The Planning Stage of On-Farm Research:

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Identifying Factors for Experimentation

CIMMYT

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The Planning Stage Of On-Farm Research:

Identifying Factors for Experimentation

Robert Tripp and Jonathan Woolley

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Preface

This publication is a product of the on-farm research training conducted by CIMMYT and CIAT over the past several years. As our staff members have developed and refined methods for teaching how to plan and set priorities in on-farm research, they have emphasized converting that experience into training materials.

We are particularly pleased that this publication represents a collaborative effort between two international agricultural research centers. CIMMYT and CIAT provide a variety of training in on-farm research, and we believe it is worthwhile to compare notes, learn from each other's experience, and, most important, learn from the experience of national program researchers and extension agents. One of the things we consistently hear from our colleagues in national programs is the necessity of coordinating their efforts with ours in teaching on-farm research methods. Publications such as this provide a forum for establishing that collaboration. Work on different crops under different conditions will necessarily lead to some variation in procedures, but there is much common ground from which general methods can be developed. Those procedures can then be refined by national program staff to fit their own requirements.

We believe that this publication will prove useful to researchers and extension agents involved in planning on-farm experimental programs. It should also be helpful for national programs in developing their own training activities. We anticipate that it will promote more collaboration between international research centers and national research programs in the development of training methods and materials. Suggestions for modifying and improving this publication will be appreciated by the authors.

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Introduction

On-farm research is a problem-oriented approach to agricultural research that begins by diagnosing the conditions, practices, and problems of particular groups of farmers. Once the problems are identified, a research program is designed to address them. A key part of any such program is conducting experiments on farmers' fields under farmers' conditions and management. Those experiments are then evaluated using criteria that are important to farmers, and the results are used to make recommendations.

This publication seeks to contribute to the development of methods for on-farm research by describing a method that can be used to decide which factors have highest priority for experiments that are planted in farmers' fields (the actual design of experiments is not discussed). It also describes how the planning of on-farm experiments can be used to suggest other activities in support of on-farm research. The procedures have been used in a wide variety of settings and should be seen as flexible guidelines, not rules.

An on-farm research program often generates so much information and so many ideas that it is difficult to decide which factors should be included in on-farm experiments. Because these programs usually have quite limited resources, and because farmers prefer to consider recommendations that address important problems, some decisions have to be made in setting priorities for the experiments. This publication presents six steps for discussing the available evidence and deciding which factors should be included in on-farm experiments.

The steps are a way to record and make explicit the rationale behind the decisions that are taken in selecting experimental factors. Furthermore, they can serve as an agenda for a meeting to plan on-farm experiments. The participants in the meeting would be the researchers and extension personnel involved in diagnostic and experimental activities. Other persons, such as specialists in subjects that are particularly relevant to the research program, may participate as well. The meeting should take place sufficiently in advance of planting so that researchers can arrange materials and sites for the

experiments. The planning may take several days, including the identification of factors and experimental design. It may take place in an office or a conference room, and the facilities should be adequate for the examination of data, the interchange of ideas, and the debate and compromise that characterize planning. These planning steps can be used before each cycle of experimentation; indeed, they can be used at any time for reviewing the rationale of an on-farm experimental program.

The primary audience for which this publication is intended comprises researchers and extension agents involved in on-farm research. To guide readers through the planning method, a detailed description of each step in the process presents its objectives, the activities involved, and its relation to the other steps. The descriptive sections are complemented by a comprehensive example that uses data from one hypothetical research area and is carried through all of the steps (see box, p. 21). The example is purposely complex to illustrate various issues that might arise in the course of planning.

Aside from its use as an aid to researchers and extensionists, this publication is also designed to be used in training courses that address planning methods. For that purpose it is best if course participants have access to data from an on-farm research program, preferably data they have developed themselves. After each step is introduced, the participants can use their data to work through it, and their conclusions can be discussed before proceeding to the next step.

This document is divided into two parts. The first provides a brief review of on-farm research and discusses some features that are particularly relevant to planning. The second part presents the six steps that constitute the planning method and the lists used to summarize the conclusions.

Part One: Planning and On-Farm Research

A Review of On-Farm Research

On-farm research (OFR) is a set of procedures for adaptive research whose purpose is to develop recommendations for representative groups of farmers. In OFR, farmers participate in identifying priorities, managing experimentation, and evaluating results. Procedures for OFR can be divided into five stages, among which there is considerable overlap and feedback.

1) Diagnosis
The diagnostic stage involves collecting and analyzing information in order to design on-farm experiments. Diagnostic activities may include a review of secondary data, interviews with local officials, informal farm surveys consisting of farmer interviews and field observations, and formal surveys with a questionnaire. The purpose of the initial diagnostic activities is to gather enough information to describe the basic features of the research area, to identify problems that limit farmers' productivity, and to begin considering possible improvements in farmers' practices. The information obtained from diagnostic activities can be used to design the first cycle of on-farm experiments. Of course, diagnosis does not end once the first experiments are planned. Many of the experiments themselves are designed for diagnostic purposes, and during the experimentation stage the need often arises for further diagnostic activities, including informal observations and formal studies.

2) Planning
The planning stage of OFR is the focus of this publication, which describes six steps used to identify experimental factors to be included in on-farm experiments, as well as to suggest other research activities. During the first year of work, information generated during the diagnostic stage is used to design a set of on-farm experiments. In subsequent years, data from those experiments play an increasingly important role in planning. The six steps outlined here are as useful for the first year, when only survey data may be available, as for subsequent years, when results of on-farm experiments are available to plan future work. But though they help identify factors for

experimentation, the six steps are only part of the process of experimental design. The other aspects of that process are treated in detail in another document.[1]

3) Experimentation

On-farm experiments are planted in the fields of representative farmers and examine a small number of experimental variables. Those experiments may be described and classified in a number of ways, but regardless of classification most of them progress from exploring production problems, to testing possible solutions, and then to verifying recommendations and demonstrating them with farmers. In this document, some factors will be referred to as "exploratory," which means that they seek to better define and characterize a particular production problem. Exploratory factors therefore serve a diagnostic function, and their results contribute to the planning of the next cycle of experiments. Other factors will correspond to possible solutions for production problems that are already well understood. The experimental variables in an on-farm experiment may represent exploratory factors, possible solutions, or some combination of the two. Nonexperimental variables are usually set at the level of representative farmer management.[2]

4) Assessment

The results of the on-farm experiments should be analyzed carefully. The analysis requires an assessment of farmers' reactions and opinions, a thorough agronomic interpretation, and careful statistical and economic analysis. The results of the assessment are then used to plan future research and to make recommendations for farmers.

5) Recommendation and Diffusion

When researchers are confident that they have enough information, they can formulate recommendations. In a system of on-farm research

1 The organization of factors in experiments, taking into account the resources available, is presented in Woolley (1987).

2 See Woolley (1987) for a discussion of the exceptions.

that functions well, extension agents participate in the entire process and so are able to transfer recommendations to farmers with skill and confidence. When farmers are actively involved in the research process, they participate effectively in the diffusion of new technologies. By monitoring farmers' opinions and use of new technologies, researchers can improve their understanding of farmers' needs and preferences.

Issues Related to the Planning Stage of OFR

There are well-established procedures for most stages of on-farm research. Survey techniques, as well as methods for statistical and economic analyses, are described in several publications.[3] It is not so easy to find references on the planning stage, even though it may be the most critical part of the process.[4] During the planning stage researchers become committed to a set of on-farm experiments and other activities that will absorb an important part of the research budget. It is essential that the rationale for these experiments be well conceived and carefully documented.

The method presented here concentrates on designing on-farm experiments intended to develop technologies that can improve farmers' productivity in the short term (three to five years). This type of adaptive research relies heavily on technologies such as new crop varieties or management practices which have been developed through applied research on and off the experiment station. However, longer term priorities for technology development can be suggested by information generated during OFR, and the steps described here can be used to propose new themes to be addressed by the research institution.

3 A description of survey techniques for OFR is found in Byerlee et al. (1980). Statistical analysis is described in any number of books, including Gomez and Gomez (1984). Economic analysis for OFR is presented in CIMMYT (1988).

4 There are some exceptions. Valuable advice on planning in adaptive agricultural research can be found in Mutsaers (1985), Van Der Veen (1984), and Huxley and Wood (n.d.).

On-farm research is also dependent on agricultural development policy, which often directs research toward particular regions, crops, or types of farmer. But OFR may also contribute to the formation of policy. This planning method can be used to identify suitable issues to be pursued with officials responsible for implementing policy or for extension.

It is assumed that the steps described here will be used to plan a research program in one specific area of a country and that the area's boundaries have been defined before planning begins. In addition, it is assumed that the research will focus on one or a few crop enterprises, considered individually or as part of a cropping pattern.[5] Which enterprise(s) researchers study may be determined in advance by the research program or identified in the course of diagnosis and planning. In any case, limited research resources make it necessary to concentrate on a few enterprises at a time.

Planning an experimental program also requires an understanding of how farmers adopt innovations. Although in certain situations farmers may need to make simultaneous changes in a number of their practices, it is always advisable to consider offering farmers intermediate steps toward the adoption of a package of practices. Most farmers are very cautious and tend to adopt one or a few new inputs or techniques at a time. This *stepwise adoption* behavior has important implications for planning an experimental program, because it may influence the number of factors that are tested at any one time and the order in which they are tested.

This paper deals only with crop research. There is every reason to believe that most of the principles described here are applicable to animal production research as well, but we do not have enough experience to speak with authority on that subject.

The Use of Diagnostic Data in the Planning Process

Effective planning depends on the information developed during the initial diagnostic activities, the diagnosis that takes place afterward (supplementary surveys, observations, crop or soil samples, etc.), and the results of the experiments themselves. A diagnosis has four goals:

- To describe the circumstances and practices of representative farmers;
- To identify problems limiting the productivity of the resources available to farmers;
- To understand the causes of those problems; and
- To begin to consider possible solutions.

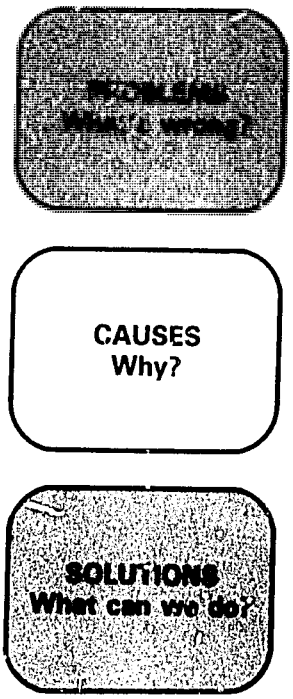
Those goals can rarely be attained completely during an initial diagnosis. Even after several years of experiments questions remain and new ones arise. Procedures for planning OFR must be designed to allow researchers to take account of uncertainties and to suggest the most efficient way to resolve them.

