FARMERS, SCIENTISTS AND PLANT BREEDING
Integrating Knowledge and Practice

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Understanding Farmers' Knowledge as the Basis for Collaboration with Plant Breeders: Methodological Development and Examples from Ongoing Research in Mexico, Syria, Cuba and Nepal

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Abstract

There has been very little comparative research on farmers' and scientists' theoretical or conceptual knowledge, sometimes leading to reliance on untested assumptions in plant breeding projects that attempt to work with farmers. We propose an alternative approach that is inductive, based on a very basic biological model of plant–environment relationships, and on a holistic model of knowledge. The method we use was developed in Oaxaca, Mexico, and is based on scenarios involving genotype × environment interactions, heritability, and genetic response to selection. It is being modified and applied in a research project with collaborating scientists and farmers in Syria (barley),

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Cuba (maize) and Nepal (rice). We are testing the ideas that: (i) farmers' knowledge is complex, and includes conceptual knowledge of genotypes and environments; (ii) farmers' knowledge is both similar to and different from scientists' knowledge; and (iii) a generalizable methodological approach permitting inclusion of farmers' conceptual knowledge in research design and execution can form the basis for enhanced farmer–scientist collaboration for crop conservation and improvement. Results to date suggest that farmers have conceptual knowledge of their genotypes and environments that is congruent with the basic biological model also used by scientists, but that their knowledge is also influenced by the specific, local characteristics of their genotypes and environments, and by their social contexts. Some examples of the practical utility of these research results are given.

Introduction

There is increasing evidence from social studies of formal scientific knowledge (Hull, 1988) and local or indigenous knowledge (Medin and Atran, 1999) that both may consist of a complex combination of intuition, empiricism and theory, and of verifiable objective observation and social construction, and may, therefore, be similar as well as different (Agrawal, 1995).

For the most part, these findings have not had an impact on social or natural science research in agriculture and agricultural development, including plant breeding. Here it is commonly assumed that scientific knowledge (SK) is theoretical, objectively verifiable and universally generalizable, in contrast to local or indigenous farmer knowledge (FK), which is assumed to be intuitional or empirical and embedded in local social and biophysical contexts. The dominance of these stereotypes means that SK and FK are often considered fundamentally different and incomparable, or FK is considered an inferior version of SK. As a result, most agricultural development projects involving FK have not considered the possibility for collaboration of farmers and scientists based on similarities in their theoretical knowledge. Is an important potential being overlooked? Is it possible that FK about plant genotypes and growing environments is in part conceptual (theoretical)? Are there similarities between FK and SK, and if so could this be an important tool for facilitating collaboration between farmers and scientists for improved production in farmers' fields?

These are the general questions we address in this chapter, based on our work in Mexico beginning in 1996, and in ongoing work begun in 2000 with barley farmers in Syria, maize farmers in Cuba and rice farmers in Nepal. We have been investigating whether farmers have theoretical concepts about their crop genotypes and environments, and to what extent SK and FK are similar because they are based on observations of universal biological relationships between plant genotypes and the environments in which they grow, and different because of differences in the many unique biophysical and social situations in which this knowledge is created. Results suggest that the increased understanding of FK that results from such research can serve to support collaboration between farmers and plant breeders.

We begin by reviewing some of the critical theoretical and practical issues regarding the role of FK in crop improvement. Next is a discussion of the theory and methods we have been using to understand FK, including a holistic model of knowledge, a biological model of plant–environment relations and scenario-based interviews. We then report some of our research findings on FK related to the three main components of the biological model (genotype × environment interaction, heritability and genetic response to plant selection). We conclude with suggestions about the potential importance of our research for collaborative plant breeding (CPB).

Scientist Knowledge and Plant Breeding

Plant breeding, including both choosing crop varieties and populations and selecting plants, is based on an understanding of plants, environments and the relationship between them (see Cleveland and Soleri, Chapter 1, this volume). There are still many complexities of plant genotype × environment interactions that are not well understood in terms of biological theory (Duvick, Chapter 8, this volume), and about which there continue to be disagreements among plant breeders; for example the effect of selection environment on the range of target environments to which a genotype is adapted (Cleveland, 2001; Soleri and Cleveland, 2001; Bänziger and De Meyer, Chapter 11, this volume; Ceccarelli and Grando, Chapter 12, this volume). However, the fundamentals are well-established and universally accepted by plant breeders: plant phenotype is the result of both genotype and environment, the degree to which a trait is heritable depends on the degree to which it is affected by the genotype vs. the environment, and genetic change in a population due to selection is dependent on the proportion of plants selected and the heritability of the trait selected for (see the section 'A biological model' below, and Cleveland and Soleri, Chapter 1, this volume).

In actual situations, understanding these basic relationships is difficult because a great number of variables affect them, and predicting the results of choice and selection is hampered by the lack of required experimental data, and of the technologies and resources necessary to gather and analyse them. Plant breeders also recognize that their theoretical understanding of plants is limited, and that much plant breeding has been based on intuition and empiricism rather than theory (Simmonds, 1979; Duvick, 1996; Duvick, Chapter 8, this volume; Wallace and Yan, 1998: 320), although intuition and empiricism are likely to be underlain by the basic theoretical understanding of genotype–environment relations (see the section ‘A holistic model of knowledge’ below).

This *fundamental biological theory* (see section below ‘A biological model’) on which plant breeding is based is the same no matter where plant breeding is practised. However, the biophysical, economic and sociocultural variables can be quite different; for example between poor farmers’ fields in marginal environments and plant breeders’ research stations, or between national agricultural policy priorities of large-scale efficiencies and increased inputs and production, and farmers’ priorities of reducing risk and optimizing crop production as part of a general household survival strategy. Work under a specific set of circumstances may lead to *interpretation of theory* that is then generalized and broadly applied (for example, when the fundamental theory that as V_E decreases, h^2 increases is understood to imply that indirect selection under low V_E is always more efficient than direct selection under high V_E), without investigating the implications of those interpretations under all circumstances. Working with farmers often demands re-examining some of these interpretations of theory that form the basis of conventional plant breeding by testing the assumptions (biological, environmental, economic, sociocultural) on which they are based. The results of these tests will have implications for both the interpretation of theory as well as the *methods* and *practices* used.

Thus, in discussions of the role of formal, scientific plant breeding in CPB, it may often be helpful to make a clearer distinction between: (i) fundamental biological theory; (ii) interpretations of fundamental theory; and (iii) methods and practice; (iii) may be very different depending on whether it is based on (i) or (ii), or on different versions of (ii). Many of the disagreements about plant breeding methods for CPB may grow out of disagreements about differences in the interpretation of fundamental biological theory, and disagreements about these interpretations may in turn be based on the belief of proponents that their interpretations of fundamental theory are not based on their unique experiences and assumptions, but rather are part of fundamental theory.

Therefore, especially for those aspects of the biophysical reality of genotypes and environments that are less well understood in terms of plant breeding theory, plant breeders’ knowledge may more likely be based on the particular experiences that each one has with the particular environments and crop varieties they work with, and thus may be less generalizable and more apt to be influenced by pre-existing knowledge (including values) specific to the plant breeder's social environment. This means that disagreements among plant breeders could arise even though fundamental genetic and statistical principles remain constant across a range of contexts, because the 'art' of plant breeding is more tied to specific individuals and/or environments (Soleri and Cleveland, 2001).

Farmer Knowledge and Plant Breeding

There has been growing interest in the potential of FK to make a contribution to agricultural development, both to increase the effectiveness of scientist and farmer research and practice, and to empower farmers. However, very little is known by outsiders about FK of plant breeding, either in farmers' own terms, or in terms of scientific plant breeding (Brown, 1999; McGuire *et al.*, 1999; Cleveland *et al.*, 2000; Weltzien *et al.*, 2000). In the urgency to redress the shortcomings of much formal research by including farmers, most work has been initiated by 'foresighted individuals working at otherwise conventional research stations' and thus having the objectives and professional pressures of such institutions (Friis-Hansen and Sthapit, 2000: 19). These individuals have typically been working in institutions whose interest and expertise is in developing research products, not in experimenting with theory and method for improving participation or in understanding FK. On the other hand, farmers have rarely had the ability, because of their low social status and lack of political power, to take the initiative in working with scientists (see Frossard, Chapter 6, this volume for an important counter example; Schneider, Chapter 7, this volume, for an historical example of how farmer participation was eliminated). Therefore, the possibility that scientific research and development might be improved by learning more about FK related to plant breeding has not typically been considered and, therefore, there was little motivation to learn more about FK.

In addition to these important social and institutional factors, our working definitions of 'knowledge' and of 'participation' based on unexamined assumptions have also contributed to the lack of research on the theoretical content of FK and on comparing FK and SK (with the resulting lack of information in turn reinforcing the effect of these variables).

Defining farmer knowledge

The lack of empirical information and theoretical analysis has contributed to our using simple, stereotyped definitions of FK (and often of SK as well), and the frequent failure to test the many assumptions underlying these definitions (Scoones and Thompson, 1993; Sillitoe, 1998). We can very roughly divide current views of FK into two categories: those that see FK as fundamentally different from SK, and those that see FK as empirically similar to SK (see Ellen and Harris (2000) and Sillitoe (1998) for reviews).

In the first group, definitions of FK emphasize that it is primarily intuition and skill, socially constructed, and based on the local social and environmental contexts and cultural values. FK and SK are seen as fundamentally different, and attempts to explain FK in scientific terms impede true appreciation of that knowledge (e.g. Selener, 1997). This implies that the role of outsiders should be to empower local people and validate FK in its own terms.

