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Farmer participatory crop improvement
Parts I, II III

Varietal selection and breeding methods
And their impact on biodiversity

Participatory varietal selection,
A case study in India

Participatory plant breeding,
A case study for rice in Nepal

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FARMER PARTICIPATORY CROP IMPROVEMENT. I: VARIETAL SELECTION AND BREEDING METHODS AND THEIR IMPACT ON BIODIVERSITY

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SUMMARY

Farmer participatory approaches for the identification or breeding of improved crop cultivars can be usefully categorised into Participatory Varietal Selection (PVS) and Participatory Plant Breeding (PPB). Various PVS and PPB methods are reviewed. PVS is a more rapid and cost-effective way of identifying farmer-preferred cultivars if a suitable choice of cultivars exists. If this is impossible, then the more resource-consuming PPB is required. PPB can use as parents cultivars that were identified in successful PVS programmes. Compared to conventional plant breeding, PPB is more likely to produce farmer-acceptable products, particularly for marginal environments. The impact of farmer participatory research on biodiversity is considered: the long-term effect of PVS is to increase biodiversity, but where indigenous variability is high it can also reduce it. PPB has a greater effect on increasing biodiversity although its impact may be limited to smaller areas. PPB can be a dynamic form of *in situ* genetic conservation.

INTRODUCTION

In most developing countries, few farmers in marginal areas have adopted improved cultivars, often because they have not been exposed to acceptable alternatives to their landraces. Alternative approaches for identifying cultivars that are acceptable to resource-poor farmers have been suggested and tried by a number of authors. Chambers (1989) reviewed the few examples of providing farmers with ‘a basket of choices’ of varied genetic material. Maurya *et al.* (1988) tested advanced lines of rice with villagers in Uttar Pradesh, India and successfully identified superior material that was preferred by farmers. In Rwanda, farmers first selected a wide range of bean cultivars from on-station trials, and then selected 21 of these from trials they grew in their fields (Sperling *et al.*, 1993). In Namibia, Lechner (W. R. Lechner, Mahanene Research Station, Oshakati, Namibia, 1991, pers. comm.) used farmer evaluation of pearl millet in on-station trials, and farmers selected a cultivar that was subsequently released and became popular. In collaborative research between ICRISAT and Rajasthan Agricultural University, farmer participatory research was used to identify pearl millet cultivars suitable for Rajasthan (Weltzien *et al.*, 1996). All of these are examples of participatory varietal selection, since farmers were evaluating near-finished or finished products. In contrast, participatory plant breeding is the selection by farmers of genotypes from segregating generations. In this paper, methods of PVS and PPB are outlined and their impact on biodiversity are reviewed. In the second paper in this series, a PVS programme in India is described in which farmers preferred rice and chickpea cultivars that were released but had not been recommended for the research area. In the third paper, a PPB programme is described, of which there are few examples in the literature, where Nepalese farmers selected chilling-tolerant rice cultivars from F_5 bulk families.

PARTICIPATORY VARIETAL SELECTION

In developing countries, most cultivars grown by farmers are old and only a few of the released cultivars are widely grown. For example, for rice in India the average age of cultivars, for which there is a demand for breeder seed, is 11 years. The average age of cultivars in certified seed production ranges from 12 to 17 years in the states of Gujarat, Madhya Pradesh and Rajasthan (Virk *et al*., 1996). Many crops have cultivars that are, on average, older than those in rice. In 1993, the average age of the cultivars for which seed producers demanded breeder seed was 13 years in chickpea, 15 years in groundnut, 16 years in sorghum and 17 years in maize (Virk *et al*., 1996). Only a few cultivars are widely grown. The two most popular cultivars in the whole of India, IR36 (released in 1981) and Rasi (released in 1977), occupy a large proportion of the area under rice cultivation. This is despite the wide choice of cultivars in rice; there have been a total of 525 releases in India up to 1993, and of these, 88 were released over the period 1988 to 1993.

One of the main reasons for low cultivar replacement rates is that farmers have inadequate exposure to new cultivars. If adoption rates are to be improved, farmers need to try a wide range of novel cultivars in their fields in PVS programmes. The cultivars should be carefully-selected, already-released cultivars, not only from the target region, but from other regions or countries. For example, in India, cultivars of the major crops can be found that have only been released and widely grown in a single state. If pre-release cultivars and advanced lines are also included, the basket of choices is enlarged and more recent outputs from plant breeding research are exploited.

