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# Participating in Development

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Approaches to indigenous  
knowledge

Edited by Paul Sillitoe,  
Alan Bicker and Johan Pottier



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# Indigenous and scientific knowledge of plant breeding

## Similarities, differences and implications for collaboration

*David A. Cleveland and Daniela Soleri<sup>1</sup>*

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Indigenous or local knowledge and modern, scientific knowledge have become increasingly separated in the process of modernization, and have often been assumed to be fundamentally different. In a world with unprecedented human impact on the environment, characterized by biophysical and sociocultural globalization, both the necessity of this separation and the assumption of fundamental differences need to be problematized. The question of how similar or different scientific knowledge and indigenous knowledge are, and how they might work together to help solve the problems of ‘development’, has immense practical and ethical implications. It also has immense theoretical importance – for better understanding the relationship between knowledge, action and environment (the world of things and actions outside of the mind) has the potential for improving the efficiency of consciously directed (teleological) human adaptation, for example for ‘sustainable’ interventions. It can help us to discriminate the general from the particular, an essential prerequisite for policy at all levels. At the same time, an important test of theory is its practical efficacy – the results of its application to understanding and solving human–environmental problems.

We illustrate the potential of theory-based investigation of indigenous and scientific knowledge by comparing the knowledge and practice of small-scale maize farmers in Oaxaca, Mexico, with that of scientific maize breeders, using a holistic theory of knowledge and basic plant breeding theory. We focus on knowledge of heritability of maize traits as determined by interaction of genotype and environment, a fundamental concept in biology (often discussed in anthropology as ‘nature versus nurture’), and the relationship between this knowledge and the practice of plant breeding. We ask two main questions. First, to what extent are farmers’ and plant breeders’ knowledges and practices similar or different regarding maize *genotypes* (varieties, populations and plants) and *growing environments* (fields, selection and test plots)? Second, how can answers to the first question contribute to the process of collaboration between farmers and plant breeders, with the goal of developing varieties that better fulfil farmers needs?

## **The problem: scientific maize breeding and local farmers**

Many people continue to go hungry in the world even though enough food is produced to prevent hunger if it is adequately distributed. The huge increases in yields and production necessary to have kept up with a rapidly expanding population are commonly attributed to modern, scientific agriculture and plant breeding that has taken place largely in optimal growing environments. In many areas where there are food shortages, food is produced by small-scale farmers who continue to practise traditionally based agriculture. Given the eventual limits to food production in optimal environments, the negative environmental effects of industrial agriculture, the political and economic costs of food distribution, and the desire of many local communities to maintain their farming identity and independence, it is likely that much of the increase in food production needed adequately to feed people in marginal areas must come from those areas (Heisey and Edmeades 1999). There is increasing concern to improve the yields of these farmers by making plant breeding more appropriate to their needs (Evans 1998; Mann 1999).

### ***Indigenous and scientific plant breeding***

Plant breeding includes both (1) the development of new varieties through artificial selection of plants by farmers and breeders within segregating plant populations, which changes the genetic make-up of the population, and (2) the choice of germ plasm that determines the genetic diversity available within a crop as the basis for selection, and the choice (by plant breeders) of which varieties to release and (by farmers) of which varieties to plant (Cleveland *et al.* 2000). Since the first domestication of wild plants about 12,000 years ago, farmer plant breeders have been responsible for the development of thousands of crop varieties in hundreds of species (Harlan 1992). Plant breeding as a specialized activity began about 200 years ago in industrial countries, and modern scientific plant breeding developed in the early part of the twentieth century, based on Darwin's theory of evolution through selection, and on the genetic mechanisms of evolution elucidated by Mendel and others (Allard 1999; Simmonds 1979).

For the last 200 years scientific plant breeding has become increasingly separated from plant breeding by farmers (Simmonds 1979). The emphasis of modern, scientific plant breeders (hereafter simply *plant breeders*), has typically been on developing *modern varieties* (MVs) adapted to *optimal* (relatively uniform, low stress), geographically widespread growing environments, and giving high yields in these environments (Evans 1993; Fischer 1996). While they have also given attention to breeding for stress tolerance, this attention has focused on stresses in relatively large-scale, optimal environments, and on commercial farmers who can afford to purchase seed, not on the farmers who

are the topic of this chapter (Bänziger *et al.* 1999; Ceccarelli *et al.* 1994; Heisey and Edmeades 1999). This contrasts with plant breeding by farmers, especially small-scale farmers in *marginal* (relatively variable, high-stress) growing environments with limited access to external inputs (hereafter simply *farmers*). These farmers often grow *farmers' local varieties* (FVs), which are usually assumed to have more narrow geographical adaptation to specific marginal growing environments, giving moderate yields in those environments (Harlan 1992; Zeven 1998).

## Maize

As with other major grain crops, high-yielding maize MVs have been bred for relatively optimal environments across wide geographic areas, and are relatively lacking in genetic diversity – only limited work has been done on breeding for the marginal environments of many small-scale farmers where yields are relatively low (Smith and Paliwal 1997).

Mexico is the centre of maize domestication and diversity, and is also the home of the Green Revolution approach to plant breeding in wheat and maize, developed at the International Maize and Wheat Improvement Centre (CIMMYT). This approach is characterized by the transfer of industrial agriculture to the Third World based on MVs (Simmonds 1990). Although in Mexico 222 maize MVs have been released by the public sector during 1966–97, and 155 private-sector MVs were available in 1997, 77 per cent of maize area is planted to FVs, with relatively low yield (2.3 Mg/h) (Morris and López Pereira 1999). In the southern Mexican state of Oaxaca, 93 per cent of maize area harvested in 1990 was under FVs (Aragón Cuevas 1995). Grain yield in Oaxaca during this period averaged 0.8 Mg/ha (INEGI 1996: 32), 40 per cent of the average yield for Mexico as a whole, and 21 per cent of the world average (Figure 10.1).

The reasons for the low adoption rate of maize MVs given by researchers, and their implications for farmer and scientist knowledge, differ greatly. They tend to emphasize the farmers, the economic system, the environment and plant breeders: (1) a lack of farmer knowledge, for example that farmers are 'only dimly aware of the potential benefits of improved germ plasm and crop management practices', and lacking the education and skills needed to manage MVs 'properly' (Aquino 1998: 249); (2) a lack of appropriate economic profit incentive for farmers due to exogenous 'technical, economic, institutional, and political factors' (Morris and López Pereira 1999); (3) the marginal growing environments (drought stress, low soil fertility, low level of inputs such as irrigation and fertilizers) of small-scale farmers in Mexico (de Janvry *et al.* 1997; García Barrios and García Barrios 1994), who cultivate most of the land planted to this crop; and (4) lack of appropriate plant breeding, that is MVs have generally not been targeted on these farmers (and

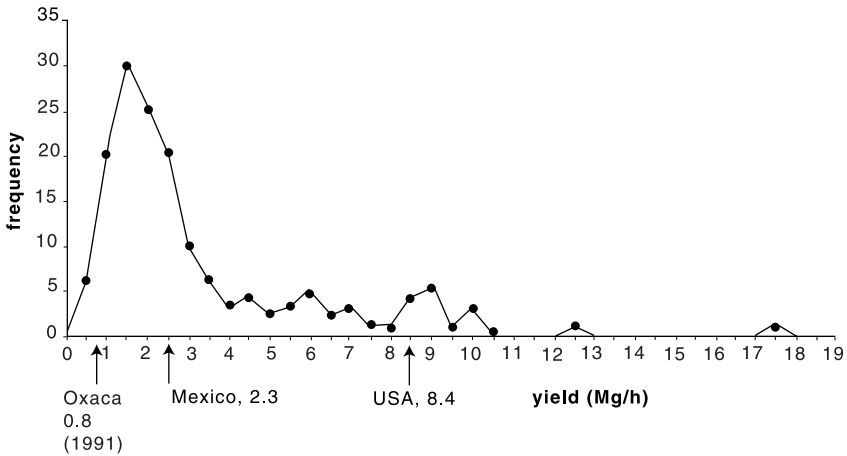


Figure 10.1 World maize yields by country, 1999

Graph based on data from FAO 2000

Note:  $n = 158$

may, therefore, produce lower yields than FVs) (Aquino 1998; Heisey *et al.* 1998; Heisey and Edmeades 1999).