The second major category of definitions of FK emphasizes that it consists primarily of rational empirical knowledge of the environment. Definitions of FK as *economically rational* tend to assume that scientists are more rational. The role of outsiders should be to facilitate the replacement or modernization of small-scale farmers, including replacement of their crop varieties (farmer varieties, FVs) with modern varieties (MVs) (Srivastava and Jaffee, 1993). Definitions of FK as *ecologically rational* emphasize farmers' accurate and, therefore, sustainable ecological knowledge of their environments, supported by many empirical data, especially in ethnotaxonomic studies of plants and animals, while recognizing variation in distribution of cultural knowledge as the result of factors including age, gender, social status and affiliation, kinship, personal experience and intelligence (Berlin, 1992). These definitions generally do not include theoretical content of FK (Medin and Atran, 1999). Here the role of outsiders is to understand how FK can be explained in terms of SK, and can make the application of SK more effective.

Participatory research has usually been based on definitions of the second type. As a result, FK has been used as either a *descriptive* or a *discriminatory* tool in participatory plant breeding (PPB). FK as a *descriptive* tool has most commonly been used. For example, a major survey of 49 PPB projects found that the primary focus was soliciting farmers' descriptions and rankings of selection criteria. For about two-thirds of these projects 'identifying, verifying, and testing of specific selection criteria was the main aim of the research', and 85% obtained farmers' selection criteria for new varieties (Weltzien *et al.*, 2000: 18, 51, 75). The main impact on scientific plant breeding appears to have been 'better understanding of new ideotypes based on farmers' experiences, specific preferences and needs' that will affect priorities of formal plant breeding and the 'process of formal variety development' (Weltzien *et al.*, 2000: 75).

More recently, using FK of crops as a *discriminatory* tool has become more common. This has been important in some PPB work, with farmers asked to choose among varieties already released in other areas (e.g. for rice and chickpea, Joshi and Witcombe, 1996), among new and experimental varieties (e.g. for pearl millet, Weltzien *et al.*, 1998), among segregating populations (e.g. F_3 bulks with barley, Ceccarelli *et al.*, 2000), or to select individual plants within segregating populations (e.g. F_5 bulks with rice, Sthapit *et al.*, 1996). When such choice or selection is accomplished using actual plants, plant parts or propagules, analysis of results can reveal farmers' implicit criteria that they may not be able to verbalize easily or at all (i.e. it may be unconscious) (Louette and Smale, 2000; Soleri *et al.*, 2000).

These approaches to understanding FK have made valuable contributions to achieving more effective crop improvement for farmers' conditions. However, the possible conceptual basis of FK has not usually been fully or even partially considered, and rigorous comparisons with SK have not been carried out; 'opportunities rarely develop for interaction between breeders and farmers beyond the survey', with the discussion 'driven by the breeders' concepts of the present situation, making it difficult for farmers to express their views in the context of their reality' (Weltzien *et al.*, 2000: 51). It may also be difficult for farmers to communicate to outsiders their knowledge that goes beyond description or discrimination. Thus, still lacking is an overarching approach to FK and SK that is broadly applicable and has the objective of facilitating understanding and interactions between the two. Below ('A holistic model of knowledge') we suggest an alternative perspective on farmer and scientist collaboration based on a new definition of knowledge.

Defining participation

Participatory research to include farmers has been an important movement in agricultural development, with the goal of making formal science more useful to farmers and more efficient from the scientist's viewpoint (Chambers *et al.*, 1989). The explicit application of participatory research to plant breeding is relatively new, and there is a wide range of understandings of what it entails, and a wide range of activities present in PPB projects (Friis-Hansen and Sthapit, 2000). The relative contribution and control by farmers or plant breeders in PPB varies substantially and is one of its most important and discussed aspects.

The lack of rigour in using the term and the lack of scientific evaluation of participatory development are seen as threats to the continued use of participation in agricultural development (Ashby, 1997).

One approach to classifying participation is to distinguish between farmers' participation in formal scientists' research ('formal-led' PPB) on the one hand, and formal researchers' participation in farmers' research ('farmer-led' PPB) on the other hand (McGuire *et al.*, 1999; Weltzien *et al.*, 2000). The definition of PPB, however, often implies that farmers 'participate' in scientists' breeding, for example that PPB 'denotes a range of approaches that involve *users* (emphasis added) more closely in crop development or seed supply' (McGuire *et al.*, 1999: 7). A review of 11 examples of farmer-led plant breeding, including PPB projects, shows that the emphasis in scientist involvement has been on transferring SK and scientific practices directly to farmers, and secondarily from farmer to farmer, with almost no acknowledgement of the possibility of theoretical FK, or of transferring FK to scientists, or of farmers leading the research (although they may be involved in defining goals) (McGuire *et al.*, 1999). A companion review of 49 formal-led PPB projects found that researchers usually use 'participation' to refer to the stage in the breeding cycle where farmers are involved and the degree or amount of their involvement at that stage, but that what farmers actually do or how they affect the breeding process is 'usually left analytically vague' (Weltzien *et al.*, 2000: 59).

Multi-level or multi-stage taxonomies are also common in participatory research (see Joshi *et al.*, Chapter 10, this volume, for a detailed discussion of this), and tend to emphasize the social and institutional participation of farmers and scientists. The implicit assumptions are that FK can be complementary to SK, and that SK can strengthen farmer knowledge and practice. For example, Biggs has suggested a typology of four modes of 'farmer participation' (contractual, consultative, collaborative and collegial) (1989) that has been successfully applied in PPB (e.g. see Joshi *et al.*, Chapter 10, this volume). As with many other approaches to participatory research, Biggs' typology is meant to help research managers 'increase the cost effectiveness of research and . . . keep research priorities focused on the clients [resource poor farmers]' (1989: 1). In terms of FK, scientists recognize that FK and SK are complementary, and that FK is useful to them, and collect and use it. In the collegial mode scientists 'work to strengthen farmers' informal research and their ability to request information and services' (Biggs, 1989: 3, 8).

Another frequently used distinction in the discussion of PPB is a dichotomy between 'functional' (biological, product-oriented) benefits and 'empowering' (social, process-oriented) benefits of PPB (Ashby, 1997, for discussion see Weltzien *et al.*, 2000: 5–6). The modes described above are frequently interpreted and used as if the increasing social and particularly physical involvement of farmers at successive levels (e.g. from contractual to collegial) is synonymous with increasing equity and empowerment, and that empowerment and biological effectiveness are not necessarily related and may actually be in conflict (e.g. Bellon, 2000). On the other hand, some researchers see empowerment and biological effectiveness as causally related and synergistic (Ceccarelli *et al.*, 2000; Ceccarelli and Grando, Chapter 12, this volume).

Theory for Understanding Farmers' Knowledge

A holistic model of knowledge and collaboration

We suggest what we call a *holistic* model of knowledge that has as its goal minimizing deductive assumptions about the nature of FK (and SK), and that inductively tests ideas based on the possibility that FK may be both socially constructed and a verifiable description of objective reality, and consists of intuition, skill, empirical data and theory. The goal is to support collaboration between farmers and scientists.

We use the word *theory* to mean knowledge of the way things (namely, plant genotypes and growing environments) in the world relate to each other, including causal relationships, on which predictions and action can be based, and which are generalizable (but not necessarily universal) (cf. Hull, 1988: 485; Medin and Atran, 1999: 9). Our use of the word theory thus includes two important aspects that are often not differentiated in discussions of FK and SK.

1. Consciously developed theory intended to be universally applicable is often associated with modern science (but may also be carried out by farmers). The fact that farmers do not have access to the same information that scientists have (e.g. of microorganisms) is not an adequate basis for saying that it is not generalizable, because all theory is partial, and leaves things out; it could not function unless it did (Hull, 1988: 485). Theory in this sense, including modern scientific theory, is also influenced by personal psychology, historical contingencies and the social context of its production (Giere, 1999).

2. Unconscious 'heuristics' build on experiences with particular genotypes and environments and are often associated with non-scientific thinking, but may also be an important part of modern science (see Duvick, Chapter 8, this volume), such as the ecologically rational 'simple heuristics' discussed by Gigerenzer and Todd (1999). In this sense, theory pervades all human observation to some degree; according to some philosophers of science 'Theory-free observation, languages and classifications are impossible' (Hull, 1988: 485).

We originally suggested the term collaborative plant breeding (CPB) as an alternative to PPB, to 'remind ourselves that this effort should not privilege either men's or women's, or farmers' or formal plant breeders' approaches, values, etc., but aim for a true collaboration based on mutual respect, regardless of the proportional contribution of each' (Cleveland and Soleri, 1997). We think that this goal can be served by using a holistic model of knowledge that supports communication across the cultural and disciplinary divides that may separate farmers, plant breeders and social scientists. The relative merits of different knowledge in terms of contribution to CPB need to be empirically assessed in each situation, and successful collaboration requires mutual respect that is based on an understanding of differences, similarities and objectives. No a priori judgements need to be made about the relative quantitative contribution of farmers and plant breeders to collaboration. In this chapter we use the term PPB to talk about farmers and plant breeders working together in a general way that includes, for example, the four stages defined by Biggs. We use the term CPB to refer to situations in which the whole range of FK is considered, including theoretical, and in which SK is not privileged. ('Collaborative' in CPB is not, therefore, the equivalent of Biggs's 'collaborative' in his modes of participation.)

