6 Breeding strategies

6.1 Introduction

Developing maize genotypes with tolerance to drought and N stress is complex. This is due to various factors, including the largely polygenic nature of the tolerance, the typically low frequency of tolerance alleles in most maize germplasm, and the difficulties commonly encountered in field evaluations. Important considerations in establishing a selection program for stress tolerance should be whether OPVs, hybrids or both types of products are needed, and what human, financial, and physical resources are available for experimental work. Additional important factors include the choice of germplasm, breeding methodology, selection environments, and essential data to collect.

6.2 Choice of germplasm

The selection of appropriate germplasm is critical, requiring careful consideration of all available information. A wrong choice cannot be corrected by using sound and efficient breeding methodologies. There are several approaches a breeder can take to develop drought and low N tolerant germplasm.

6.2.1 Improving locally adapted, elite germplasm for drought and low N tolerance

CIMMYT evaluated a wide range of landraces for drought and low N tolerance, but there were few (about 3%) that compared favorably with elite, adapted germplasm for drought or low N tolerance, and even fewer that compared favorably with elite, adapted germplasm under high yielding conditions. Additionally, we have found genetic variability for drought and low N tolerance in all types of elite germplasm. Thus, **improving adapted, elite germplasm for drought and low N tolerance** is probably nearly always better than working with landraces. A compromise approach would be to create synthetic populations from local landraces and improved, adapted varieties.

6.2.2 Improving non-adapted but drought and/or low N tolerant populations for local adaptation

CIMMYT-Mexico and much more recently CIMMYT-Zimbabwe and CIMMYT-Kenya have developed germplasm with high levels of drought and/or low N tolerance. A breeder may want to use such germplasm or any other known source of drought or low N tolerance. Such materials may not be well adapted in terms of disease resistance, maturity, etc., to the target environment. Screening for general adaptation by the breeder may be necessary, and only the best adapted among the introduced stress-tolerant materials should be used. Adaptation can usually be further improved through selection, and for many breeders it is easier to select for adaptation (suitable maturity, disease resistance, yield potential) than for drought or low N tolerance.

6.2.3 Formation of new breeding germplasm through introgression

The third and more complex strategy is to develop a new breeding population by introgressing locally adapted germplasm with source drought or low N tolerant germplasm. This approach raises several issues: which source germplasm should be used? What proportion of local and source material is appropriate? How much recombination is necessary before the population is ready for intense selection? And how can molecular markers facilitate this process?

6.2.3.1 Which source population(s) to use?

A breeder should check first the information that is already available for the potential source germplasm:

- General adaptation: lowland tropical, subtropical/midaltitude, highland, temperate.
- Grain color and grain texture.
- Maturity: it is better to use heat units than calendar days for characterizing the maturity of a genotype.
- Disease resistance.
- Tolerance to abiotic stresses.
- Heterotic pattern and response.
- Combining ability: it takes a lot of effort to identify a line with good combining ability, and if possible only lines with proven combining ability should be introduced.
- Other value-added traits.

A breeder should introduce only germplasm that matches farmers' preferences (grain color, texture, size) and the environment (disease resistance, maturity, need for acid soil tolerance etc.). If hybrids are the desired product, the heterotic response of an introduced line should be known so that the line can be used in the appropriate heterotic group.

6.2.3.2 Evaluation of source population(s) in the target environment

Once source germplasm is introduced, it should be evaluated in the target environment. Such an evaluation might be of:

- Population or line *per se*: This should be done not only for gathering initial data on maturity, performance, disease resistance, etc., but also for increasing seed of the most promising germplasm.
- Selfs of a population: to select directly the most highly adapted fraction of a population.
- Population x local tester topcross combinations.
- Line x local tester topcross combinations.
- Diallels of local and exotic populations or lines.

The frequency of useful 'exotic' lines is typically low, and a breeder should invest only in germplasm that proves to have as many valuable traits as possible. Even if only germplasm that meets certain basic requirements such as maturity, grain color and texture, and disease resistance (see previous paragraph) is introduced, a breeder should likely invest only in about 10-25% of all germplasm introduced.

6.2.3.3 What proportion of ‘local’ versus ‘source’ germplasm?

The proportion of ‘source’ germplasm will depend on the balance between the adaptation of the source germplasm and the drought or low N tolerance level of the local population(s). If the local and source populations do not differ much in performance, the F_2 population should be used as a base foundation population. If the difference in performance between parents is large, one to three backcrosses to the superior germplasm are appropriate.

6.2.3.4 How much recombination in ‘local x source’ populations?

It is beneficial to recombine ‘local x source’ populations for 2-3 generations with mild phenotypic selection for general adaptation following the introgression process, before intense inbreeding and selection are initiated (Geadelmann 1984). This breaks up linkages between desirable and undesirable genes. During recombination it is important to maintain an adequate effective population size (usually > 200 successful pollinations) to avoid genetic drift.

