.* 1990).

### Materials and methods

Individual farm families in two communes were chosen for yearly monitoring from planting date (October 1990) until harvest (May 1995) (Fig. 1). In one commune there had been more intervention of agricultural technology than in the other which was more isolated. Work within the latter is reported here. One or more dispersed plots (Fig. 2) were chosen at random from the yearly array planted. A 5-m<sup>2</sup> sample was harvested. The farmer and one of the coauthors, both knowledgeable in individual potato varieties, identified, separated, weighed and counted tubers.

Three main groups of varieties were recognized:

- the native mealy type (NH)
- the native, mealy improved varieties (NMH) of which good plants have been selected positively in the experiment station

- the watery varieties (MA) resulting from efforts of the national breeding programme for the region.

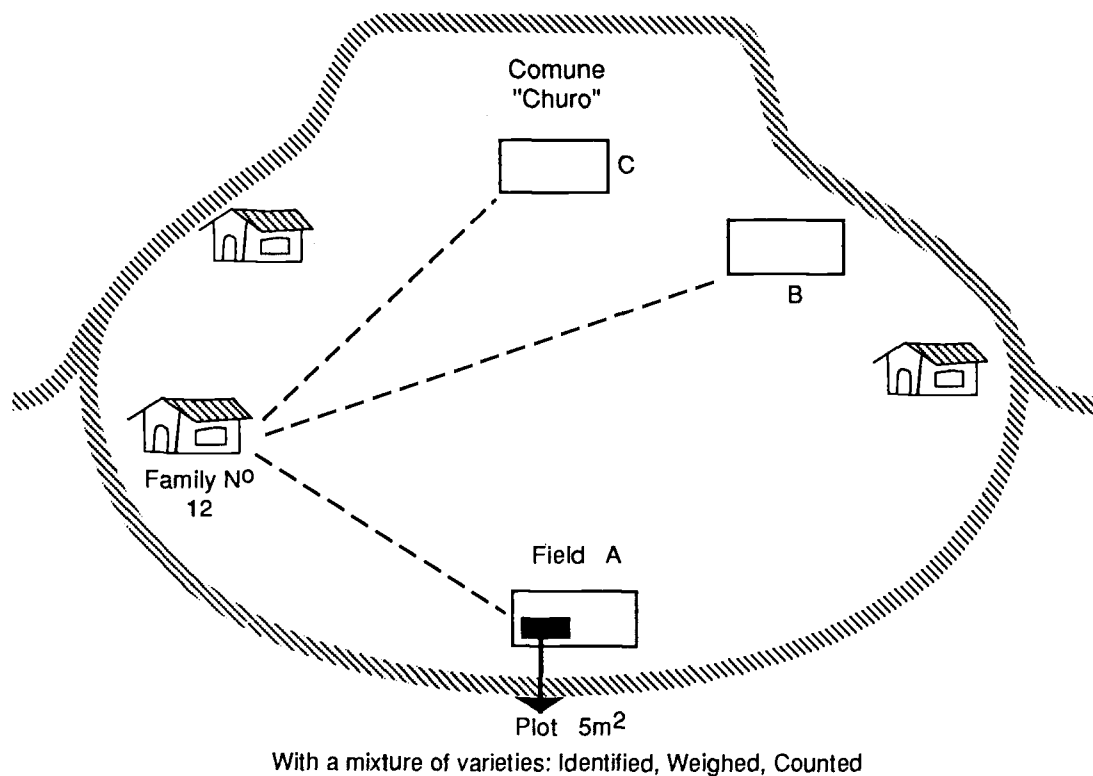


Fig. 1. Fields related to one family and sampled for potato variety mixtures.

### Results

The season effect was highly influential on yields, although an extreme drought year did not occur during the five seasons. Farm family, dispersed plot size and composition of mixture harvested did not affect yield variation significantly (Table 1). Variety data covered four aspects.

Table 1. Yields of the mixtures in 5-m<sup>2</sup> samples from three family plots, 1990-94

Family		1991	1992	1993	1994
12	Plot (m <sup>2</sup> )	300	750	500	300
	No. varieties	6	7	5-9	12
	Yield (kg)	6.91	5.9	3.2-4.3	4.0
13	Plot (m <sup>2</sup> )	400	300	225	900
	No. varieties	5	9	6-12	13
	Yield (kg)	4.7	7.8	4.4-12	5.1
17	Plot (m <sup>2</sup> )	300	400	-	300
	No. varieties	6	8	-	9
	Yield (kg)	4.9	4.6	-	4.7