A biological model

As a framework for evaluating farmer breeding we use the elementary biological model on which plant breeding is based, as it is presented in standard texts (e.g. Simmonds, 1979; Falconer and Mackay, 1996). First, variation in population phenotype (V_P) on which choice and selection are based is determined by genetic variation (V_G), environmental variation (V_E), and variation in genotype × environment (G × E) interaction ($V_{G \times E}$), thus $V_P = V_G + V_E + V_{G \times E}$. Broad sense heritability (H) is the proportion of V_P due to genetic variance ($H = V_G/V_P$), while narrow sense heritability (h^2) is the proportion of V_P due to additive genetic variance ($h^2 = V_A/V_P$), that is, the proportion of V_G considered directly transmissible from parents to progeny, and therefore of primary interest to breeders.

Second, response to selection (R) is the difference, for the traits measured, between the mean of the whole population from which the parents were selected and the mean of the next generation that is produced by planting those selected seeds under the same conditions. R is the product of two different factors, h^2 and S ($R = h^2S$), where S is the selection differential, the difference between the mean of the selected group and the mean of the whole original population selected from. Expression of S in standard deviation units (the standardized selection differential or selection intensity; Falconer and Mackay, 1996: 189) permits comparison of selections among populations with different amounts or types of variation. The results of selecting for a given trait improve as the proportion of V_P contributed by V_A increases.

The biological relationships described in these simple equations underlie plant breeders' understanding of even the most complex phenomena that they encounter (Cooper and Hammer, 1996; DeLacy *et al.*, 1996). For example, two widely respected English language plant breeding texts state that the relationship between genotype and phenotype is 'perhaps the most basic concept of genetics and plant breeding' (Allard, 1999: 48), and of $R = h^2S$, that 'If there were such a thing as a fundamental equation in plant breeding this would be it' (Simmonds, 1979: 100).

We use the biological model to understand farmers' perceptions in fundamental terms in order to facilitate collaboration, including increasing farmers' status in plant breeders' eyes, and increasing farmers' ability to use their own knowledge of their FVs and growing conditions. Potentially our research could also enable farmers to compare plant breeders' theories with their own. We are aware of the 'intimate links between knowledge and power' that have been ignored by many indigenous knowledge advocates who, perhaps unconsciously, privilege scientific knowledge while simultaneously lauding indigenous knowledge (Agrawal, 1995: 430). We seek methods to identify similarities and differences but do not assume that when there are differences between farmers and breeders, that the farmer is always 'wrong', nor, on the other hand, do we assume that outsiders have been negligent in understanding farmer knowledge and practice in their own terms (see Scoones and Thompson, 1993). Indeed, it is these similarities and differences that we have found the most challenging and stimulating to our own understanding and thinking.

It is important to note that while the emphasis here is on exploring FK, an understanding of SK may be equally critical to the long-term success of CPB, and we use the model in other parts of our research to understand plant breeders' knowledge and *differences among* plant breeders (Cleveland, 2001; Soleri and Cleveland, 2001; Cleveland and Soleri, 2002).

Methods

Interview scenarios

The method we use in framing questions to farmers is based on hypothetical scenarios that build on the key concepts of the biological model: genotype × environment interaction, heritability and genetic gain from selection. The method was developed in Oaxaca, Mexico, and is being modified and applied in a research project with collaborating scientists and farmers in Syria, Cuba and Nepal. The range of sociocultural and biological variables (including farmers, scientists, crops and environments) requires adapting scenarios to each of the different sites by: (i) referring to the biological model; (ii) including both components that are familiar and those that are unfamiliar to farmers; (iii) referring to crop-specific reproductive systems and local propagation methods; and (iv) addressing issues and practices central to scientists' and farmers' approaches. An example of a novel component in the scenarios is an *optimal* field that is uniform and in no way limits plant growth, in contrast to a farmer's *typical* field that is relatively variable and often has high levels of biotic and abiotic stresses. The optimal field facilitates an understanding of farmers' knowledge in terms of the biological model because in the optimal field the source of any variation among plants will be primarily genetic, not environmental.

Translating the 'optimal field' into terms familiar to farmers was a major challenge and took many iterations. During the first year in Mexico we defined the optimal field as one in which nothing was lacking for plant growth, there was plenty of water, the soil was good (i.e. there was plenty of manure, compost or chemical fertilizer), and there were no insects or other pests and diseases, or any abiotic stresses, such as flooding or high winds. We included uniform planting of seed, i.e. equal spacing. Farmers thought of many ways in which the planting or the plants resulting might not be equal, such as a farmer dropping many more seeds in one planting hole by accident, or a maize plant producing two rather than the usual one ear, and we gradually developed the scenarios to account for all of these factors.

We used lots of visual aids in the scenarios (Figs 2.1 and 2.2) and these proved to be very valuable both for ourselves and for the farmers we interviewed. For example, in Mexico we used maize ears from local farmers' fields when talking with farmers about ear length and photographs of different tassels from local fields when talking about tassel colour. Beginning in Syria, we used ten each of small rocks or crumpled paper balls of three sizes to represent years with good, 'normal' and poor rainfall; farmers selected from these to create a distribution of years defined by rainfall during a typical 10-year period (Fig. 2.3).

Other materials and methods

In Syria, Cuba and Nepal the work involved collaboration with plant breeders and/or social scientists working with farmers on PPB or related work. In all sites we interviewed farmers from two communities with contrasting biophysical environments, one typically characterized as favourable and the other as difficult for the cultivation of the crop of interest. These contrasts were often based on different average precipitation, but also on soil quality and availability of agricultural inputs

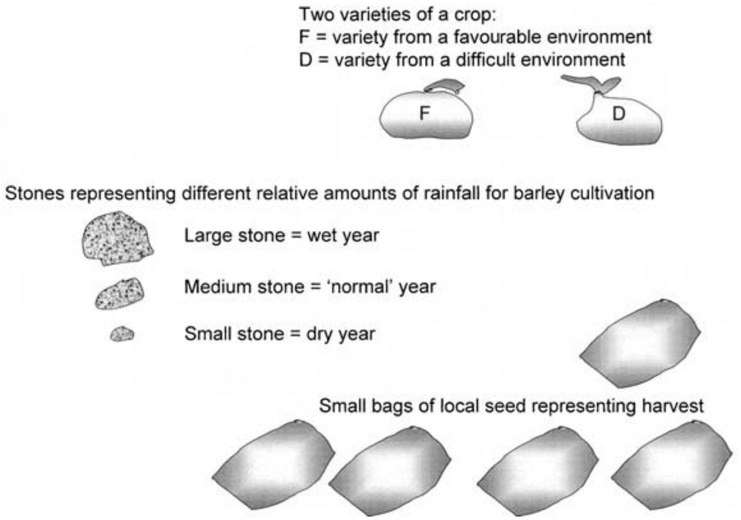

Fig. 2.1. Visual aids used for G × E scenarios.

Fig. 2.2. Nicasio Hernandez Sanchez and Daniela Soleri discuss the expression of traits with high and low average heritabilities in different environments described in scenarios used in Oaxaca, Mexico. Pictured are colour photos of tassels and ears of maize. (Photo by D.A. Cleveland, used with permission of subjects.)

Fig. 2.3. Farmer Juri Aboud discusses local rainfall distribution, risk and its affect on her choice of a barley variety in a scenario described to her in Mardabsi, northern Syria. She is selecting stones of three different sizes to represent the average distribution of dry, normal and wet years in a 10-year period. (Photo by D. Soleri, used with permission of subject.)

(irrigation, agrochemicals, machinery) (Table 2.1). The crop species we focused on differed by site, but in each case was the major local crop: maize (> 95% outcrossing; Craig, 1977) in Mexico and Cuba, barley (0.6–3.8% outcrossing; Allard, 1999: 41) in Syria (the major crop for small ruminant feed, the primary source of livelihood) and rice (0–3.0% outcrossing; Poehlman and Sleper, 1995) in Nepal.

In the following three sections we present results from our ongoing research investigating FK related to genotype × environment interaction, heritability and genetic gain. We include specific methods and findings in each section.

Farmers' Knowledge of Genotype × Environment Interaction

The environmental scale for which crop varieties should be developed is an important decision for both farmers and plant breeders, and is directly related to interactions between variations in plant genotypes and those growing environments, $V_{G \times E}$. Environmental variation can be partitioned into several components: $V_E = V_L + V_T + V_M$ (V_L = variance due to *location*, e.g. soil and climatic variables; V_T = variance due to *time*, e.g. season or year; and V_M = variance due to human *management*). $V_{G \times E}$ represents the degree to which genotypes behave

Table 2.1. Descriptions of the study sites.

Site and community[a] (no. of farmers)	Crop and % outcrossing	Elevation (masl)	Average annual precipitation (mm)	Community population size	Average field size (ha)	Average yield (t ha^{-1})
Mexico (13)	Maize (*Zea mays mays*), > 95%					
D (5)		1780	468	2533	0.7	0.5
F (8)		1490	685	2800	0.4	0.8
Cuba (31)	Maize (*Zea mays mays*), > 95%					
D (20)		80	1350	204	0.5	1.5
F (11)		15	1320	8000[b]	27.9	1.5[c]
Syria (40)	Barley (*Hordeum vulgare* L.), 0.6–3.8%					
D (20)		495	300	1450	7.3	0.9
F (20)		360	340	6000	2.0	3.0
Nepal (10)	Rice (*Oryza sativa* L.) 0–3.0%					
F		660–1200	3979	5458	0.7	2.4

[a] D, community in relatively more difficult growing environment; F, community in relatively more favourable growing environment.

[b] Population size is for town, however, only members of three production cooperatives (total population approximately 1220) within that town area were interviewed.