A successful participatory varietal selection programme has four phases:

1. a means of identifying farmers' needs in a cultivar,
2. a search for suitable material to test with farmers,
3. experimentation on its acceptability in farmers' fields, and
4. wider dissemination of farmer-preferred cultivars.

Identification of farmers' requirements. Farmers requirements have first to be identified, to give them more appropriate genetic material to test. This can be done by using several methods, either separately or in combination. They include participatory rural appraisal (PRA), the examination of farmers' crops around harvest time, and the pre-selection of varieties by farmers from trials of many entries grown on a research station or on a farm. If resources permit, in areas where there is a diversity of landraces in farmers' fields, the local germplasm can be collected and grown in a trial, on station or on farm, with recommended cultivars as a control. This provides information that a PRA cannot reveal because:

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

Search for suitable released material and advanced lines. A search is made for cultivars that most closely meet the important identified characteristics, particularly those relating to maturity, plant height, agro-ecological niche, and grain quality. Cultivars are selected from new and old releases at any level (national, zonal), and from pre-release material at an advanced stage of testing.

It is assumed that existing systems of centralised breeding have produced cultivars adapted to low-yielding, marginal environments that will be preferred by farmers over those they are currently growing. Results from India, described in a second paper, have shown that cultivars suitable for resource-poor farmers exist amongst the released cultivars, but farmers have had no opportunity to try them in their fields. However, most result from partially decentralised breeding, since they have only been released for specific regions. There is also indirect evidence from trials such as the scientist-managed, pearl millet multilocational trials analysed by Witcombe (1989). Although the breeders' practice of selecting on mean performance across locations sometimes did not identify the best cultivar for low-yielding environments, it always selected cultivars that yielded more than average in those environments. In effect, there was only a weak demonstration of specific adaptation to marginal environments. Analyses for several cereal and legume crops tested in multilocational trials in India confirmed this result (Virk *et al.*, 1996).

However, it cannot be assumed that centralised breeding is an efficient way of producing cultivars adapted to marginal environments. Although the multilocational trials studied by Witcombe (1989) and Virk *et al.* (1996) provided no evidence that selection for broad adaptation was a poor strategy when breeding for marginal environments, the range of genotypes tested and the number of lower-yielding environments were limited. Specific adaptation to high- and low-yielding environments should be found in trials of highly diverse material in very diverse environments.

The range of genetic material in multilocational trials is limited by breeders, who do not enter genotypes that have extreme environmental adaptation because they assume that they will fail. Extremely early- and late-maturing entries, that are likely to have highly specific adaptation, rarely perform well in multilocational trials because there is strong stabilising selection for flowering time (Virk *et al.*, 1996). The range of low-yielding environments in the multilocational trials is limited, either because in well-managed trials low-yielding environments occur infrequently, or because scientists deliberately exclude the data from them (Virk *et al.*, 1996). In contrast, decentralised breeding encourages the use of specifically adapted material and very low-yielding environments.

Experimentation on farmers' fields. Various testing and evaluation systems can be employed and they vary greatly with the extent of farmer participation (Table 1). Many 'on farm trials' are conducted by researchers on farmers' fields with little or no involvement of farmers. At the other extreme, farmers can be given a range of cultivars to grow without intervention from outsiders such as scientists and development workers. Outsider inputs in evaluating the material are also minimised by asking farmers, in informal discussions, which of the cultivars they prefer, or by merely waiting for farmers to demand seed. On the basis of such discussions or demand, decisions can be made on what cultivars to multiply and supply to farmers. Informal research with minimal outsider inputs is highly cost effective, and is recommended to organisations with limited resources that wish to provide seed of farmer-acceptable, improved cultivars.

Other methods lie between the extremes of maximum and minimum inputs from outsiders. Participation of scientists increases when farmers are asked to grow more than one introduced cultivar, since it necessitates an experimental design in which farmers, if unaided, can easily make planting errors. The contribution of scientists will also vary according to the amount and type of data collected. For example, quantitative estimation of yield using field-sampling techniques in replicated experiments requires considerable inputs from scientists. However, most researchers using participatory methods have asked each farmer to grow only one introduction side by side with their local cultivar without change in management, and have collected data on the farmers' perceptions of the cultivars.