A description of farmers' circumstances should encompass both natural circumstances such as soils and climate and socioeconomic circumstances such as farmers' resources, local institutions, and markets. It is attained through a review of secondary data and various kinds of surveys. which also provide a description of production practices in major crop enterprises. Understanding how farmers' practices are conditioned by their circumstances is an important part of the diagnosis.

Besides being descriptive, the diagnosis should be analytic. Beginning with the diagnostic stage and extending into planning and experimentation, researchers should think in terms of problems, causes, and solutions. These three terms are central to the discussion of planning as it is presented in this publication because they provide a way to order the establishment of research priorities and correspond to the questions, "What's wrong?", "Why?", and "What can we do?".

What is meant by the term "problem"? The objective of OFR is to identify cases of low productivity and try to resolve them. Low productivity is reflected by low yields and incomes or by high production costs. But simply identifying an instance of low yields or high production costs will not provide direction to a research program. Problems must be described in greater detail.

In many instances problems can be described as biological limiting factors, such as nitrogen deficiency or weed competition. Other problems involve resource use. It may be that inputs are not used efficiently, that land or labor could be employed more intensively or production costs could be lowered, or that a crop of higher value might be substituted for the current crop. In any of these cases, the fact that productivity could be improved is evidence of a problem, which should be described either in terms of a biological limiting factor or inefficient resource use.



The careful specification of a problem is essential but frequently is not enough to indicate a course of action. The causes of a problem must be identified as well, because knowing the causes helps to determine possible solutions. For example, suppose there is a disease that affects maize that is planted late. The maize is planted late because farmers plant their sorghum first. The *problem* is the maize disease. One of its *causes* is late planting, which in turn is caused by the need to plant the sorghum on time. In this case, simply proposing an earlier planting date for maize would not be a possible solution, because it would interfere with planting sorghum. Possible solutions that are suggested by analyzing the causes of the problem include not only a disease-resistant maize variety but also an earlier maturing maize variety or a quicker method for planting sorghum.

It is important to maintain a clear distinction between problems, causes, and solutions, although that is not always easy. In specifying problems researchers will naturally think ahead to possible solutions. Through their own experience and knowledge of the literature, researchers will be aware of crop varieties, products, and techniques and will inevitably compare farmers' practices to the technologies that are available. But in the planning process the first step is a careful specification of problems. That step is followed by an identification of their causes, and only after that are possible solutions considered.

For this planning method to be most effective, the diagnostic survey and any other diagnostic studies preceding the first experiments should be organized around the concepts of problem, cause, and solution. Surveys should first describe farmers' conditions and practices and then move on to an initial identification of problems. As the survey work proceeds, researchers must try to identify the causes of those problems and, where appropriate, explore the feasibility of possible solutions. Those latter objectives may be pursued by conducting more detailed informal interviews and field observations, and/or designing a questionnaire. Researchers should be familiar with the steps in the planning process before beginning diagnostic work.

This method assumes that the research is aimed at well-defined groups of farmers.[6] A careful definition of the types of farmers who are likely to benefit from the research is essential to the planning process. That definition is important at two points: first, when clearly specifying the characteristics of farmers who share a particular problem, and second, when identifying farmers in that group who are eligible for a particular solution.

The Steps in the Planning Process

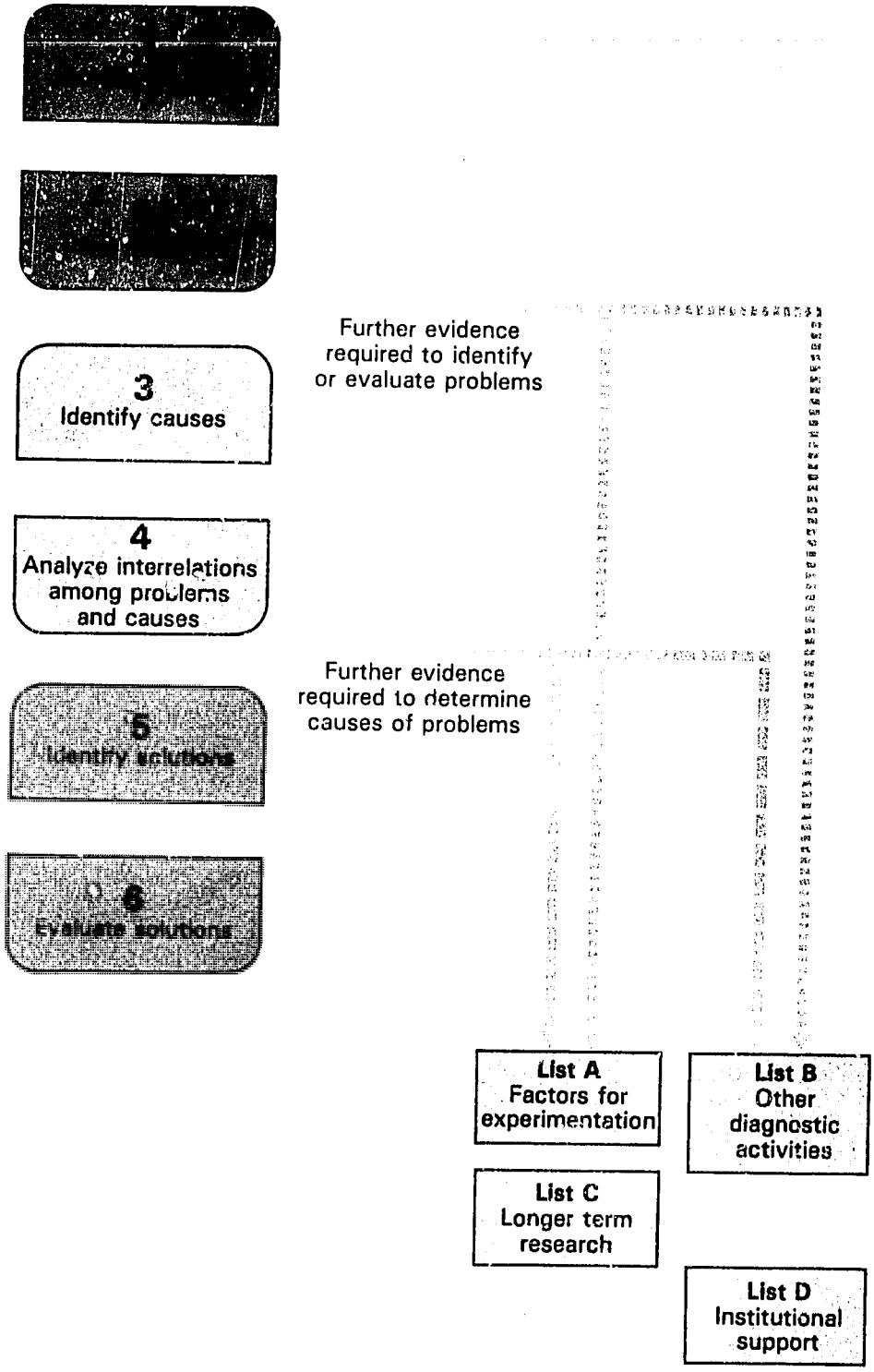
There is certainly no single correct approach to planning. Many methods have been developed for planning in administration, business, and other fields.[7] This method of selecting factors for on-farm experiments is derived from considerable experience, especially in conducting practical training courses in a wide variety of settings. But the method should be taken as a guide rather than a rigid set of rules, and researchers may want to modify it to suit their own needs.

The method is based on a series of steps (Figure 1) corresponding to the distinctions between problems, causes, and solutions. Step 1 is the identification of problems and, where necessary, the specification of means for gathering further information to define a problem. Once the problems are listed, Step 2 subjects them to a review in which a rough order of priority is assigned to each problem according to the number of farmers affected, the importance of the crop, and the seriousness of the problem.

6 One term for describing a group of farmers with similar circumstances and for whom a particular recommendation is appropriate is "recommendation domain." The use of recommendation domains is discussed in greater detail in Harrington and Tripp (1984). Alternative terms for describing these groups of farmers are used in the literature.

7 For a summary of some planning methods see Delp et al. (1977).

Figure 1.
Steps in the planning process



Step 3 involves identifying causes for each of the problems and, where the causes are not known, specifying the evidence required for their identification. Step 4 summarizes the interrelations between problems and their causes.

In Step 5 researchers will seek possible solutions to each problem for which there is sufficient evidence. The solutions must take into account what is known about the causes of the problems and should include several alternatives, if possible. Step 6 then narrows the list of possible solutions by evaluating each one for potential benefits, ease of adoption by farmers, and ease of investigation.

The results of the six steps are summarized in four lists (Figure 1). The first presents factors for on-farm experiments (either exploratory factors that help examine a problem or its causes, or factors that correspond to possible solutions). The second list contains suggestions for other diagnostic activities to help understand particular problems or causes. A third contains suggestions for research activities, on farms or the experiment station, that respond to longer term research needs. The fourth list suggests opportunities to transmit the data of on-farm research to officials responsible for policy implementation or extension.

Summary

On-farm research can be viewed as having five stages: 1) diagnosing farmers' conditions and problems; 2) using that information to plan a program of experiments; 3) carrying out a program of on-farm experiments; 4) analyzing the results; and 5) deriving recommendations for farmers. This document focuses on the second stage, planning.

Several characteristics of on-farm research are relevant to the planning stage. First, the research should focus on a small number of crop enterprises. The interactions of these enterprises with the rest of the farming system must be taken into consideration, but it will not be possible to do research on many enterprises at the same time. Second, the research program should focus on the possibility of making incremental changes in farmers' practices, beginning

with farmers' current practices and planning a strategy that allows them to gradually improve the productivity of their resources. Third, the planning should be based on a diagnosis of the research area that includes a description of farmers' conditions and practices, an identification of production problems, and an explanation of their causes.

The planning process described here is divided into six steps. The first is an identification of problems and a review of supporting evidence. The second is a ranking of these problems in order of importance. The third step is an identification of the causes of the problems and a review of supporting evidence. The fourth is a consideration of the interrelationships among all of the problems and causes that have been identified. The fifth step is a list of possible solutions to the problems. The sixth step is an evaluation of the suggested solutions and a selection of those solutions that seem to have the best chances of success.

The products of these six steps are summarized in four lists:

A) Factors for on-farm experiments (these factors address problems and suggest solutions that researchers feel can have an impact on the farming system in the short term, within five years);

B) Other diagnostic activities such as surveys, observations, and laboratory tests to identify problems or their causes;

C) Longer-term research activities on the experiment station or through on-farm trials, to develop solutions that require more time; and

D) Suggestions for developing support from institutions responsible for extension, credit, or input policy in order to ensure that the results of the research program can be used by farmers.

Part Two: The Planning Steps

Step 1. Identify Problems Limiting the Productivity of the Farming System

On-farm research is a problem-oriented approach to adaptive research, in which priorities are set according to an understanding of the production problems of particular groups of farmers. It is thus very important that, as the first step in the planning process, problems be carefully defined.

