Scenarios as a Tool for Eliciting and Understanding Farmers' Biological Knowledge

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Modern scientific knowledge and indigenous or traditionally based knowledge are often assumed to be fundamentally different and incomparable. Testing this assumption is important theoretically and for supporting scientist-farmer collaboration to improve farmers' well-being in their own terms. We illustrate the use of scenarios based on a basic biological model to understand farmers' theoretical biological knowledge. Scenarios depict aspects of the model in terms comprehensible to farmers and relevant to collaboration with scientific plant breeders. Results suggest that scenarios are useful for eliciting traditionally based biological knowledge and that farmers' theoretical biological knowledge is based on the same model as that of scientists.

Keywords: *scenarios; indigenous knowledge; scientific knowledge; farmers; plant breeding; participatory research and development*

Documentation and understanding of indigenous knowledge (IK, also referred to as traditional knowledge), in a way that facilitates collaboration between local people and outside researchers for meeting local goals, is a challenge facing ethnoecological research. In this article, we describe the use of scenarios for eliciting farmers' biological knowledge relevant to collaborative work in agriculture, including policy.

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The theoretical goals of our research on IK (specifically farmers' knowledge; FK) and scientists' knowledge (SK), are to learn (1) how farmers understand the basic biological model of relationships between plant genotypes and growing environments that determine plant phenotypes including the results of seed selection, (2) how this understanding affects farmers' practices and expectations, and (3) how FK of the basic biological model is similar to or different than SK of this model. We focus on the theoretical, as opposed to the descriptive or discriminatory, aspects of FK.

Our practical goal is to contribute to collaboration between scientists and local people in the search for equitable solutions to local environmental problems, specifically to find ways to improve the results of plant breeding in farmers' own terms. This participatory plant breeding (PPB) or collaborative plant breeding is an area of increasing interest to both farmers and plant breeders and the subject of a growing number of projects (Cleveland and Soleri 2002b; McGuire, Manicad, and Sperling 2003; Weltzien et al. 2003).

UNDERSTANDING BIOLOGICAL KNOWLEDGE

The relationship between different forms of biological knowledge, including indigenous and scientific, has been a source of disagreement among scholars as well as practitioners. This disagreement, whether implicit or explicit, is important because it affects decisions about project design, data collection, and implementation (Sillitoe 1998; Ellen and Harris 2000).

Can IK and SK Be Compared?

Social scientists often contrast SK and IK in essentializing ways: seeing the former as rationalistic, reductionist, theoretical, generalizable, objectively verifiable, abstract, and imperialistic, in sharp contrast to the latter, seen as organic, holistic, intuitive, local, socially constructed, practical, and egalitarian (e.g., Scott 1998:340). Yet, while many of farmers' complicated practices observed by outsiders may appear to be untheorized responses to changing, unpredictable circumstances, concluding that IK is atheoretical "practice" begs the question of the mental basis of behavior and equates farmers' presumed inability to verbalize this basis to naive outsiders with no theory.

On the other hand, there is evidence that SK and IK are more similar than different and that both are in some aspects culturally relative, local knowledge and in other aspects generalizable (Agrawal 1995). Since the 1920s, work by social scientists, historians, and philosophers on the nature of SK has explicitly explored the role of personal psychology, historical contingencies, and social context in its production (Giere 1999). SK and IK may also be similar in their theoretical content. We define theories as generalizable (though 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 (see Hull 1988:485; Medin and Atran 1999:9; Cleveland and Soleri 2002a).

Biological Knowledge in Participatory Plant Breeding

Inclusion of FK along with SK is central to PPB. However, FK has been treated primarily as descriptive or discriminatory, and the possibility that FK might also be theoretical has not usually been considered. Rigorous comparisons with the interpretations of 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. 2003:60). It may also be difficult for farmers to verbalize to outsiders their knowledge that goes beyond description or discrimination, and most outsiders do not have the methodological tools, resources, or incentives required to ask farmers about their theoretical knowledge.

Therefore, research on FK in plant breeding has not been concerned with the dynamic interaction between plant genotype and the growing environment that determines plant phenotype. Yet this interaction is fundamental to (1) agricultural production because it determines the yield, processing quality, taste, and all other consumption traits, and (2) plant breeding because it determines the results of phenotypic selection in comparison to its goal of genetic improvement (Soleri and Cleveland 2004). We developed the scenario method to elicit theoretical FK on these topics.