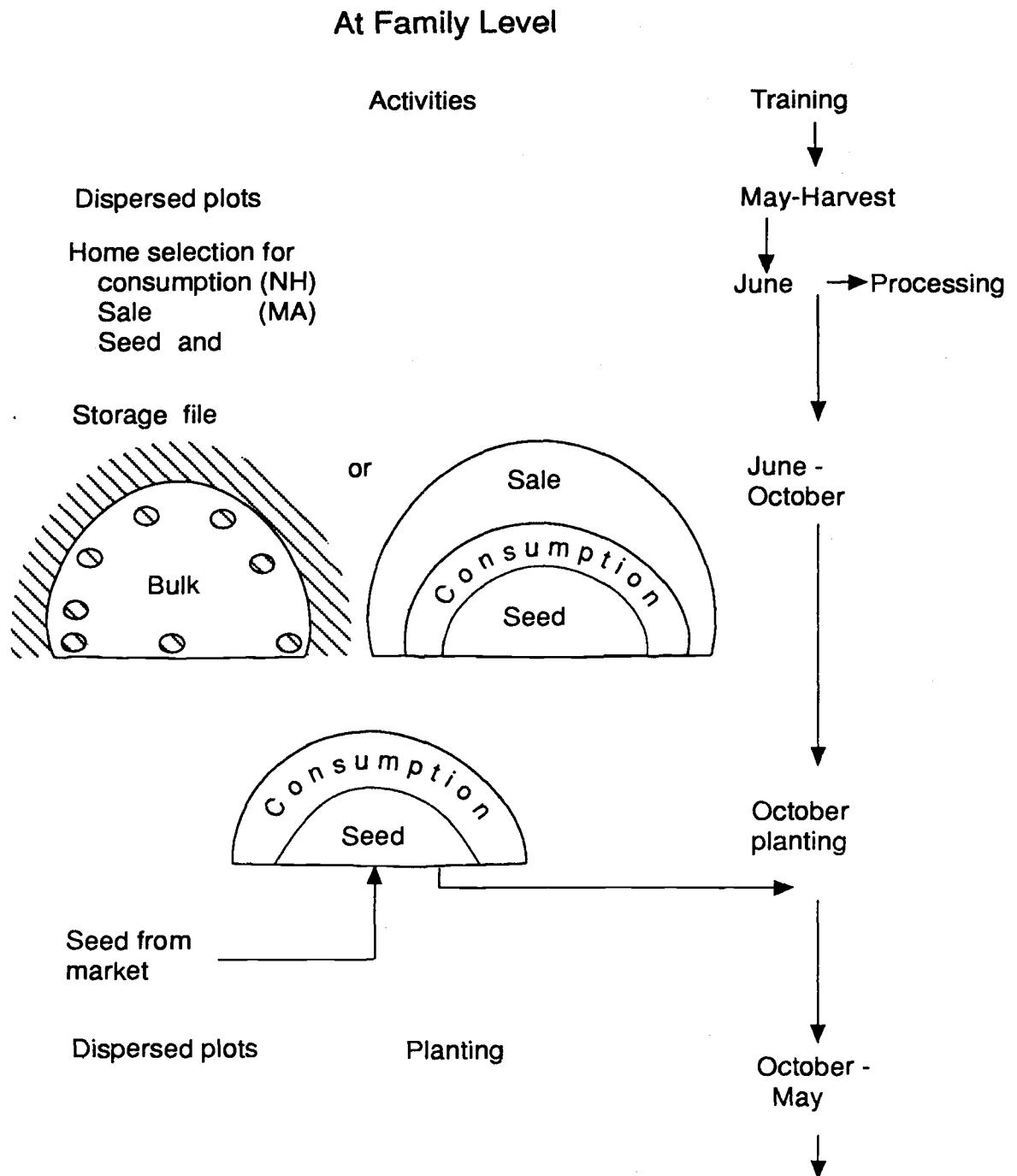


Fig. 2. General activities with potato tubers from May harvest to October planting (Puno).

***Presence and absence of varieties in the mixture***

Selected native mealy varieties were most common in the mixtures in all 5 years (Table 2). In the improved watery (MA) and the native mealy (NH) groups two subgroups can be separated: three to six varieties which are common and present most of the time (Yungay, Andina (MA); Santara, Llujtapara, Sacampaya, Cheara

Choque, Peruanito and Ccoillo (NH); or another group which appear once or twice during the monitoring period such as Chaska, Alka Tarma, Candarave (MA) and Imilla Roja, Acopallalla, Tuni (NH). Five varieties (e.g. Sutamari, Amajaya) of the 26 identified during the five seasons were absent in May 1995. At that time, sampling covered more plots. Have these varieties disappeared from the farm family mixture?

**Table 2. Presence (x) or absence (-) of potato varieties in 5-m<sup>2</sup> plots in the 1991-95 harvests (Churo, Puno)**

Variety	Family														
	12					13					17				
	91	92	93	94	95	91	92	93	94	95	91	92	94	95	
<b>NMH</b>															
Imilla Bl.	-	-	x	x	x	x	x	x	x	x	x	x	-	x	
Imilla Ne.	x	x	x	x	x	x	x	-	x	x	x	x	-	x	
Ccompis	x	x	x	x	-	-	-	x	x	x	x	-	-	x	
<b>MA</b>															
Yungay	x	x	x	x	x	-	x	x	x	x	-	x	-	x	
Andina	-	-	-	x	x	x	-	x	-	x	-	-	-	x	
TTC	-	-	-	-	x	-	-	x	-	x	-	x	x	x	
Others (3)	-	-	x	x	x	-	x	-	-	x	-	-	-	x	
<b>NH</b>															
San Imilla	-	-	-	-	x	x	x	x	x	x	-	-	-	x	
Santara	-	-	-	x	x	x	x	x	x	x	-	-	x	x	
Llujtapara	-	-	x	-	-	-	x	x	x	x	x	x	-	x	
Sacampaya	x	x	x	-	-	-	x	-	-	x	x	-	x	x	
Cheara Ch.	-	-	x	-	x	-	x	x	-	x	x	-	-	x	
Ccoillo	-	-	-	-	x	-	-	x	x	x	-	-	x	x	
Peruanito	-	-	-	x	x	-	-	x	x	-	-	-	x	x	
Imilla Roja	-	-	-	-	x	-	-	-	-	x	-	x	-	x	
Acopallalla	-	-	-	-	x	-	-	-	-	x	x	-	x	x	
Alka Imilla	x	x	-	-	-	-	-	-	-	-	-	-	-	-	
L. Sutamari	-	-	-	-	x	-	-	-	-	-	-	-	-	-	
Tuni	-	-	-	-	-	-	-	x	-	-	-	-	-	x	
Amajaya	-	x	-	-	-	-	-	x	-	-	-	x	-	-	
Sutamari	x	x	-	x	-	-	x	-	-	-	-	-	-	-	
Chupica P.	-	-	x	x	-	-	-	-	-	-	-	-	-	-	
Total	6	7	9	11	15	5	10	13	9	15	7	7	6	17	

#### **Proportion by weight of each variety in the mixture**

The native selected group (NHM) comprised from 1% to 20-40% of the mixture in a fairly constant pattern (Table 3). The improved watery varieties (M) were present in a variable array from 1% to 90% depending on each variety. Yungay was most ubiquitous. The native mealy group preferred for home consumption and processing formed 1% to 20-30% of the mixture.