Table 1. Methods of varietal selection with varying degrees of farmer participation

Methods in increasing order of farmer participation	Evaluation includes	Example institutions
1. Researcher-managed and evaluated on-station trials (Farmers may visit station to identify farmer-acceptable material)	Yield data (Farmer evaluation)	Research
2. Researcher-managed on-farm trials. Replicated design. (Farmers may be involved in evaluation)	Yield data (Farmer evaluation)	Research
3. Farmer-managed, replicated design, on-farm trials, with scientists' supervision. Several entries per farmer	Yield data Farmers' perceptions	Research
4. Farmer-managed, unreplicated design, on-farm trials. One cultivar per farmer. Replication across farmers	Yield data Farmers' perceptions	Research Extension NGO
5. Trials as in 4	Farmers' perceptions only	NGO Extension Research
6. Farmer-managed trials. No formal design either within a farm or across farmers	Informal, anecdotal	NGO Extension Research

[1]NGO = Non Governmental Organisation

In Nepal, at Lumle Agricultural Research Centre, one of the simplest methods of PVS (method 5 in Table 1) has been used (Joshi *et al*. 1996). An Informal Research and Development (IRD) programme was started in 1990 to help overcome the problems caused by a weak extension network that generally gave farmers poor access to new crop cultivars. Farmers were offered small quantities of seed of crop varieties (released, pre-release and advanced lines) to grow under their own conditions without intervention from researchers. For example, seeds of five pre-released and one released variety of spring-sown rice were distributed to 1 802 farmers in 20 villages of western Nepal in 1992 (Joshi *et al*. 1996). In this region 90% of the rice area was covered by a single variety, CH 45. In 1993, a survey of a sub-sample of 192 farming households showed that one third of them were growing an introduced cultivar for the second time, proving the effectiveness of this simple approach. In a second paper, particular methods of PVS, and the results from employing them in India, are described

Wider dissemination of farmer-preferred cultivars. PVS is usually conducted with farmers situated in a small geographical area. Nonetheless, the cultivars that are selected will have a recommendation domain larger than the area of research which is always a small part of a larger ago-ecological zone. The larger recommendation domain allows the economies of scale of the more formal seed sector to be exploited, and permits the dissemination to extend beyond farmer-to-farmer spread or community-based seed production. It is hence highly desirable, in any development project where seed supply of improved cultivars is an important component, to have linkages with public or private sector seed producers that can produce and supply the seed of identified cultivars.

An important factor for wider dissemination 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. Hence, if the cultivars preferred by farmers are already released, the large-scale provision of seed will be easier than for advanced lines, and this is an important justification for the inclusion of released cultivars in a PVS programme.

Unfortunately, if a preferred cultivar is not released, then in most developing countries a time-consuming release procedure has to be followed that requires data that a participatory approach does not normally generate. 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.

PARTICIPATORY PLANT BREEDING

Participatory plant breeding, in which farmers select from segregating material, is a logical extension of participatory varietal selection. However, the first choice should be PVS since PPB is more resource-consuming. PPB needs to be used when the possibilities of PVS have been exhausted, or when the search process fails to identify any suitable cultivars for testing. PPB can exploit the results of PVS by using identified cultivars as parents of crosses.

Participatory plant breeding methods are poorly documented, and there are few examples in the literature. In rice, Thakur (1995) screened F_2 material in farmers' fields, but subsequent generations were grown by researchers. In Ethiopia, landraces of sorghum have been enhanced by mass selection by farmers in collaboration with scientists from the Plant Genetic Resources Centre (Worede and Mekbib, 1993). In the Philippines, farmers are involved in PPB by selecting from progeny of crosses between traditional and improved cultivars of rice. Unfortunately, the methods used are not described in detail (Salazar, 1992). Joshi and Witcombe, in collaboration with Dr S. N. Goyal of Gujarat Agricultural University, have started PPB in maize with the fourth random mating generation of a composite created from six, farmer-accepted, open-pollinated cultivars. In a third paper, a well-documented example of PPB in rice is described.