6.3 Breeding schemes

6.3.1 Integrated strategies for developing stress-tolerant maize germplasm

The extent to which selection for stress tolerance can be included in a breeding program depends on the breeding scheme used. A few strategies will be outlined below, though there are many others that can be employed. **In any breeding program, however, the following need to be clearly defined:**

- The type of product to produced: OPV, hybrid, topcross hybrid, etc.
- The most important characteristics of the product: maturity, grain characteristics, necessary stress tolerance and disease resistance, etc.
- The strategy for developing and deploying the product.

All breeding programs use a step-wise selection procedure to identify the best performing progenies, given limited resources. First, a large number of progenies are evaluated with few replicates and at few sites **(screening)**, then the more successful progenies, or their descendants, are evaluated with more replicates and at more sites **(testing)**.

Screening: If drought and/or low N tolerance are important breeding goals, evaluation under these stresses should be included in the screening phase, and the results should be combined with results obtained under unstressed conditions. Only the best germplasm (i.e., genotypes that possess stress tolerance and have good yields under optimum conditions) should be advanced to the testing phase.

Testing: The testing phase should include sites that are representative of conditions under which farmers grow maize. If drought and N stress are frequent in farmers’ fields, these conditions must be included. We suggest you include results from both managed stress sites and randomly stressed sites (e.g., farmers’ fields) during the testing phase. These multilocation trials need to be set up in a manner that considers the difficulties of stressed sites. One should not hesitate to increase the number of replicates and reduce the number of entries in such trials.

6.3.1.1 Example 1: A variety evaluation program of a national program that does not have its own maize breeding nursery

A certain national program may routinely evaluate about 60 genotypes introduced from other breeding programs for suitability to its country's growing conditions. Drought and N stress are important constraints for farmers in this country.

Conventional approach: Conventionally, this program would screen the 60 genotypes at 2 to 3 experiment stations under well-fertilized and perhaps irrigated conditions (screening phase). The best 12-16 genotypes would be increased and evaluated at 6 to 8 well-fertilized, rainfed sites during the following 2-3 years, using 4 row plots and 3 replicates (testing phase). The breeder observes that results from drought-stressed sites during the testing phase are often not significant for entry effect and that considerable GxE interactions occur because of random drought stress. The release decision is therefore based mainly on performance under high yielding, well-watered conditions.

An approach that considers the demand for drought and low N tolerant germplasm: Under this approach, this program would screen the 60 genotypes under well-watered, well-fertilized conditions (main season), under managed N stressed (main season) and under managed drought stressed conditions (dry season), for a total of three managed environments. Disease ratings are taken in the main season experiments. The best 20 genotypes from the first year would be reevaluated in the second year under the same three managed environments. The best 4-6 genotypes that have a high yield potential, are drought and low N stress tolerant, and have the desired disease resistance and grain texture, based on two years' results, are increased for multilocation trials. Note: under this approach the breeder can apply a more severe selection pressure after the screening phase, because stresses that are relevant in the target environment were included in the screening phase. The 4-6 genotypes are then evaluated at 6-8 locations, using 6 replicates per site, 2-row plots, and a fertilized and unfertilized treatment at each site. Because of the higher number of replicates during multilocation testing and the fewer and better pre-screened entries, this approach uses about the same resources as the conventional approach, but will likely result in cultivars that are better adapted to farmers' conditions.

6.3.1.2 Example 2: A hybrid breeding program

A certain national program may routinely produce its own test crosses, evaluate them, advance the best lines, and produce hybrids that are then evaluated at several locations. Again, drought and N stress are important constraints for farmers in this country.

Conventional approach: Conventionally, this program may annually develop about 200 S_3 lines with good disease resistance and per se performance. They are crossed to 2 to 3 testers and the test crosses evaluated at 3 to 5 experiment stations under well-fertilized and (possibly) even irrigated conditions (1st screening phase). Progenies of the 10 best lines (good combining ability under high-yielding conditions, good disease resistance, *per-se* performance, standability, and grain characteristics) are chosen for making single- and triple-cross hybrids. These hybrids are then evaluated at 3 to 5 experiment stations under well-fertilized and perhaps irrigated conditions (2nd screening phase). The best 12-25 hybrids enter multilocation testing at well-fertilized, rainfed sites during the following 2-3 years, using 4 row plots and 3 replicates (testing phase). The breeder observes that results from drought-stressed sites during the testing phase are often not significant for entry effect and that considerable GxE interactions occur because of random drought stress. The release decision is therefore mainly based on performance under high yielding, well-watered conditions.