**Table 3. Proportions (%) by weight of a variety in mixtures, Churo, Puno, 1991-95**

Variety	Family		
	12	13	17
MA			
Yungay	3-33	1-33	4-61
Andina	7-26	4-90	*T-16
TTC	11-15	2-15	T-11
Others (3)	5-20	8-17	15
N-M			
Imilla Bl.	3-12	1-18	2-20
Imilla Ne.	7-37	1-37	9-82
Ccompis	5-21	4-26	1-21
NH **			
Sani Imilla	11-14	4-43	4-16
Santara	10-12	1-31	T-15
Llujtapara	2-25	1-8	1-11
Sacampaya	4-20	4-8	5-32
Cheara Ch.	14-38	2-69	T-33
Ccoillo	13-33	1-83	4-32
Peruanito	2-18	1-35	1-41

\* T = Trace.

\*\* Five varieties with 1-3 observations only.

### ***Tuber size***

The character tuber size (tuber weight divided by tuber number for each variety) could indicate seed quality and/or virus damage. Critical data for negative virus effects on yields have not been produced in this area. Low virus-transmitting insect populations and virus cross-protection are suggested mechanisms. In this case, tuber size showed all patterns of possible response (Table 4).

**Table 4. Tuber size variation over five seasons, 1991-95**

Tuber size	Variety group**		
	MA	NMH	NH
Maintained	Yungay	Imilla negra	Ccoillo
Increased	Andina	0	Santara
Reduced	Candarave	Ccompis	Sacampaya

\*\* MA = improved watery; NMH = native mealy improved; NH = native mealy.

### ***Variety flow of *Oxalis tuberosa* in Yunguyo province***

Two critical times for variety flow have to be recognized. At harvest (April through June 1995) when oca varieties are sold for consumption, and at planting time (September to November 1994) when seed tubers are looked for in order to complement sufficient yearly seed supply. Three varieties (17% of all marketed) were present in one and not in the other period.

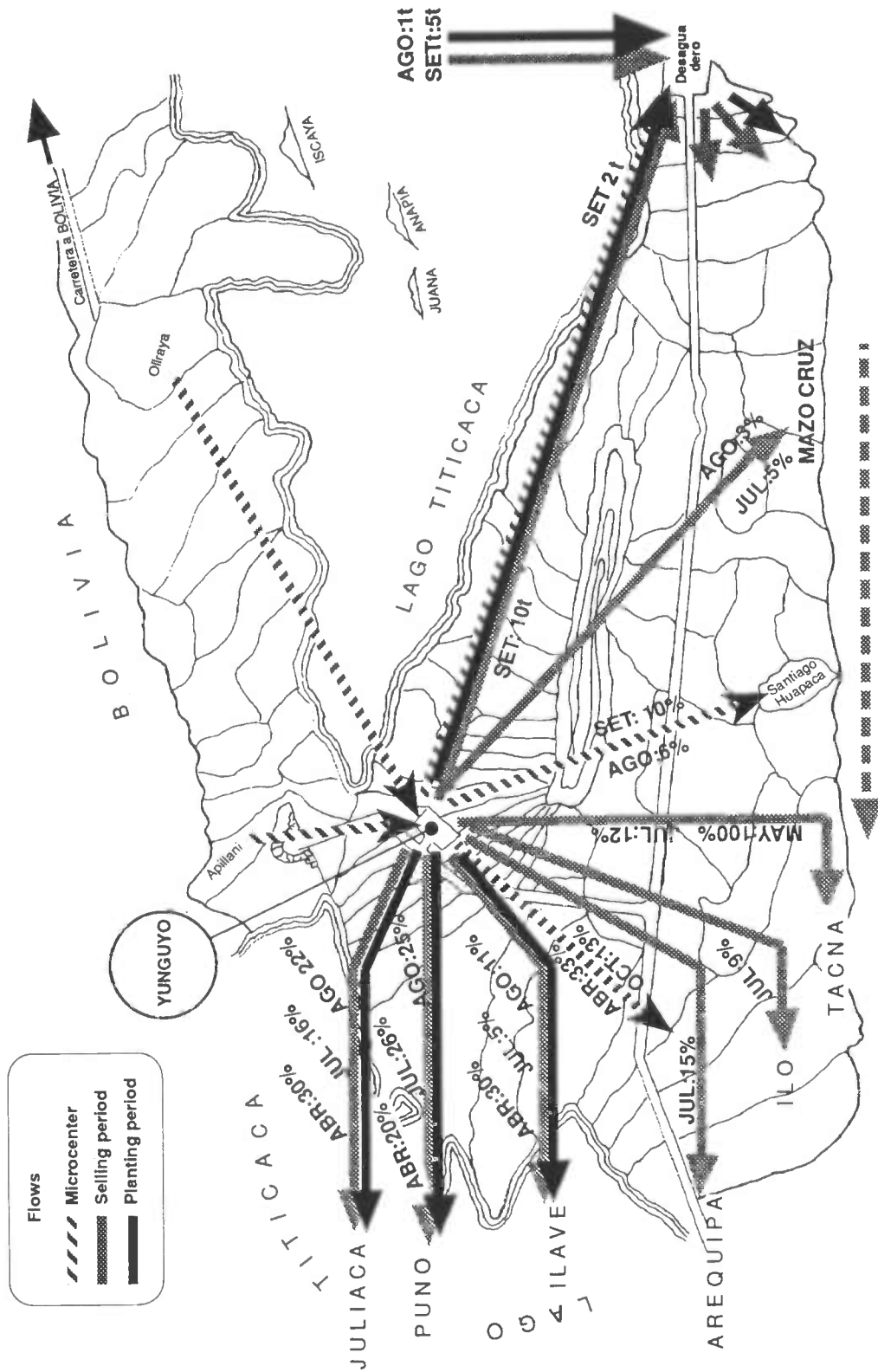


Fig. 3. Oca flows (%), t) from communes to the Yunguyo market in the planting and selling season (1994/95).

The Yunguyo market is the centre of movement and three flows can be determined (Fig. 3): one within the province and in direct influence of the market; two during harvest where oca goes either to the coast or to the north of the lake basin, and three as seed tubers at planting time. These include varieties from neighbouring Bolivia where variety requirements are different.