For the purpose of this publication, "problems" are biological limiting factors or inefficiencies in the use of resources that restrict the productivity of a farming system. Problems should be described in a way that clearly illustrates their relationship to low yields, low income, or inefficient resource use.

The type of evidence used in identifying a problem should also be noted. Was the problem identified through experiments, a survey, field observations, laboratory tests, or other methods? In some cases where there is not yet sufficient evidence to confirm that the problem exists, researchers will list tentative problems. In those cases it is necessary to describe what additional evidence (from experiments or other methods) is required to further specify or confirm the problem.

Problems should always be identified jointly by researchers[8] and farmers, and researchers should always take account of farmers' perceptions and priorities. One of the principal goals of any diagnosis is to understand what farmers see as their problems. Although farmers will not always be aware of some problems that researchers are able to detect, they will often point out factors that researchers might otherwise have missed.

In addition, the problems that researchers identify should always be seen in the context of the entire farming system. For example, it may appear that interplant competition caused by high plant population is a problem in maize fields. But farmers

8 In this publication, on-farm "researchers" may be researchers, extension agents, or both working as a team.

may be managing their maize to provide both grain and forage. Once the importance of animals to the farming system is understood, high plant populations may cease to be seen as a problem.

The resources available to farmers are important elements of the farming system and help define which problems farmers face. Those resources should be taken into account when considering how to improve the productivity of farming systems. In some situations where land is abundant and labor is scarce, farmers may find that planting relatively large areas, managing them less intensively, and getting lower yields than they might otherwise obtain from a small, well-managed plot is a rational use of their resources. Thus the definition of problems requires a good understanding of the farming system, an appreciation of farmers' resources, perceptions, and priorities, and a continual dialogue between farmers and researchers.[9]

The type of research described in this document focuses on one or a few crop enterprises, and the importance of choosing those crops in the context of the farming system must be emphasized. When the need for subsistence food is a priority, crops essential to the local diet may receive attention first. In other cases cash income may be most important, and crops that are marketed should receive priority. In still other cases, animal production or the maintenance of draft animals is crucial to the farming system, and work on forage crops is most important.

Considerable care should be devoted to defining problems because this step will determine the course of subsequent steps in the planning process. It may be useful to divide the following discussion between two general types of problems, those related to biological limiting factors and those related to inefficient resource use, with the understanding that these categories overlap to some extent. After that discussion, attention will turn to the kind of evidence needed to consider a problem in subsequent planning steps.

9 An excellent example of this type of dialogue is found in Rhoades and Booth (1982).

Limiting Factors
Those things that agronomists normally think of as limiting factors, such as nutrient deficiencies, too much or too little moisture, weeds, or insects and other pests (including storage pests), are probably the most common examples of problems, as the term is defined here. Limiting factors that exhibit year-to-year variability, such as drought or frost, are sources of risk for farmers and must be considered, too.

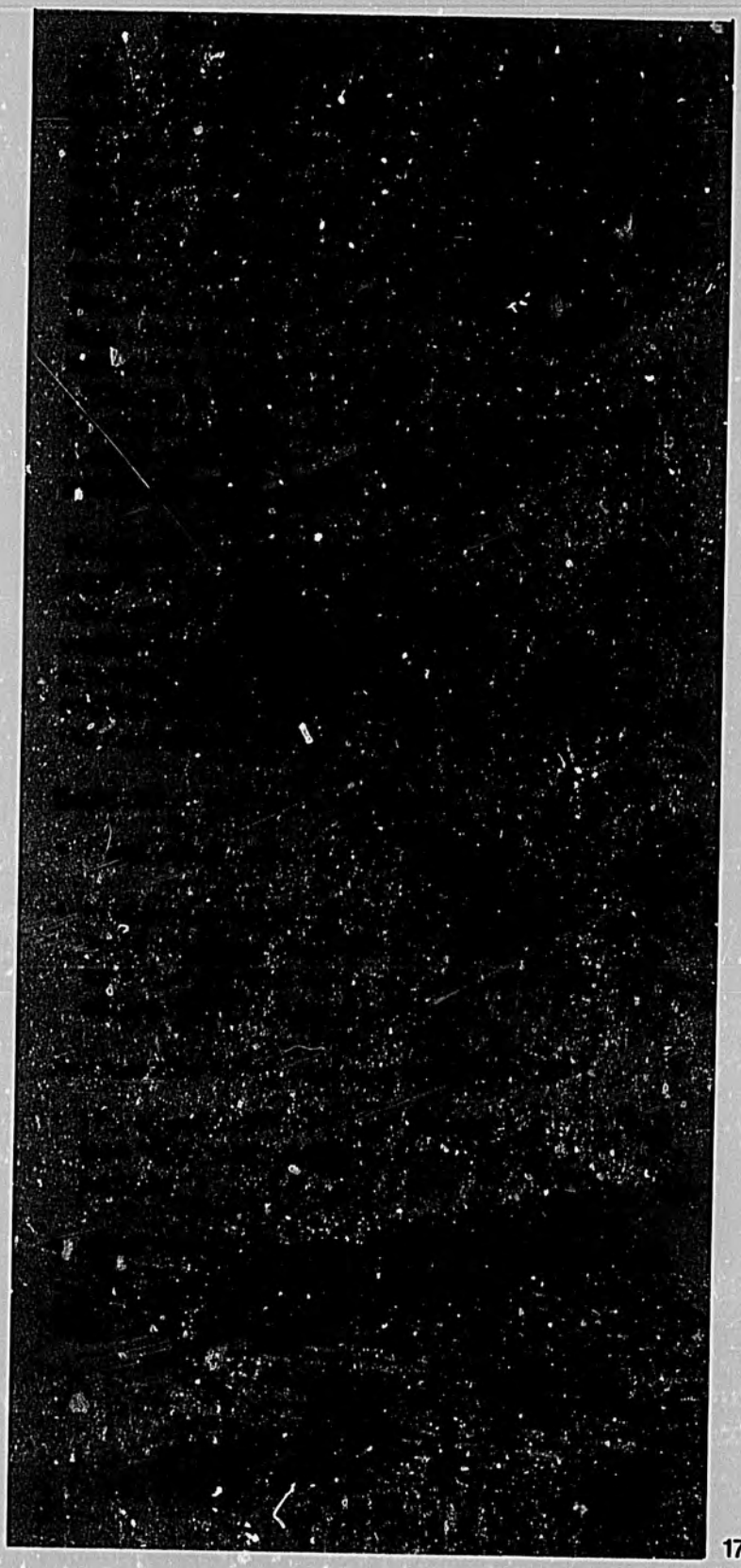
Limiting factors need to be described as precisely as possible:

- The particular nutrient deficiency needs to be specified: **The bean crop is affected by phosphorus deficiency.**

- The type of insect responsible for crop damage needs to be identified: **The maize suffers from stem borer attack approximately one year in two.**

- The period of the crop cycle when drought is most likely to occur needs to be established: **Drought often affects the wheat crop late in the growing season.**

Distinguishing problems from causes and solutions—In defining problems equated with limiting factors, it is important to distinguish them from causes and solutions. For instance, if farmers lose wheat to late-season drought when the crop is planted late, the problem is "late-season drought," *not* "late planting," which is one of the causes. Similarly, a problem might be described as "severe stem borer attack in maize" but *not* as "farmers don't use insecticides," which expresses a possible solution (see also box, p. 17).



Symptoms and problems—To identify limiting factors, agronomists use a wide variety of evidence, including symptoms of nutrient deficiencies, diseases, or pests; abnormal growth characteristics; or the analysis of yield components. The emphasis here is not on the skills required to interpret that evidence, but rather on the necessity of describing problems as precisely as possible. In developing evidence for a problem it is important to distinguish between the symptoms and the problem itself. If a symptom provides clear evidence of a problem, then there is no difficulty. For example, if striped leaves on maize plants, combined with other evidence (soil or tissue analyses, or exploratory experiments), point clearly to a magnesium deficiency, then the magnesium deficiency should be taken as the problem. But striped leaves may indicate one of several mineral deficiencies. If it is only suspected that this symptom is caused by magnesium deficiency, then that deficiency should be listed as a tentative problem, and additional evidence should be sought. Striped leaves themselves should not be listed as a problem.

Similarly, such abnormal growth characteristics as short internodes in beans or barren plants in maize certainly indicate problems but they do not provide enough information for researchers to think about solutions. More evidence must be obtained before the problem can be defined. For example, barren maize plants might be associated with a nutrient deficiency or interplant competition. One or more of the factors most likely to be associated with the abnormal growth characteristic should be considered as tentative problems, and more evidence should be gathered before the problem is finally defined. (Ways to develop evidence for tentative problems are described on p. 24.)

Interactions between problems—There may be interactions between two or more of the problems that have been identified. If both nitrogen deficiency and weed competition are problems, the nitrogen deficiency may partly result from the weed competition. Since the possibility of such interactions is dealt with in Step 3, the two problems should be listed separately in this first step.

Inefficient Resource Use

Problems that limit the productivity of the farming system may also be related to inefficient resource use. Such problems are often recognized because researchers are aware of more efficient alternative practices, but the problems should be defined in such a way that various solutions can be considered.

Sometimes there may be evidence of inefficient use of inputs. Problems of this nature include, among other examples, the excessive use of pesticides, the use of inappropriate products (compound fertilizers where single-nutrient fertilizers are sufficient), or the misuse of irrigation water. High costs of particular operations, such as weeding or tillage, are problems that may also arise from inefficiency.

> **Example:** Farmers apply a basal dressing of 10-30-10 fertilizer, but there is no evidence of a response to phosphorus or potassium.

Perhaps in some cases land or labor could be used more effectively. Land may be idle, although labor is available; opportunities for relay cropping or intercropping may exist; it may be possible to exploit a second growing season. Those sorts of situations may become apparent through an analysis of resource use, or might be suggested by such occurrences as seasonal food or fodder shortages.

> **Example:** Farmers leave most of their land idle during the minor rainy season.

Farmers' incomes might be improved by changing a crop or crop variety. If one type of bean receives a higher price in the market, or if a new crop offers possibilities for raising farmers' incomes, then those options should be examined. However, caution should be exercised when considering alternative varieties or crops until there is assurance that markets can accommodate the new product.

> **Example:** Farmers receive low prices for their maize crop, and there is an increasing demand from nearby towns for vegetables.