[c] Yields at the favourable location have dropped significantly since the economic crisis of the 'special period' began in 1989, see Ríos Labrada *et al*., Chapter 9, this volume.

consistently across a number of environments. Low quantitative G × E means little relative change in performance over environments (Fig. 2.4a). High quantitative G × E is characterized by marked changes in performance with changes in environmental factors (Fig. 2.4b) and is associated with reduced stability of performance (defined as variance across environments) of an individual genotype. Qualitative G × E between two or more varieties means that they change rank across environments (Fig. 2.4c), and is often referred to as a 'crossover' because the regression lines for yield (or other traits) cross over at some point (see Bänziger and De Meyer, Chapter 11; Ceccarelli and Grando, Chapter 12; and Ríos Labrada *et al*., Chapter 9, this volume).

In the presence of qualitative G × E, distinguishing between forms of V_E based on their repeatability and predictability is part of an approach proposed by some plant breeders to develop crop varieties appropriate for difficult environments (Cooper, 1999; Ceccarelli and Grando, Chapter 12, this volume). A narrow range of repeatable and predictable V_E would be addressed through selection for *specific* adaptation, while *broad* adaptation would be sought to less predictable or

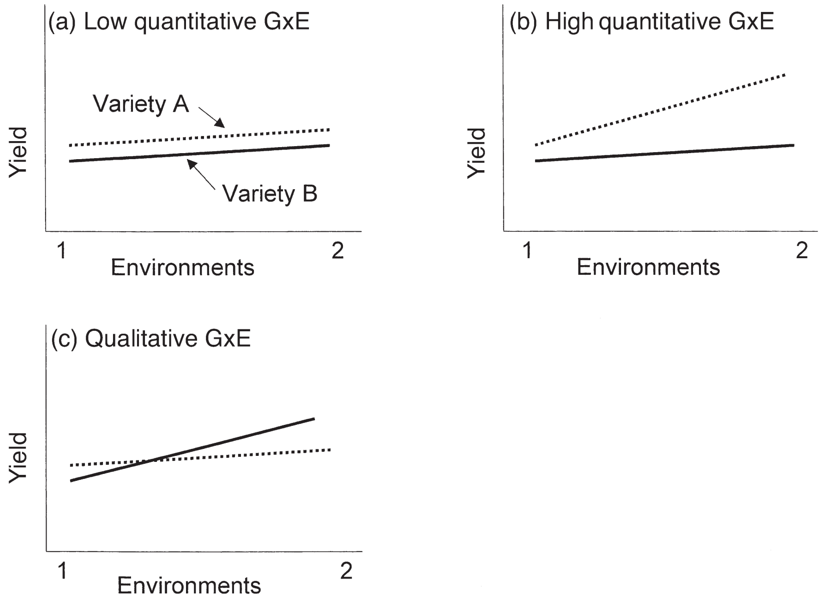

Fig. 2.4. Graphic representation of G × E interactions.

non-repeatable V_E. That is, seeking broad adaptation means identifying the variety with the best performance over the range of environments (best overall average), while specific adaptation is achieved by identifying the variety with the best performance (absolute value) in a single environmental type in the range. Temporal V_E (V_T e.g. within and between season precipitation) and variance due to location (V_L e.g. durable soil characteristics, slope and orientation), also referred to as spatial V_E, differ in that the relative unpredictability of V_T makes it particularly challenging. For this reason specific adaptation to spatial V_E and broad adaptation to V_T may be sought under this approach.

Farmers' perceptions of different forms of qualitative G × E across different spatial and temporal environments were elicited through scenarios based on the biological model, $V_P = V_G + V_E + V_{G \times E}$. We asked farmers: if the same two varieties were compared in different growing environments, would their relative phenotypes for yield be the same or different? In other words, does a change in environments result in a *rank* change in terms of yield (Figs 2.5 and 2.6)? A key assumption in the scenarios was that local crop populations originating in contrasting growing environments would represent the possibility of such interactions that farmers may have observed or at least the components of the scenarios (some of the genotypes and environments) would be familiar to them. Because of the substantial evidence that a desire for

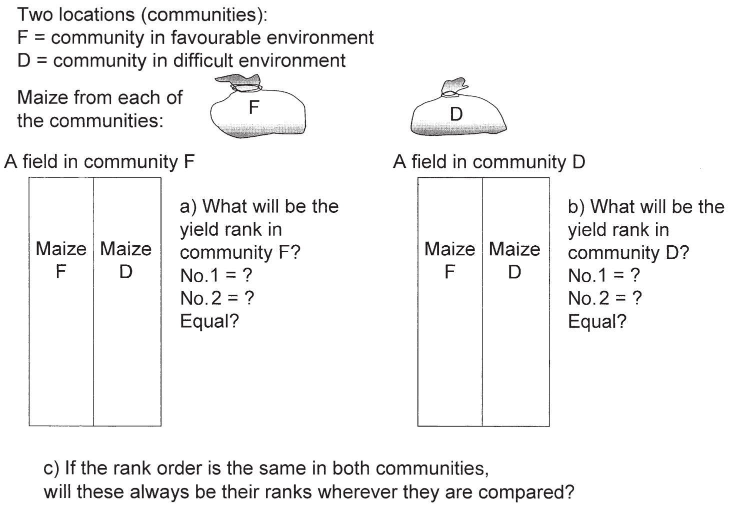

Fig. 2.5. Qualitative spatial G × E: interlocation scenario.

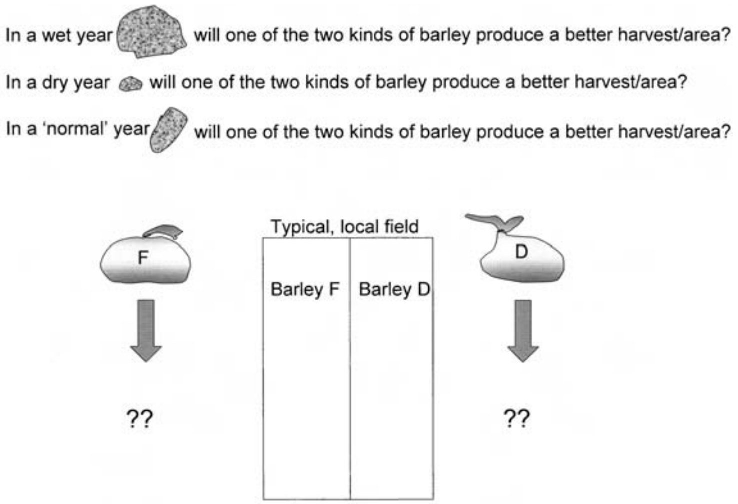

Fig. 2.6. Qualitative temporal G × E scenarios.

diverse postharvest or other qualities is often the reason for maintaining multiple varieties of one species (e.g. see Joshi *et al.*, Chapter 10; McGuire, Chapter 5; Smale, Chapter 3; and Zimmerer, Chapter 4, this volume), the scenarios described varieties of a crop that originated in different and distant environments, but were exactly the same in all other ways. These scenarios were not used in Mexico as they were developed after that work was completed.

Spatial G × E

Farmers often have to choose varieties for different locations (spatial environments) such as a range of fields for a given planting season (i.e. time is held constant). If farmers do not perceive qualitative G × L (crossovers) in varietal performance between fields, then there may be no agronomic reason for them to grow different varieties. When they do perceive crossovers between varieties for two locations, then they may have to decide whether to grow one variety in both, or if the extra yield obtained by growing two different varieties in the two locations, compared with the extra effort required, will produce a net benefit.

In our research we asked 'Is spatial V_E important to farmers and, if so, at what scale?' (e.g. see Fig. 2.5). Our scenarios regarding qualitative G × E in response to spatial V_E looked at three levels of spatial variation: (i) *between locations* (typically represented by distinct communities) with contrasting growing conditions (e.g. relatively favourable and difficult for the crop considered), one of them being the farmers' own location; (ii) *among fields* within the farmers' own location; and (iii) *within one* typical *field* in the farmers' own location. The null hypothesis in each case was that farmers would not be aware of such interactions.

The proportions of positive responses concerning the presence of qualitative G × E at some scales in Syria and Nepal represented significant deviations from the null hypothesis (Table 2.2). In addition, the site-based findings suggest a few overall trends. First, between location G × E is the most frequently recognized at all sites but the percentage of farmers noting this varied substantially from 25% in Cuba to 100% in Nepal. Second, for this same scenario in the two sites where farmers from communities in contrasting growing environments were interviewed (Cuba and Syria), more farmers in the favourable growing environment noted the potential for G × E, while those in the difficult environment more frequently gave different interpretations of the interactions they predicted between genotypes and environments (Figs 2.7 and 2.8). Third, at all sites, the percentage of farmers stating that G × E may occur between locations, as compared to within locations, and then compared to within a field in one location decreased, although at different rates in different sites.

The trends noted in the first and third points can be understood to a large extent through consideration of the context of this knowledge. The majority of responses appear to reflect differences in crop mating systems and their impact on the capacity of selection to eliminate intrapopulation diversity in favour of locally beneficial alleles (Allard, 1988). Environmental heterogeneity is seen as differentiating between varietal performances at all spatial levels most frequently among farmers working with crop species with low rates of outcrossing and least frequently among those cultivating a highly outcrossing species.

Combined with crop mating system, extent and scale of environmental heterogeneity as well as scale and type of management may account for these response trends as well. For example, in comparing the communities with difficult environments included in this study, Syrian fields were almost 15 times the size of Cuban and 10 times the size of Nepalese fields (see Table 2.1), and the production in the former is entirely mechanized while today in Cuba it rarely is and in Nepal all fields are hand worked. The scale and type of management in Nepal permits identification and use of rice varieties that may be more specifically responsive to particular sub-locations between and within

Table 2.2. Summary of farmers' perceptions of qualitative spatial and temporal G × E interactions for their primary crop in their environments; Cuba, Syria and Nepal.