There are many participatory plant breeding methods for predominantly self-pollinating crops, that have different degrees of farmer participation (Table 2). Method 5 of Table 2 employs the greatest farmer participation and the greatest number of generations with farmers. Although it requires little breeder input during the selection stages, an essential role is played by plant breeders in the early and late generations and PPB is not intended to make them redundant. In all methods plant breeders are the facilitators of the research, since they have the essential understanding of the underlying genetics of parental selection and subsequent genetic segregation. Nonetheless, following from successful PPB, experienced farmers may wish to select parents and carry out breeding programmes of their own (method 6), although if they are to be performed efficiently continuing assistance from breeders is required.

Plant breeders also have an essential role in feeding the results of PPB into the official release and seed production system. Cultivar release is still a very desirable end product. It makes the results of the participatory research more widely available and the benefits are gained of the large-scale seed multiplication of successful released cultivars. Products from PPB can be entered into the formal trials and release system using a scientist-led breeding scheme run in 'parallel' to that of the farmers. In the parallel breeding scheme, the products that are proving popular with farmers are entered into formal trials, and made sufficiently pure for seed certification purposes (Table 3). The parallel scheme can start after any number of generations of farmer selection; in the example in Table 3, it commences at the F_5 stage by sampling individual plants to begin selection for uniformity in an F_6 progeny row nursery.

Table 2. Methods of plant breeding in predominantly self-pollinating crops with varying degrees of farmer participation

Methods in increasing order of farmer participation	Site specificity	Example
1. All generations grown by plant breeders on station. Farmers involved at pre-release stage or even after release	Wide adaptation targeted. Early generations may all be in single location followed by multilocational testing	CGIAR[1] NARS[1] DC[1] programmes
2. Early generation (F_2) in farmers' fields. All other generations and procedures with plant breeder on station	Single location testing site for F_2	Thakur (1995)
3. 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 test best advanced lines across locations	Recommended by Galt (1989)
4. From F_3 or F_4 onwards farmers and plant breeders collaborate to select and identify the best material on farm (and also on station). Farmers select. Plant breeders facilitate the process. Release proposal prepared by plant breeder	Possible to run selection procedures on early generations in more than one location	Sthapit *et al.* (1996)
5. Breeder gives F_3 or F_4 material to farmers. All selection left to farmers. At F_7 to F_8 or later, breeders monitor diversity in farmers' fields and identify best material to enter in conventional trials	Extremely easy to run selection schemes in many locations	Salazar (1992)
6. Trained expert farmers make crosses and do all selection with or without assistance from breeders. Breeders can place best material in conventional trials	Specific to farmers, requirements	None yet-- second generation technology

[1]CGIAR = Consultative Group on International Agricultural Research, NARS = National Agriculture Research Systems, DC = Developed Country

Comparison of participatory plant breeding with conventional methods. The most important differences between PPB and Conventional Breeding (CB), considered mainly from the viewpoint of self-pollinated crops, are summarised in Table 4.

In CB, breeders can grow hundreds, or even thousands, of F_4 or F_5 lines in a nursery if no or only a few replicates are employed. In PPB, an F_4 or F_5 line is grown by only one or very few farmers, and the number of farmers is much more restricted than the number of lines in a nursery. Even if several lines are given to each farmer, with an increased possibility of planting errors and an increased risk to farmers, the numbers are still severely limited. PPB makes a virtue of this limitation since success is more likely than in CB because:

- at least one parent of any cross is well-adapted to the local environment,
- genotype x location interactions are greatly reduced, because selection is always in the target environment,
- the impact of genotype x year interactions is probably reduced since the local parental material is already adapted to the year to year variation that is likely to be encountered, and
- because few crosses are made large F_2 and F_3 populations can be grown to increase the possibility of identifying transgressive segregants that give rise to desirable F_4 to F_5 progeny.