Institutions and Infrastructure

Factors related to institutions and infrastructure are often mentioned as problems but do not really

qualify. Diagnosis in on-farm research often reveals institutional inadequacies—poorly developed markets, low crop prices, lack of extension or credit, bad roads, and so forth. Such factors are undeniably important elements of the farmers' environment and should be included in a description of the research area, but they do not qualify as problems in the context of planning an on-farm experimental program. In many cases, however, inadequate institutions or poor infrastructure may be considered *causes*. If a fertility problem is partially due to the lack of credit for purchasing fertilizer, or if extension advice is not available for helping farmers control insects, then on-farm research data from experiments and surveys can be brought to the attention of policymakers who deal with credit or extension. That kind of information is included in List D, so that it can be reviewed by researchers and decisions can be taken about the most effective way to discuss those issues with policymakers.

Presenting Problems to be Addressed in Planning
All of the problems that have been identified should be listed. Table 1 (p. 22) shows one way to do so. It lists all of the problems identified in the example research area (see box, p. 21). This example will be followed throughout the rest of the publication. Table 1 also lists the evidence available to confirm each problem and indicates where additional evidence is required.

Evidence of problems—In addition to identifying the problems, researchers should specify the type of evidence available to confirm or support the existence of each. Much of the evidence for problems may come from the results of on-farm experiments. Exploratory experiments give evidence of responses to various factors and interactions among them, as is the case with nitrogen and phosphorus deficiencies in maize (Table 1, column 2, 1, 2). Further experiments help researchers refine the definition of problems and identify new ones, as when experiments with earlier maturing maize varieties pointed the way to identifying drought as a problem (3). Field observations may provide evidence in other cases, as with anthracnose in beans (6), and farmer surveys can reveal additional information, as with the high cost of weeding in maize (4).

Table 1
List problems (Step 1)

Nitrogen deficiency in maize	"Poor soils" mentioned by farmers; two years of experiments have shown response to nitrogen in maize.	No more evidence required.
Phosphorus deficiency in maize	"Poor soils" mentioned by farmers; two years of experiments have shown small, noneconomic response to phosphorus. Many fields show usual signs of phosphorus deficiency.	No more evidence required.
Drought stress in maize at ear filling	Field observations. Two years of experiments have shown significant yield advantage for earlier maturing variety.	There is sufficient evidence that problem is important; examine meteorological data to determine frequency of drought and whether the last two years were representative (List B).
High cost of weeding maize	Survey data show that farmers do two and sometimes three hand weedings. The cost of labor in the study area has risen 50% in the last three years.	There is sufficient evidence that problem is important; interview farmers who are beginning to use herbicides regarding their experiences and opinions (List B).
Nitrogen deficiency in beans	"Poor soils" mentioned by farmers; yellow leaves suggest nitrogen deficiency.	No more evidence required.

6 Anthracnose attack on bean pods (about one year in three)	Field observations, conversations with extension agents, and interviews with farmers.	No more evidence required.
7 Root rots of beans during crop establishment (tentatively identified as a problem)	A few farmers' reports during interviews (other farmers probably have beans that suffer from this problem but it goes unrecognized).	Field sampling to determine severity and laboratory tests to confirm species responsible (List B).
8 Low plant population in beans	Field observations (not certain to what extent the problem is due to root rots, poor seedbed, formation of soil crust, or poor seed quality).	No more evidence required regarding the problem, but more evidence of its cause(s) is needed—see Step 3.
9 Broad-leaf weed competition in beans (tentatively identified as a problem)	Field observations indicate that there may be some yield loss: farmers complain of weeds in beans.	Exploratory experimentation is needed to see if there is a response to broad-leaf weed control (List A).
10 Waterlogging in bean fields	Field observations.	No more evidence required.
11 Nitrogen deficiency in tobacco	Symptoms of nitrogen deficiency are apparent	No more evidence required.

Each year, a thorough review of previous experimental results and data from other research activities is required, as well as a new listing of problems, in accordance with the evidence available. In this process some problems may be eliminated from the original list and new ones added.

Tentative problems and further evidence—Often researchers will note problems that require more evidence. If little evidence is available regarding a problem, then considering solutions is rarely worthwhile. Instead, more effort should be spent in confirming the existence or the nature of the problem. The degree of confidence that researchers have in the evidence for a specific problem will determine how they should proceed. There are several possibilities.

In some cases, researchers may feel that there is enough evidence to justify examining solutions to a problem but may still suggest gathering additional evidence. To better quantify the problem of drought in maize (3), researchers propose an examination of meteorological data. To further investigate the high cost of weeding maize (4), they will interview farmers to gather additional evidence regarding the costs of different weeding methods.

Sometimes a problem is only tentatively identified, and more evidence is required before solutions can be sought. Broad-leaf weed competition in beans (9) is one such case, and an exploratory experiment is proposed to judge its seriousness. The experimental factor(s) are chosen to obtain a clear "yes" or "no" answer to the question: Is broad-leaf weed competition a problem in bean production in the research area?

In cases such as this the experimental factor(s) may be possible solutions to the problem (such as a particular herbicide). But it must be realized that here the "solutions" really serve a diagnostic function, and that once the problem is confirmed other solutions (such as extra hand weeding) may be considered. In other cases, experimental factors may be used for diagnosis although they would not be feasible solutions. For example, soil liming might be used to determine how much soil acidity reduces

yields even if liming is too expensive to be a potential solution for farmers. Instead, if the problem proves to be important researchers might look for a variety tolerant to acid soils.

Finally, there are instances in which nonexperimental evidence may be useful to help identify or characterize a problem. In the case of root rots in beans (7), field sampling and laboratory tests are proposed to confirm the existence of the problem.

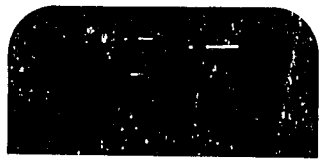
If researchers believe that no additional evidence for a problem is required, then they can proceed to examine causes. If additional evidence is sought, the type of evidence required should be noted. When so little evidence exists that researchers are uncertain if the problem is really present, then they should list the type of evidence required. That evidence may be an exploratory experimental factor (to be included in List A), or some other type of diagnostic information (List B).

Summary

The first step in planning on-farm experiments is to list problems that limit the productivity of the farming system under study. These problems may be described as either biological limiting factors or as inefficiencies in resource use. Care should be taken to describe the problems as precisely as possible.

Evidence for each problem should also be presented. It may be derived from previous experiments, surveys, or other diagnostic techniques. Researchers should decide if they have enough confidence in the evidence to identify or confirm the problem.

When the problems and supporting evidence have been listed, they are ready for consideration in Step 2, where they will be ranked in rough order of importance.



Step Two.
Rank the Problems

Although it may be fairly easy to describe many problems encountered in a given research area, it is usually impossible to investigate more than a few at a time. Research programs have limited budgets and priorities must be set. Furthermore, the idea of investigating a few priority issues at one time is consistent with the strategy of on-farm research, which is to make gradual changes in farming systems. It is therefore important to evaluate problems that may become research topics to determine which should receive priority.

Step 2 is only an *initial ranking* of the problems listed in Step 1. If the list of problems is very long (greater than 10 or so), it may be possible to eliminate some. But even if no problems are eliminated, an initial ranking helps establish a sense of priorities. Problems that receive a low ranking but which have important relations to other problems (see Step 4) or which have easily accessible solutions (see Step 6) may certainly be addressed in the experimental program being planned. Problems that receive low rankings in this review and lack either obvious interactions with other problems or easy solutions may be eliminated from consideration altogether.

Recall that some problems considered in Step 1 may not be well defined. Even so, they should be reviewed. A tentative problem may still be sufficiently important to warrant investigation either through experimentation or other techniques for gathering data.

Problems should be ranked every year. The ranking assigned previously should be reviewed in light of new evidence from experiments and other sources. Over time the importance of certain problems may diminish, whereas others may be assigned higher priority for future work. Maintaining consistency in the experimental program is an important consideration when researchers rank problems. *Priorities* may change from one year to the next, depending on the results of the research program, but the *content* of the on-farm experiments should exhibit a logical progression from year to year rather than skip from one topic to another.

There are numerous ways of assigning priorities to a set of research problems. The method suggested here employs three criteria to do so:

- The distribution of the problem;
- The importance of the particular crop enterprise to the farming system; and
- The loss of yield or income for which the problem is responsible.

The application of these criteria to the example is presented in Table 2 (pp. 28-29).

Distribution of the Problem

It is necessary to specify which farmers are affected by the problem. How many farmers in the research area grow the crop (or crops) in question? Of those farmers, how many have crops affected by the problem? Finding the answers to those questions may require only a straightforward estimate of the proportion of farmers in the area who grow the crop. All tobacco farmers seem to have nitrogen deficient crops (problem 11, Table 2), but few farmers grow tobacco and the problem gets a very low rating.[10]

A rough estimate of the number of farmers who grow the crop *and* have the problem is necessary. If only certain farmers seem to have the problem, a description of that group should be made. Most maize farmers have the problem of nitrogen deficiency, so it gets a high ranking. On the other hand, drought is primarily a problem for maize farmers in the north, so its rating is lower. Few farmers have waterlogging in their beans (10), so it gets a low ranking. The problem of root rots in beans is still unconfirmed and only tentatively identified as corresponding to a particular group of farmers.

Importance of the Crop Enterprise

In some cases a target crop or crops will already have been selected for on-farm research because it is either included in the mandate of the research organization or in national agricultural development

10 Specifying which farmers are affected by a particular problem may also involve weighting the estimate in favor of particular kinds of farmers. For example, government policy may give higher priority to a problem affecting a crop grown by small-scale farmers than to a problem found in a crop produced by larger scale farmers.

Table 2
Rank problems (Step 2)
(XX = very important; X = somewhat important; 0 = not important)

Nitrogen deficiency in maize	Most farmers. XX	Maize XX	XX	1
Phosphorus deficiency in maize	Most farmers. XX	Maize XX	X	2
Drought stress in maize at ear filling	Farmers who live in the northern part of the research area, which is more prone to drought. X	Maize XX	XX	2
High cost of weeding maize	Most farmers. XX	Maize XX	X	2
Nitrogen deficiency in beans	Most farmers. XX	Beans X	X	3
Anthracnose attack on bean pods (about one year in three)	Most farmers. XX	Beans X	X	3

Root rots of beans during crop establishment (?)	About half of the farmers (?). (Those who plant beans every year on the same field are probably affected most.) X	Beans X	XX(?)	(3)*
Low plant population in beans	Most farmers. XX	Beans X	XX	2
Broad-leaf weed competition in beans (?)	Most farmers (?). XX	Beans X	X(?)	(3)*
Waterlogging in low-lying bean fields	A few farmers who have low-lying fields. 0	Beans X	X	5
Nitrogen deficiency in tobacco	Farmers who grow tobacco (less than 10% of all farmers). 0	Tobacco X	XX	4

* Tentative problem; more evidence required

policy. But in other cases research topics must be selected from among the problems affecting various crops. To do so, researchers must determine whether the crop enterprise is a significant source of income or subsistence *for the farmers who grow it*, and/or if it utilizes significant amounts of farmers' land, labor, or capital. In other words, if changes were made in the productivity of the resources devoted to the enterprise, how much of a contribution would they make to the system's overall productivity? Sometimes a problem extends to more than one crop (e.g., a problem related to effective tillage) and merits a higher ranking than is given to a problem affecting just one crop. At other times the problem relates to a new or recently introduced crop, and researchers may want to cautiously estimate the crop's potential importance.