Approach that considers the demand for drought and low N tolerant germplasm: Under this approach, this breeding program includes performance under managed drought stress when developing the S_3 lines. For instance, 1,000 S_1s could be screened in an unreplicated trial under managed drought (using an augmented design) and only the best 200 advanced to S_2, using remnant seed of the same S_1s. Disease resistance and per se performance are considered while developing S_3s from these S_1s. The S_3s are crossed to 2 to 3 testers and the test crosses evaluated at two sites under well-fertilized, well-watered conditions, under managed flowering drought stress, and under managed N stress (1st screening phase). Progenies of the best lines (good combining ability under high-yielding, drought stressed and N stressed conditions, good disease resistance, *per se* performance, standability and desirable grain characteristics) are chosen for making single- and triple-cross hybrids. These hybrids are evaluated at two sites under well-fertilized, well-watered conditions, under managed flowering drought stress, under managed grain-filling drought stress, and at two sites under managed N stress (2nd screening phase). The best 4-6 hybrids enter multilocation testing in both fertilized and unfertilized fields on-farm using 6 replicates per site. Again, because of the higher number of replicates during multilocation testing, the fewer and better pre-screened entries, this approach uses about the same resources as the first approach, but will likely result in hybrids that are better adapted to farmers' conditions.

6.3.2 Population improvement schemes

Maize provides a wide array of options with respect to breeding methodologies. One choice is between intrapopulation and interpopulation improvement methods. Within intrapopulation improvement methods, alternatives are:

- Individual plant versus family selection.
- Non-inbred families versus selfed progenies.
- *Per se* performance versus test cross performance.

Within interpopulation improvement methods, alternatives are:

- Test crosses involving individuals versus families.
- Half-sib versus full-sib test cross progenies.
- Parental versus non-parental testers.

6.3.2.1 Individual plant selection schemes

Two common procedures are simple mass selection and stratified mass selection (Gardner 1961). The procedures are not recommended for traits with relatively low heritability, such as grain yield under drought or low N stress. They can be quite effective for highly heritable traits, such as selecting for disease resistance after introgressing an exotic stress-tolerant but disease susceptible genotype into well-adapted, disease resistant germplasm. One selection cycle can be completed every season. The experimental area can be stratified to reduce differential environmental effects. Tassels of undesirable plants can be eliminated before flowering to prevent pollen contaminating selected plants. A few cycles of mass selection may successfully eliminate the most susceptible fraction of the population before switching over to a family-based improvement method. This is a good option where human, financial, and physical resources are limited.

6.3.2.2 Family-based selection: *per se*

Family-based selection methods result in greater gains when traits under selection are complex and of low heritability, but are more demanding in resources, record keeping and overall management. Progenies such as half-sib, full-sib, S_1, S_2, etc., are evaluated. Progress can be expected from any one of these methods. The choice of method will be guided by the availability of off-season test sites, the ability to store remnant seed, the choice of product (variety, hybrids or both), desired traits, heritability, progeny seed quantities, the degree of control over pollination (both parents or only one parent), and the time required to complete a selection cycle.

Half-sib improvement methods in which detasseled half-sibs (females) are pollinated with pollen from a bulk of all half-sibs (male) are commonly practiced using an unreplicated layout. Because the females are detasseled, ASI cannot be observed. For drought and low N tolerance improvement, it is therefore more desirable to plant replicated trials of half-sib progenies and use remnant seed for recombination of selected families. Heritability of yield from half-sib progenies is lower than that for other types of progenies. However, where resources are limited, this may be the most cost-effective selection scheme.

Full-sib family recurrent selection has been used extensively at CIMMYT to improve populations for drought and low N tolerance. Replicated trial sets of full-sib progenies are evaluated under drought, low N and well-watered, well-fertilized conditions. Selection is made based on performance in all environments and considering other factors such as disease resistance, grain texture etc. A single cycle of selection requires at least two seasons to complete.

Selfed progenies: When breeding procedures are based on selfed progenies, it takes longer to complete a cycle of selection, but this approach significantly improves tolerance to inbreeding over time. Formation of many S_1 or S_2 progenies is recommended. These can be prescreened in unreplicated observation nurseries under drought or low N and the selected fraction (perhaps only 30% of the original progenies) can be examined in more detail in replicated evaluations under, say, drought-stressed, N stressed and well-watered, well-fertilized conditions. Where prescreening in the main season is possible, disease susceptible progenies can be eliminated. Seed supplies may become limiting. This can be solved by using selected S_2 ear bulk seed developed from each S_1 progeny. To maintain population gains over longer periods, it is recommended that no fewer than 20-40 inbred progenies be recombined.

6.3.2.3 Family based selection: test crosses

Here the test crosses of S_2 or more inbred progenies are evaluated. The time required to complete a cycle of selection will thus depend on the materials that are test-crossed. Such schemes are useful when the emphasis is on combining ability, hybrid-oriented germplasm, and the integration of population and hybrid development. They can also be recommended where the need is to identify superior, early generation lines for further inbreeding or improving a population *per se*. Evaluation for stress tolerance can be emphasized during the formation and prescreening of selfed progenies as well as during test cross evaluation.