BIOLOGICAL MODELS

When starting our research on FK and SK in plant breeding, we wished to avoid the trap of testing FK using SK as the standard, as has been done elsewhere (e.g., Briggs et al. 1998). We saw the need for a neutral ontological comparator that could function as a bridge between FK and SK, although finding such a comparator risks philosophical and practical difficulties (Ellen and Harris 2000:27–28). We chose the basic biological model of genotype-environment relationships (MGER).

The MGER is universally accepted by biologists, including plant breeders, but they disagree among themselves about its interpretation at higher levels of generalization, for example, whether selection in optimal or marginal environments leads to genotypes that are better adapted to marginal environments (Ceccarelli and Grando 2002). This variation in scientists' interpretations suggests that, if farmers do, in fact, think in terms of the MGER, it would be a valuable comparator, facilitating consideration of FK and SK on equal grounds. We use MGER in our research on plant breeders' knowledge and differences among plant breeders (Cleveland 2001; Soleri and Cleveland 2001).

We used the two parts of the MGER on which plant breeding is based (Cleveland, Soleri, and Smith 2000), as presented in standard texts (e.g., Falconer and Mackay 1996; Simmonds and Smartt 1999). First, variation in population phenotype (observable characteristics) (V_P) on which choice (discrimination between different groups of plants) and selection (discrimination among individual plants within a group) are based is determined by genetic variation (V_G), environmental variation (V_E), and variation in genotype (genetic constitution)-by-environment ($G \times E$) interaction ($V_{G \times E}$); thus, $V_P = V_G + V_E + V_{G \times E}$.

Second, response to selection (R) for a trait is the difference between the mean of the whole population from which the parents were selected and the mean in the next generation produced by planting those selected seeds under the same conditions. R is the product of two 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 entire original population (Falconer and Mackay 1996:189). Heritability (h^2) is that part of V_P that can be passed directly from parent to progeny.

In our use of the MGER, we make several assumptions. (1) The MGER models empirically observable patterns in the real world. (2) Among both farmers and scientists, there are some who are particularly good observers of their environments, crops, and interactions between these if they occur and others who are poor observers, resulting in variation within groups. (3) Variation in knowledge within and between groups can also be caused by experiences with different genotypes and environments and by different values and preexisting knowledge. (4) Differences between FK or SK and the MGER do not mean that FK or SK is wrong, and differences between FK and SK do not mean that either is inferior to the other.

Thus, the experience of MGER under diverse circumstances can result in local interpretations of the model, by either farmers or scientists, which can be sources of learning for both scientists and farmers (Cleveland and Soleri

2002a, 2002b). When FK differs from that presumed by scientists' interpretation of MGER, we do not conclude that FK is inferior to SK, or vice versa, but try to understand the difference in terms of the specific genotypes and environments each works with, as well as other factors in their experience.

CREATING SCENARIOS

Scenarios create a hypothetical situation to which people can respond. While certainly simplifications of reality, scenarios are typically stories that embody some of the irreducible complexity of that reality (Peterson, Cummings, and Carpenter 2003). Scenarios are used to include underrepresented groups in planning (Heemskerk 2003), for risk analysis (e.g., National Research Council of the National Academies 2002), and for public discussion of alternative futures (e.g., Costanza 2001; Peterson, Cummings, and Carpenter 2003). Alternative futures scenarios explicitly recognize fundamental differences in value-based assumptions (our "preanalytic visions" in the words of Costanza 2001) that are the basis for alternatives and are embodied in distinct, plausible scenarios. We believe our use of scenarios to elicit local, theoretical biological knowledge is novel. However, like alternative futures scenarios, our scenarios explicitly recognize contrasting preanalytic visions—in this case between those of conventional agricultural development and plant breeding (technological progress and change are unilineal and fundamentally the same everywhere, and required resources are available) and those of major alternatives (technological progress and change may take diverse forms, and resources are limited). These contrasting fundamental worldviews contribute to different interpretations of the MGER.