In the research area, maize occupies more land than beans and is the principal item in the diet. It has the highest ranking. Beans, which are important in the diet and increasingly important as a source of cash income, receive a medium ranking. Tobacco also gets a medium ranking, because although few farmers grow this crop, it makes a fair contribution to the incomes of those who do. (Remember, the number of farmers growing each crop was accounted for when the distribution of the problem was determined.) Most farmers grow a few tomatoes in their gardens, but tomatoes are unimportant in local incomes or diets, so problems in tomato production were not considered.

Seriousness of the Problem

Researchers should estimate whether the problem is responsible for a significant yield loss or serious inefficiency in resource use. That judgment may be difficult, especially if a problem is not well defined, but an estimate of a problem's potential importance should be attempted. In making the estimate, two elements of the problem are considered:

- **The severity of the loss.** For farmers whose crops are affected by the problem, how much yield per hectare is lost because of it, or how much income per hectare is lost because of inefficient resource use?

- **The frequency of the problem.** Does the problem occur every year, or only in a certain percentage of years?

The product of these two elements (severity times frequency) gives an estimate of the seriousness of the problem.

In the example, nitrogen deficiency (1) leads to more serious yield loss than does phosphorus deficiency (2). Broad-leaf weed competition in beans (9) may be moderately important, but researchers are not yet certain of that conclusion (hence the "?"). Drought stress (3) is responsible for sizeable yield losses in maize (again, note that the number of farmers with the problem was determined along with its distribution). More information is required on the frequency of drought: if it does not occur every year, its ranking may drop, as is the case with anthracnose in beans (6). Although it causes serious yield loss, anthracnose occurs only one year in three, and when both severity and frequency are considered, the problem receives a medium rating for seriousness.

Relative Importance of the Problems

When assessing the relative importance of problems researchers should take account of all three criteria (distribution, importance, and seriousness). Rankings should be assigned for each criterion. In certain cases some criteria might be given extra weight. This procedure obviously provides only a rough ranking, but it is an important start at setting priorities for the on-farm experimental program. In the example in Table 2, rankings are given using a simple system of Xs and Os, in which the highest priority is assigned to problems with the greatest number of Xs, but other methods of reviewing the rankings are also possible.

In the example, the problems of nitrogen deficiency in tobacco (11) and waterlogging in beans (10) were eliminated from further consideration. But note that a

decision to postpone or abandon research on a particular problem does not depend only on its ranking. It is also necessary to ask:

- How is a problem related to other problems? (See Step 4.)
- Are solutions readily available? (See Step 6.)
- What resources are available for on-farm experiments?

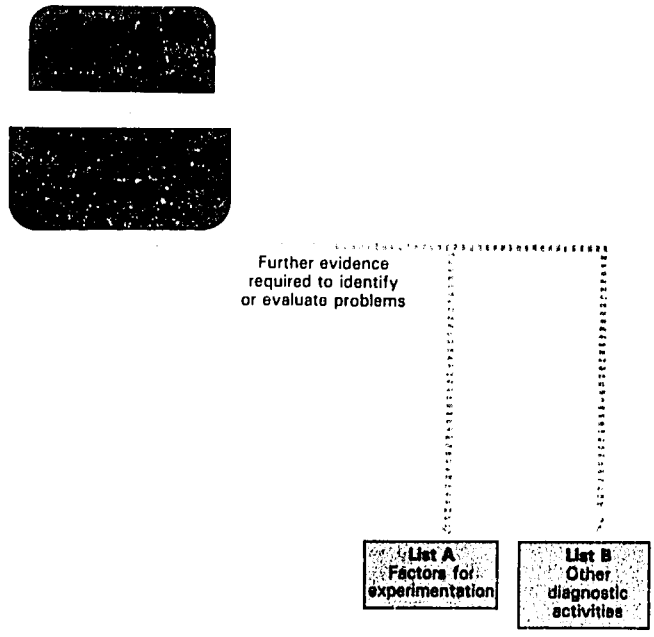
As these factors are taken into account they can be compared with the ranking given to problems in order to decide the final composition of the experimental program.

Summary

Step 2 ranks in rough order of importance the problems that have been identified. Even problems that have been only tentatively identified should be considered here. If researchers have identified a large number of problems they will eventually have to eliminate some from immediate consideration. The initial ranking carried out in this step is not precise, but it will help researchers decide which problems have a higher priority for the research program.

Problems should be ranked using well-defined criteria. The criteria suggested here are: 1) the distribution of the problem, including a definition of which farmers in the research area are affected; 2) the importance of the crop enterprise to the farming system; and 3) the loss of yield or income for which the problem is responsible.

After the ranking in Step 2, problems that researchers feel are of sufficient importance, and for which sufficient evidence is available, are passed to Step 3, where their causes are analyzed. Problems that are potentially important but for which more evidence is needed generally do not receive attention in Step 3. Instead, researchers note the type of experimental evidence (in List A) or information from other diagnostic techniques (List B) that is required.



Step 3.
Identify Causes of the Problems

All of the problems identified in Step 1 that are supported with sufficient evidence can be treated in Step 3. Even problems that are only tentatively identified may be analyzed in Step 3 if researchers feel it is helpful. If some problems were assigned a very low priority in Step 2, they need not be considered in Step 3.

The object of Step 3 is to develop enough information related to a particular problem to identify appropriate solutions. The causes of a problem may be management practices (or their absence—see box, p. 43), natural or socioeconomic conditions, or even other problems. Occasionally solutions can be identified without knowing a great deal about the causes of a problem, but in many cases lack of care in defining causes limits the chances of identifying reasonable solutions. Giving attention to the causes of a problem is an important stimulus for identifying imaginative solutions. If causes are not well understood, it may be necessary to conduct experiments or other investigations to clarify them. The causes of problems examined in the on-farm research program should be reviewed each year and defined more precisely as more information becomes available (see box, p. 41).

Diagramming Causes and Problems

The causes of problems may be fairly complex, and it is often helpful to diagram the relationships between causes and problems.

Diagrams for the entire example are shown in Figure 2, pages 37-39, and discussed in the box on pages 35-36. If there are several causes for a problem, the diagrams may get rather large. Three brief examples of diagramming problems and causes follow on page 40.

Analysis of Causes in the Example

Figure 2 illustrates the analysis of the causes of the problems that were identified in Step 1.

1. Nitrogen deficiency in maize is attributed to several factors, including low levels of fertilizer application; surface application of fertilizer, which tends to be washed away with heavy rains; soil erosion; and low levels of organic matter in the soil, partly caused by farmers reserving crop residues for forage.

2. Phosphorus deficiency in maize is judged to occur because farmers do not apply phosphorus fertilizers. Researchers also propose to test the hypothesis that phosphorus is fixed in these soils when it is applied. The nitrogen deficiency also contributes to the problem.

3. Drought stress in maize at ear-filling time is caused when the rains end early, especially in the northern part of the research area. In addition, the local variety, which farmers brought with them from an area where rainfall is higher, matures quite late. Moisture retention is limited by the lack of organic matter, which, along with soil erosion, is judged to contribute to drought stress.

4. The high cost of weeding maize is caused by the number of weedings (two to three) that farmers perform and by the rapidly increasing cost of labor in the area.

5. Nitrogen deficiency in beans occurs because farmers do not apply nitrogen fertilizer to beans (although they do apply phosphorus fertilizer). The low level of organic matter in the soil and soil erosion are additional causes of the problem.

6. Anthracnose attack on bean pods is caused by local varieties' high susceptibility to disease, and because farmers practice no control methods.

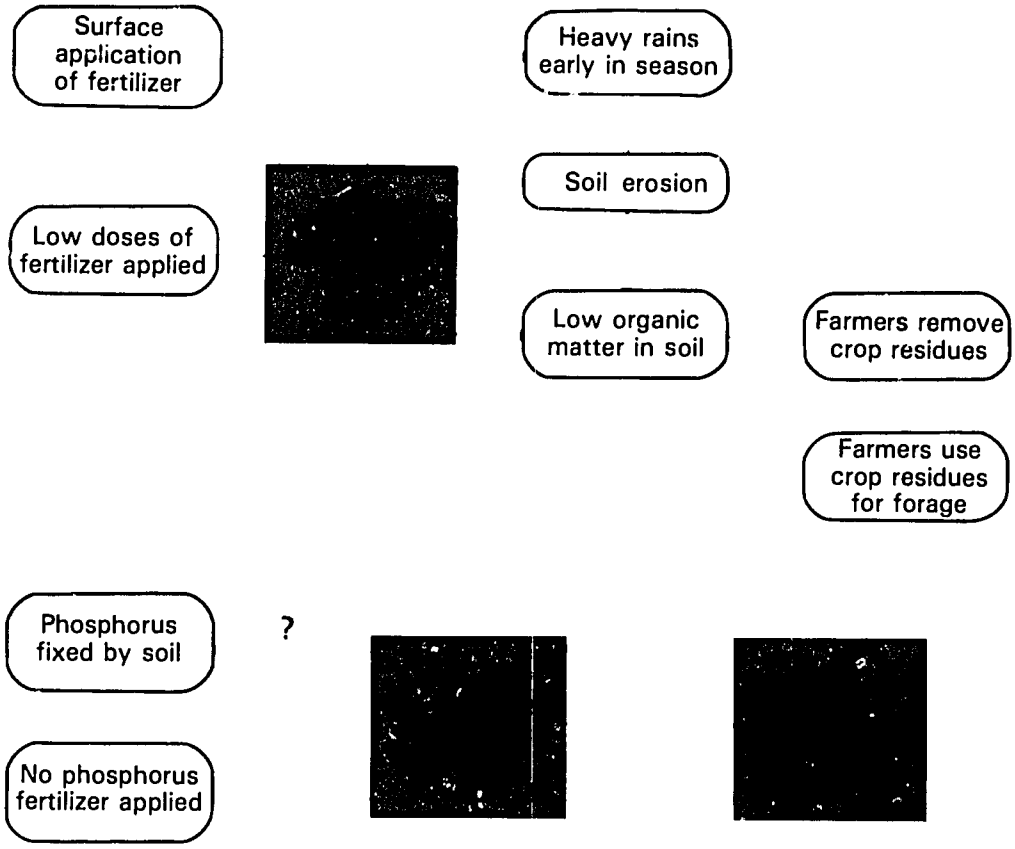
7.* The problem of root rots in beans is not yet firmly established. Researchers speculate that if it is confirmed as a problem it will be found mostly on fields that are planted to beans every year. Those are stony or sandy fields that farmers deem inappropriate for other crops, and the lack of rotation causes pathogens to build up.