6.3.2.4 Interpopulation improvement alternatives

Two commonly used methods discussed here include reciprocal recurrent selection/half-sibs (RRS-HS) (Comstock et al. 1949) and reciprocal recurrent selection/full-sibs (RRS-FS) (Hallauer and Eberhart 1970; Hallauer 1973). Such schemes result in improved populations and superior OPV products as well as improving hybrid-oriented features of the two populations by increasing the level of heterosis between them. In addition these schemes allow the extraction of early-generation lines with good general combining ability (GCA), provide a sound basis for recycling early generation lines, identify superior testers on a continuous basis, and may identify new conventional and non-conventional hybrids. The schemes are not particularly suitable if the populations do not tolerate inbreeding, and the *per se* performance of lines and parent populations is ignored during selection. The original schemes also recommend evaluating S_0 test crosses and recombining the parental S_1 seeds of good performing plants. The modified schemes attempt test crosses (HS or FS) on S_1 or S_2 progenies and also permit selfed progeny evaluation for elimination of undesirable progenies. The RRS-FS schemes have an added advantage over RRS-HS, in that only 50**%** of resources are spent on test cross progeny evaluation trials. Both original and modified schemes permit selection for drought and low N at one or more stages during the selfed progeny regeneration and evaluation stages and during the evaluation of test cross progenies. These types of interpopulation improvement schemes are not a necessary requirement for hybrid development, but from a long-term perspective they should generate useful early generation lines.

6.3.3 Development of drought and low N tolerant lines and hybrids

Types of hybrids emphasized (topcross hybrids, double-, triple-, or single-cross hybrids) will depend on the stage of hybrid development and seed industry infrastructure, but an evolution from non-conventional to conventional and from multiparent to two-parent hybrids seems logical. Populations improved for drought or low N tolerance are useful sources for extracting drought or low N tolerant inbred lines.

6.3.3.1 Line - hybrid correlations

The relationship between the performance of inbred lines and their hybrids is an important issue in hybrid development. Inbred line information indicative of hybrid performance is desirable to reduce hybrid trial evaluations. Lafitte and Edmeades (1995) reported that the correlation between S_2 *per se* and topcross performance under low N was only 0.22. Betran et al. (1997) have reported correlations of around 0.4 between S_3 *per se* and topcross performance for some stress-related traits under drought, indicating that inbred lines insufficiently predict hybrid performance under drought or low N. The practical implication of these findings is that drought or low N evaluations of lines may be justified in early generations when numbers of progenies are yet very large, but the performance of advanced lines is best evaluated in hybrid combination.

6.3.3.2 Choice of appropriate testers

The choice of testers is a critical yet difficult decision in hybrid development. Appropriate choices will have a strong effect on the outcome of a program designed to identify stress-tolerant hybrids. Testers can be inbred, non-inbred, populations, synthetics, or hybrids. The choice involves a blend of theoretical and practical considerations. For example, should one use a broad or narrow genetic base tester, high or low yielding, one with high or low frequency for stress tolerance traits, good or poor GCA, one or several testers, and related or unrelated testers? Testers with a low gene frequency for the selection traits emphasized are theoretically attractive but are not commonly used, particularly regarding yield. For drought and low N selections, they might be more practical, since many conventionally developed testers have never been selected for drought or low N tolerance. **A desirable tester must facilitate discrimination among genotypes for combining ability and desirable traits, simultaneously identify useful hybrid products for direct use, and be compatible with a practical maize breeding program** (Vasal et al. 1997). For practical purposes, we recommend using the same testers for evaluating combining ability under drought or low N stressed conditions, as they are used for evaluating combining ability under well-watered, well-fertilized conditions.

6.3.3.3 Dosage effects

Preliminary results on the genetic control and modes of action for drought and low N tolerance show the following:

- Lines are more affected by drought and N stress than hybrids.
- As drought stress increases, so does the importance of general combining ability and additive genetic effects.
- In contrast to drought, non-additive effects are more important under low N stress.
- Dosage effects are important under drought but not under low N stress, suggesting the need for including drought tolerant parents on both sides of the hybrid to achieve acceptable drought tolerance, where stress is severe.
- Line-hybrid correlations are generally lower under stress than non-stressed conditions.

6.3.3.4 Line and hybrid improvement by introgression

Here we discuss strategies to improve line and hybrid performance. Our most important decision is to identify the source germplasm (lines, synthetics, populations, hybrids, etc.) most likely to contribute the most favorable genetic factors for drought or low N tolerance to the elite recipient line or hybrid. Several methods of selection of the donor source have been described by Beck et al. (1997). The objective is to identify source germplasm with the highest frequency of favorable dominant alleles that are not present in an elite hybrid. A detailed discussion of these methods is complex and we refer readers to these sources for further information.