	Percentage of farmers responding spatial V_E as potential source of qualitative spatial G × E at the level of			Percentage of farmers responding temporal V_E as potential source of qualitative temporal G × E[b]
Site and community[a] (no. of farmers)	Between locations	Between fields in one location	Within fields in one location	Between years with contrasting precipitation in one location
Cuba total (31)	25	4	0	13
D (20)	6	0	0	20
F (11)	55	13	0	0
Syria total (36)	67*	22	16	39*
D (19)	63*	21	11	32
F (18)	71*	22	22	47*
Nepal[c] (10)				
F	100[d]*	100[d]*	30[d]	60

[a] D: community in relatively more difficult growing environment, F: community in relatively more favourable growing environment.

[b] Responses to scenarios regarding two varieties originating in two contrasting locations, one relatively wet, the other relatively dry, due to either precipitation or reliable irrigation.

[c] The work in Nepal is just starting, only ten households in one community had been interviewed at the time of writing.

[d] Responses to scenarios regarding two varieties originating in contrasting, farmer-defined sub-locations occurring in one location.

*Significant χ^2 test for goodness of fit to the null hypothesis that farmers would not perceive qualitative G × E interactions, $P \leq 0.05$.

fields that may not be possible or necessary with the scale of Syrian barley cultivation, or with levels of gene flow due to cross-pollination by wind in maize in large, heterogeneous, areas of cultivation in small fields in Cuba.

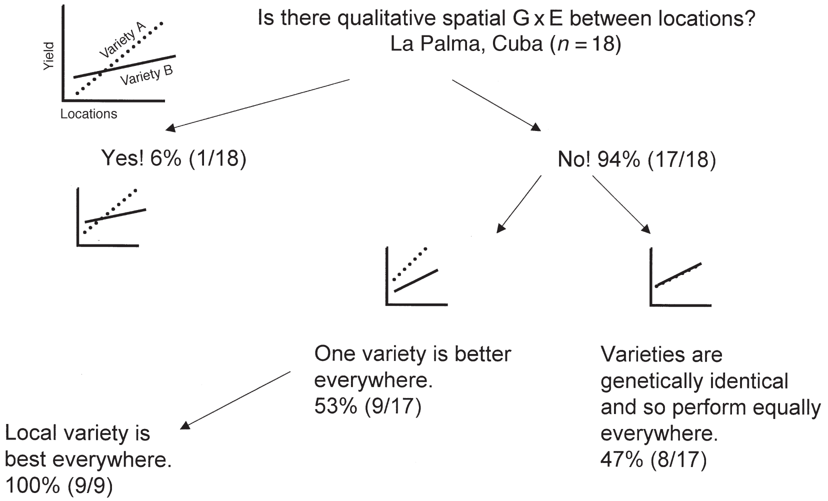

Fig. 2.7. Farmers' characterization of the relationship of varieties' performance across environments in spatial G × E scenario in a Cuban community with a relatively difficult growing environment.

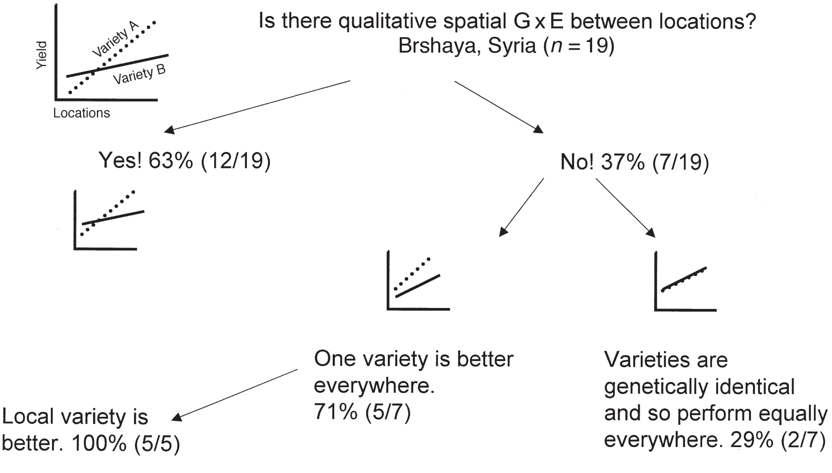

Fig. 2.8. Farmers' characterization of the relationship of varieties' performance across environments in spatial G × E scenario in a Syrian community with a relatively difficult growing environment.

Our results suggest that in some cases farmers are very aware of qualitative spatial G × E. Some explicitly stated that they maintain or seek multiple, distinct varieties because of this, as for rice in Nepal within specified sub-locations or fields within those sub-locations, or in Syria for particular soil types within a location or even within fields at a location, while in other spatial environments they were not concerned by it. In those cases the alternative interpretations offered by farmers directly paralleled interpretations of G × E interactions observed and reported by some plant breeders: for example, describing the presence of high quantitative G × E (see Fig. 2.4b) with one variety always better than another variety but in some places this superiority being greater; or no G × E because $V_G = 0$, thus all 'varieties' are actually the same genetic population that has been given different names in the locations where it is being grown. In practice, both of these interpretations imply that there is no need for farmers to maintain or seek distinct (named) varieties for their growing environments.

Temporal variation and risk perception

An important factor affecting a farmer's choice between varieties to grow in a given location is how she perceives variation in yield (and income) over time for that location (temporal G × E), as well as average yield. Important but unpredictable components of the growing environment like precipitation can result in yield variation among varieties over time that could be expressed as quantitative or/and qualitative G × E (Cooper, 1999; Cooper *et al.*, 1999). If variety A has a higher average yield and lower yield variance than variety B through time in a given location, then the choice would be A. However, if variety A has a higher average yield but also a larger yield variance, then the choice between the two varieties will depend on her attitudes towards risk and on her ability to manage it; she may or may not be willing to sacrifice average yield in order have a more stable yield, or a 'smoother income stream' through time (Walker, 1989).

In the growing environments included in this study, precipitation is considered either the most, or one of the most important constraints to agricultural production and the main cropping season depends on rainfall for growth, not only stored soil moisture. We asked farmers about the potential for qualitative G × E in response to annual variation in precipitation defined broadly by them as 'wet' vs. 'dry' rainfall years for crop yield, not addressing timing or distribution of rainfall. They were asked to make this comparison between a local variety originating and maintained in a relatively wet environment, and one from a dry environment, as defined by average rainfall. The same biological model as described above for spatial G × E applies here, the only difference being that the environments referred to are temporal and are characterized by precipitation, as opposed to being spatially delineated.

The findings regarding farmers' perceptions of qualitative temporal G × E as defined by year-to-year variation in rainfall (Table 2.2) show the same trend as shown for perceptions of spatial G × E. Increasing proportions of farmers interviewed in Cuba, then Syria and finally Nepal foresaw possible qualitative interactions among those two varieties over time. Again, the different mating systems of their crop species may contribute to these differences. If that is the case, we could interpret the responses as indicating that in highly selfing species specific adaptation to a particular level of average rainfall was foreseen by a greater percentage of farmers than was the case for those growing more highly outcrossing species.

To understand farmers' attitudes to the risks posed by qualitative temporal G × E we asked them to choose which of two varieties would be best for them, one with high average yields and high yield variance over precipitation regimes (a highly responsive variety, HRV), the other with relatively low average yields but with higher yield stability (a stable variety) (Fig. 2.9). Because farmers' knowledge of future rainfall is uncertain or imperfect, the HRV represents a greater risk if farmers have few resources to rely on in cases of a poor harvest.

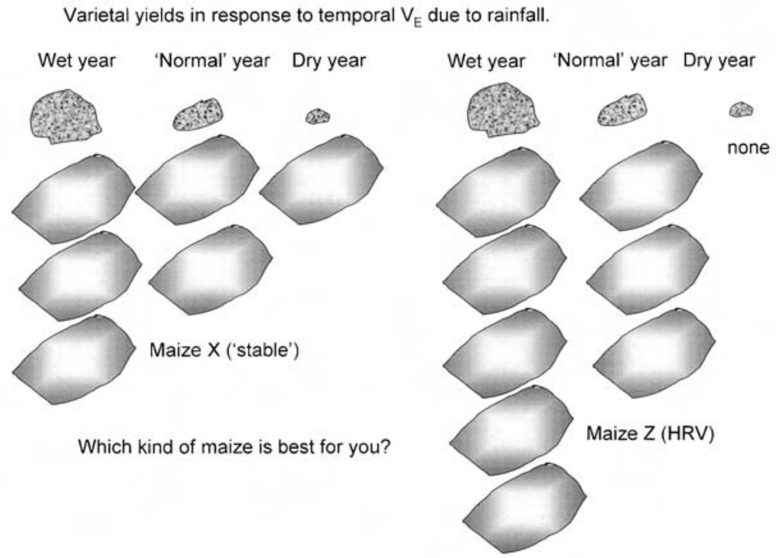

Fig. 2.9. Scenario for eliciting farmers' preference of varietal response to qualitative temporal G × E.