Table 3. A participatory plant breeding scheme in self-pollinating crops

Year	Generatio	Farmers' role	Breeder's role
1	P_1 x P_2	Can assist in choosing parental material	Make crosses
1	F_1		Grows F_1
2	F_2	Can grow on farm	Select from large plot with spaced plants
3	F_3 rows	Visit nursery for joint evaluation	Joint evaluation and evaluate in disease nursery
4	F_4	Evaluate each other's material and select within their own bulk	Survey farmers' fields and evaluate in disease nursery
5	F_5	Continue best bulks with single-plant selection. Best material given to other farmers	Sample 100-400 single plants from most widely accepted bulk
6	F_6	As above	Grow Progeny Row Nursery (PRN) to select 'true to type' rows
7	F_7	As above	Submit entry in formal trials with seed from PRN. Use farmer-saved seed for farmer trials, and multiply breeder seed from PRN seed
8	F_8	As above	Use breeder seed for formal trials system
9	F_9	As above	Submit release proposal based on formal trial data and farmer data

All these advantages apply to decentralised breeding regardless of whether increased farmer participation is employed. The role of farmer participation is to reduce demands on research station land, and eliminate the need for breeders to do single-plant selection in many of the generations. Most importantly, it ensures that all farmer-relevant traits, including post-harvest ones, are evaluated. PPB is particularly efficient when post-harvest quality traits are involved that are difficult to assess in the laboratory. Farmers are able to select for such traits because farmers and their families are the ultimate judges of quality in any cultivar.

Even though PPB is not targeted at broad adaptation (Table 4) there is no reason to suppose that the products of PPB will have very narrow domains. In CB, many breeding programmes are based at only one location, and multilocational trials are used to test and select the finished products. In PPB, early-generation, multilocational testing can be employed using farmer participation to ensure that cultivar domains are not too narrow (see the third paper in this series).

Unlike CB, PPB requires the co-operation of farmers and Sthapit *et al.*, (1996) give an example of enthusiastic co-operation by farmers in PPB. Until more PPB programmes are done in many countries it will not be known if this is the exception or the rule. However, from the degree of co-operation found in many PVS programmes it is unlikely that co-operation from farmers will prove to be a constraint in the adoption of PPB. Of course, socio-economic factors and logistical considerations need to be carefully considered when selecting the participating villages and farmers, but this does not differ from the needs of CB where the correct selection of testing sites is also crucial.

Methods of PPB for cross-pollinated crops. For predominantly open-pollinating crops plant breeders can create broad-based populations (composites) and give the third or fourth random mating generation to farmers for mass selection, as was done in the maize breeding programme in Gujarat cited above.

Large plots of the composite have to be grown by farmer, or the farmer has to isolate small plots by time of flowering or distance from other plots of the same crop. It may be better to avoid entirely the complications of asking farmers to employ these difficult planting strategies. Instead, on-station selection can be employed in the early generations with farmers' participation limited to determining the acceptability of the material. When large amounts of seed become available in later generations, farmers that already like the material can carry out mass selection on large populations.

Progeny testing is more efficient than mass selection and can be used in PPB even though it demands much greater inputs from farmers and plant breeders. However, carefully-selected farmers need to be trained to grow and evaluate the progeny trials in the main season, but the clear genetic differences between the progeny in a trial may facilitate their active participation.

In the simplest method of progeny testing, farmers harvest seed from selected plants in the main season. The seed from each individual plant is a half-sib family produced from natural outcrossing. Half-sib family trials are grown in the next main season by farmers to select the best families for subsequent recombination by breeders in the off-season using remnant seed. More resource-consuming progeny testing methods, that use full-sib or S_1 families, require greater inputs from breeders to hand pollinate plants to produce the families. Greater inputs are not required from farmers. Indeed, the greater genetic differences among the families in the farmers' trials will help raise their interest and awareness of plant breeding methods, as well as producing the greater genetic advances expected from using such families.

The same generation of a composite can be selected by several geographically separated farmers and all of their selections recombined in a single population. Recombining several farmers' selections reduces the risk associated with reliance on only one farmer, reduces resource requirements, and produces more widely adapted populations. Of course, it will reduce the genetic gains that could be achieved with the best selection made by a farmer at a single site. However, the need to maintain and test each farmers' population separately requires resources that exceed those of a small-scale breeding programme.

After each selection cycle, the recombination products are open-pollinated populations that can be subjected to further selection. If they are regarded as finished products, they are placed in the formal trials system or entered into seed multiplication programmes. Assuming the application of similar resources, the number of finished products produced by PPB or CB is more limited in a cross-pollinated than in a self-pollinated crop. However, the limited number of finished open-pollinated varieties is compensated by the greater genetic variability within them that provides wider adaptation. Since PPB uses locally-adapted parental material, selects in the target environment, and takes fully into account farmers' preferences, a breeding programme based on even a single composite is a reasonably risk-averse strategy.