A pragmatic approach that is taken by many breeders is first to evaluate source inbred lines for *per se* adaptation to the target environment. Again, many lines, maybe 60 to 80%, may be discarded in this step, and only lines with desirable disease resistance, maturity, and grain characteristics are then crossed to the local tester lines and their combining ability and heterotic response determined under managed stress and unstressed conditions.

Introduced stress tolerant lines may be used directly as one of the parents in a hybrid that is then released. More often, however, stress-tolerant lines need to be introgressed into local germplasm. After the initial cross between source and recipient line, selection and or inbreeding can be initiated either immediately or after one or more recombinations or backcrosses. Repeated recombination before initiating inbreeding increases the chances of obtaining inbreds with stress tolerance *and* good agronomic performance. Backcrossing is advantageous if one parent has more loci with favorable alleles than the other, if the parents are diverse, or if the level of dominance is high (Dudley 1984).

6.4 Biotechnology: Potential and constraints for improving drought and low N tolerance

6.4.1 Biotechnology applications in maize breeding programs

Biotechnology tools continue to develop rapidly, opening new possibilities. So far, in most maize breeding programs, applications will be for:

- **Fingerprinting of inbred lines**: the information can be used to identify lines used as parents in a hybrid, or to predict heterosis in crosses by estimating genetic distance between parents.

- **Line conversion**: a trait (or traits) of interest is transferred from a donor line to a recipient elite inbred line. Where a single trait is to be transferred, marker-assisted backcrossing can reduce the need for backcrosses from the usual four to five to around two. At the same time, the amount of "linkage drag" associated with transfer of unwanted parts of the donor genome to the recipient line is reduced (Ribaut and Hoisington 1998).

6.4.2 Marker-assisted selection (MAS) for drought and low N tolerance

Marker-assisted selection will be an effective way to save time in breeding if:

- The heritability of the trait is high and field evaluation is very costly or simply cannot be done at your location.
- Environmental effects are significant, heritability is low, and classical selection is expensive or slow, or if the conditions for selection are only present occasionally (e.g., selection for drought tolerance in the rainy season).
- If you want to backcross a known gene into an inbred line as rapidly as possible.

Because of the importance of anthesis-silking interval, CIMMYT tried to identify quantitative trait loci (QTL) for ASI and yield components under drought in maize. Six QTL were identified on chromosomes 1, 2, 5, 6, 8 and 10, accounting together for approximately 50% of the phenotypic variability of ASI. The QTL segments were stable over years and stress levels. In contrast, all but two yield QTL were inconsistent in their position in the genome in different water regimes. At one important genomic position, the allele contributing to a reduction in ASI also contributed to a grain yield decrease, and for this reason CIMMYT's marker-assisted selection strategy for drought tolerance is now based on an index of best QTL for both traits (Ribaut et al. 1996; 1997a; 1997b; 1997c).

Preliminary results suggest that MAS based on a strategy combining both ASI and grain yield QTL identified under drought could be a powerful tool to improve drought tolerance in tropical maize inbred lines and perhaps also in open-pollinated populations. It is noteworthy that, when mapped in the same F_2 population as was ASI under drought, ASI under low N has several QTL in common with those observed under drought. Thus, we can expect that improvements in ASI using marker-assisted selection should also result in improvements in tolerance to low N.

The advent of marker assisted selection opens up real prospects for new strategies in breeding that combine conventional and marker technologies that suit the genetics of the both the trait and the plant.

- Molecular markers allow the handling of very large numbers of genotypes during backcrossing while giving the breeder the tools to quickly reduce those numbers, based on their genomic composition.
- Large-scale F_2 marker assisted selection schemes for developing elite, trait-enriched populations fixed for traits of interest and segregating elsewhere are an exciting prospect for programs dedicated to developing broadly-based, elite, value-added germplasm.
- Marker-assisted selection opens the possibility of testing the desirability of specific traits by developing near isogenic lines that differ only for the DNA segments associated with the trait of interest—a tremendous tool for physiologists involved in testing the value and importance of secondary traits in selection.

7 The role of the farmer in selection

It goes without saying that if the variety being developed for improved tolerance to drought and low N is unacceptable to farmers for other reasons and is not adopted, all the research work invested in that variety will be wasted. It is critically important, therefore, that farmers be involved in the selection and testing process, and that researchers pay careful attention to farmers' views on what constitutes an appropriate and attractive maize variety under their circumstances.

7.1 What is farmer participatory research and why is it important?

Farmer participatory research represents:

- A dialogue between farmers and scientists to solve agricultural problems.
- A way to increase the impact of agricultural research by developing technologies that are more widely adopted.
- A path to more productive, stable, equitable, and sustainable agricultural systems.

The goal of this chapter is to present basic concepts and methods for incorporating a farmer participatory approach into breeding for drought and low N tolerance in maize.