Our central challenge in scenario creation is representing MGER in terms meaningful to farmers while maintaining biological accuracy. We followed these basic steps: (1) identification of issues central to scientists' and farmers' practices and important for future collaborative work in the form of research problems and specific hypotheses, (2) construction of scenarios based on the MGER, and (3) adaptation of scenarios to each community in terms of local society and culture, farming practices, growing environments, and crops (especially mating systems). This requires spending time with farmers (in the field and household and chatting with them about their practices, crop varieties, and fields) and collaborating with scientists who have worked with local farmers for long periods. A general survey that asks farmers for descriptive information about their farming may also be appropriate.

Research Problems and Hypotheses

We identified research problems and hypotheses relevant to PPB that could be tested using scenarios. The basic problems were to determine if FK reflected the basic biological MGER, and if so, how that model was interpreted in terms of (1) the allocation of genotypes to growing environments, based on G × E interactions, and (2) expectations for seed selection. In addition, we wanted to (1) compare farmer and scientist interpretations of the MGER and (2) learn other new insights about the local context and FK.

G × E interactions. How farmers or plant breeders allocate genotypes or varieties to growing environments reflects assumptions about the local outcome of G × E interactions. Based on the preanalytic vision of conventional agricultural development as described above, the assumption commonly made by plant breeders is that a limited number of varieties developed on experimental stations are appropriate for meeting farmers' needs; that is, that the same genotypes will provide optimal performance across all environments (i.e., there is absence of qualitative G × E; see Figure 1a, local FV [farmers' variety] versus other FV1; Atlin, McRae, and Lu 2000), although there is accumulating evidence that this assumption is invalid, especially for marginal environments (Ceccarelli and Grando 2002). Even in PPB, when this assumption is not made, the question becomes, "What level of adaptation is optimal for farmers?" (i.e., "How many different varieties for a given area will be optimal?"; Ceccarelli and Grando 2002).

Our research question asked, "Do farmers anticipate a qualitative G × E interaction among the environments and varieties they are working with?" That is, do farmers think that particular varieties are adapted to particular environments and thus perform better in those than varieties originating in contrasting environments (see performance of local FV versus other FV2, Figure 1a)? Implicit to this question in the context of PPB is "Does their knowledge make them behave differently than assumed best by scientists?" and "Can scientists learn new insights from farmers?" Our hypothesis was that "farmers do not anticipate qualitative interaction at any level, seeing the same variety as best in all environments described in the scenario."

Response to selection. Farmers, especially in marginal environments, often have much lower yields with their traditional crop varieties than is the case with modern varieties in more favorable environments. One reason for this cited by conventional plant breeders is farmers' ineffective or inadequate seed selection (R = 0), and in the past ten years, PPB projects to improve farmers' selection have been increasing (Rice, Smale, and Blanco 1998;

Centro Internacional de Mejoramiento de Maíz y Trigo 2003). A basic assumption of these efforts is that farmers' goal for selection is the same as plant breeders': cumulative genetic improvement that will be reflected in ongoing directional change in the population mean for a particular phenotypic trait or traits. Our research question asked, "Do farmers see cumulative, directional change as the goal of their seed selection?" Our hypothesis, based on the common assumption, was that "farmers see selection as a means to produce cumulative directional change in a trait."

In each case, we were investigating common assumptions that are interpretations of how the MGER works under farmers' conditions and have long influenced project activities and scientist-farmer interaction. However, the specific projects and scientists we worked with represented exceptions in that they were either open to other perspectives or had themselves already been investigating different interpretations of the MGER under local circumstances.

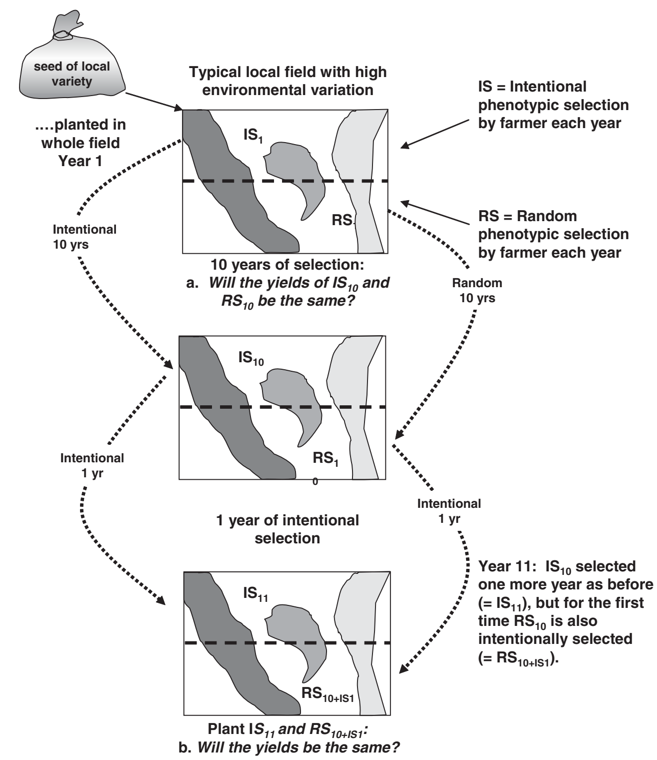
Constructing a Scenario Based on the MGER