Table 4. A comparison of participatory and conventional plant breeding in self-pollinated crops[1]

Participatory plant breeding	Conventional breeding
Parents, crosses, and early generation population size	
Landraces and locally-adapted cultivars commonly used as parents	Elite cultivars commonly used as parents
A few carefully chosen crosses are made	Often many crosses are made
Very large early-generation populations from each cross	Small or medium-sized early-generation populations
Methods	
Farmer-unacceptable material identified early. Very suitable when quality traits are important	Farmer-unacceptable cultivars can be released. More suitable when high yield is most important criterion
Bulk pedigree breeding used since number of lines limited by number of farmers. Requires less resources but may be less efficient	Pedigree breeding often the preferred method. May give greater genetic advance than bulk pedigree breeding
Increased intra-cultivar diversity, but causes seed certification difficulties. A pure-line cultivar or more uniform mixture can be produced using little extra resources	Produces uniform pure-line cultivar. Procedures for testing release, and certification of cultivar already in place
Adaptation	
Most suitable for producing cultivars with specific adaptation to marginal environments.	Most suitable for producing cultivars with wide adaptation for non-stressed, high-input environments
Replication across locations in early generations simpler ensuring reasonably wide adaptation	More difficult to replicate early generations across locations
Genotype x location (GxL) interaction between farmers' fields and research station eliminated	GxL large because multilocational trials are conducted at higher input levels than those used by resource-poor farmers
Farmer awareness, adoption and risk	
Farmers awareness of cultivar choice raised	No participatory involvement of farmers
Early farmer-to-farmer spread of material occurs	Little and late farmer involvement. Several years can elapse between finished product and exposure to farmers
Farmer exposed to risk of poor material (but farmers are very good at managing risk and quantities are small)	Farmers exposed to risk due to genetic vulnerability caused by widely adapted cultivars being grown over large areas
Material can be given to farmers only after disease screening. Plants exposed to farmer-relevant races of pathogens	Disease screening often done on multilocational basis to breed for broad range of host-plant resistance

[1]Many of the comparisons also apply to open-pollinated crops, particularly those on Adaptation and on Farmer awareness, adoption and risk.

IMPACT OF FARMER PARTICIPATORY RESEARCH ON BIODIVERSITY

Biodiversity in crops. Biodiversity in crops is very difficult to define and a number of simplifications are made in the following discussions that mainly apply to self-pollinated crops. If PVS results in one cultivar partially replacing another then biodiversity is increased, but the extent is determined by the dissimilarity between them. If several cultivars replace an existing cultivar it is assumed that there is an increase in biodiversity. However, there could be a loss of biodiversity if the replaced cultivar was highly dissimilar not only to the new cultivars that replaced it, but to other cultivars that remain.

Agricultural biodiversity is not only a function of the total number of cultivars. An agroecosystem having large proportions of the area occupied by a few cultivars is more genetically vulnerable than one where the cultivars occupy nearly equal areas, even if in both agroecosystems the total number of cultivars is the same. Difficulties then arise between balancing the total number of cultivars in an agroecosystem against how equally they occupy the cultivated area. For example, in the case of the adoption of Kalinga III rice, that is replacing local landraces (Joshi and Witcombe, 1996), does it reduce or increase biodiversity? Assuming it does not replace any single landrace completely, it has contributed to an increase in biodiversity by increasing the number of cultivars grown, but it has also reduced biodiversity by the sole occupation of areas where previously several landraces were grown.

Biodiversity can be considered over both space and time. As one cultivar replaces another there is a temporary increase in biodiversity over time because, until the replacement is complete, there are two cultivars in farmers' fields instead of one. When PVS increases replacement rates, and thus reduces the longevity of individual cultivars, biodiversity is increased over time. This increase is useful since pathogens and pests are exposed to a particular genotype for less time and have less chance to overcome host-plant resistances.