7.2 What is new about farmer participatory research?

Farmer participatory research emphasizes three aspects: farmers' knowledge, farmer experiments, and farmer exchange of information and technologies.

7.2.1 Farmers' local knowledge

Farmers have an extensive and well-developed knowledge base on their environments, crops, and cropping patterns built up over many seasons and even generations. Farmers' local knowledge is often made up of **perceptions**, or mental images based on repeated observations in the normal course of life and work on the farm. This information is normally organized into hierarchical categories (also called "taxonomies") with names and defined properties. Farmers normally have taxonomies for such areas of direct interest as crops, crop varieties, soils, insects, among others. Farmers' knowledge also comprises many **rules of thumb**—logical propositions that relate two events in a cause and effect manner. This applies mainly to things that can be easily observed and are relatively straightforward. Drought is one such phenomenon, whereas a steady decline in soil fertility over the years may pass almost unnoticed. Where things are hard to see with the naked eye or have multiple causal factors, farmers often have incorrect knowledge or none at all. Farmers' knowledge is dynamic, changing in response to new observations and evolving circumstances.

7.2.2 Farmer experiments

Farmers carry out experiments on their own and generate innovations – not every farmer does the same things on the land, so what are the reasons for the evolution and diversity of practices? Farmers' experiments or comparisons of alternatives play a key role in their livelihoods, since they can thus evaluate new and unproved technologies without jeopardizing scarce resources. Farmers' and scientists' experiments often differ in that farmers' experiments usually lack a control treatment, include many factors that may be modified simultaneously, and are usually not replicated in the formal sense. The main source of data is the farmers' own observations, and they lack the tools to observe many things scientists traditionally observe, as well as the statistical methods to test probabilities. Nonetheless, they have a well-developed idea of risk, and hence an informal understanding of probabilities.

7.2.3 Farmer exchange of information and technologies

Farmers actively exchange information and technologies among themselves. This is usually an informal, even social process, but it is perhaps the major way in which a farmer learns new ideas, perceives long-term risk, obtains new seed, etc. Farmers' exchange of information can also happen through mechanisms such as migration, off-farm work and casual contacts. Social barriers sometimes constrain these exchanges in unexpected ways, such as barriers between social castes, fear of witchcraft, or a fear of generating envy.

7.3 Participatory methodologies

7.3.1 With whom should we work?

How do we select participants? The answers we get and how representative they are will depend very much on how we select our informants. The following are possible strategies for selecting farmer partners:

- **Incidental selection**: Persons whom we encounter and are willing to talk to us, without any effort on our part to identify them.
- **Selecting key contacts**: We select participants based on well-defined criteria and with the help of local contacts who know the scene.
- **Random-selection**: We choose participants using some sampling procedure.
- **Self-selection**: Persons volunteer to participate. For example, when there is an open invitation to an event they come, or they make contact with the scientist on their own.

7.3.2 How to interact with participants

Types of interviews/interactions include **individual** and **group**. The first involves a one-to-one interaction between the scientist and the farmer, when often a large number of questions get asked of the farmer. In group interactions, the scientist meets with several participants. Here the objective is to ask relatively few questions, generate discussion among farmers, and identify areas of agreement and disagreement.

7.3.3 Methods for grouping farmers and responses

7.3.3.1 Grouping farmers

Gender and wealth are fundamental in classifying responses on varietal preferences. Wealthy farmers may handle issues such as risk differently from those who are poor, and they may have special varietal preferences. This makes it necessary to classify a known group of farmers into wealth categories. Informants should know the community well, should include both males and females, and should help develop a list with the names of the farmers to be ranked. Informants should be asked to list the characteristics of prosperous and poor farmers, as well as those of intermediate wealth. Then the name of each farmer should be read to the informants, who should assign him/her to one of the three categories of wealth. Often the use of cards depicting the characteristics of each wealth rank can be used to speed the process.

7.3.3.2 Grouping responses

Two approaches are frequently used to determine characteristics of local varieties and assess their importance to farmers. One involves groups and the other individuals.
The methods are the same for both:

- Identify all local varieties in the community of interest.
- Identify positive and negative traits that farmers consider important.
- Generate a comprehensive list of the traits.
- Rate the traits in terms of their importance to farmers.
- Rate the performance of each variety with respect to each trait.

Since the approaches are basically the same, we will focus on the group approach. For this approach several groups should be formed, each with individuals that share socioeconomic or gender traits considered important. For example, groups may comprise one of males and one of females, a group of farmers with small land holdings and one of farmers with large land holdings, etc. The idea is to try to ensure that communal diversity is fairly reflected. In addition, dividing farmers into homogeneous, contrasting groups allows assessment of the variation in farmer-perceived traits for varieties and a sense of the importance each group assigns to specific traits.