Constructing a scenario is an iterative process, best carried out with a small number of farmers over an extended time, requiring multiple pretests and adjustments. In Mexico, we worked with thirteen families (including participant observation and informal and formal interviews with twenty-seven adults) for about eighteen months over a six-year period (1996–98, 2002). It is also advisable to ask colleagues with extensive experience and expertise in the area of biological research being addressed to review the scenarios, focusing on biological accuracy and coherence. Our collaboration with quantitative geneticist Steven E. Smith has been very valuable, as has our collaborabation with maize breeder Flavio Aragón Cuevas in Oaxaca beginning in 2003. In our work in Cuba, Mali, Nepal, and Syria, we worked with plant breeders and other scientists, technicians, and students from local or national institutions who had extensive experience working with local farmers in PPB (Soleri et al. 2002; Soleri et al. 2003).

For the $G \times E$ scenario, we depicted V_E at different locally familiar levels (communities, fields in one community, places within a field, and different times in the same geographic level); we held V_G constant by using the common local genotype—in this case, the most common FV in the area—and another FV from a locally known community with a contrasting growing environment and asked farmers if there would be interaction ($V_{G \times E} > 0$) and of what sort (Figure 1).

For the selection scenario, we used a criterion identified by farmers as important (e.g., ear length, panicle size, etc.; Soleri, Smith, and Cleveland

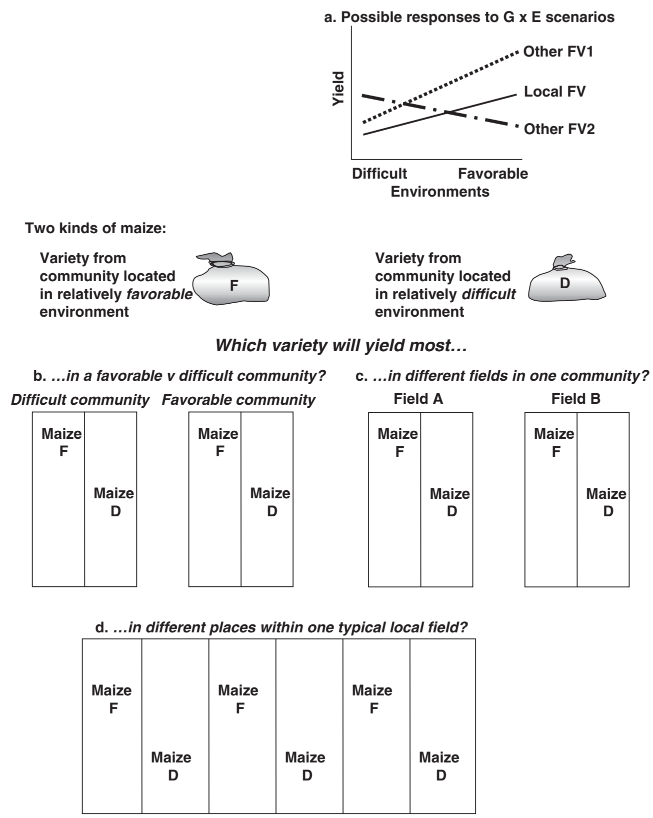
FIGURE 1
G × E Scenarios



2000; Soleri et al. 2002). We used locally familiar V_G (local FV), described V_P (e.g., “Imagine you are selecting from a pile of maize ears of different sizes”), and S (e.g., “only long, large ears are selected” as is typically done for intentional selection, and “ears of any size are selected” for random selection) and then asked farmers to predict R under different selection strategies.