### Comparing local and scientific knowledges as the basis for collaboration

The recent development of modern, scientific plant breeding, and its separation from farmers has resulted in a great divide between the maize breeding and production of small-scale farmers growing FVs in marginal environments (which is largely unknown to most plant breeders), and maize breeding programmes which are directed towards production by larger-scale farmers growing MVs in relatively optimal environments (largely unknown to small-scale farmers in marginal environments).

The first step in a comparison of indigenous and scientific knowledge is necessarily a definition of 'knowledge'. We define 'knowledge' as the non-genetic information possessed by an individual, as distinct from action or practice, though it can only be observed as expressed in behaviours or practice (including speech and writing) (Cleveland 2001). We define 'epistemology' as the process by which stimuli from the external physical world (e.g. from stars, wheat plants, yield trial data, journal articles, a colleague's or neighbour's verbal comments) are first received and then processed into physical patterns

within a person's brain, which may subsequently be perceived subjectively as knowledge, or may remain as unconscious knowledge. This process is influenced by the biological structure and function of the brain, the technologies and practices used, and by pre-existing knowledge, as well as by the particular portion of external reality the individual experiences. Knowledge is shared to a greater or lesser degree within groups of different sizes to which individuals belong. Defined in this way, knowledge is similar to common concepts of culture in anthropology, which exists at the individual level and is shared to varying degrees with others (see, for example, Brumann 1999 and accompanying comments).

### ***Indigenous knowledge as locally constructed skill versus scientific knowledge as generally verified theory***

Many anthropologists and other social scientists often contrast scientific and indigenous knowledge in ways that seem to essentialize them, seeing the former as rationalistic, reductionist, theoretical, generalizable, objectively verifiable, abstract and imperialistic, in sharp contrast to the latter, which is seen to be organic, holistic, intuitive, local, socially constructed, practical and egalitarian (Escobar 1999; Scott 1998: 340). Ingold, for example, argues that indigenous knowledge is acquired through the process of 'enskillment', rather than through conscious conceptualization (Ingold 1996a, 1996b). Scott sees the 'basic procedure' of scientific plant breeding as 'exactly the reverse' of that of indigenous farmers, who are seen to have a much more complete and sophisticated understanding of objective reality in the development of their crop varieties, whose plant breeding knowledge he characterizes as 'craft', practice or 'mētis' (Scott 1998: 302, 340). Sillitoe sees indigenous knowledge as 'conditioned by sociocultural tradition, being culturally relative understanding inculcated into individuals from birth, structuring how they interface with their environments' (Sillitoe 1998b: 204), and as being more a 'skill' than conceptual, and as 'contingent and often local, not systematised and universal' as is scientific knowledge (Sillitoe 1998a: 229).

A closer reading of the literature suggests we need to reconsider these common anthropological ideas on empirical grounds and because they may impede theoretical understanding of knowledge, and potential collaboration between indigenous people and scientists (Agrawal 1995). It seems prudent to make as few *a priori* assumptions as possible, and formulate hypotheses about scientific knowledge and indigenous knowledge that can be empirically tested.

The universal as opposed to local nature of indigenous knowledge has been argued both from an evolutionary biological viewpoint, for example in terms of adapted epistemologies (Cosmides and Tooby 1996), and from an empirical viewpoint, as in the many studies comparing indigenous and scientific taxonomies of plants and animals (Berlin 1992). While many farmers' complicated practices observed by outsiders may appear to be untheorized

responses to changing and unpredictable circumstances, concluding that indigenous knowledge is 'practice', this begs the question of the mental basis of behaviour, and equates farmers' inability to verbalize this basis to naive outsiders with the absence of theoretical understanding. As with scientific knowledge, theory and intuition are not mutually exclusive.

Indigenous and scientific knowledge also appear to be similar in being composed of different types of knowledge (substantive or empirical, formal or normative, theoretical or deductive, and intuitive or unconscious). Ellen reviews the results of research on subsistence of rainforest peoples, including his own with the Nuaulu of Seram, eastern Indonesia, in terms of their knowledge of nature. He concludes that observations of 'particular instances' (substantive knowledge of many individual species) leads inductively to 'knowledge of general principles', and in knowledge transmission these 'overarching deductive models of how the natural world works are privileged over accumulated inductive knowledge' (Ellen 1999: 106). These models (or theories) function at a macro-scale as a 'folk synecology', for example in connecting observations at the species level with forest structure and dynamics (Ellen 1999: 107).

We define theories as generalizable (not necessarily universal) concepts about the way things in the world relate to each other, including causal relationships, on which predictions and action can be based (c.f. Hull 1988: 485; Medin and Atran 1999: 9). According to some philosophers of science, 'Theory-free observation languages and classifications are impossible' (Hull 1988: 485). There is no such thing as a purely observational term, since our descriptions of our observations are necessarily affected by theory, and apparently non-theoretical terms such as 'animal' and 'dorsal' are theory-laden (Hull 1988: 8).

Limited theoretical understanding due to epistemological limitations (e.g. lack of microscopes) does not mean that conceptual indigenous knowledge cannot be the basis for effective practice. For example, Trutmann *et al.* (1996: 68) show that while farmers have 'no concept of the biological causes of individual diseases', their 'functional explanations for putrefaction' developed from 'thinking through their observations in their own cultural idioms' and result in management practices that are effective in reducing loss of yield from disease (Trutmann *et al.* 1996). However, this does not mean that these farmers' knowledge may not be theoretical, because all theory, including Western scientific theory, is always partial, and because operationalizing theoretical concepts always leave things out; they could not function unless they did (Hull 1988: 485).

On the other hand, scientific knowledge, like indigenous knowledge, can also be culturally relative, 'local' knowledge. Agrawal points out that criticisms of the failure of science-based approaches to Third World development on the grounds that they 'ignored the social, political and cultural contexts in which they were implemented' suggest that 'it is likely that the so-called technical



solutions are just as firmly anchored in a specific milieu as any other system of knowledge' (Agrawal 1995: 425). Dove suggests that indigenous knowledge and scientific knowledge may also be alike in their limited ability to comprehend complex natural phenomena (Dove 1996). Work by social scientists, historians and philosophers on the nature of scientific knowledge since the 1920s has explicitly explored the role of personal psychology, historical contingencies and social context in its production (Giere 1999).