Each group is asked to compose a list of maize types or varieties sown. Effort should then be made to identify types or varieties that are the same but go by different names. (For each pair of varieties that can be formed from the list, ask whether they are the same or different. For example, for a set of three varieties, A, B, and C, we would ask: is variety A the same as variety B, is variety A the same as variety C, and is variety B the same as variety C?) Once "synonyms" have been eliminated, ask the group to list the positive and negative traits of each variety. One method to accomplish this is, for each variety, to request a show of hands on who has discontinued its use and why. With the farmers' answers, compile a list of traits they consider important. An example of the type of data that results from this exercise is presented in Tables 1 and 2. Compiling a comprehensive list from the farmers' answers may present a few problems, since farmers may refer to the same characteristics in different ways; once again, judgement is needed to identify synonyms.

To assess the importance of these traits and farmers' general demand for certain traits, supplement the list generated above with a few traits considered important by researchers but not mentioned by farmers (for example, traits related to response to N or to drought). Then, ask the group to rate each trait through a show of hands of those who consider the trait very important, then of moderate importance, and finally, those who think it is not important at all. (Alternately, voting can be simplified by asking who considers the trait important or not.)

Different groups within the same community may have different traits in their lists. This can be interpreted as indicating that they weight traits differently. Ideally, one would like to have the same list for all groups, and then proceed with the rating exercise again by group, to obtain systematic comparisons across groups. However, this will require added time, breaking the flow of the exercise, and dividing it into two sessions. In addition, if the list is too long, higher priority may have to be given to the traits mentioned in all groups, and lower importance to those mentioned only in one or by few people.

To assess the performance of local varieties for each trait, identify farmers who sow a particular variety. Then ask them to vote by raising hands on whether it performs well, satisfactorily, or poorly for a given trait, using this same line of questioning for each trait on the list. For example, for variety A, who sows it (count the number who raise their hands)? Then ask who thinks it is very good at withstanding drought (count those who raise their hands), who thinks it is satisfactory, and who thinks it is poor. Do the same for each trait on the list. Though long, this exercise provides a good assessment of local varieties' important traits. If the list is too long, queries can focus on traits identified as very important by most farmers in the previous exercise.

In this way, researchers can assess how local varieties supply the traits farmer demand and, thus, identify opportunities for improvement and possible trade-offs. For example, if a new variety performs well for one important trait but poorly for another important one, farmers can be asked whether this is acceptable.

To analyze the results of interviews, compare the traits mentioned across groups. Which were the traits everybody mentioned and which were not? Is there any pattern? Which were the traits mentioned by males and females? Which ones were mentioned by only one of these groups? In terms of ratings, what were the frequencies associated with each trait by group? These frequencies provide a quantitative estimate of the importance of the traits, which can be placed in simple tables with frequencies for cross-group comparisons. Are there differences? What is the consensus in terms of performance by trait? What are the trade-offs that farmers perceive in their local varieties (that is, for a particular variety, the simultaneous occurrence of a high frequency of a very good rating for a certain trait and a poor rating for another)?

The methods that rely on individuals are the same: 1) eliciting a set of traits that are important, 2) rating their importance, and 3) rating the performance of sown varieties with respect to the traits. These exercises are done individually, usually with a relatively large and representative random sample of farmers. Other socioeconomic information can be collected, so that afterwards researchers can relate the ratings to specific farmer conditions and make statistical inferences about their relationships. The individual approach requires more time and money.

Grain quality/type traits are very important for adoption. Here is it helpful to have samples of ears for farmers to categorize. Have, for example, ears with a range of textures to show farmers and have them rank them for desirability, being careful in a group setting to get the views of all present. When the most desirable type has been identified, then ask what it is that makes this type of grain so good. Possible responses are: storage quality, recovery rate of flour when milled, ease with which the grain can be shelled, color, depth of dent, or some trait associated with its performance as seed, etc.

7.3.3.3 Combining farmer groups and responses

- Identify groups of male or female farmers within a village or a region that share similar socioeconomic and biophysical conditions (farmer domains).
- Interview farmers that have been ranked by wealth and gender and ask them to classify their variety (or varieties) into one of the classes established above.
- Determine if particular varieties are associated with specific wealth classes among males and females.
- Use this two-way classification to develop varietal development goals and a target farmer group.

7.3.4 Evaluation of agricultural technologies

Identifying and understanding farmers' and scientists' perceptions of a technology (variety, or a management option that will lessen the impact of drought or low fertility) are fundamental to evaluating and improving it. Researchers need to identify the characteristics of a technology that are important to the farmer or scientist (such as crop varieties, fertility inputs, etc.) and ask whether these are considered benefits or costs. Another way is to ask informants to list the advantages and disadvantages of a technology. The frequencies associated with each answer should be calculated in general and for each farmer domain. The following is an example of responses from a group of farmers to a set of questions regarding their preferences for varieties:

Table 7.3.4.1. Disadvantages identified by maize farmers in Oaxaca, Mexico, for a particular variety.