In addition to including components that are familiar to farmers, it is also important to include unfamiliar ones, thereby asking farmers to extend their theoretical knowledge into new situations they have not experienced, asking them to predict a scenario outcome. For the scenario concerning response to selection, the novel idea was switching methods of selection (ten years of random selection followed by one year of intentional) and conducting a hypothetical side-by-side comparison (see Figure 2). Because most farmers

FIGURE 2
Selection Scenarios



practice intentional selection, this was familiar and also provided a basis for describing unfamiliar random seed selection ("Imagine covering your eyes and picking whatever clean maize ear you touched for seed; big, little, medium," or "Imagine harvesting and bulking all of your barley and then choosing seed"). The comparison was depicted as a split plot experiment in their own field, with both sides receiving the same management and inputs. We also conducted selection exercises with farmers using maize ears from their own fields and field trials, allowing calculation of S, R, and realized h^2, enhancing the findings of the selection scenario (Soleri, Smith, and Cleveland 2000).

Using visual aides to illustrate the scenarios was valuable for us and for the farmers. For example, in Mexico, we used maize ears from local farmers' fields when talking about ear length and photographs of different tassels from local fields when talking about tassel color. Small bags of local FV seed were used to represent units of yield in scenarios about differences in yields between varieties. Small rocks or crumpled paper balls of three sizes were used to represent years with high, normal, and low rainfall; to describe growing conditions; and for farmers to use in representing a distribution of years defined by rainfall during a typical ten-year period (see Figure 3).

Adapting Scenarios to Local Contexts

Working with different crops and farmers and farming systems often demands substantial modification of each scenario. The scenarios we used to discuss the G × E interaction and response to selection with farmers were developed during early work in Mexico (Soleri and Cleveland 2001) and modified and applied in a research project with collaborating scientists and farmers in Syria, Cuba, Nepal, and Mali (Soleri et al. 2002; Soleri et al. 2003). After pretesting and some adjustments, colleagues fluent in the local languages presented the scenarios to more than two hundred farmers, preceded by an explanation of objectives of the work. Participation in the interview was voluntary and anonymous unless permission was explicitly given by farmers. All responses were recorded on an interview form.

The variation in sociocultural and biological variables required adapting scenarios to each of the different sites. At the same time, the core idea and specific elements of each scenario has to be maintained. For example, it is not unusual for environment and crop mating systems to interact. Farmers in Mexico growing maize (<5% autogamous) tend to plant the same variety over multiple, diverse environments in one community while farmers in western Nepal growing rice (>97% autogamous) divide their heterogeneous environments in the same community into four ecosystems and allocate different sets of varieties to each. Thus, while in Mexico, the scenarios about the G × E interaction across three levels of environmental variation (between communities, among fields in one community, within a single field) between genotypes from two different communities required only three scenarios, in Nepal, those same three environmental levels had to be investigated with two sets of genotypes: comparing genotypes originating in the same class of ecosystem but from two communities and two genotypes from different ecosystems occurring in the same community. With these adaptations, we were able to ensure that locally important FK concerning G × E interactions was not omitted.

FIGURE 3
Using Rocks of Different Sizes to Represent Years of High, Normal, and Low Rainfall, Syrian Farmer Juri Aboud Explains the Distribution of Rainfall for Barley Production in Her Community

SOURCE: Photo by D. Soleri, used with permission of subject.

Similarly, how seed is selected can differ substantially, for example, from identifying a "good" area in a Syrian barley field from which to save seeds or from walking through a Nepali rice field and cutting the best individual heads. Nevertheless, these are practices that differ from randomly choosing any plants as seed sources—though the outcome may not differ (Soleri, Smith, and Cleveland 2000)—and selection scenarios were adapted to accommodate local practices such as these while still maintaining the essential contrast between intentional and random seed selection.

RESULTS

Below are brief examples of research results from our use of scenarios, with suggestions for how they could contribute to PPB projects. Data were analyzed using the PROC FREQ function, SAS (SAS Institute 2001).