Perhaps one reason for the continued resistance by many social scientists to attempts to explore possible similarities between indigenous knowledge and scientific knowledge is that, if they are found, it will inevitably lead to the privileging of scientific knowledge (Sillitoe, this volume). The dominance of scientific knowledge in development projects based on assumed similarities between them (e.g. Sherwood 1997) continues the tradition of privileging scientific knowledge based on modernist ideas of differences between indigenous knowledge and scientific knowledge. It may be that many proponents of indigenous knowledge as different (and 'better') than scientific knowledge are using an essentialist definition of science similar to that of some advocates of positivist science. This definition ignores current research in social studies of science and the writings of scientists themselves, resulting in a situation similar to that in anthropology, where erroneous assumptions about the role of positivism in science cause some anthropologists to reject the notion of a 'science' of anthropology (Roscoe 1995).

### ***Beyond participation: possibilities for collaboration***

The deepening global human–environmental crisis has led to a sense of urgency in understanding the possible contribution of both indigenous knowledge and scientific knowledge to solutions. Nader, for example, writes that 'globalisation renders the search for a more balanced, indeed more scientific, treatment of disparate knowledge systems inevitable' (Nader 1996: 6–7). Sillitoe also sees indigenous knowledge as being able to challenge and thus advance scientific understanding of natural processes (Sillitoe 1998a: 227), and suggests the 'need to develop a coherent indigenous knowledge intellectual framework to interface effectively with Western science' (Sillitoe 1998b: 215, n.4). Yet, contrasting views of indigenous knowledge and scientific knowledge in an essentialized way make it difficult to conceive of the possibility of collaboration between indigenous peoples and scientists in the sense of mutual sharing of ideas. Scott, for example, sees farmers as capable of incorporating the results of scientists' 'epistemic work', but sees science incapable of acknowledging or including farmers' practice (Scott 1998: 304), and Sillitoe sees as problematic the possibility that 'local people can frame their problems in a manner intelligible to scientists', and that 'Science determines its own research agenda' based on 'models it used to understand the world' (Sillitoe 1998a: 230, 232).

Collaborative plant breeding (often referred to by its acronym, CPB, and also known as participatory plant breeding, PPB) has emerged in the last decade as a popular focus of development, with major initiatives, for example by the Consultative Group on International Agricultural Research (CGIAR) and several of its Centres (CGIAR 1997) and by the Community Biodiversity Development and Conservation programme (CLADES *et al.* 1994). Collaborative plant breeding is based on the critical assumption, often unexamined, that plant breeders' and farmers' knowledge is compatible.

However, most of the research on plant breeding has been done either (1) by social scientists focusing on the social aspects, who have not used biological theory or an empirical understanding of biophysical reality, or (2) by plant breeders and biologists focusing on the biological aspects, who have not used social theory or an empirical understanding of social reality and knowledge. The result is that little is known of plant breeding indigenous knowledge in relation to scientific knowledge. A review of key articles suggests that the data needed to address questions about farmer plant breeding (knowledge, practice, results) in terms of biological theory are often scant or non-existent, and that the answers to these questions that do exist in the literature are often very different, even contradictory, and may be based on unexamined and unrecognized assumptions (Cleveland *et al.* 2000). As a consequence, many collaborative plant breeding efforts appear to emphasize either the biological aspects of plant breeding, for example the transfer of technology, or the social aspects, for example empowering farmers (McGuire *et al.* 1999), with little integration of biological and social issues, theoretically or empirically.

For example, a four-level taxonomy of participation (contractual, consultative, collaborative and collegial) developed by Biggs (1989) is commonly used as a measure of participation, and reflects what many see as its goals. Participation is defined quantitatively, primarily by physical effort on the part of farmers; that is, the greater farmers' efforts the more they are participatory, and therefore the greater the impact in terms of social goals such as equity and empowerment. However, social goals may in fact be relatively independent of biological goals. For example, the introgression of alleles conferring disease tolerance into a local variety may produce biological and social benefits with no farmer participation, and farmer participation in improving mass selection may increase the self-esteem of local farmers, but have no biological benefits. An alternative is to consider 'participation' qualitatively, as a relationship between farmers and plant breeders characterized by ongoing interaction including discussion of the conceptual basis of plant breeding practice, mutual respect and the common goal of meeting local needs. This relationship could be present regardless of the specific plant breeding strategy or level of physical involvement of either farmers or breeders. Such a relationship may well require deeper understanding of similarities and differences between farmers' indigenous knowledge and plant breeders' scientific knowledge.

## Methods

In exploring the nature of indigenous knowledge and scientific knowledge of plant breeding, we have used a naturalistic and holistic model of knowledge combined with a basic biological model of plant breeding (discussed below) to analyse farmers' knowledge of their maize varieties in Oaxaca, compared with maize breeders' knowledge.

### ***A holistic, naturalistic approach to scientific knowledge and indigenous knowledge in plant breeding***

The goal of our research is to find a way to compare conceptual (theoretical) scientific knowledge with indigenous knowledge by literally integrating social and biological theory. It requires collaboration between natural and social scientific disciplines that has been seen as necessary by others to further indigenous knowledge research (Sillitoe 1998b: 216). We start with the biological model that informs plant breeding theory and practice because it is accessible to us, a part of our culture, and because it appears to have a high level of objective accuracy and intersubjective validity, i.e. it appears to refer to an empirical reality that both farmers and scientists experience. In addition, at the level of classification of biological organisms, there appears to be a fairly high level of correlation between local and scientific systems, implying a common conceptual basis (Berlin 1992; Boster 1996). However, we assume that there is also indigenous knowledge of plants and growing environments that may be quite different from that of scientists, and may not be amenable to explanation in parallel scientific terms.

We use both a holistic theory of knowledge and plant breeders' biological theory as our theoretical base for achieving increased understanding of farmer and plant breeder knowledge of the relationship between crop plants and their growing environments. This is a simple model of the relationships between objective biophysical and social reality, epistemology, knowledge, practice (behaviour) and the effects of practice on biophysical reality, using terms and concepts found in the current literature (Figure 10.2).

We take a *holistic* approach, a middle ground between the objectivist (positivist, utilitarian, internalist) and constructivist (relativist, intellectualist, externalist) perspectives (Cleveland 2001). While the ideal of a 'holistic' approach has a long history in anthropology (and other disciplines), the current debate over indigenous and scientific knowledge seems to us to have strayed far from this ideal. The 'science wars' and the debate in the social studies of science about the superiority of internalist versus externalist approaches is also testimony to lack of a holistic approach.

As a result, a holistic approach is being advocated to counter the polarized divide in theoretical approaches to knowledge and practice in social studies of science (Bourdieu 2000; Harding 1998; Hull 1988), anthropology (Ellen 1996;