8. Low plant population in beans is confirmed as a problem but researchers are uncertain of the cause(s). The problem may be due to root rots, if they turn out to be present. Another possibility is that the single tillage operation farmers perform provides an inadequate seedbed, which leads to poor stand establishment. A related hypothesis is that soil crusting interferes with stand establishment. Finally, farmers' lack of adequate seed storage methods may lead to low quality seed that germinates poorly.

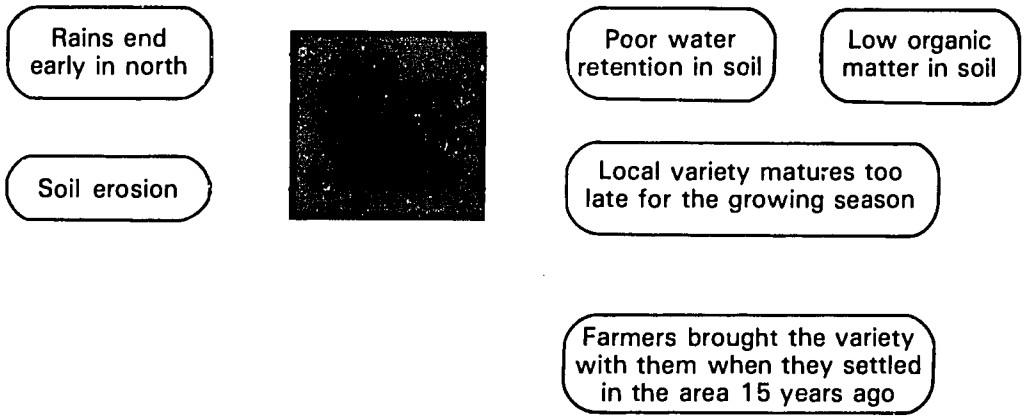
9.* Broad-leaf weed competition in beans is not yet confirmed as a problem, but researchers have several ideas regarding possible causes. They are 1) low bean plant populations in most fields encourage weed competition; 2) poor tillage practices do likewise; and 3) most labor is devoted to weeding maize.

* Tentative problem

Figure 2.
Analysis of causes



Exploratory experimentation on phosphorus placement is needed because no economic response to broadcast fertilizer was noted (List A).



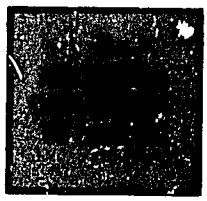
(continued)

Figure 2.
Continued

Cost of labor increasing rapidly

Farmers do 2 or 3 weedings in maize

Soil erosion

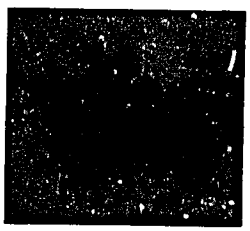


No nitrogen fertilizer applied

Low organic matter in soil

Extension does not recommend nitrogen for beans

Local bean varieties susceptible to anthracnose



No chemical disease control used

Seed and soil are not treated

Many bean fields not rotated

Certain sandy or stony fields are used only for beans

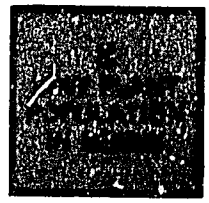
*Tentative problem

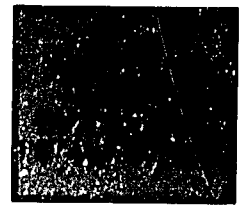
Poor seed storage

Poor seed quality ?

Soil forms crust ?

Heavy rains early in season



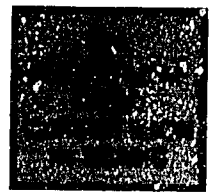


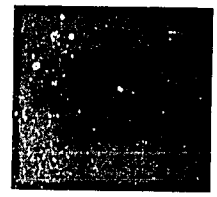
? Poor seedbed

? Only 1 superficial tillage

Further investigation is needed on possible causes of low plant population in beans (List B). **Seed quality**—Germination tests on farmers' seed. **Soil crusts and seedbed**— Observe emergence rates with farmers' soil conditions and land preparation practices. **Root rots**—Observations and laboratory tests.

Only 1 hand weeding in beans



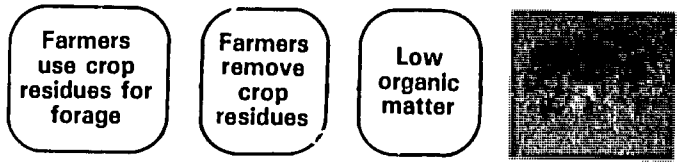


Farmers do 2 or 3 weedings in maize

Only 1 superficial tillage

*Tentative problem

- **Causes of causes**—Often it is necessary to give more information about a particular cause, and doing so may create chains of causes. One of the causes of nitrogen deficiency in maize is low organic matter, which in turn is partially due to farmers' practice of removing crop residues and using them for fodder. The diagram for the causal chain looks like this:



- **Multiple causes**—More than one cause may be identified for a particular problem. If several factors contribute to a problem, all of them should be presented. The diagram may be quite complicated, as is the case with nitrogen deficiency in maize (Figure 2).

  If two causes act together, the arrows can be joined, as shown in the diagram where the surface application of fertilizer is particularly inappropriate because heavy rains wash the fertilizer away. When a cause is uncertain, the relationship can be indicated with a question mark (?). If it is later shown that this cause is unimportant, it should be removed from the diagram.

- **Problems as causes**—Sometimes two problems are related to each other, in which case it is important to specify how one problem contributes to the other. Nitrogen deficiency is seen as a contributing cause of phosphorus deficiency in maize (2) (Figure 2).

Definitions of Problems and Causes

Sometimes the difference between problems and causes is unclear. In the example, erosion is presented as a *cause* of nitrogen deficiency and drought stress. It may be argued, however, that erosion itself is a *problem*, representing a serious inefficiency in resource use. There would be no difficulty in treating erosion as a separate problem that is a contributing cause of other problems.

The definitions of problems and causes occasionally change as on-farm research progresses. For the problem of low plant population in beans (8), several causes are proposed. They include poor seedbed preparation, poor seed quality, soil crusting, and root rots (itself a problem). If it is found that poor seedbed is the principal cause, the analysis can be simplified:

If it is found that root rots are the principal cause of low plant population, the description of the problem will change. Low plant population can simply be considered a *symptom* of the root rot problem and there will be no separate diagram for low plant population.

This sort of adjustment is normal as problems and causes become better defined during the course of investigation.

Limitations in Identifying Causes

The number of causes—The number of causes or possible causes listed for a problem should be limited. They should not include wild guesses, nor should they extend the causal chain to extremes. If there is evidence that a foliar insect is damaging a crop, it is probably not worthwhile to relate the physiology of the insect to the damage that it does. But researchers do want to ask if the insect's occurrence is associated with a particular rotation, time of planting, or other possible contributing cause that would help them consider alternative solutions to the problem. Natural conditions such as wind or rain may be listed as causes if they help in considering possible solutions. *A useful rule is that only enough information regarding causality should be developed to help researchers think of practical solutions to the problem.*

When researchers consider the type of diagnostic work required to identify causes, they may find it helpful to list all possible causes and then work toward eliminating the less plausible ones. Diagrams with many hypothesized causes are not very useful because excessive detail and extraneous causes lead to unfocused analyses. On the other hand, including too little information limits the possibility of finding imaginative solutions.

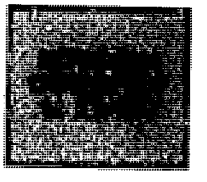
Problems that do not require causes to be listed—It is sometimes the case that no causes need to be provided for a particular problem, as in the example of the foliar insect problem. If the climate and other conditions are appropriate for the insect and if no management factors or other circumstances which might exacerbate insect attack (and lead researchers to think about possible solutions) are identified, then there is no need to diagram any causes for the problem:

The Absence of a Practice as a Cause

Farmers' practices are commonly identified as causes of problems. Late fertilizer application may be one cause of a nutrient deficiency, for instance. But what if farmers don't use any fertilizer, as is the case with nitrogen deficiency in beans (5)? Can this "non-practice" be used as a cause? Sometimes it is useful to explain a particular problem by noting that farmers do *not* do something and, where possible, to explain why:

Extension does not recommend nitrogen fertilizer for beans

No nitrogen fertilizer applied



But it is important to realize that fertilizer is not the only means to overcome the nutrient deficiency. The danger of including non-practices as causes is the tendency to limit the search for solutions. The fact that farmers do not use fertilizer helps explain the presence of the problem, but researchers should inquire if there are other causes that suggest alternative solutions.

If researchers are considering why farmers do not do something, care must be taken in listing the causes. For instance, if it appears that a crop can be planted at a particular time of year, but farmers leave the land idle, possible causes should include only those reasons expressed by farmers (e.g., lack of labor) or obvious to researchers (e.g., adverse climatic conditions). Speculation as to what *might* happen should a crop be planted—for example, nutrient deficiencies might develop—should take place when evaluating possible solutions (Step 6, criterion 1) and not when analyzing causality.

Further evidence required—If a problem is not considered sufficiently important it should not be analyzed in Step 3 (so problems 10 and 11 do not appear in Figure 2). Likewise, if a problem was not well defined in Step 1, it need not be considered in Step 3. Although problems 7 and 9 are not yet confirmed, they appear in Figure 2 because researchers wish to consider the possible causes of the problems. But if a problem is not well defined, proposing research to explore possible causes is rarely worthwhile until the problem is confirmed.

Sometimes researchers will decide that they need more evidence regarding the causes of a problem before proceeding to consider possible solutions. In Figure 2, two such cases are illustrated. Problem 2 (phosphorus deficiency in maize) requires more information regarding the fixation of phosphorus, and an exploratory experiment on fertilizer placement is proposed. The experimental factor should be included in List A. Problem 8 (low plant population in beans) may be due to one or more causes. The proposed investigation includes germination tests on the seed used by farmers and observations on emergence rates in farmers' fields. These diagnostic techniques should be noted in List B.