At each site farmers' responses were nearly evenly divided between the HRV and stable variety (Table 2.3). However, in Cuba and Syria, where farmers from communities with relatively difficult and favourable growing environments were interviewed, a significantly higher percentage of those in difficult environments preferred the stable variety. To interpret these results it seems useful to note that a higher proportion of Syrian as compared to Cuban farmers had experienced crop failure, and within each site a far larger percentage of farmers in difficult environments had experienced crop failure (Table 2.3). Although farmers at both sites and locations within these described a similar proportion of wet and dry years, expectations for qualitative temporal G × E between two varieties in response to rainfall variation were lower among Cuban farmers at all levels than among Syrian farmers. Once again, mating system and its impact on selection and adaptation seems likely to contribute to the differences between Cuban and Syrian responses. Still, biological factors are not necessarily complete explanations of farmers' choices. Other potentially important

Table 2.3. Farmers' estimations of rainfall distribution, experience of crop failure and choices between varieties that are highly responsive (HRV) vs. stable under temporal V_E, characterized by annual variation in precipitation useful for agriculture.

Location and community[a] (no. of farmers)	Percentage of farmers choosing a		Percentage of farmers choosing stable variety in communities with D vs. F[a] environments	Farmers' estimations of rainfall distribution over time (% years typically wet-'normal'-dry)	Percentage of farmers reporting having experienced crop failure
	HRV	Stable variety			
Cuba total (29)	41	59	*	30-40-30	28
D (18)	28	72	76	30-40-30	33
F (11)	64	36	24	30-50-20	14
Syria total (40)	48	52	*	30-40-30	51
D (20)	25	75	71	20-50-30	89
F (20)	70	30	29	30-40-30	15
Nepal	–	–	–	–	–
F (10)	50	50	–	30-50-20	0

[a] D: community in relatively more difficult growing environment, F: community in relatively more favourable growing environment.

*Significant χ^2 test for goodness of fit for distribution of respondents choosing a stable variety across communities with difficult and favourable environments within a study site, $P \leq 0.05$.

factors in farmers' choice between HRV and stable varieties not considered in this research include household economy and social structure, community support networks, cultural values concerning risk, storage capability and markets.

These findings concerning farmers' genetic perceptions of qualitative spatial and temporal G × E can have practical significance for CPB. First, farmers' locally specific insights into scales at which qualitative G × E may be present can inform and alter experimental design (cf. Zimmerer, Chapter 4, this volume). This has happened in Syria through close, long-term interactions between scientists and farmers; whether these changes would have been accomplished more rapidly had farmers' conceptual knowledge been included earlier in that work remains to be tested elsewhere. Second, spatial scales considered important by farmers for varietal discrimination may be indicative of their receptivity to new material and the extent to which it may be used across a range of local growing environments. Third, concern for qualitative temporal G × E and the risk that may accompany it may not always be the same across or within communities. If other factors remain the same, changes may be required in breeding strategies, and explicit evidence of this, to address unpredictable sources of crossover interactions and the consequent risk to some households.

Farmers' Knowledge of Heritability and Implications for Selection

The heritability scenarios were designed to improve understanding of how farmers perceive the influence of V_G and V_E on expression of a particular trait and implications of this for selection. Building on the biological model, a simple interpretation of realized h^2, an estimate of h^2 based on a population's response to selection (Falconer and Mackay, 1996: 197ff.), was used in these scenarios. Based on this, the greater the similarity of the progeny population phenotype to the parental phenotype across different environments, the greater the h^2.

In the scenarios the contribution of V_A was represented by the relationship between phenotypes of maternal and progeny generations (Fig. 2.10). The contribution of V_E was represented by the contrasting growing environments described; a typical, variable field vs. an optimal, uniform field. The null hypothesis was that farmers see a relatively small contribution by V_A to total V_P (low h^2) saying that seeds from plants with a given trait would produce a progeny population with diverse phenotypes of that trait when planted in a typical field, and mostly progeny with the same phenotype as the parents when planted in an optimal field, attributing V_P predominantly to V_E and

Fig. 2.10. Photographs of different coloured tassels and maize ears to represent the seed planted from plants with different coloured tassels, used in scenarios in Oaxaca, Mexico (photo by D.A. Cleveland).

$V_{G \times E}$. The alternative hypothesis was that farmers see the trait as primarily determined by V_A, thus the progeny plants' phenotypes would be the same as the parents' regardless of the field environment. Our hypotheses did not include xenia (the effects of the pollen parent) or of segregation in the formation of progeny phenotypes, although some farmers did mention this. In these scenarios we compared traits known in the literature to have low (Fig. 2.11) and high (Fig. 2.12) average heritabilities relative to each other, and were also traits noted by farmers.

To interpret the findings of the h^2 scenarios requires two nested comparisons at each site that refer to the null hypothesis. First, considering each trait separately, in a typical vs. optimal field, 'Does the *proportion* of responses predicting progeny phenotypes being the same as parental ones differ according to the environment?' The proportion of responses differed significantly from that expected under the null hypothesis for high h^2 traits of tassel (Mexico), husk (Cuba) and seed colour (Syria and Nepal) in a typical environment (Table 2.4). That is, the number of responses foreseeing progeny phenotypes the same as parental ones did not change across environments for those traits, leading to rejection of the null hypothesis, and implying that farmers considered these traits to have high realized h^2. The null hypothesis was, however, accepted based on responses for traits of low average h^2.

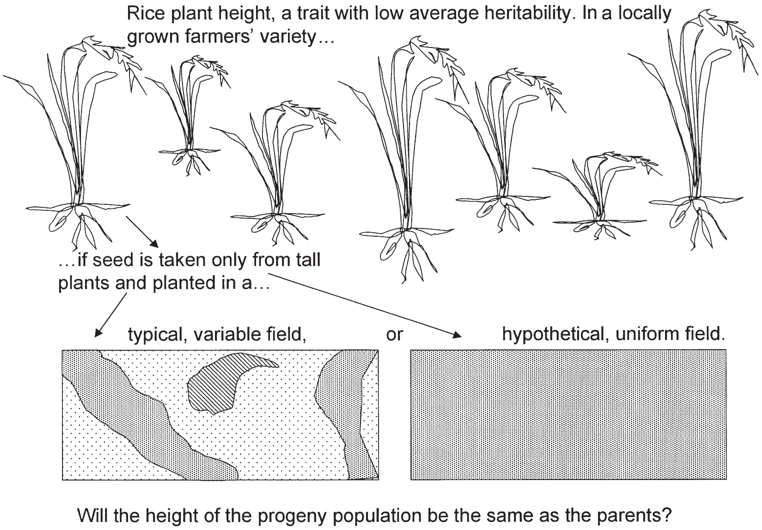

Fig. 2.11. Heritability scenario for trait with low average heritability (rice plant height, from Nepal scenario).

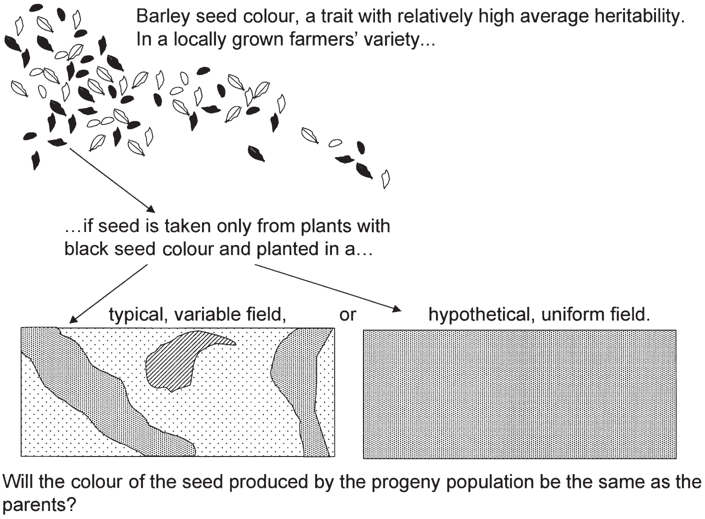

Fig. 2.12. Heritability scenario for trait with high average heritability (rice grain colour, from Nepal scenario).

Across sites most farmers saw V_E as influencing progeny phenotypes for these traits, while a small proportion of responses anticipated a replication of parental phenotypes for traits with low h^2 when sown in a variable environment. A much higher proportion stated that the

Table 2.4. Testing the H_0: Farmers do not recognize the contribution of V_A to V_P. Farmers' perceptions of heritabilities for traits of high and low average h^2 in Mexico, Cuba, Syria and Nepal.

	Percentage of farmers stating that progeny will have same phenotype as parents when grown from seed sown in a/n			
	Trait with low average h^2		Trait with high average h^2	
Site, crop (no. of farmers)	Typical, variable field	Optimal, uniform field	Typical, variable field	Optimal, uniform field
Mexico, maize*	Ear length (< 0.50[a])		Tassel colour** ([b])	
(13)	0	92	70	70
Cuba, maize*	Ear length (< 0.50[a])		Husk colour** ([b])	
(31)	3	97	77	71
Syria, barley*	Plant height (0.62[c])		Seed colour** (0.90[c])	
(36)	8	86	69	69
Nepal, rice*	Plant height (0.85[d])		Seed colour** ([e])	
(10)	0	100	100*	100

[a] Hallauer and Miranda (1988).

[b] Published h^2 values not available, many pigmentation traits of maize have been used as easy to observe genetic markers, and as such are considered to have relatively high h^2 (Coe and Neuffer, 1988: 135).

[c] Rasmusson (1985).

[d] Calculated from Sthapit (1994).

[e] Not available.

*Fisher's exact test of independence of farmers' response distributions for high vs. low average h^2 traits in a typical field, $P \leq 0.001$.

**Fisher's exact test of independence of farmers' response distributions for similarity between parental and progeny phenotypes for the same trait in typical vs. optimal fields, $P \leq 0.001$.

parental population's phenotype for the same trait *would* be replicated in a uniform environment, that is V_E and perhaps $V_{G \times E}$ make a larger contribution to V_P than does V_A.