Understanding Farmers' Theoretical Biological Knowledge: G × E Interaction and Response to Selection

Do farmers think in terms of the MGER? Nearly all farmers (194/206) responded to all of the scenarios. For the G × E scenarios at all levels except between communities, aggregated farmers' responses deviate significantly from randomness expected under the null hypotheses and follow patterns attributable to the same variables (V_G, V_E, and $V_{G \times E}$; Table 1). Failure to reject the null hypothesis at the between-communities level appears due to influence of crop mating system (cross- versus self-pollinating)—significantly more of those (72%) not anticipating G × E were maize farmers (see below).

What is farmers' interpretation of the MGER as revealed by the G × E scenarios? Farmers' responses varied substantially across environments and crops, with qualitative G × E anticipated by fewer farmers at the intrafield than between-field or between-community levels (see Table 1). A statistically significant effect at all levels was crop mating system (see Table 2), with anticipation of qualitative G × E interaction at all levels higher among farmers growing predominantly self-pollinating (barley, rice, sorghum) compared to highly cross-pollinating (maize) crops. Socioeconomic and biophysical variables can also affect scenario results, as described in the earlier comparison of Mexican, Syrian, and Nepali growing environments.

TABLE 1

Farmer Responses to G × E Scenarios

Country (n)	*Percentage of Farmers Responding That Spatial V_E Is a Potential Source of Qualitative $G \times E$* Between Locations	Between Fields	Within One Field	*Percentage of Farmers Responding That Temporal V_E Is a Potential Source of Qualitative $G \times E$*
Mexico (60)	30*	12*	5*	29*
Cuba (29)	24*	3*	0*	13*
Syria (37)	64	22*	16*	39
Nepal (40)	80*	67*	36	57
Mali (40)	90*	49	36	55
Total (206)	56	30*	18*	36*

*Chi-square test of goodness of fit to the null hypothesis that anticipation of G × E is random, $p < .05$.

TABLE 2

Difference between Farmers' Responses to G × E Scenarios Based on Mating System of Their Crop (Number of Responses)

	*Between Location $G \times E$**		*Between Field $G \times E$**		*Within Field $G \times E$**		*Temporal $G \times E$**	
Predominant crop mating system	Yes	No	Yes	No	Yes	No	Yes	No
Cross-pollinating (Mexico and Cuba)	25	64	8	80	3	86	21	69
Self-pollinating (Syria, Mali, Nepal)	90	25	51	61	34	81	54	64

*Chi-square test of independence of the null hypothesis that the distribution of responses is the same among farmers working with different crop mating systems, $p < .05$.

TABLE 3
Farmers' Expectations for Response to Seed Selection

Location, Crop (n of Farmers)	*Percentage of Farmers Stating That Yield of Intentionally Selected$_{10}$ > Randomly Selected$_{10}$ (Question a)*	*Percentage of Farmers Stating That Yield of Intentionally Selected$_{11}$ > Randomly Selected$_{10}$ + Intentionally Selected$_{1}$ (Question b)*
Mexico, maize (59)	39*	10*
Cuba, maize (29)	93	43*
Syria, barley (20)	95	57*
Nepal, rice (40)	98	43*
Mali, sorghum (40)	88*	55*
Total (189)	76*	37*

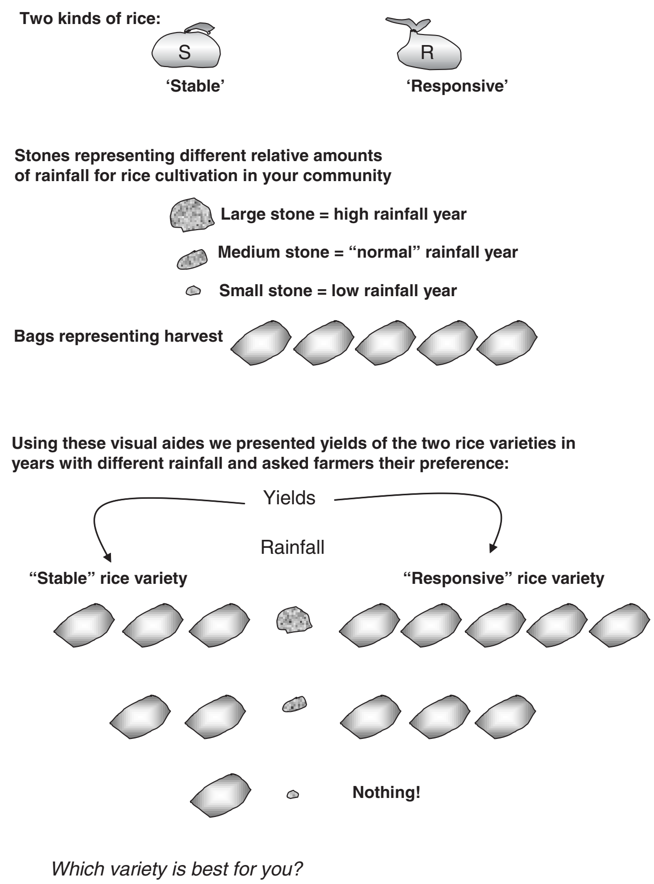
*Fisher's exact test of the null hypothesis that farmers would always see intentionally selected seed as having a higher yield than randomly selected seed, $p < .05$.