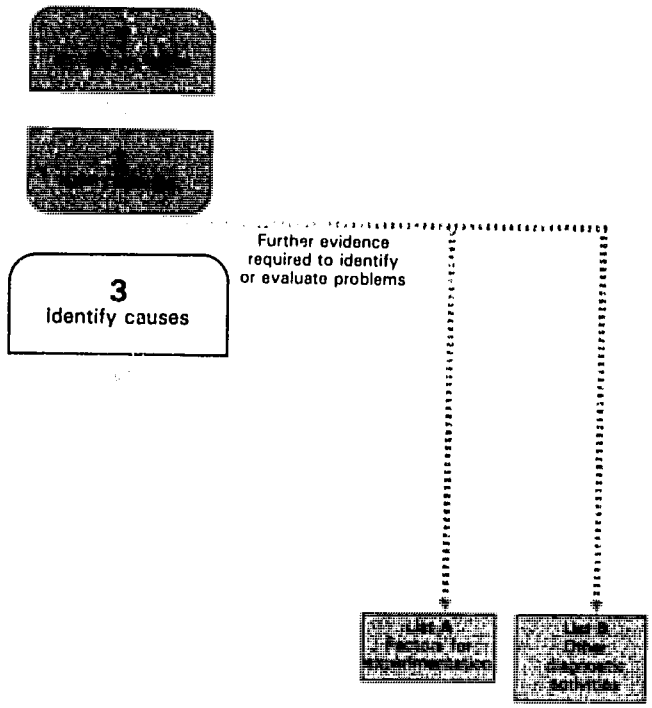
Summary

The third step in the planning process is to identify the causes of problems for which there is sufficient evidence (from Step 1) or for which it would be useful to analyze causes. The cause may be farmers' natural or socioeconomic circumstances or cultural practices. This step should only be done for problems that researchers believe are important enough to deserve attention (from Step 2).

Because the causality of problems is sometimes quite complex, it is helpful to diagram causes and problems by using an arrow to lead from causes to problems. In some cases a chain of causes may lead to a particular problem, or in other cases several causes may contribute to a problem.

The evidence for the causes of each problem may come from previous experiments, surveys, or other diagnostic techniques. Researchers should decide if they know enough about the causes of the problem to go on to consider possible solutions, or if they need more evidence to identify or confirm the causes.

When the causes have been listed, they are passed to Step 4, where interrelations among problems and causes are considered.



Step 4.
Analyze Interrelations among Problems and Causes

To help select priority problems and consider which factors might be examined in the same experiment, it is useful to review the interrelations of problems and causes identified in the previous steps. The review should include all well-defined problems from Step 1 that are of high enough priority, along with their known and possible causes.

One way to make interrelations among problems and causes evident is to try to combine the individual diagrams of problems and causes from Step 3 into a single summary diagram. Each problem and cause appears only once in the new diagram. If there are a large number of problems and causes, arranging the summary diagram may take several drafts. There is no single "correct" diagram; it is simply an aid to visualizing the interrelationships. The example is presented in Figure 3, pages 48-49.

When there are many problems and associated causes, one summary diagram may be too large and complicated to be useful. In this case smaller, partial summaries examining problems that exhibit strong interrelations should be considered. If different problems are associated with different groups of farmers, separate summaries may be called for. If the research program is studying more than one crop enterprise, separate summaries for each could be developed if there are no interactions between the enterprises. In Figure 3 the summaries for the two crops are presented together because of two interactions. Labor for weeding maize affects weeding in beans, and the two crops also share the problem of nitrogen deficiency. As research continues, other interactions involving the management practices used by farmers in growing the two crops might be uncovered, especially when the crops are grown in rotation.

Analyzing interrelations is useful not only for helping decide which problems and causes should receive more attention, but also as a reference later in the planning process when researchers consider the design of experiments. Recall that problems that are still not well defined need not appear in this analysis.

Although root rots and broad-leaf weed competition in beans are not yet confirmed as problems, they appear because of possible interactions with other problems.

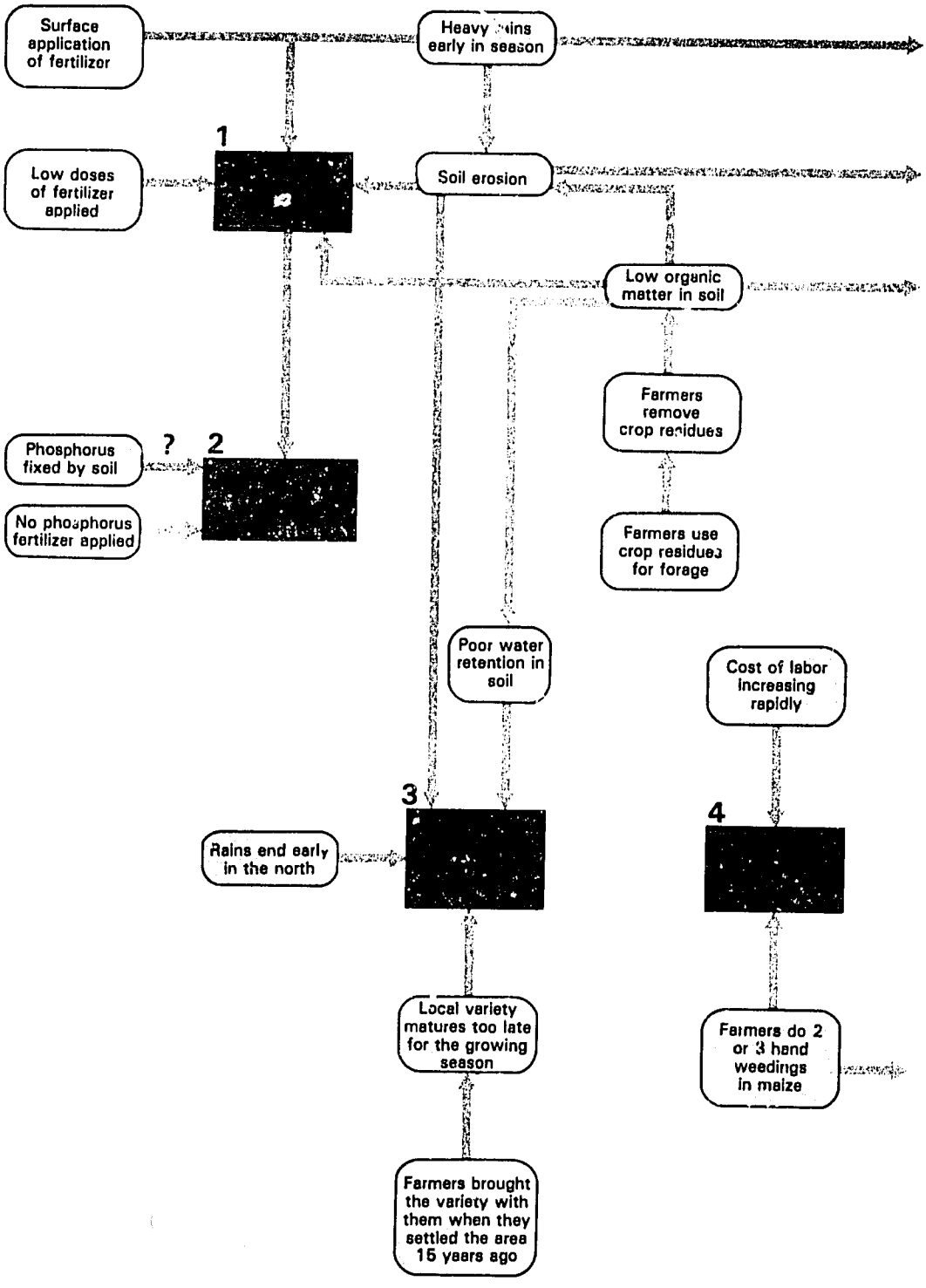
In carrying out the analysis, it is helpful to pay attention to four kinds of associations among problems and causes.

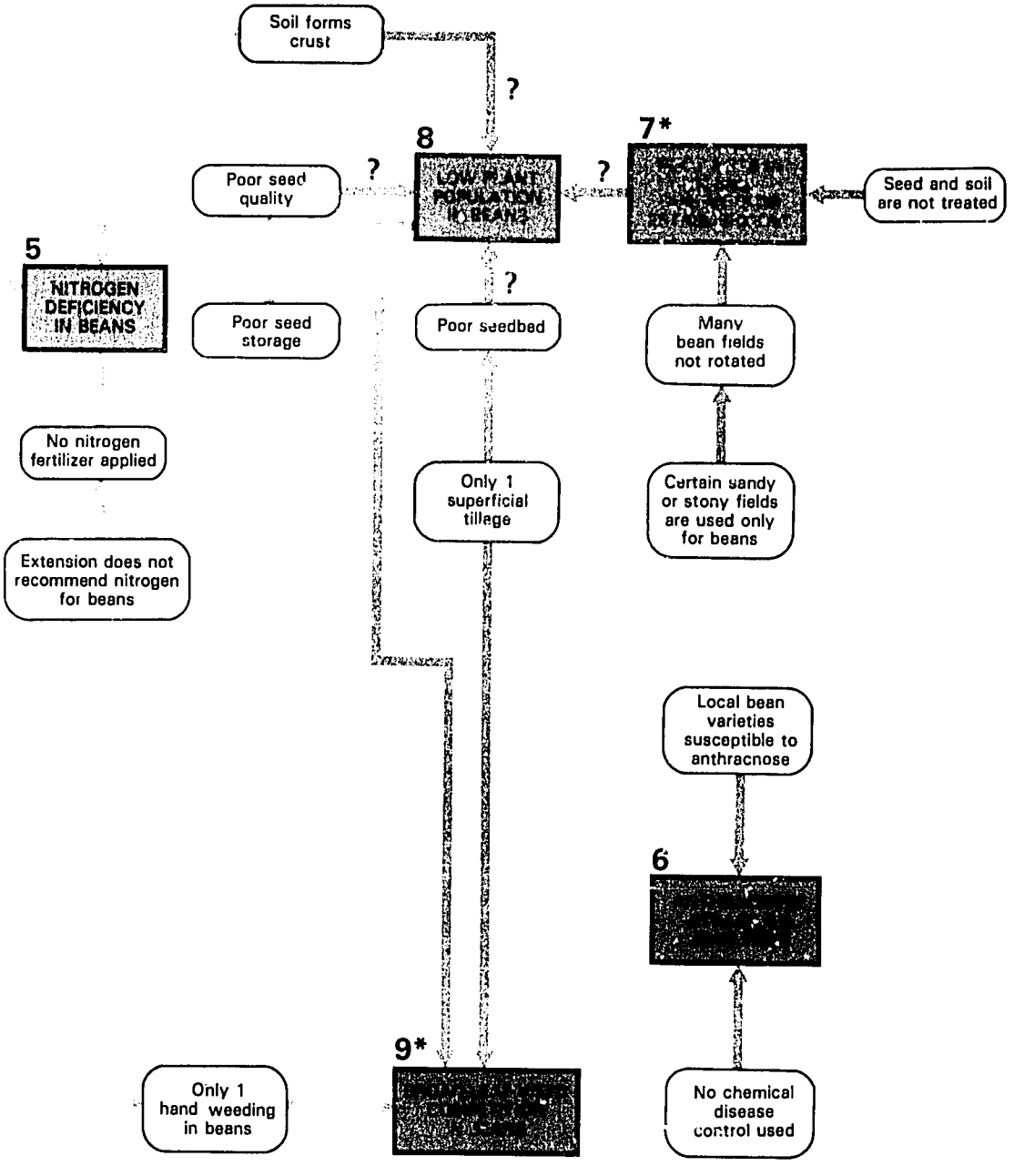
- **A particular cause is involved in more than one problem.** Such causes may deserve extra attention when considering possible solutions because they may offer possibilities for resolving several problems at once. One example of that situation is low soil organic matter as a cause of three problems: nitrogen deficiency in maize and beans and drought stress in maize. Improving soil organic matter may help solve all these problems. Another example is that reducing the amount of labor for weeding maize might not only lower the cost of weeding maize but also make more labor available to improve broad-leaf weed control in beans.