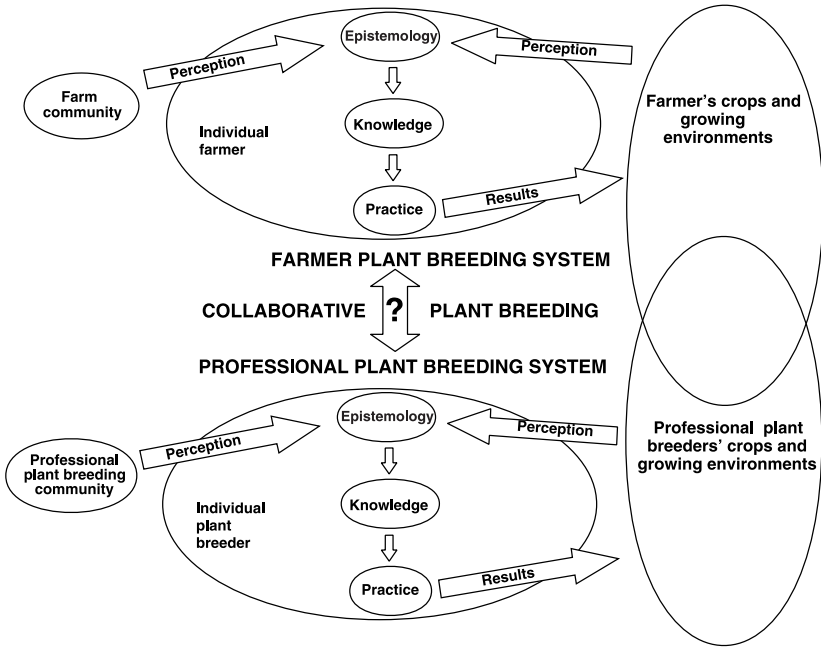


Figure 10.2 A holistic model of plant breeding knowledge

Schweizer 1998; Sillitoe, this volume), ethnobiology (Medin and Atran 1999) and natural sciences (Gould 2000). It sees scientific knowledge *and* indigenous knowledge as both constructed by epistemological processes influenced by social and historical factors which affect, for example, values and technologies. On the other hand, it also sees scientific knowledge *and* indigenous knowledge as a reflection of both the general patterns, and the local and individual variations of biophysical reality and of human cognition (Boster 1996). The result is a complex ‘knowledge’ which requires empirical investigation to understand its origins, nature and relationship to practice in any particular case.

Epistemology is defined in our model as the process by which stimuli from the external physical world (e.g. from maize plants, a journal article, a planting song, a colleague’s or neighbour’s verbal comments) are first received and then neurologically processed into physical patterns within a person’s brain that are subsequently perceived subjectively as knowledge. This process is influenced by the biological characteristics of the individual, by the technologies and actions employed by the individual, and by pre-existing knowledge.

**Plant breeders’ biological model**

As a framework for comparing farmer and plant breeder knowledge and practice we use the basic biological theory of evolution and development (e.g.

Falconer 1989), which is the explicit basis of modern scientific plant breeding (Allard 1999; Simmonds 1979), and underlies plant breeders' understanding of even the most complex phenomena they encounter (Cooper and Hammer 1996; DeLacy *et al.* 1996).

The core of biological theory and practice in plant breeding is the relative contribution to individual phenotypes (phenotypic variation,  $V_P$ ) of the genotype (genetic variation,  $V_G$ ), the environment (non-genetic or environmental variation,  $V_E$ ), and genotype-by-environment ( $G \times E$ ) interaction. Thus, we have the equation ( $V_P = V_G + V_E + V_{G \times E}$ ).  $V_{G \times E}$  represents the degree to which genotypes behave consistently across a number of spatial or temporal environments. Quantitative  $G \times E$  is characterized by marked changes in performance with changes in environmental factors. Qualitative  $G \times E$  between two or more varieties is often referred to as a 'crossover' because in the commonly used regression analyses, the regression lines for yield (or other traits) cross over at some point (see Figure 10.7, below). Heritability ( $H$ , described here in the broad sense) is the proportion of  $V_P$  due to  $V_G$ , ( $V_G/V_P$ ). Traits with high average  $H$  vary less with variation in the environment than traits with low average  $H$ . Heritability is a major determinant of the response to selection ( $R$ ), which, for a specific trait, is the difference 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,  $H$  and  $S$  ( $R = HS$ ), where  $S$  is the selection differential, the difference between the mean of the whole population from which the parents were selected, and the mean of the group selected from that population to form the seeds for the next generation (Falconer 1989).

Using the biological model we seek to understand farmers' perceptions in breeders' terms and concepts 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. Conceivably 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 singing the praises of indigenous knowledge (Agrawal 1995: 430). We 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; Uphoff 1992). We acknowledge that successful plant breeding, by either farmers or formal breeders, does not depend on a complete empirical or theoretical understanding of the biological mechanisms involved (Duvick 1996; Simmonds 1979). We also use the model in our research to understand plant breeders, and *differences among* plant breeders.

### **Case studies of maize breeding**

We undertook the research with farmers as part of a larger study of farmer selection and the genetic structure of their maize populations, working with thirteen farming households in two communities in the Central Valleys of Oaxaca, Mexico for a period of sixteen months (June 1996–October 1998) (for details see Soleri and Smith 2002; Soleri, Smith *et al.* 2000b; Soleri and Cleveland 2001). We collected data in Spanish through participant observation, informal discussions, formal interviews, farmer selection exercises (in which they identified the best ears for planting from a sample of ears from plots in their fields) and on-farm experimental plot research. We used standard statistical tests for significance ( $P \leq 0.05$ ) wherever appropriate. We worked with eight farm families in Santa Maria (pseudonyms are used for communities throughout), a community in the Zimitlan Valley, and with five families in San Antonio, a community in the Mitla Valley. This is a marginal environment for maize production, with 88 per cent of summer production grown under rainfed conditions, and with most households experiencing harvest ‘failure’ about one out of every four years (Dilley 1993).

We carried out research on scientific plant breeding through informal interviews with an opportunistic sample of plant breeders ( $n \approx 20$ ), and through an analysis of the plant breeding literature. Our research with both farmers and plant breeders is ongoing, and is being extended to other families in the two communities, and to other locations and crops.

## **Farmers**

### **Trait heritability and intrapopulation selection**

The formal interviews presented farmers with hypothetical scenarios constructed with elements, some of which were familiar and some novel to them. The scenarios made use of traits with high average H (tassel colour) and medium-to-low average H (ear length) that were familiar and of interest to farmers. We asked about expression of these traits in both a variable, high-stress (*marginal*) field typical of the region and a hypothetical, uniform, low-stress (*optimal*) field, one that in no way limits plants’ growth potential, an environment that farmers had not experienced. Our purpose was to present hypothetical situations that would facilitate discussion of the abstract concept of heritability, i.e. to improve our understanding of how farmers perceive the influence of  $V_G$  and  $V_E$  on maize phenotypes. The potential role of  $V_G$  was represented by the relationship between phenotypes of parental and progeny generations, and the potential role of  $V_E$  by the contrasting growing environments.

*Tassel colour* (including yellow, red and purple) is a highly heritable trait that farmers in both communities pointed out to us. In San Antonio a household sought out a yellow maize population with purple tassels because of the pleasure of looking across a field of green plants with purple tassels. In Santa

Maria a household had developed and grew a white maize population with purple tassels, cobs and husks. They did so because when making tamales (steamed maize flour dough) with these purple husks, the purple colour is transferred to the food – a desirable effect. The null hypothesis was that farmers see a relatively small contribution by  $V_G$  to total  $V_P$ , attributing  $V_P$  predominantly to  $V_E$  – that seeds from plants with a given tassel colour produce plants with a diversity of tassel colours when planted in a marginal environment, and mostly tassels of the given colour when planted in an optimal environment. The alternative hypothesis was that farmers see tassel colour primarily determined by  $V_G$ , that the tassel colour of the progeny plant would be the same as that of the parent regardless of the environment.

Using photographs to represent a local population of maize that included plants with both purple and yellow tassels, we asked farmers what tassel colour would result if seed were only taken from plants with purple tassels and those seed were planted in (1) a marginal field, and (2) an optimal field (Figure 10.3). The majority of responses to these scenarios stated that tassel colour would be purple in either field, that is, it would not be affected by the growing environment. The remainder stated that there would be a mixture of colours, and that after five years of isolation from cross-pollination with other populations and continued selection for that colour, the population would have all purple tassels.