What other new insights were gained from the G × E scenarios? An example of an unexpected insight gained was in one Syrian community where some farmers indicated qualitative interaction at a level (within a field) not typically considered by scientists but supported by empirical tests (S. Ceccarelli, personal communication). Ceccarelli has found that even when the possibility of interactions at any level were hypothesized and then documented by some scientists, many others resisted this because it represented a deviation from the accepted interpretation of theory in agricultural research at the time (Ceccarelli and Grando 2002).

What is farmers' interpretation of the MGER as revealed by scenarios concerning genetic response to selection? Although most farmers saw intentional selection providing benefits, and only 24% believed random selection resulted in equal or better yields (see Table 3, question a), benefits are not necessarily seen as cumulative. Overall, 55% saw benefits achieved after one cycle of selection for key quantitative traits (see Table 3, question b), with no further progress being made after that, $R = 0$. This differs significantly from plant breeders' concept of selection resulting in cumulative change, R > 0.

What other new insights were gained from scenarios concerning genetic response to selection? Most farmers know how to achieve R > 0 for qualitative traits, and farmers' persistence in selection for quantitative traits with little chance for R > 0 appears due to their perception of better seed quality (leading to higher germination and early vigor), as well as to habit. In contrast, plant breeders see selection and choice of quality seed for planting as separate activities (Soleri and Cleveland 2001, 2004).

FIGURE 4
Scenario for Farmers' Evaluation of Risk: Yield Stability



Other Uses of Scenarios for Understanding FK

In addition to investigating theoretical knowledge, scenarios may be used in ethnoecological research for the same purposes as common in other disciplines: risk assessment and values concerning possible futures.

Farmers' evaluations of risk posed by crop varieties with different responses to V_E have been documented in two different comparisons: differences between two crop varieties in yield stability in response to temporal V_E (yearly rainfall), representing FVs versus modern varieties (see Figure 4;

Soleri et al. 2002; Soleri et al. 2003), and varieties with different seed procurement requirements and evolution of resistance in yield-limiting pest populations, representing FVs versus transgenic modern varieties (Soleri et al. 2003). Farmers' values concerning use of and rights to their FVs were documented with Zuni Native American farmers (Soleri et al. 1994).

CONCLUSION

Using scenarios based on fundamental models of how the external world works (e.g., MGER) and the local context provides a method for eliciting knowledge that can be used to design more in-depth studies and can facilitate communication and collaboration between local people and outside scientists, although application in a project remains to be tested. Use of scenarios is based on the assumptions that both FK and SK can include empirical observations, values, personal beliefs, and experiences and that neither FK nor SK is given privileged status in analysis. Interpretation of scenario interviews seeks to understand the basis for differences and similarities in knowledge and practice among and between local peoples and scientists.

When interpretations of the MGER by farmers are different than plant breeders' they can be empirically investigated. For example, "Does $G \times E$ among studied genotypes exist at a specific level?" Results can be discussed by referring to variables important in both FK and SK, for example, genotypes and environments, and may result in changes in project design, (e.g., plant breeding for different varieties for each local environment instead of one variety for a larger area, or vice versa). Similarly, understanding farmers' theoretical knowledge and goals regarding seed selection creates an opportunity for their direct collaboration with scientists in project design that is more relevant for their needs.

In our experience, carefully constructed scenarios are a valuable tool for understanding FK of fundamental concepts about plant breeding and values concerning other important agricultural policy issues that rarely include input from local people.

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