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## Farmer selections within segregating populations of common bean in Colombia

*Julia Kornegay, Jorge Alonso Beltran and Jacqueline Ashby*

CIAT, A.A. 6713, Cali, Colombia

### Abstract

If farmers were taught the basics of plant breeding, would the varieties they develop be higher yielding and more acceptable to other farmers within a region than those developed by plant breeders in researcher-managed field trials? This question was the basis for a plant breeding/farming participatory research study undertaken by CIAT in the Valle del Cauca, Colombia. The study had two major objectives: (1) to compare overall performance and agronomic characteristics of farmer- and breeder-selected lines across environments, and (2) to assess farmer perceptions of useful genetic variation. Eighteen  $F_2$  populations were grown in five environments: CIAT-Palmira (CIAT's main research station, 1000 m asl), CIAT-Darien (a CIAT field station at 1450 m asl), and three farms in the Darien region (1400-1500 m asl). A simple breeding strategy was used by CIAT and the farmers to advance segregating populations to homozygous advanced lines. The segregation of different traits within each population was pointed out to the farmers, but they were instructed to use their own criteria in making plant selections. The resulting 18 advanced lines, 9 parents and the local variety Calima were yield-tested in each of the five environments. Yields from CIAT-Palmira, CIAT-Darien, and farms were not correlated, nor were yields correlated among farms. All advanced breeding lines had yields as high as or higher than Calima. The selection criteria most frequently used by farmers were seed colour at harvest (98%), seed size (96%) and number of pods (95%), followed by foliar diseases (primarily angular leaf spot) (94%) and plant growth habit (83%). The advanced line TM 27 G1, with large, red, round seed type, developed by one of the farmers, was the most preferred among all advanced lines tested by farmers. This was followed by the traditional varieties Calima and Nima. The farmers were capable of selecting lines with good commercial qualities, but the most preferred lines did not have the highest yields or best disease resistance combinations. No one farm produced consistently superior lines over the others. Other lines with good farmer evaluations were from CIAT-Palmira. Lines from CIAT-Darien combined good yield and disease resistance, but their grain types were not acceptable. It is recommended that CIAT continue to use both CIAT-Palmira and CIAT-Darien for the development of high-yielding, multiple disease resistant bean lines for the Andean midaltitude regions. Greater emphasis should be placed on the selection on solid red bean types for Colombia.

### Introduction

Small farming systems within the tropics are typically complex and location specific. Public-sector institutions can not afford to develop and adapt new technologies to each specific system. Consequently, many of the recommended technologies, in particular new varieties released from national or regional crop improvement programmes are designed to address a broad set of general needs. These materials may be broadly adapted but are seldom designed to meet the specific requirements of different types of farmers who, because of various resources or market opportunities,

will have contrasting preferences for varietal traits. This problem of specificity is especially acute for plant breeding and the release of new varieties targeting resource-poor farmers

The typical selection time needed to develop a new bean variety is about 6 years, starting from the execution of the cross to the final selection of homozygous advanced lines. In addition, another 3-6 years are needed for adaptation trials, prior to the official release of a new variety. At least half to two-thirds of the total variety development time is spent in researcher-managed station trials. In most conventional breeding programmes, only at the end of the development process is the farmer allowed access to the new lines. Access usually involves adaptation/validation of the genetic material to edaphoclimatic, biotic and abiotic stresses encountered on-farm. However, even at this late stage it is not usual to solicit feedback from future users or adopters of the varieties about the extent to which the new materials are acceptable. Even if such feedback were to be obtained, knowing whether and why farmers are likely to adopt the new varieties, at a late stage in their development, leaves little scope for plant breeders to make changes in the bred traits. As a result, new varieties are often released with disappointing results in terms of the rate and extent of adoption by farmers, even in areas where the varieties have been targeted.

Farmer participatory research can help to reduce the time involved in post-development testing of new breeding lines, and can reduce the number of unacceptable varieties being released. Farmers, like plant breeders, have their own criteria by which they evaluate new varieties. The success of a new variety depends on how many of the farmers' criteria are incorporated into the breeding lines and how great is the variety by environment interaction. By involving farmers in an earlier stage of the breeding process than is usual, it may be possible to incorporate their preferences and expertise in a more systematic manner. Experience involving farmers early in the evaluation and screening of advanced lines has shown that bean varieties selected with farmer participation are better adapted locally than those selected by breeders working on their own (Sperling *et al.* 1993). Although the advantages of decentralizing the variety testing process are well understood by plant breeders, it is still unusual to involve farmers in determining desirable traits to be incorporated into the breeding programme before crossing actually takes place, for example. In spite of the advances made in decentralizing the variety testing process, plant breeders have not risked making selections under the nonuniform conditions typical of small farmers. Nor have plant breeders studied the possibility of having farmers make selections within segregating populations that conform to their needs.

In fact, very little empirical information has been obtained under controlled experimental conditions that would enable plant breeders to assess the advantages and disadvantages of involving farmers in the early stages of a plant breeding strategy. In addition to the question of whether there are serious risks of farmers selecting materials which incorporate undesirable characteristics, such as susceptibility to endemic diseases, for example, which are invisible to the eye of the farmer, there is the question of whether farmers can make selections from highly heterogeneous segregating populations without becoming thoroughly confused. If farmers are taught the basics of plant breeding, and are able to select from segregating populations, would the varieties they select perform better with respect to both breeders' and farmers' criteria?

This is the question which guided the research reported in this paper. The purpose of this investigation was to compare overall performance and agronomic characteristics of farmer- and breeder-selected lines across environments, and to assess farmers' perceptions of useful genetic variation.

## Materials and methods

### *Selection of sites*

Three main evaluation sites located in the Valle del Cauca Department of Colombia were used for the farmer/breeder selection study (Table 1). All sites were within a 2-hour drive of CIAT's main research station in Palmira, Colombia. CIAT-Palmira is the main breeding site of the Bean Programme. CIAT-Darien is a researcher-managed site consisting of 5 ha of rented fields in the Darien municipality of the Valle del Cauca. The primary use of this site is for breeding beans tolerant to low soil fertility (primarily low soil P). The farmer participatory breeding trials were carried out in the Darien municipality, within 20 km of CIAT-Darien. This region is characterized as a midaltitude mixed-farming region. Coffee, beans, maize, horticultural crops and beef/milk are important products in this municipality.