The pattern by which this replacement takes place is important. There is greater biodiversity when the new cultivars spread from many foci rather than from a single point. An example of spread from many foci was seen in the case of new chickpea cultivars adopted in India as a result of PVS (Joshi and Witcombe, 1996). Of the 23 farmers interviewed, 5 had given seed to 19 other farmers that, on average, lived 7 km from the donor farmers. This spread from many foci will give a more complex pattern between farmers' fields and provide a useful increase in biodiversity. In Nepal, a similar pattern was seen in the adoption of rice varieties. In 20 villages, 92 households were interviewed about the dissemination of seed of introduced, spring-sown rice varieties. About 30% of the households had given seed to other farmers, and 10% of the seed exchanges were to farmers from outside of the project villages. As in the case of chickpea in India, some of the seed exchanges were with distant villages, in some cases more than 50 km away. The vulnerability of a crop to a disease lessens as field-to-field differences increase. This strategy of field-to-field variability was recommended for disease control by Priestley and Bayles (1980). Regional variation in cultivar diversity was also suggested as useful in disease control by Frey *et al.* (1977).

Participatory varietal selection. There are infinite combinations between the variability of existing crops and the new variability amongst cultivars that partially or completely replaces them (Fig. 1). Hence, when farmers in an area are exposed to new cultivars in a PVS programme the outcome may be an increase or a reduction in biodiversity in that area. Changes in biodiversity depend on the existing variability in farmers' fields, the genetic dissimilarities among the new cultivars offered to farmers, and the number they adopt. The number adopted is determined by their acceptability to farmers, and the variability in the target environment, both physical and socio-economic.

A most important variable is the range of diversity that farmers can be offered. The basket of choices is likely to be larger when there are decentralised breeding programmes rather than breeding programmes with coordinated multilocational trials designed to produce cultivars with wide adaptation. The more variability there is for quality traits, and the better the adaptation of the cultivars to the local environments, the more likely that several cultivars will be adopted. In the case of PVS in chickpea in India (Joshi and Witcombe, 1996), three cultivars are being adopted and partially replacing the local. All of these cultivars are adapted, but they differ in quality (*kabuli* versus *desi* seed type) and in maturity. Each cultivar (early *kabuli*, early *desi* and medium-maturing *desi*) is grown because it has different market prices and niches.

Great physical diversity in the environment increases the likelihood that more than one cultivar will be adopted by farmers. In the case of rice in India (Joshi and Witcombe, 1996), Kalinga III is adopted for the more drought-prone areas, whilst Sathi-34-36 is grown in fields with deeper soils. Diversity of economic use will also make it more likely that several cultivars are adopted. High-yielding cultivars with poor grain quality may be chosen because they reduce risk or give greater returns as a cash crop, whilst lower-yielding cultivars with high quality grain may be chosen for home consumption, and for special social and religious occasions.

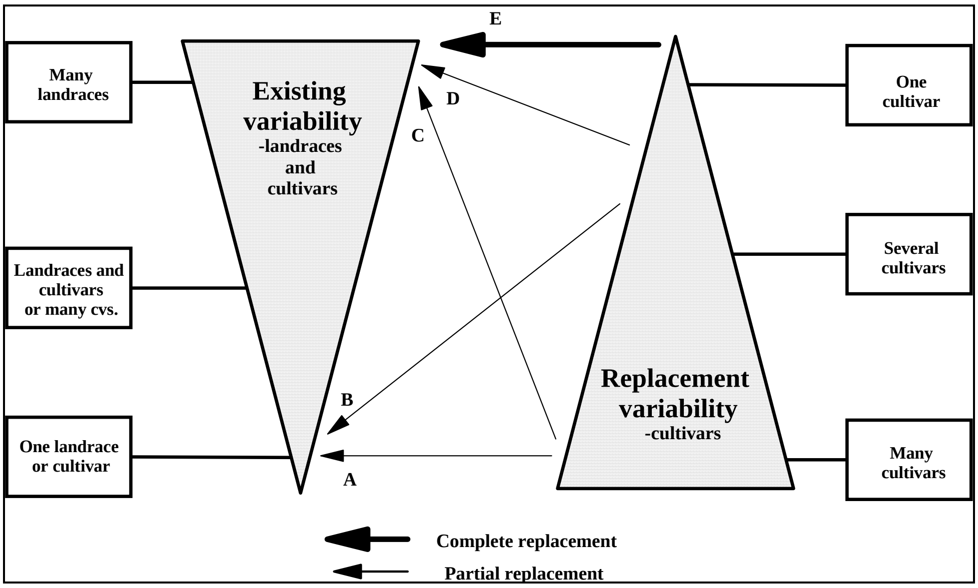

Figure 1. Examples of the infinite possibilities of replacement of existing variability with new genetic material. All examples are referred to in the text, and are given in decreasing order of beneficial impact on biodiversity: A. PPB in Nepal (Sthapit *et al.*, 1996). B. PVS in chickpea in India (Joshi and Witcombe, 1996) and PVS in rice in Nepal (this paper). C. PVS in beans in Namibia (Sperling *et al.*, 1993). D. PVS in rice in India (Joshi and Witcombe, 1996). E. Rice in the Gambia (Cromwell and Wiggins, 1993).