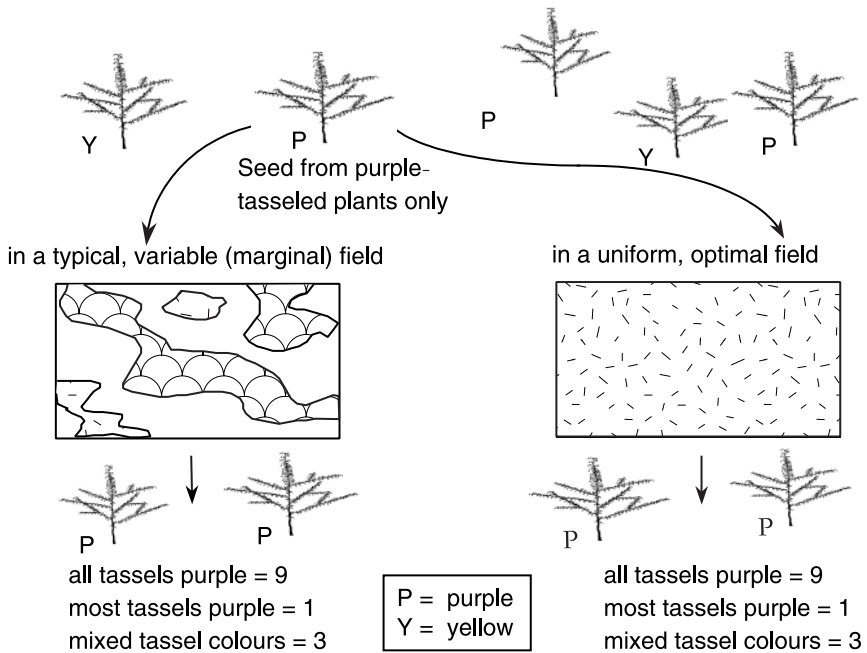


Figure 10.3 Genetic perceptions: responses to tassel colour scenario

Some farmers went further in their explanations. For example, two of the households pointed out that even after five cycles of isolation and selection for tassel colour, occasional non-selected phenotypes would still occur – a few yellow tassels among the population selected for purple tassels – a result that plant breeders would attribute to crossing and continuing segregation in a heterogeneous population.

*Ear length* is one of farmers' central selection criteria in both communities (Soleri, Smith *et al* 2000). The null hypothesis was that farmers see a relatively small contribution by  $V_G$  to total  $V_P$ , that seeds from long ear cobs produce plants with a diversity of ear lengths when planted in a marginal environment, and mostly long ears when planted in an optimal environment. The alternative hypothesis was that farmers see ear length primarily determined by  $V_G$ , with progeny phenotype for the most part the same as that of the parent, regardless of the environment. As with tassel colour, our hypotheses did not include the effects of the pollen parent or of segregation in progeny phenotypes, although these were noted by some farmers.

Using a variable sample of maize ears from a local field to 'demonstrate' the scenarios, we asked farmers what would be the length of the ears produced in a marginal environment as compared to those produced in a uniform environment, if they planted only seed from the long ears from a typical harvest of variable sized ears (Figure 10.4). The farmers stated that the marginal environment would produce a harvest of variable ear lengths while the harvest from the uniform environment would consist of uniformly long ears. One farmer noted that there would always be some variation present in any environment.

Responses to the scenarios (Table 10.1) showed general agreement among farmers regarding high and low heritability traits. Genetic variation and the capacity to select from it were clearly recognized for the high heritability trait, tassel colour. Here, farmers see phenotypic variation consistently expressed despite contrasting environments, and they attribute this variation to a non-environmental source. In contrast, for the low heritability trait (ear length), farmers see no  $V_G$ , attributing progeny phenotypes to their growing environment, not to their parental phenotype.

**Table 10.1** Summary of farmer perceptions of heritability for two traits and effect on progeny performance for one trait in maize

Phenotypic trait selected for in parents	Heritability: Farmers' expectations for progeny phenotypic variation in an environment that is					
	Marginal			Optimal		
	none	some	much	none	some	much
Tassel colour	9	1	3	9	1	3
Ear length	0	0	13	12	1	0



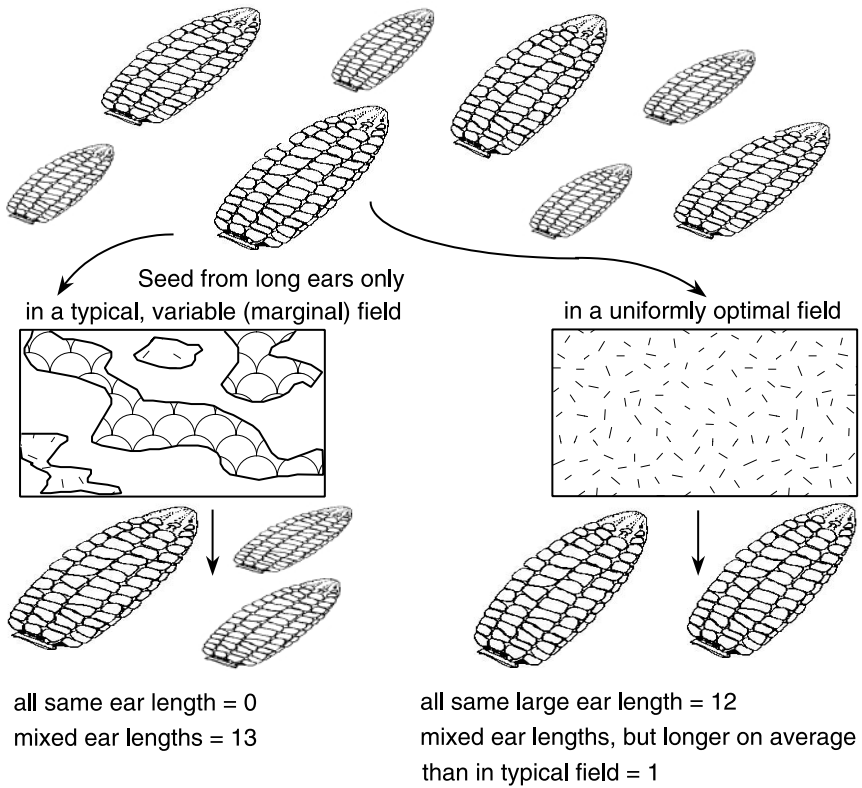


Figure 10.4 Genetic perceptions: responses to ear length scenarios

**$V_G, V_E$  and interpopulation descriptors**

Differences between the perceptions of other aspects of their maize populations among farmers in the two communities expand our understanding of farmer knowledge. Although Santa Maria and San Antonio are only approximately 65 km apart and both communities have good access to major markets, there is a distinct difference in farmers’ naming practices regarding their white maize varieties in the two communities (Table 10.2). In both locations *blanco criollo* (local white) maize is the primary class of maize cultivated.