**Table 1. Characterization of evaluation sites**

	CIAT - Palmira	CIAT - Darien	Farms - Darien
Type of site	Main research station	Field station - rented farmland, researcher-managed	Farmer managed
Altitude	1000 m asl	1450 m asl	1400-1500 m asl
Soil management	fertile soils, no fertilizers applied	soils deficient in P, phosphorus applied in minimum dosage	soils deficient in P, high levels of chemical fertilizer and chicken manure applied
Irrigation	yes	no	no
Mechanization	yes (soil preparation, cultivation, fumigation)	partial (soil preparation)	partial (soil preparation)

### *Selection of farmers*

Three farmers in the Darien municipality were selected to collaborate in the breeding study. The farmers (Gerardo Valencia, Julio Cesar Azcarate and Hugo Guarin) were selected because of their experience as bean producers, their interest in experimentation and their ability to communicate easily. Also taken into consideration was the similarity among farmers in terms of cropping systems and agronomic management practices, age and ethnic group. These farmers had collaborated with CIAT in previous on-farm bean trials.

The farmers were brought to CIAT-Palmira and CIAT-Darien to show them breeding trials and to outline the breeding method that was to be used. Trial management on the research stations and farms, the objective of the experiment, and the need for neutrality by the farmers and researcher (using methods proposed by Ashby 1991) were discussed.

### *Selection of parental lines and local controls*

Ten bean lines were chosen to be used as parents and/or controls in the trials (Table 2). Two lines, Argentino and Cargabello, are landraces from different regions of Colombia. Two varieties, Calima and Nima, are bred lines released by the



Colombian national programme, ICA, about 25 years ago and are popular varieties in the midaltitude (1000-1700 m asl) regions of Colombia. Calima is the check variety used in all trials. The six remaining lines are modern varieties developed by the bean programme in CIAT. There is considerable variation among lines in growth habit, seed type and response to diseases.

**Table 2. Lines and varieties used as parents and checks in the study**

Line/variety	Growth habit <sup>2</sup>	Seed colour, size	Rust <sup>3</sup>	Angular leafspot	Anthrax-nose	Origin
Argentino	1	dark purple, small	R	I	I	Narino
And 685	1	pink/purple mottled, large	R	I/R	I/R	CIAT
And 690	1	red/pink mottled, medium	R	I/R	S	CIAT
Calima <sup>1</sup>	1	red/white mottled, large	I	I	S	ICA
Cargabello	1	red/white mottled, medium	S	S	S	Darien
DRK 5	1	dark red, large	R	S	S	CIAT
DRK 16	2	dark red, medium	I	I	R	CIAT
DRK 18	1	dark red, large	R	R	S	CIAT
Nima	1	red/white mottled, large	R	I	S	ICA
SUG 5	1	cream/red striped, large	I	R	R	CIAT

<sup>1</sup> Check variety grown by farmers.

<sup>2</sup> 1 = determinate and 2 = indeterminate bush growth habit.

<sup>3</sup> R = resistant, I = intermediate, S = susceptible.

#### **Selection methodology used by farmers and CIAT breeders**

The lines were crossed in different combinations and 18 F<sub>2</sub> populations were selected for the breeding study. A simple selection procedure was developed for advancement of the populations to F<sub>6</sub> lines (Table 3). Both the farmers and CIAT breeders used the same selection method to advance the generations.

The 18 F<sub>2</sub> populations and 10 parental and check lines were planted in all five selection sites. Approximately 200 F<sub>2</sub> seeds per cross per site were sown. Each farmer used his own design in planting the populations. The parents and controls were

grown in randomized complete block designs with three replicates in 12.8 m plots. Each farmer made a map of his trial with the identification of the plots. The final  $F_6$  selections were united into a single trial which was planted across all five sites in a randomized complete block design with three replicates. The farmers were asked to evaluate all the lines and to rank the 10 overall best.

Each farmer carried out the breeding procedure using his own selection criteria. The time of selection and the number of plants selected was the decision of the farmer, but to establish a reasonable number of entries in each trial, the breeder suggested to the farmer the number of lines to select each cycle. The purpose of this was to adjust the trial to the normal dimensions of the farmer's field and to force the farmers to use selection pressure.

**Table 3. Selection methodology used by farmers and breeders**

Generation	Method	Selections/site
$F_2$	18 populations sown in each selection site, single pod decent at harvest	5 best populations selected
$F_3$	Individual plant selections made at harvest	20-30 individual plant selections/cross
$F_4$	Progeny rows, best rows bulked individually	5 lines/cross
$F_5$	Yield trial of lines, each site selections maintained separate	6 best lines
$F_6$	18 lines yield tested across all sites	farmer ranking of 10 best lines overall

The farmers evaluated each generation twice in an open-interview format. This strategy captures and registers the spontaneous reactions of the farmers to the different bean genotypes. The first evaluation was made when the beans were still vegetative, just forming pods, and the second was done at harvest when the pods were dry. These evaluations permit the development of a population profile. By using the frequency and percentage of each evaluation criterion of the farmer it was possible to identify the most preferred populations and the most preferred traits. During the growing season, data were recorded on plant growth habit, plant vigour, disease incidence, pod cleanliness, pod number, pod length, yield, seed colour, seed size and seed form.

## Results and discussion

### $F_6$ yield trial across sites

Yields among groups of selections tested across all sites were not significantly different. The highest overall yields were obtained at the CIAT-Palmira site and the lowest were at CIAT-Darien. These differences are mainly attributable to differences in soil fertility (Table 4). At CIAT-Palmira, the highest-yielding group of selections were those originally selected at CIAT-Palmira, while the lowest-yielding group corresponded to selections made at CIAT-Darien. These results indicate that lines selected for high yields under low soil fertility may not be the highest yielding under

high fertility. On two farms, no differences were detected for yield among groups of selections.