The second comparison was between responses for the two traits (high vs. low h^2) at one site, asking, 'Does the *pattern* of response differ?' The answer here was clearly 'yes'; the pattern of responses regarding those two types of traits was significantly different at all sites (Table 2.4).

While the h^2 scenarios are based on a number of assumptions that we are continuing to clarify, the results have yielded some useful insights. In all locations the traits of high average h^2 are ones that at least some farmers have manipulated via selection, implying an awareness of an aspect of V_P similar to what V_G represents in SK. The low h^2 traits are all ones farmers stated as criteria they use to define a desirable crop; for example, long maize ears in Mexico and Cuba, moderate (neither tall nor short) plant height in Syria and Nepal. However, despite using ear length as a criterion in their selection, farmers in Mexico (Soleri and Cleveland, 2001) and Cuba did not expect a response to this selection in the form of an increase in the frequency or magnitude of that trait. In Mexico this may be explained by farmers selecting large ears to ensure the quality of their planting material (large, heavy kernels), not for cumulative genetic improvement of their crop population.

Simple and self-evident as this may seem, it took us 3 years of interviews, selection exercises, participant observation and field trials to reach this understanding! We had initially shared the assumption underlying most plant breeding, that conscious human selection for yield-related traits has directional population change as its primary goal (Simmonds, 1979). However, the evidence that ear length is a primary selection criterion (from interviews, participant observation and selection exercises) was inconsistent with the results anticipated by farmers (from interviews and participant observation) and confirmed in our field trial (Soleri *et al.*, 2000). Responses to the h^2 scenarios and other questions offered a different perspective (Soleri and Cleveland, 2001). Responses to the h^2 scenario for ear length in Mexico suggested to us that farmers saw that trait to be overwhelmingly the result of the growing environment. If they recognize a genetic component for ear length, it was not evident in the interviews, and farmers do not believe that they can make lasting changes in their varieties by selecting seed based on ear length. Instead, farmers appear to value ear size because of its correlation with seed size (e.g. as 100 grain weight, $r = 0.32$; Soleri, 1999) and their perception (conscious or unconscious) that large seed size is in turn positively correlated with such traits as seed quality and seedling vigour (Fig. 2.13).

One reason for the difficulty we and others may experience in understanding farmers' selection could be the result of our assumptions about farmers' and plant breeders' seed systems. A fundamental difference between them is that in farmers' systems genetic resources conservation, crop improvement and seed production functions are all accomplished primarily within the same seed lots or local populations, whereas in plant breeders' systems these functions are spatially and temporally distinct (Soleri and Smith, 1995; Smale *et al.*, 1998). It seems likely that in farmers' systems some functions take precedence over others at different times depending on both socio-economic and biophysical circumstances. Outsiders operating under the assumptions

Fig. 2.13. Delfino Jesus Llanez Lopez performing selection exercise on a sample of 100 ears from a study plot in one of his fields, Oaxaca, Mexico. (Photo by D.A. Cleveland, used with permission of subject.)

of formal plant breeding systems may have difficulty seeing the possibility of alternative functions for practices such as selection.

Farmers' Expectations for Response to Selection

Over time, selection of plants from a heterogeneous population to obtain planting material for the next generation can affect allelic frequencies, and thus response to selection, R. Mass selection appears to be the most common form of selection used by farmers, involving the identification of superior individuals in the form of plants, and/or propagules, from a population and the bulking of seed or other planting material to form the planting stock for the next generation. This approach requires only a single season, and relatively little effort compared with other selection methods (Simmonds, 1979; Weyhrich *et al.*, 1998). If practised season after season with the same seed stock, mass selection has the potential to maintain or even improve a crop population, depending upon the mating system, trait heritability, trait G × E, the selection intensity and gene flow in the form of pollen or seeds into the population.

Surprisingly little research has been done on farmers' selection goals considering their importance for the selection process, especially for farmers in marginal environments (Weltzien *et al.*, 1998). The implicit assumption has often been that farmers must be attempting directional selection for quantitative, relatively low h^2 traits like yield, the main goal of plant breeders. However, there appear to be relatively few data demonstrating that farmers have directional selection for quantitative traits as a conscious goal, in contrast with data on farmers' conscious choice of new varieties.

Though not necessarily constant in its response from one generation to the next, and with a diminishing rate of change over generations due to reductions in both V_P and h^2 (Falconer and Mackay, 1996: 201ff.), in plant breeding directional selection is conceived and practised as a cumulative process. This research sought to directly test the null hypothesis that farmers' seed selection was intended to produce cumulative, directional change in their crop population, as assumed for directional selection in formal plant breeding. The alternative hypothesis was that farmers have other reasons for discriminating within their harvest to identify planting material.

Based on results of the h^2 scenarios in Mexico, we created scenarios for work at the other sites to gain greater understanding of farmers' expectations for selection. Beginning in Cuba, a scenario was created presenting a comparison between the results within a subpopulation (identified as S) of typical, farmers' selection using specified selection criteria, and results within a subpopulation (identified as R) of random selection (i.e. a relaxation of all artificial selection pressures). The scenarios specified that R and S were subunits of the same original population in the same growing environment, and that selection occurred in both over the same time period (Fig. 2.14). Farmers were asked 'After 10 years of selection, how would subpopulations R and S compare for yield?' The scenario then described an additional cycle in which artificial selection was used in both subpopulations; S for the 11th year (S_{11}) and R for the first time after 10 years of random selection (R_{10+1}). Again, farmers were asked to compare yields between the progeny subpopulations grown from the seed selected according to this scenario (Fig. 2.15).

The same scenario was adjusted for interviews in Nepal and Syria because at those sites the most common means of identifying planting material from within the entire population is by choosing between field plots planted to the same variety in the former, and by identifying an area within one field from which seeds are obtained in the latter. In the scenarios, typical local selection was compared with a random choice of field plot or area within a field.

Almost all farmers at all sites saw their selection as providing benefits over random selection (Table 2.5, R_{10} vs. S_{10}). However, based on responses to the comparison of S_{11} vs. R_{10+1}, many of them also felt

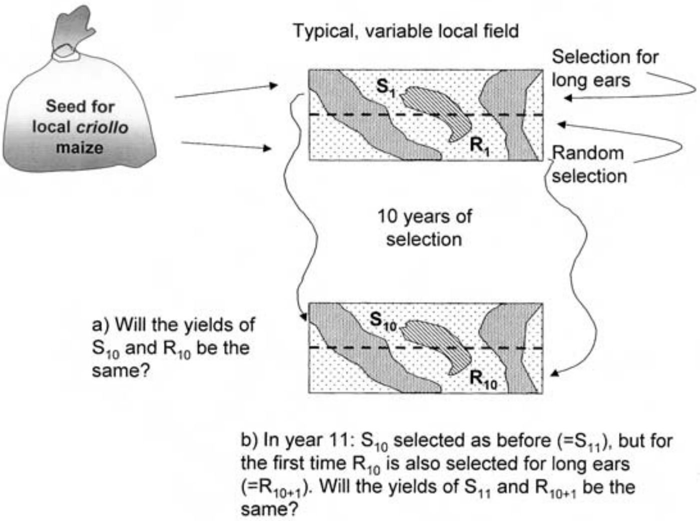

Fig. 2.14. Scenario to understand farmers' expectations for response to selection over time.

that the benefits of selection are not cumulative, since they can be attained in one cycle. Interaction with plant breeders can influence farmers' expectations. For example, in Cuba, 80% of those who did see cumulative benefits from selection were participants in the beginnings of an on-farm PPB project that included presentation of basic plant breeding concepts. However, there are other variables such as age, education, experience with other plant or animal selection that were not considered in this research that may account for the difference in responses to this scenario.

The basis of the responses foreseeing no cumulative change from selection may well differ between and within sites and could include low h^2 due to large V_E and/or small V_G, or lack of effective methods. Identifying reasons for this response seems important both for understanding farmers' practices and goals, but also for detecting impediments to gains from selection, or even why such 'gains' may not be beneficial. For example, in Syria scientists did not have evidence that farmers were aware of intrapopulation selection and its potential benefits (Ceccarelli and Grando, 2000, ICARDA, personal communication). However, discussing a scenario in which they were asked what they would do with a highly variable new barley population including some of the best and worst plants they had ever seen, 43% of those farmers ($n = 40$) stated that they would select the best individuals for planting the following season. Despite the farmers' awareness of intrapopulation selection, based on past experience this is often abandoned after two

Fig. 2.15. Farmer Loreto Mederos explains his perception of scenario outcomes to Humberto Ríos Labrada in La Palma, Cuba. (Photo by D. Soleri, used with permission of subjects.)

Table 2.5. Farmers' expectations for response to selection.

Location, crop (no. of farmers)	Percentage of farmers stating that the yield of $R_{10} > S_{10}$	Percentage of farmers stating that the yield of $R_{10+1} \geq S_{11}$
Cuba, maize (29)	3	59
Syria, barley (20)	0	45
Nepal, rice (10)	0	90

R_{10} = population randomly selected in the local growing environment for 10 consecutive years.
S_{10} = population intentionally selected in the traditional, local manner and environment for 10 consecutive years.
R_{10+1} = population randomly selected in the local growing environment for 10 consecutive years and then intentionally selected in the traditional, local manner and environment for 1 year.
S_{11} = population intentionally selected in the traditional, local manner and environment for 11 consecutive years.

cycles because progeny are not true to type. If presented with more advanced segregating populations these farmers might be motivated to make greater use of their knowledge of the benefits of individual plant selection.