Nonetheless, when conditions allow several or many cultivars to be adopted, then it is more likely that great diversity already exists in farmers' fields. Hence, in areas where highly variable landraces are the main or only crop the success of PVS will reduce biodiversity. This dilemma is faced by non-governmental organisations (NGOs) that wish to conserve biodiversity and help resource-poor framers. For example, an NGO, the Save the Children Federation, in the Gambia was faced with "the dilemma of seeing just one of its introduced rice varieties almost completely replace the range of local varieties previously grown, which were no longer suitable because of declining rainfall" (Cromwell and Wiggins, 1993).

At a wider, national level, the widespread adoption of participatory methods will almost certainly increase the replacement rate of cultivars, so that the average age of cultivars grown by farmers will be reduced and biodiversity over time increased. It is also likely that adoption ceilings of improved cultivars, both in general and in particular, will increase at the cost of reduced biodiversity. PVS can overcome inefficiencies that limit the adoption of an improved cultivar to a relatively small area and reduce biodiversity at a national level. A good example is the rapid adoption of Kalinga III in western India when the cultivar was previously only released in eastern India (Joshi & Witcombe, 1996). However, in the longer term, PVS should have a beneficial effect on biodiversity. If many more farmers are exposed to many more cultivars, the number of cultivars adopted will increase and a more complex patchwork of cultivars between fields, districts and regions will be produced.

Participatory plant breeding. It is easy to predict the impact of participatory plant breeding on biodiversity, which will increase under nearly all circumstances. When compared to PVS, the increase in biodiversity will be at both the intra- and inter-varietal level. The effects of PPB will be more uneven than with PVS, because the potential increase in genetic diversity within a village is extremely large, whilst increase in diversity with PVS is limited to the varietal diversity in the basket of choices. Biodiversity is increased within villages by the adoption of material for particular niches. An example is given, in the third paper of the series, of biodiversity in rice being increased in Nepal because a farmer in a PPB programme adopted a bulk for a particular micro-niche, his poorest plot.

In predominantly self-pollinating crops, PPB employs bulk population breeding whereby farmers mass select segregating bulks such as the F_{5}. Hence PPB increases biodiversity at the intra-cultivar level overcoming the “disease of cultivar uniformity” (Lopez, 1994). The intra-cultivar variability for disease resistance genes in multiline cultivars is recommended as a strategy for reducing disease (Browning and Frey, 1981), but intra-cultivar diversity for other genes is deliberately minimised. The intra-cultivar diversity generated from PPB is more akin to a varietal mixture and such mixtures have been effective in disease control (Wolfe, 1990).

PPB is also a logical second stage to PVS, and if the appropriate breeding methods are employed then it comes closest to the ideals of genetic conservation. After PVS has successfully identified farmer-preferred cultivars (PVS cultivars) they can be crossed either with landraces or with high-yielding, released cultivars. The landrace is chosen as a parent to give genes for adaptation, or a released cultivar is chosen to give genes for high yield potential. When landrace x PVS cultivar crosses are used and there is maximal farmer input (methods 5 and 6 in Table 2), then the breeding strategy most closely resembles *in situ* conservation of landraces. In the past, farmer experimentation on naturally existing genetic variation produced landraces. PPB enhances such farmer experimentation and increases genetic variation by deliberate hybridisation between the landraces. It also enhances the efficiency of selection by raising farmers’ awareness and knowledge through interaction with scientists. Nonetheless, it cannot be ruled out that some useful genes present in the landraces will be lost so *ex situ* conservation will still be desirable. Certainly, if there is a desire to wholly preserve the existing landraces then *ex situ* conservation is essential. We can say that *in situ* PPB conserves and creates genetic resources in farmers’ fields whereas *ex situ* conservation preserves genetic resources.

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