The three best-yielding lines in CIAT-Palmira were the lines originally selected in CIAT-Palmira (Table 5), but two lines selected by farmers ranked among the top five in this site. Similarly, the four top-yielding lines in CIAT-Darien were lines originally selected in Darien, and one line was selected by Farmer Gerardo. On-farm, two out of the five best-yielding lines were from CIAT-Darien, two from CIAT-Palmira and one by Farmer Hugo. These results indicate that selections made by CIAT breeders in CIAT-Palmira and CIAT-Darien had greater overall yield potential than the lines selected by the farmers.

**Table 4. Mean of advanced lines across all sites**

TM Lines	Sites of yield trials					Mean
	CIAT-Pal	CIAT-Dar	Farm-G	Farm-H	Farm-J	
CIAT - Palmira	2215 a	792 a	820 a	1135 a	1431 a	1183
CIAT - Darien	1854 b	371 cd	518 b	1114 a	1552 a	1173
Farm - Gerardo	1964 ab	582 b	480 b	1313 a	1430 a	1154
Farm - Hugo	2049 ab	269 d	821 a	1295 a	1535 a	1194
Farm - Julio	2063 ab	456 bc	752 a	1198 a	1469 a	1188
Mean	2025	533	674	1172	1487	

Means followed by the same letter within the same column are not significantly different at  $P = 0.05$  level.

**Table 5. Five best-yielding lines/site.**

CIAT-Palmira	CIAT-Darien	Farms
TM-3-C3	TM-14-D1	TM-5-D3
TM-1-C9	TM-5-D3	TM-3-C5
TM-11-C10	TM-13-D2	TM-8-H4
TM-3-J1	TM-14-D2	TM-1-C9
TM-1-C7	TM-27-G2	TM-5-D2

Line codes with C indicate that the selection was made by breeders at CIAT-Palmira, D at CIAT-Darien, J by farmer Julio Cesar Azcárate, G by Gerardo Valencia, and H by Hugo Guarín.

No significant correlation coefficients were found for yield among the three main selection sites of CIAT-Palmira, CIAT-Darien, and Farms. Nor were yields among the three farms correlated (Table 6). These results show that genotype  $\times$  environment interactions can be as great among farms within a similar agroecology as between farms and experimental stations in different agroecologies.

#### **Selection criteria of farmers**

Farmer evaluation of populations and lines throughout the breeding cycle showed that seed colour (associated with market preferences) was the most important criterion, followed by seed size (large seeds) and pod number (yield) (Table 7). Foliar diseases, particularly angular leaf spot, ranked fourth.

**Table 6. Correlation coefficients for yield of F<sub>6</sub> lines across selection sites**

Among sites		
	<i>CIAT-Darien</i>	<i>All farms</i>
CIAT-Palmira	-0.35	0.27
CIAT-Darien	0	0.07
Among farms		
	<i>Farm Hugo</i>	<i>Farm Gerardo</i>
Farm-Julio	0.24	0.16
Farm-Hugo	0	0.24

**Table 7. Farmer evaluation criteria during F<sub>2</sub>, F<sub>3</sub>, F<sub>4</sub>, F<sub>5</sub> and F<sub>6</sub> selections**

Farmer criteria	Frequency mentioned <sup>1</sup>	
	N	%
Seed colour (associated with market)	1066	98
Seed size (45 g/100 seeds)	1043	96
Number pods (yield)	1034	95
Foliar disease (angular leaf spot)	1017	93
Plant size (tall ± 60 cm, erect)	897	83
Pod size (Calima)	830	77
Seed shape	89	8
Lodging	42	4
Uniform maturity	27	2

<sup>1</sup> Percentage calculated based on 1083 observations (3 farmers x 5 seasons x 72 lines).

**Table 8. Farmer classification of 10 best lines**

Line	Parents	Color	Farmer			Total points	Global ranking*	Yield (kg/ha)
			A	B	C			
TM-27-G2	DRK 5 x Argentina	Red	3	2	1	6	1	1144
Calima	Local variety	Red mottled	2	3	2	7	2	1014
Nima	Local variety	Red mottled	1	4	3	8	3	1042
TM-20-G4	AND 658 x SUG 5	Red mottled	7	1	5	13	4	1004
TM-10-C3	AND 658 x Argentino	Red	5	6	4	15	5	1040
TM-1-C7	DRK 16 x DRK 18	Red	4	7	8	19	6	1125
TM-3-J1- J1	DRK 16 x NIMA	Red mottled	7	4	8	19	7	1163
TM-8-H1	DRK 18 x NIMA	Red mottled	6	8	6	20	8	1089
TM-8-H4	DRK 18 x NIMA	Red mottled	7	8	7	22	9	1345
TM-3-C5	DRK 16 x NIMA	Red	7	8	8	23	10	1347

\* = highest ranking, 10 = lowest ranking.

Among the final 18 lines, the farmers ranked each and chose the 10 best (Table 8). Some lines received equal ranking with others by the same farmer. Line TM-27-G2, a cross between a local landrace and a CIAT modern variety, was ranked highest overall. This line has large red seeds. The second and third lines were Calima and Nima, the local control varieties. Lines with a low ranking of 9 and 10 by the farmers had the highest yields among all the top selections, but their seed colour and size were not considered to be of the highest quality. In ranking the lines, the farmers were willing to sacrifice yield over small quality differences. Only two lines were selected from crosses between modern varieties; the rest came from crosses of modern varieties with local materials. This shows that inclusion of local varieties in a breeding programme is necessary to recover quality traits appreciated by farmers.

### Conclusion

Farmers participating in this study were able to follow the breeding methodology recommended by the researchers and successfully developed advanced lines from early segregating populations over a 3-year period. Differences were found between breeder-selected and farmer-selected lines. The breeders concentrated more on yield and stress tolerance while farmers were concerned with quality traits related to local markets. The farmer-selected lines tended to have more attractive seed colours and patterns and medium to large seed size. The breeders permitted lines to be developed whose seed characteristics were not as well appreciated by the farmers. Farmers also made trade-offs between commercial quality and yield in their selections, which demonstrates the great importance of quality characteristics in the farmers' ideotype of an improved variety.