In Santa Maria varieties of *blanco* are categorized solely on features observed in the ear after harvest – particularly kernel/ear type (*cuadrado* versus *bolita*), as well as pigmentation of the cob, and tassel. No distinct local *blanco* varieties were identified by farmers as maintained for cultivation in particular environments (locations, years or management practices). In contrast, San Antonio farmers categorize varieties of *blanco* on the basis of their cycle length (*tardón*, long cycle, versus *violento*, short cycle), as measured by days to

Table 10.2 Summary of objectives, methods and findings\* used in the investigation of farmers' perceptions and interpopulation variation of local *blanco* maize varieties

Question	Method	Findings	
		Santa Maria	San Antonio
What are farmers' declared varieties of local <i>blanco</i> maize?	Formal interviews	Two varieties based on ear and kernel morphology: <i>cuadrado</i> and <i>bolita</i>	Two varieties based on cycle length: <i>violento</i> and <i>tardón</i>
What are farmers' estimations of cycle length of their local <i>blanco</i> maize varieties?	Formal interviews	Cycle length estimates for <i>cuadrado</i> and <i>bolita</i> are not significantly different	Cycle length estimates for <i>violento</i> and <i>tardón</i> are significantly different
Is there a significant difference in reproductive phenology between farmer-declared long- and short-cycle <i>blanco</i> varieties in San Antonio?	Comparison with orthogonal contrast <sup>1</sup> of days to anthesis of varieties based on field trials	N.A.	The <i>violento</i> populations (n = 2) had significantly shorter days to anthesis than did the <i>tardón</i> populations (n = 2).

Notes:

\* Significance set at  $P \leq 0.05$

<sup>1</sup> A method for analysing planned multiple comparisons, based on t-tests

anthesis and harvest, and say that they maintain these varieties because of their different performances in response to  $V_E$ , specifically year-to-year variation in amount and timing of precipitation. Based on farmer estimates, the differences in cycle lengths for *tardón* and *violento* in San Antonio are significant, whereas there are no significant differences in farmer estimates of cycle lengths for the main types of white maize in Santa Maria (Soleri and Cleveland 2001).

These findings suggest that intra field  $V_E$  appears greater to farmers in Santa Maria than  $V_E$  between fields/years and, therefore, that maintaining separate varieties (distinct 'sets' of  $V_G$ ) for different fields/years is not worth their effort. This is not so in the eyes of San Antonio farmers. Rather, the findings suggest the hypothesis that one of the factors contributing to farmers' maintenance of distinct varieties of a class of maize (*blanco* in this case) is their assessment of the magnitude of  $V_E$  among their growing environments and the costs and benefits to them of maintaining each variety.

Attention to cycle length in San Antonio may be one reason why, despite gene flow through seed exchange and subsequent pollen movement, we found in field trials a significant difference in days to anthesis between white maize varieties from these two communities (Soleri and Smith 2002).

### Conclusions about farmers' knowledge and practice

These findings suggest that farmers' theories must be understood in context. As with formally trained researchers, it appears that most farmers base their understanding of  $V_G$  and  $H$  on their own experiences. That they recognize  $V_G$  is evidenced by responses to scenarios regarding a trait with high average  $H$  (tassel colour). That they recognize  $V_E$  is evidenced by the farmers in San Antonio maintaining varieties with different cycle lengths. As such, farmers' responses may not so much deny the presence of  $V_G$  in their maize populations for traits of low average  $H$ , but reflect their unfamiliarity with optimal growing environments and indicate the overwhelming influence of  $V_E$  in local fields, obscuring  $V_G$  in low heritability traits (Figure 10.5). This may be a major reason why farmers do not express an interest in changing their existing maize varieties, only in maintaining them, or adopting new varieties if they want to improve production (Soleri, Smith *et al* 2000), a finding similar to that of research with farmers in Jalisco, Mexico (Louette and Smale 1998).

These findings are important for collaborative plant breeding because they suggest that the assumptions of plant breeders (and those of other outsiders

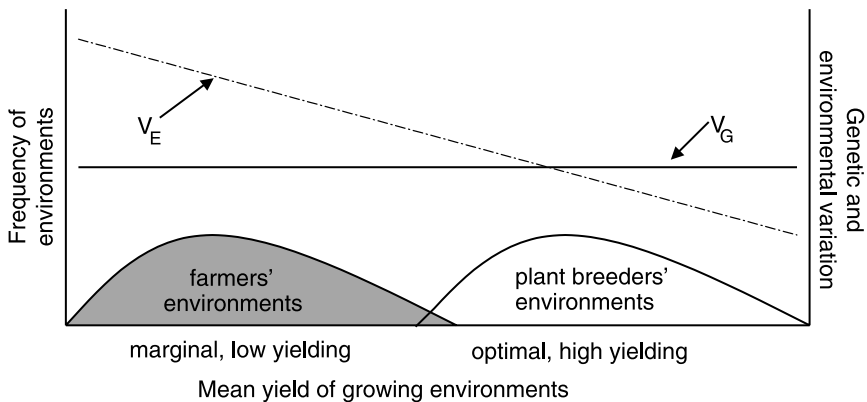


Figure 10.5 Graphic representation of the hypothesis of experience limiting perceptions and theory:  $V_E$  obscuring  $V_G$  in farmers' experience of  $V_P$

based on plant breeding theory and practice) may underestimate and/or misunderstand farmers' plant breeding knowledge, including their interest in and expectations of plant breeding. Understanding farmers' plant breeding in terms of plant breeders' biological model is not straightforward, because the genotypes, environments and epistemologies of farmers and plant breeders are different in some ways, and similar in others. This means that if collaborative plant breeding projects based on invalid assumptions about farmers' plant breeding fail, outsiders may conclude that 'collaboration' does not work because farmers cannot understand the basic ideas of scientific plant breeding, or that scientific plant breeding is inappropriate for farmers' situations. Such conclusions are not justified without first understanding farmers' plant breeding knowledge, and to do this a methodology such as the one used here may be useful.

## Plant breeders

There is a great deal of controversy among plant breeders' (including maize breeders) about the extent to which selection in optimal environments results in widely adapted MVs, that is varieties that also have superior yield in marginal environments, a phenomenon termed *yield spillover* (MV D, compared with FV B, Figure 10.6). When there is no spillover, there may instead be qualitative  $G \times E$ , known as a *crossover*. A crossover is a change in rank of varieties across the range of environments in which they are grown, which in regression analysis means that their slopes cross over. For example MV C outyields FV B in the more optimal environments, but B outyields C in the more marginal environments (Figure 10.6).

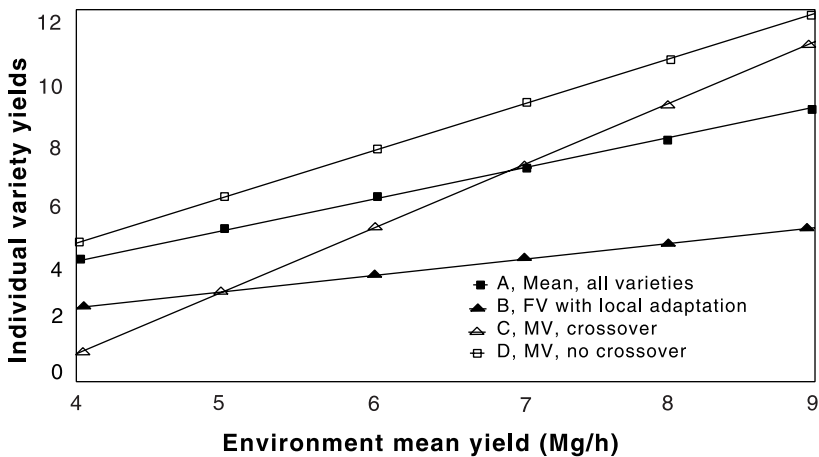


Figure 10.6 Spillovers and crossovers

### **Emphasizing selection in optimal environments**

The more conventional approach is one that emphasizes selection and testing of new varieties in optimal environments, with the assumption that such varieties will also be higher yielding in farmers' marginal environments (Romagosa and Fox 1993). This approach is justified theoretically (in terms of genetic response,  $R$ ) because it is more efficient (more rapid increase in  $R$ ) to carry out selection in optimal environments where heritabilities are higher due to lower  $V_E$ , and empirically by the widespread adoption of MVs in the Third World (e.g. in the Green Revolution) (Byerlee 1996), including, for example, high adoption rates for maize hybrid MVs among limited resource farmers in more marginal environments in Zimbabwe (Heisey *et al.* 1998).