Concern	Farmers' answers	Percentage	Cumulative
Yield	Low production	7.41	
	Low yield	18.52	
	Small cobs	7.41	
	Few rows	3.70	37.04
Storage	It rots	22.22	
	Not resistant to weevils	7.41	
	The cob rots	11.11	
	The grain rots	3.70	44.44
Abiotic stress	Tall plants (lodging)	14.81	14.81
Biotic stress	Attacked by pests	3.70	3.70
Total		**100**	

Table 7.3.4.2. Advantages identified by maize farmers in Oaxaca, Mexico, for a particular variety.

Concern	Farmers' answers	Percentage	Cumulative
Consumption	Good for making atole	3.87	
	Good quality	1.66	
	Color	8.29	
	Good for pasture	2.76	
	Good taste	12.15	
	Good for making tortillas	13.26	
	Good dough	1.66	
	Good for making tostadas	0.55	44.20
Yield	Thick grain	0.55	
	Produces cobs	0.55	
	High weight	12.71	
	Good production	1.66	
	Good yield	0.55	
	Good yield by volume	18.23	
	A lot of grain	0.55	34.80
Duration	Early	10.50	10.73
Sale	Sells well	2.21	2.26
Processing	Easy to shell	1.66	1.69
Adaptation	Well adapted	1.66	1.69
Abiotic stress	Withstands drought	1.10	
	Withstands cold	0.55	1.66
Biotic Stress	Withstands pests	0.55	
	Withstands weeds	0.55	1.10
Storage	Stores well	2.21	2.21
Total		**100.00**	

7.3.5 Learning from past technologies

Conditions and technologies used by farmers change. The challenge is how to use farmers' memories to learn about technological change. Identify informants of different age groups and gender, and identify a key and commonly shared moment in their lives (e.g., first marriage, outbreak of war, or a severe flood). Ask the informants about their current technology, and then about the one that served the same purpose at the key moment you have identified. Ask them to describe the current and past technologies, their advantages and disadvantages, and the reasons they abandoned or modified the past technology. If informants are in different age groups, this helps provide a sequence of events.

7.3.6 Farmers as experimenters

Why should farmers and scientists interact to carry out experiments? Scientists can help farmers improve their own experiments by providing some basic training and guidelines, and help farmers try and evaluate new technologies. Scientists also gain useful input about the technologies. In this case, the scientists should also provide basic training and guidelines for carrying out experiments, but the agenda is defined by the new technology.

Farmers' experiments may differ from those of scientists: Farmer's experiments usually lack a control treatment, several factors vary at once, they are usually unreplicated, and data collected are usually only impressions and observations.

Guidelines for developing experiments with farmers

- **Test only one factor at a time**. If there are several factors, test each one independently in a different field or section of the field
- **Emphasize the need for a control treatment**. Explain to the farmer the importance of a control treatment, to be able to interpret the results of the experiment. If there are several independent experiments in different fields, use the same control treatment to facilitate the comparisons and interpretations of results.
- **Emphasize the need to maintain all conditions, besides the experimental one, equal.** Jointly decide with the farmers what those conditions are, and agree on how they will be kept constant.
- **Establish the indicators and criteria to judge the outcome of the experiment**. Farmers and scientists may focus on different indicators to judge and interpret the outcome of an experiment and to assess the costs and benefits. The scientist should ask the farmer: what does s/he expect from the experiment? What elements would s/he focus on to judge it? Under what circumstances would the farmer judge one treatment to be better than the control? (And scientists should ask themselves the same questions!)
- **Replicate experiments among farms**: Farmers usually do not replicate their experiments and see replication as a waste of resources, because they lack the tools to utilize replications properly. They may also be unable to handle spatial variability in the plot. If replication of an experiment is considered important, do it across farms, even though experimental conditions may not be the same across farms. Convince farmers with replicates of the same experiment to agree on the conditions that should be maintained constant.

7.4 Conclusions

What should we be doing to ensure input by farmers into our plant breeding decisions? Two simple steps can be taken that could greatly improve our breeding goals, public awareness of what it is we are doing, and our chances of success:

- Be involved in interacting with groups of farmers selected as described above. Use samples of ears showing a wide diversity of characteristics to elicit opinions. Try to determine what farmers are already doing to handle risks associated with drought and low fertility. Identify management strategies that farmers use when drought threatens or actually occurs. Keep a written record of your interview procedure and the results.
- Involve farmers in your trials. Have them come to on-farm evaluation sites and to the experiment station and systematically collect their views and their preferences for the genotypes you are developing. Conduct a brief survey of those who come to determine who they actually are. Develop links with farmers who are keen to try out some of their selections on their own fields, and use this as a means of moving improved germplasm onto farmers' fields.