In Colombia, 70% of the bean market is dominated by Calima (red/white mottled) and Radical (solid red) grain types. The line that was ranked number one overall, TM-27-G2, had an attractive large, red and round seed. The market price of this seed type was 30% higher than that of the red/white mottled local types. The price differential of TM-27-G2 offset its lower yield compared with other higher yielding lines that were developed. Therefore, unlike the breeders who concentrated on yield and stress resistance, the farmers' main selection criterion was related to market factors, especially seed colour. Afterwards, other traits were considered. Small changes in the intensity of seed colour would reduce a bean line's chance of being accepted.

Lines developed at CIAT-Palmira were readily acceptable to the farmers. Indeed, among the top 10 ranked lines, three were developed at CIAT's main research station. All remaining lines were either local well-known varieties, or farmer-developed lines. No lines from CIAT-Darien made the top ranking, although several had high yields on farms. Selection for greater low soil fertility at CIAT-Darien did not result in lines with highly attractive seed colours. Further cycles of breeding are needed to incorporate attractive seed types into more stress-resistant lines.

The  $G \times E$  interaction among farms for yield was just as great as  $G \times E$  interaction between research stations and farms. There is no guarantee that one farmer's selection will perform well on a neighbour's farm. Lines from CIAT-Palmira, selected under high fertility, performed well on-farm under high fertility, but performed poorly in trials under low fertility.

This study showed that farmers have definite requirements for the varieties they choose, and can work together successfully with breeders, starting at a very early stage in the breeding process, to select mutually acceptable materials. The results demonstrate that high levels of disease resistance were not of top priority to farmers,

nor was yield, but that participation by farmers catalyzed the inclusion in the breeding strategy of other traits deemed important by them.

Most public breeders are aware that modern varieties should contain a basic set of traits that may not be of immediate value to farmers in a particular region or season. In this case, several of the lines bred by the farmers turned out to be susceptible to anthracnose disease, which is a seed-borne disease and can be devastating in cool, wet seasons. All bean varieties released in Colombia are required to be resistant to anthracnose. If for some reason the disease or constraint does not present itself during a selection cycle, the farmers may not realize its importance except over a lengthy period of observation, trial and error. This finding demonstrated the importance of emphasizing that participatory plant breeding involves a partnership between farmers and breeders, with each partner bringing specialized knowledge to the development of new varieties.

In bean breeding at least, the study shows that farmers are well able to develop new varieties, and can actively take part in advancing segregating populations to homozygous advanced lines. Formal plant breeding efforts can therefore strengthen indigenous breeding by farmers with specialized methods, and can complement it by including varietal traits not accessible to farmers' empirical observation over a short period of time. Our conclusion is that some selection should be conducted by the breeders prior to sending segregating populations to farmers for local selection. This will help ensure that a basic set of minimum requirements is maintained in the farmer-selected lines. As a result, both breeders and farmers are likely to achieve a mutually satisfying result with greater efficiency and more rapidly than has conventionally been the case.

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## Summary

The objective of a workshop on participatory plant breeding was to develop a strategy for alternative approaches to classical centralized plant breeding, which has concentrated primarily on high-yielding varieties in favourable agricultural environments. This implies a shift in direction in the plant breeding profession, for the breeding programmes of the Consultative Group on International Agricultural Research, and in the management and use of germplasm. This strategy would:

- link formal-sector breeding with farmer's breeding, selection and conservation of plant genetic resources
- attempt to combine the best of scientists' and farmers' knowledge in research and development in an innovative way
- seek to maximize both agrobiodiversity and productivity
- suggest strategies for the implementation of such approaches within the CGIAR and NARS.

Modern varieties, the product of institutional plant breeding, are most widely adopted in favourable environments. They are also popular where the environment can be adapted to the requirements of the crops by using external inputs such as fertilizers, irrigation and chemical control of pests and diseases. High-input agricultural practices are often not available in more marginal production areas. The constraints are economic, technical and institutional:

- **economic** because farm households lack resources and cannot afford the risk involved in compensating for the high costs of external inputs
- **technical** because plant breeding has not been very successful in adapting crops to more extreme and variable environments
- **institutional** because breeding is expensive and is usually only justified for large geographic areas sharing a common environment.

A major challenge in plant breeding is how to address the problems of resource-poor farmers in marginal environments who have often contributed important genetic diversity to the institutional system with little benefit in return.

The need to consider local specificity or genotype  $\times$  environment interaction is now accepted by most plant breeding programmes. However, there is no agreement on how to achieve this. Methods proposed range from the need for multilocational testing to various degrees of on-site selection and various levels of plant breeder and farmer involvement in the selection process. Fundamental in the process are traditional agricultural systems. There is now substantial evidence that farmers maintain and improve their landraces in a continuous process of selection. This is a system parallel and complementary to the institutional system, with its own comparative advantages. Breeding approaches have direct implications for the farming community's efforts in biodiversity management and use.

### Challenges to the institutional system

Breeders tend to take a very technological view of their discipline and are quick to move when scientific research opens up new avenues of pursuit. Many new and challenging opportunities are offered when farmers are actively involved in the breeding process. Just as biotechnological techniques have been incorporated into plant breeding, participatory techniques require serious consideration as a means of widening the scope of plant breeding and increasing the number of farmers



benefiting from the work. The CGIAR could make some major contributions in this area, in addition to providing breeding materials, including:

#### ***Methodology development***

- for participatory breeding
- for on-farm breeding
- for combining breeding for productivity with options to maintain genetic diversity
- for change and local adaptation
- for diagnosis of local systems
- for cooperation between different partners
- for linking national seed systems with decentralized local seed systems.

#### ***Training***

- for CGIAR and national breeders
- for NGOs
- for farmers and community organizations.

This would entail developing appropriate training materials in all aspects of the total seed system, including breeding and selection, seed multiplication, storage and handling at the local/community level.

#### ***Partnerships***

- demand-driven partnerships with organizations that represent farmers, including NGOs
- partnerships with universities (both in the southern and northern hemispheres) to widen the scope of training in plant breeding.