A review of on-farm trials in five Third World countries, comparing maize varieties containing improved CIMMYT germ plasm adapted to farmers' environments with FVs, found evidence of crossovers in a minority of cases, and concluded that MVs generally outyielded FVs even in the 'worst environments studied' (Pham *et al.* 1989: 205). In another report of CIMMYT maize breeding research the authors concluded

These observations suggest that CIMMYT's strategy [selection in relatively optimal environments] for population improvement and cultivar development has been successful for developing superior maize cultivars for the resource-poor farmers of the developing world, where most of the low-yielding environments occur.

(Pandey *et al.* 1991: 289)

Three recent articles by plant breeders describing evaluation of maize genotypes across a range of environments (two reporting CIMMYT research) conclude that selection in optimal environments produces genotypes with higher yields than locally adapted genotypes in marginal target environments (Ceballos *et al.* 1998; Duvick 1992; Pandey *et al.* 1991). When the data reported in these studies are compared with those of the three articles described in the following section, the former appear to reflect a narrower range of environments, especially in the higher yielding environments (Figure 10.7).

### **Emphasizing selection in marginal environments**

The major alternative to the yield spillover viewpoint asserts that yield in different environments can be negatively correlated and, therefore, that MVs selected in optimal environments may show qualitative  $G \times E$  for yield when evaluated along with varieties adapted to low-yielding environments, resulting in crossovers between MVs and FVs. In fact, crossovers in performance between varieties are 'common' (Evans 1993: 165ff.). It has been suggested that one reason for crossovers is that plant breeders have targeted relatively

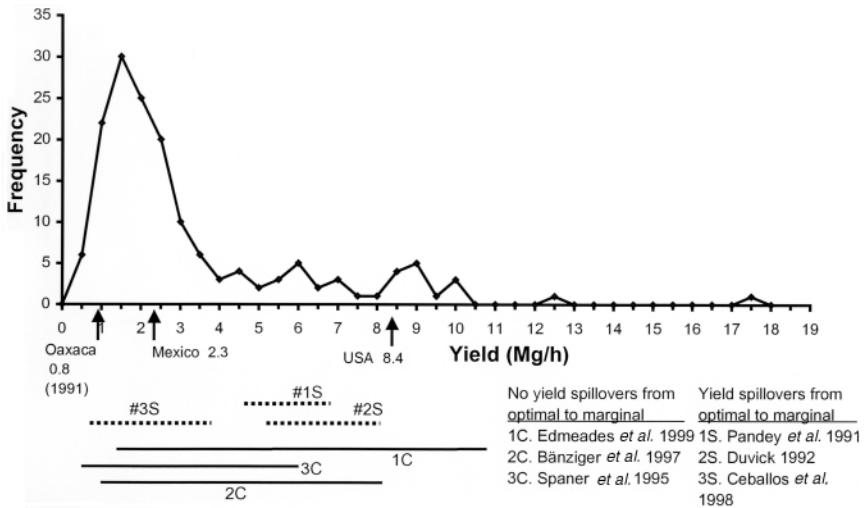


Figure 10.7 Yield spillovers in maize germplasm trials from optimal to marginal environments (compared with world maize yields by country, 1999, see Figure 10.1)

optimal environments (with high-input farmers), with the result that ‘selection has inevitably, but unconsciously’, been for high-yielding, high-response varieties that may often have low yields in marginal environments. For high performance in marginal target environments, selection must take place in these environments (Simmonds 1991). In contrast, crossovers are attributed by advocates of the spillover approach to a lack of conventional breeding effort in optimal environments, not to the failure of this approach (Pingali and Rajaram 1999).

Three recent articles by plant breeders describing evaluation of maize genotypes across a range of environments (two reporting CIMMYT research) conclude that selection should take place in marginal environments that have similar stresses to the target environments (Bänziger *et al.* 1997; Edmeades *et al.* 1999; Spaner *et al.* 1995). When the range of environments reported in these articles are compared with those of the three articles described in the previous section, they appear to be dealing with a wider range of environments, especially at the low yield end of the distribution (Figure 10.7).

**Conclusions about plant breeders’ knowledge and practice**

The reasons why plant breeders disagree about the possibility of yield spillovers in maize breeding from selection in optimal environments may be

partially dependent on their different experiences, namely: (1) the environmental stresses and corresponding genotypic adaptations they study (e.g. drought, acid soil, or low nitrogen levels); (2) the range of genetic diversity present among the varieties being compared; and (3) the degree of difference in the range and type of  $V_E$ , especially in stress levels, between the environments in which selection and testing occur (test environments) and those in which cultivation by farmers occurs (target environments) (Cleveland 2001).

The examples we present, based on preliminary analyses, provide some support for the third explanation (Figure 10.6), which has also been suggested for other crops (Ceccarelli 1996). If this explanation is valid, then plant breeders with little or no experience with farmers' marginal environments will be unlikely to anticipate the crossovers between MVs and FVs that can occur there (Figure 10.8). This has also been our experience in our informal interviews with plant breeders. Compare this with a parallel hypothesis based on farmers' knowledge illustrated in Figure 10.5.

In addition, there is some evidence to support the hypothesis that choice of selection environments is influenced by values, as reflected in statements plant breeders make about the goals of maize breeding (Cleveland 2001). On the one hand, those favouring selection in optimal environments tend to emphasize the need for farmers to modernize in order to make their farming systems appropriate for cultivation of the MVs that plant breeders produce. For example, 'Since improved varieties are usually better able to take advantage of this extra investment, they can thus be regarded as an incentive for farmers to raise their level of inputs and to improve their management of

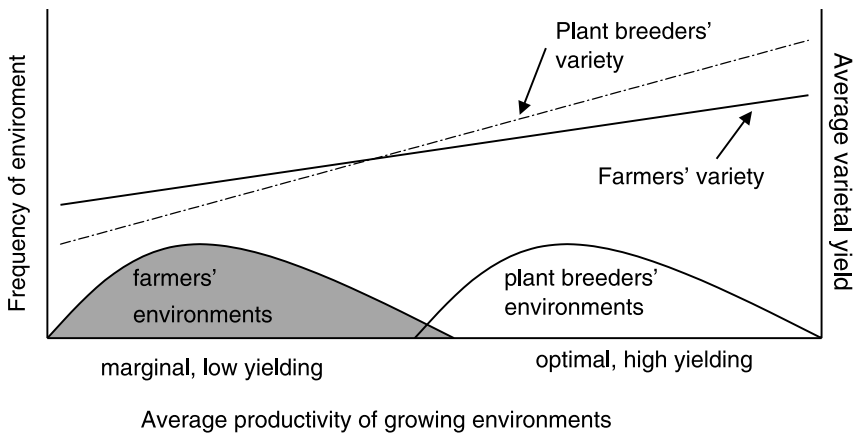


Figure 10.8 Graphic representation of hypothesis of experience limiting perceptions and theory: range of  $V_E$  limiting plant breeders' observations of  $G \times E$

Partially based on Ceccarelli 1989 and Ceccarelli et al. 1994).

maize' (Pham *et al.* 1989: 205). In terms of farmers' reasons for not adopting MVs, this emphasizes lack of economic incentives rather than economic, institutional or physical barriers. There may also be the assumption that there are cultural barriers, i.e. ignorance of small-scale farmers (Aquino 1998).