Farmers' perceptions of the potential to improve their populations via selection – and thus their selection expectations and goals – will probably be influenced not only by their understanding of genetic variation in the population and h^2 for traits of interest, but also of alternative uses of their time and labour. If they do not believe population improvement to be possible or cost-effective, one alternative may be to choose different varieties or populations or infuse their own varieties or populations with new genetic variation as has been documented for maize farmers in Mexico (Louette *et al.*, 1997).

Conclusion

Approach to knowledge in CPB

Do farmers have a conceptual knowledge of critical issues concerning the relationships between their crop genotypes and growing environments and, if so, is that congruent with scientists' knowledge of those same issues? Testing this hypothesis is central to our research and exploration of knowledge in relation to application in CPB. There are two major points suggested by the findings to date.

First: Do farmers have *conceptual* knowledge and is it *congruent* with SK? Although these findings do not conclusively affirm our central hypothesis, they are in no way inconsistent with it. They suggest the presence of a conceptual component in farmers' knowledge of relationships between their crop genotypes and growing environments. That this component is in some ways congruent with scientists' knowledge is supported by their ability to understand and answer scenario questions about abstract ideas such as $G \times E$, h^2 and R. It is also supported by the explanations presented by some for their responses that corresponded in many ways to plant breeders' expectations regarding varietal performance across environments (e.g. Figs 2.7 and 2.8). Indeed, interpretation of these findings – though ongoing – is facilitated by some plant breeders' analyses of their own knowledge, in terms of theory, interpretation, intuition and practice (Bänziger and Cooper, 2001; Duvick, Chapter 8; Ceccarelli and Grando, Chapter 12, this volume).

Second: Why are there *differences* and *similarities among* farmers and *between* farmers and scientists? These findings indicate that farmers' conceptual knowledge is partially defined by context. As with formally trained researchers, it appears that most farmers base their understanding of V_G and h^2 on their own experiences. That is, differences in knowledge may be more the result of differences in crops, environments and sociocultural variables, rather than in knowledge of basic biological relationships. For example, farmers' perceptions of the potential for qualitative G × E (Table 2.2) may be at least partially attributed to the mating system of the crop and the growing environments they are working in. Farmers' responses to h^2 scenarios (Table 2.4) may not always deny the presence of V_G in their populations for traits of low average h^2, but reflect their unfamiliarity with optimal growing environments and indicate the overwhelming influence of V_E in local fields, obscuring V_G in low h^2 traits (Fig. 2.16a). Similarly, it has been suggested that the interpretations of theory underlying some plant breeders' practices reflects their experiences (Ceccarelli, 1989, 1996; Cleveland, 2001). For example, contrasting assumptions among plant breeders regarding appropriate selection environments for highly stress-prone target environments have been attributed to contrasting experiences with range and type of V_E, affecting the likelihood of anticipating the G × E interactions that might occur in the marginal fields of many farmers (Fig. 2.16b).

Thus, FK can be congruent with the basic biological model, and thus generalizable, and at the same time be in conflict with the basic

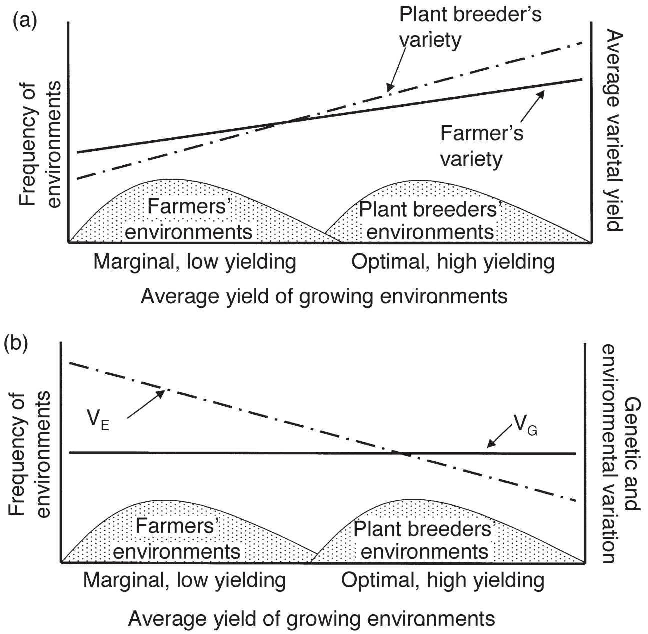

Fig. 2.16. Graphic representation of the hypothesis that both farmers' and plant breeders' knowledge may be contextual. (a) Range of V_E experienced limiting plant breeders' observation of G × E and affecting their interpretation of theory. (Partially based on Ceccarelli, 1989.) (b) V_E in their fields limiting farmers' perception of V_G for low h^2 traits.

biological model, and be locally specific. This is similar to the situation with scientific plant breeding (Cleveland, 2001; Cleveland and Soleri, 2002). What is often not appreciated is the extent to which scientists think that their practice is the result of applying grand theory, when in fact practice may be based on heuristics developed for their particular circumstances and may not be generalizable. Very few plant breeders have specifically questioned the extent to which accepted conventional practice, generally believed to be based on grand theory and thus generalizable to farmers' contexts, is actually based on context-specific heuristics, thus not necessarily generalizable to all contexts (Ceccarelli and Grando, Chapter 12, this volume).

Methods

This discussion of our ongoing research demonstrates the development and use of a method for understanding farmers' conceptual plant breeding knowledge. While much remains to be investigated, we feel that the results to date show that the scenario methodology, even when applied to a small sample of farmers, can provide information concerning FK that is relevant and useful for CPB. The fundamental elements of this methodology, the holistic model of knowledge and the basic biological model, each contribute to its utility. The holistic model of knowledge proposes a perspective focused on the components of knowledge and their similarities and differences. In so doing it avoids essentialisms, instead supporting inductive investigation of those components. The basic biological model provides a valid comparator for exploring knowledge of farmers and plant breeders about empirical relationships between their crop populations and their environments. As such, it creates a common ground on which issues fundamental to plant breeding can be discussed and locally relevant solutions sought.

Implications for collaboration

This research suggests three ways that understanding farmers' conceptual knowledge can be useful for CPB. It can:

1. Demonstrate to outside researchers that farmers do indeed have a conceptual basis for their choice and selection practices and that, therefore, their role in CPB can be more substantive and central than had been previously thought, regardless of the actual strategies that are chosen.

2. Alert outside researchers to issues they may be unaware of, assumptions that may be incorrect about environments, genotypes or farmers' interests, e.g. scales of V_E influencing varietal choice, desirability of HRV vs. stable varieties, knowledge of and experience with within-population plant selection.
3. Inform researchers of perceptions of farmers that underlie practices; e.g. why certain things are done (as with selection in Mexico, Cuba and Syria), and so offer opportunities to discuss, investigate and improve those practices. Similarly, this approach may be useful in other fields such as soil management and conservation biology.

In addition, the application of the methodology we have outlined can provide new insights into the differences that exist among plant breeders, often resulting in very different interpretations and applications of plant breeding theory. In so doing this approach may help to elucidate problems in applying SK to CPB.

What do points 1–3 imply for how farmers and scientists can work together? The distinction between 'functional' and 'empowering' participation may be less relevant when using a holistic model of knowledge, since social and biological benefits of collaboration would be expected to be more synergetic (see Ceccarelli *et al.*, 2000; Ceccarelli and Grando, Chapter 12, this volume).

This approach suggests an alternative to common uses and measures of FK in participation, a change from a quantitative to a qualitative emphasis. A *qualitative* approach means that the source, amount and other aspects of ideas and effort are not the defining characteristics of participation. This relationship would be present regardless of the specific strategy or level of physical involvement of either farmers or breeders. A qualitative approach might foster a relationship between farmers and plant breeders characterized by ongoing substantive interaction including discussion of the conceptual basis of plant breeding practice, mutual respect and the common goal of meeting local needs. Achieving such a relationship will probably require deeper understanding of farmers' and plant breeders' knowledge and the similarities and differences between them. Testing ideas on the *conceptual* content of FK, and on similarities and differences between the knowledge of farmers and scientists is a new area of research opening up new possibilities for PPB and other activities.

There is a small but increasing number of crop improvement projects worldwide in which perceptive breeders have included farmers' participation to attain positive results and in some cases unprecedented successes (e.g. Bänziger and de Meyer, Chapter 11; Ceccarelli and Grando, Chapter 12; Joshi *et al.*, Chapter 10, this volume). The research reported here in no way detracts from those successes, and indeed has had the benefit of many insights provided by them. The empirical results of these projects demonstrate that significant results can be obtained in PPB that are not based on results of research on the theoretical component of FK.

However, it may be that the results of the projects just mentioned depend in an important, but undocumented way, on the personalities of the scientists involved (Ceccarelli *et al.*, 2000; Friis-Hansen and Sthapit, 2000), which has contributed to their willingness to try new approaches, including listening to farmers, and rethinking the application of basic plant breeding theory in terms of farmers' circumstances. Indeed, they may have already, at an informal or even unconscious level, incorporated many insights into farmers' theoretical knowledge into their work. Therefore, if the methodology we are testing is adequately robust and adaptable, it could provide a means to enable more scientists to approach their plant breeding challenges with the perceptiveness of those already successful practitioners.

We are suggesting the exploration of a new approach to participation that appears to have potential, but which has not been applied systematically over the long term; this is the next step. The results reported in this chapter are based on small samples and further testing and methodological development is required and will undoubtedly provide new or different insights. Still, these findings suggest the value of expanding this applied research within CPB projects to facilitate practical results. An approach to collaboration that includes conceptual contributions and interactions from both farmers and scientists appears to have the potential of increasing both biological and social effects, and thus, hopefully, realizing some of the real benefits collaboration has to offer.

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