There obviously needs to be balance in the economies of scale. Institutional research alone cannot and should not address specific problems of small isolated groups of farmers. This problem needs to be considered in linking institutional plant breeding and seed production with local seed systems in meaningful cooperation and division of labour, including NARS and NGOs in the process.

## Participants

**Conny Almekinders**  
 c/o Dept. of Agronomy  
 Agricultural University of Wageningen  
 Haarweg 333  
 6709 RZ Wageningen  
 The Netherlands  
 Fax: 31-8370-84575  
 Email: conny.almekinders  
 @akker.agro.wau.nl

**Jacqueline Ashby**  
 IFPRI  
 1200 17th Street NW  
 Washington DC 20036-30006  
 USA  
 Fax: 01-202-467-4439  
 Email: J.Ashby@CGNET.COM

**Trygve Berg**  
 NORAGRIC  
 PO Box 5002  
 N-1432  
 As  
 Norway  
 Fax: 47-64-940760  
 Email: Nortb@noragric.nlh.no

**Salvatore Ceccarelli**  
 ICARDA  
 PO Box 5466  
 Aleppo  
 Syria  
 Fax: 963-21-213490 or 225105

**David Cooper**  
 FAO  
 Via delle Terme di Caracalla  
 00100 Rome  
 Italy  
 Fax: 39-6-5225-5533  
 Email: David.Cooper@FAO.ORG

**Walter de Boef**  
 CPRO-DLO-CGN  
 Droevendaalsesteeg 1  
 Postbus 16  
 6700 AA Wageningen  
 The Netherlands  
 Fax: 31-8370-18094  
 Email: w.deboef@cpro.agro.nl

**Pablo Eyzaguirre**  
 IPGRI  
 Via delle Sette Chiese 142  
 00145 Rome  
 Italy  
 Fax: 39-6-575-0309  
 Email: P.Eyzaguirre@CGNET.COM

**Hubertus Franzen**  
 ATSAF  
 Eller Str. 50  
 53119 Bonn  
 Germany  
 Fax: 49-228-9846-99

**Esbern Friis-Hansen**  
 Centre for Development Research  
 Gammel Kongevej 5  
 DK-1610 Copenhagen V  
 Denmark  
 Fax: 45-33-25-81-10  
 Email: esbern.friis.hansen@cdr.dk

**Stefania Grando**  
 ICARDA  
 PO Box 5466  
 Aleppo  
 Syria  
 Fax: 963-21-213490 or 225105

**Jaap Hardon**  
 CPRO-DLO-CGN  
 Droevendaalsesteeg 1, Postbus 16  
 6700 AA Wageningen  
 The Netherlands  
 Fax: 31-8370-18094  
 Email: J.hardon@cpro.agro.nl

**Miguel Holle**  
 CIP  
 Apdo. 1558  
 Lima 100  
 Peru  
 Fax: 51-14-351570  
 Email: M.Holle@CGNET.COM

**Masa Iwanaga**  
 IPGRI  
 Via delle Sette Chiese 142  
 00145 Rome  
 Italy  
 Fax:39-6-575-0309  
 Email: M.Iwanaga@CGNET.COM

**Julia Kornegay**  
 CIAT  
 Apdo. Aereo 6713  
 Cali  
 Colombia  
 Fax:57-2-445-0273  
 Email: J.Kornegay@CGNET.COM

**Surapong Sarkarung**  
 IRRRI Bangkok Office  
 PO Box 9 - 159 BKN  
 Bangkhen, Bangkok 10900  
 Thailand  
 Fax:66-2-561-4894  
 Email: S.Sarkarung@CGNET.COM

**Louise Sperling**  
 E 11/2 Vasant Vihar  
 New Delhi 110 057  
 India  
 Fax:91-11-4622707  
 Email: postmast.idrc@ernet.in

**Peter Trutmann**  
 Swiss Centre for International Agriculture  
 (ZIL)  
 ETH-Zentrum  
 8092 Zurich  
 Switzerland  
 Fax:41-1-632-1086  
 Email: Trutmann@iaw.agr.ethz.ch

**Theo J.L. van Hintum**  
 CPRO-DLO-CGN  
 Droevendaalsesteeg 1  
 Postbus 16  
 6700 AA Wageningen  
 The Netherlands  
 Fax:31-8370-18094  
 Email: th.j.l.van.hintum@cpro.agro.nl

**Ronnie Vernooy**  
 IDRC  
 250 Albert Street  
 PO Box 8500  
 Ottawa ON K1G 3H9  
 Canada  
 Fax:01-613-567-7749  
 Email: Rvernooy@idrc.ca  
 or R.Vernooy@CGNET.COM

**Joachim Voss**  
 IDRC  
 250 Albert Street  
 PO Box 8500  
 Ottawa ON K1G 3H9  
 Canada  
 Fax:01-613-567-7749  
 Email: Jvoss@idrc.ca  
 or J.Voss@CGNET.COM

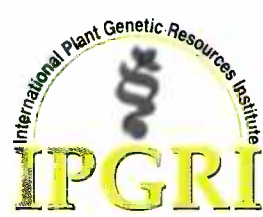
**Joachim A. Wadsack**  
 GTZ  
 Dag-Hammarskjold-Weg 1-5  
 Postfach 51 80  
 65726 Eschborn  
 Germany  
 Fax:61-96-797173

**Eva Weltzien Rattunde**  
 ICRISAT  
 Patancheru 502 324  
 Andhra Pradesh  
 India  
 Fax:91-40-241239  
 Email: E.Weltzien@CGNET.COM

**John R. Witcombe**  
 Centre for Arid Zone Studies  
 University of Wales  
 Bangor  
 Gwynedd LLS7 2UW  
 United Kingdom  
 Fax:44-12148-371533  
 Email: J.R.Witcombe@bangor.ac.uk

**Maria J.O. Zimmermann**  
 Av. 85, no. 300 Ap. 501A  
 Setor Marista  
 74166-900 Goiania-Go  
 Brazil  
 Fax:55-62-212-2960  
 Email: M.Zimmermann@  
 CGNET.COM or CGI 154





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