On the other hand, those favouring selection in marginal environments tend to emphasize the need for plant breeders to adapt their breeding goals to meet the needs of farmers' situations and environments, and emphasize the difficulty of reducing poverty via technical change (Heisey and Edmeades 1999). For example:

Maize yields in farmers' fields in many tropical countries... [are] in stark contrast to yields ... reported on breeding stations in those same countries ... Farmers' fields are rarely characterised by only one abiotic stress ... Resource constrained farmers in many parts of the tropics may apply no fertiliser at all.

(Bänziger *et al.* 1999: 1035)

The scientific knowledge of plant breeders that exists on an unconscious or intuitive level may also affect their practice, though this possibility has received much attention from researchers. Simmonds suggests that selection by conventional breeders has 'unconsciously' been for varieties with high response in optimal environments, and high-yielding, high-response varieties that have low yields in marginal environments (Simmonds 1991), or what some plant breeders have referred to as 'cryptic breeding' (Smith and Zobel 1991: 57). One prominent plant breeder has stated that:

Modern methods of statistical design and analysis add precision to all of these decisions and quantitative genetic theory adds rationality to breeding plans, but art and experience – not precision genetics – are the key to successful use of these useful tools.

(Duvick 1996: 543)

## Conclusions

At the beginning of this chapter we asked two general questions. The preliminary answers from our research are summarized below.

*First*, to what extent are farmers' and plant breeders' knowledges and practices similar or different regarding maize genotypes (varieties, populations and plants) and growing environments?

- 1 There are *similarities* between farmers and plant breeders in their knowledge of the determinants of plant phenotypes, in that both recognize the joint contribution of genotype and environment. The knowledge of both



is theoretical because it includes causal relationships that are the basis of predictions and plans.

- 2 There are *differences* between farmers and plant breeders because of the differences in the specific kinds of genotypes and environments they work with, and differences in epistemological tools: for example, farmers' more holistic knowledge of genotypes and environments versus the plant breeders' more specialized knowledge of genetics, statistics, and their technological ability and resources to control environmental and genotypic variables.
- 3 These differences *between* farmers and plant breeders are paralleled by *similar* differences *among* both farmers and plant breeders that appear to be in part the result of working with different environments. For example, plant breeders differ from farmers in regard to their observations and theory regarding the possibility of yield spillovers from selection in optimal to marginal environments, while Oaxacan farmers differ from plant breeders in terms of theory for discriminating between genotypes in terms of growing cycle length.

*Second*, how can answers to the first question contribute to the process of collaboration between farmers and plant breeders, with the goal of developing improved varieties for farmers?

- 4 It is important to question the extent to which plant breeding 'theory' applied to collaborative plant breeding is in fact an elaboration of fundamental biological theory based on narrow interpretations and untested assumptions. Understanding the basis for disagreements among plant breeders about plant breeding theory and practice can help.
- 5 Plant breeders' assumptions may need testing by formulating hypotheses applied to (a) farmers' biophysical and sociocultural environments; (b) farmers' theoretical as well as empirical knowledge; and (c) disagreements about theory among plant breeders in terms of differences in assumptions and values (e.g. about the possibility and desirability of farmers adopting MVs), and in the genotypes and environments they work with.
- 6 Problematizing the relationship between farmer and plant breeder knowledge based on a holistic theory of knowledge can contribute to the formulation and testing of specific hypotheses within the context of collaborative plant breeding projects.
- 7 Both farmers' indigenous knowledge and plant breeders' scientific knowledge are important for collaborative plant breeding. Plant breeders who emphasize their technical epistemology often focus on genetic response to selection (R), and are puzzled when farmers reject their advice, just as farmers are puzzled that plant breeders do not understand that any improvement in yield, for example, has to be weighed against the costs of the extra time and resources required.

- 8 The search for generalizations about farmer and plant breeder knowledge and practice, and for policy based on them to guide collaborative plant breeding, is valid, but we need to be careful of superficiality.
- 9 If collaborative plant breeding projects fail, it may be because they are based on invalid assumptions regarding the interpretation of plant breeding theory. Therefore, it is not valid to conclude from such failures that farmers cannot understand the basic ideas of scientific plant breeding, or that scientific plant breeding is inappropriate to farmers' situations.

While farmers' knowledge is local, it can also be based on the same generalizable theories about crops and environments as plant breeders'. The contingencies of plant breeders' experiences with unique genotypes, environments and social contexts renders their knowledge local also. Understanding that farmer and scientist knowledges are both local and both generalizable may open up new possibilities for communication between farmers and scientists, and for understanding how these knowledges can complement each other to the benefit of both groups.

While plant breeders may all believe that the fundamental biological model is universally valid, they increasingly disagree on its interpretation as the number of variables and their relationships increase. We have suggested that claims for generalizability, especially by breeders unfamiliar with the situations of farmers, may be invalid, in the same way that claims of farmers based on locality may be invalid because they do not have wider experience of genotypes and environments. The minority of plant breeders with wider experience, and the minority of farmers with wider experience, may have conceptions of genotypes and environments different to the majority. This can form the basis for furthering theoretical understanding that can be communicated to a larger number of farmers and plant breeders.

Our holistic theoretical approach to understanding knowledge is meant to problematize assumptions about fundamental or inherent differences between indigenous knowledge and scientific knowledge, and facilitate investigation of possible similarities as well as differences. We have assumed that greater understanding can provide farmers and local scientists with conceptual tools they can use to adapt or develop their own innovations to best meet their needs. This is also an assumption that needs to be carefully tested, however. Though we are well aware that our application of holistic knowledge theory has so far been biased towards the scientific model, a holistic approach helps us to be cognizant of the limits of that model, and is leading us in the direction of more detailed investigation of the sociocultural and epistemological basis of farmer and plant breeder knowledge, including work with farmers and plant breeders in different areas of the world, working with different crops (Soleri, Cleveland *et al.* 2000).

## Note

- 1 We thank the collaborating farm households in Oaxaca who taught us much and brought great patience and good humour to our work together; the municipal authorities of the study communities for permission to conduct this work; M. Smale and M. E. Smith for discussion and advice; and S. E. Smith for stimulating discussion and assistance in many forms. Our research has been supported in part by grants to Daniela Soleri from the American Association for University Women, Association for Women in Science; Research Training Grant for the Study of Biological Diversity (University of Arizona), Sigma Xi, the US–Mexico Fulbright Commission, and the USAID–CGIAR Linkage Program; grants to David A. Cleveland from the Committee on Research, Faculty Senate, UC Santa Barbara, the Institute for Social, Behavioural and Economic Research, UC Santa Barbara, and the National Science Foundation (SES-9977996); and the financial and logistic support of the Economics Program of CIMMYT through M. Smale, and of the Maize Program of CIMMYT through S. Taba.

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