- **Two problems are interrelated.** In this case it is necessary to ask if one problem must be resolved before work begins on the other. Farmers are likely to change their practices in steps, and the sequence of those steps must be considered in deciding which problems and causes deserve attention first. A solution to the nitrogen deficiency problem is required before, or concurrently with, work on phosphorus deficiency in maize. Although a number of the relationships are not yet established, Figure 3 provides material for further speculation. For instance, if it is confirmed that broad-leaf weed competition is a problem in beans and that one of its principal causes is low plant population, the possibility exists that weed competition might be at least partially reduced by something as seemingly unconnected as improvements in seed storage.

- **A problem has several contributing causes.** In such cases, the causes may best be examined in the same experiment. In Figure 3, two causes that contribute to the root rot problem are the lack of crop rotation and the lack of seed or soil treatment. If both causes suggest possible solutions to the root rot problem, those solutions should be tested in the same experiment.

Figure 3.
Problems and causes in maize and beans





Tentative problem

- **A problem has no causes in common with other problems.** Research on such a problem may proceed independently. Anthracnose appears to be a case in point, so that experiments to examine the problem need not include any other experimental factor.[11]

Summary

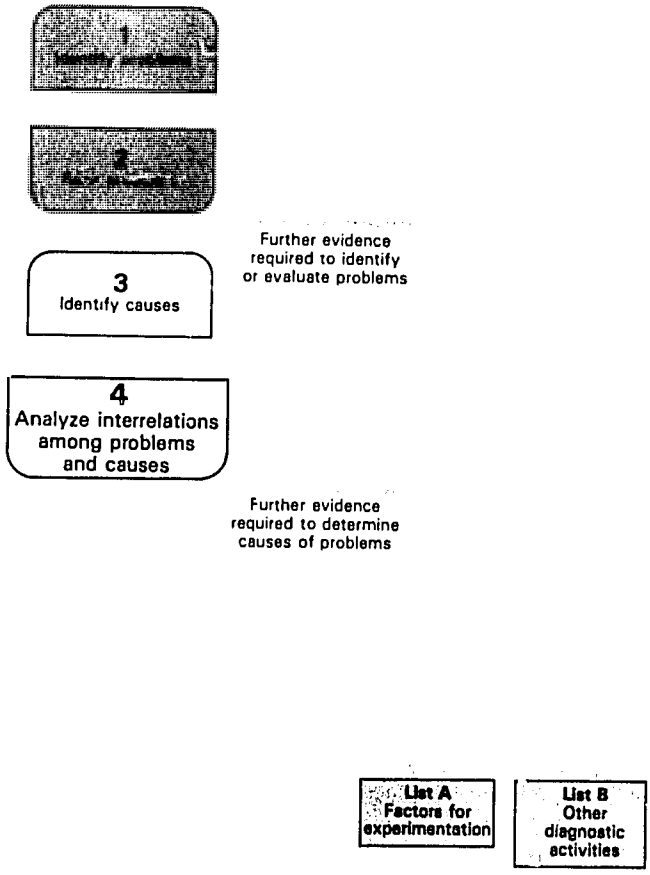
The fourth step is an attempt to examine the interrelations among the problems and causes that have been identified. Very often problems are related to each other, either directly or through shared causes. This step allows researchers to see those relationships and to think about their implications.

The best way to examine interrelations is to try to combine the causal diagrams for each problem into one complete diagram. If the research is studying different crops or different groups of farmers that have nothing in common, separate diagrams for those crops or farmers may be drawn.

An examination of the overall relationship is helpful for thinking about research priorities. A cause that is related to more than one problem may deserve extra attention where solutions are proposed. If one problem contributes to another, the first may need to be addressed before, or concurrently with, the second. If a problem has several contributing causes, those may be addressed in the same experiment. Finally, if a problem has no causes in common with other problems, it may be addressed separately in the experimental program.

11 Unfortunately, there is an interaction in this case. It is probable that increasing plant population will increase the anthracnose problem, as the effects of anthracnose tend to become more severe with higher plant population. So experimentation on these two problems should be considered together. See p. 57.

After these interrelations are examined, the problems and causes that researchers consider to be sufficiently important are passed to Step 5, where solutions are proposed. Problems whose causes are not well defined are generally not considered in Step 5. Instead, researchers note the type of experimental evidence (in List A) or information from other diagnostic techniques (in List B) that is required.



Step 5.
Identify Possible Solutions to the Problems

In Step 5 possible solutions to the problems are identified. This step can only be taken when researchers have enough confidence in the evidence available for a problem and its cause(s). Thus only a few problems are presented in Table 3: nitrogen deficiency in maize (1), drought stress in maize (3), the high cost of weeding maize (4), nitrogen deficiency in beans (5), and anthracnose in beans (6). All are problems with sufficient evidence of their causes. Recall that other problems have not been abandoned, but are treated in List A for exploratory experimentation or in List B for additional diagnosis.

Researchers should try to consider as broad a range of solutions as possible in this step (in Step 6 the list of solutions will be narrowed). The proposed solutions may be inputs, crop varieties, cropping patterns, or cultural practices. They should be specified as clearly as possible (e.g., type of herbicide), but exact dosage or levels will be determined when designing the experiment.

Researchers should devote considerable time to brainstorming when they develop ideas about possible solutions. It is often useful to list technologies available for the area. Participants in the planning session should review the work of the local research service in breeding and crop management, and consider other innovations reported in the literature. In Table 3, solutions 6a (new bean varieties) and 6d (lines with greater market acceptability) were suggested by local bean breeders based on progress in their varietal development program. Solution 6b (products for foliar disease control) came from some work that pathologists did on the experiment station.

In considering solutions to problems, the place to start is their causes. Causes help suggest ways of attacking problems. In the case of drought stress in maize (3), not only is an earlier maturing variety considered a potential solution, but analysis of the causes suggests a possible solution in the form of an intercrop to control erosion. Examining the causes of a problem may help rule out some possible solutions as well. When it is considered that one of the causes

Table 3
Identify possible solutions to problems (Step 5)

Nitrogen deficiency in maize	a) Apply 80 kg N/ha, half at planting and half at 30 days, in hole at side of maize (this solution has been tested with success in previous experiments). b) Incorporate maize residues to build up organic matter in the soil. c) Purchase chicken manure and apply to fields. d) Plant leucaena strips to control erosion and supply nitrogen through leaf litter and periodic pruning for mulch.
Drought stress in maize at ear filling	a) Plant early maturing maize variety A, which has been tested for two years and is ready for recommendation. b) Plant leucaena strips for erosion control.
High cost of weeding maize by hand	a) Apply pre-emergence herbicide C and postpone first weeding to 40 days. b) Apply pre-emergence herbicide D and postpone first weeding to 40 days. c) Apply pre-emergence herbicide E and postpone first weeding to 40 days.
Nitrogen deficiency in beans	a) Apply nitrogen fertilizer. b) Purchase chicken manure and apply to fields. c) Inoculate seed with rhizobium. d) Plant leucaena strips to control erosion and supply nitrogen through leaf litter and periodic pruning for mulch. e) Incorporate maize residues to build up organic matter in the soil.
Anthracnose attack on bean pods	a) Plant tolerant bean varieties J, K, and L. b) Use mixture of fungicides M and N. c) Use mixture of fungicides P and Q. d) Plant 10 anthracnose-tolerant bean lines (more marketable seed type).

The following problems are not considered for possible solutions:

Phosphorus deficiency in maize (2). The cause of the deficiency is not clear. Exploratory experimentation will see if phosphorus is being fixed by the soil. (See List A.)

Root rots of beans during crop establishment (7). The importance of the problem is not yet certain. Field observations and laboratory tests will be carried out. (See List B.)

Low plant population in beans (8). The cause of the problem is not clear. Field observations and germination tests will be carried out. (See List B.)

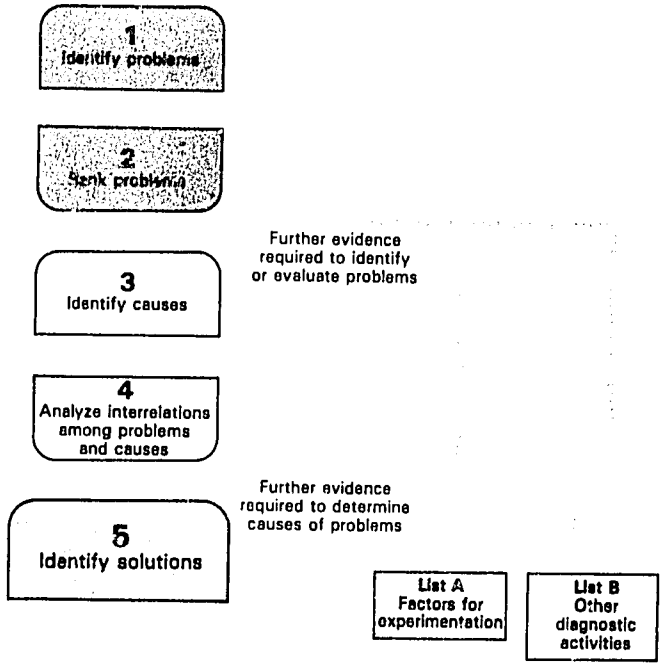
Broad-leaf weed competition in beans (9). The importance of the problem is not yet certain. Exploratory experimentation will measure the yield loss from weed competition. (See List A.)

of nitrogen deficiency in maize (1) is the *method* of applying fertilizer, it becomes obvious that simply increasing the dosage *is not* a possible solution.

In some cases a solution to a problem will already have been tested in the experimental program in previous cycle(s), and sufficient evidence of its success may mean that it is ready for demonstration to farmers. This is the case for solution 3a, a new maize variety that has performed very well in the past two years' experiments. Solution 1a (fertilizer application) has also been tested for two years and is ready for a final verification.

Summary

The fifth step in planning on-farm experiments is to list solutions for those problems for which researchers have sufficient evidence and whose causes are understood well enough to suggest possible solutions. Possible solutions for each problem should therefore take into account what researchers know about the causes. Researchers should note any solutions that they think might be feasible based on research conducted by their institutions or reported in the literature, or based on their experience. Each of the proposed solutions will be evaluated in Step 6.



Step 6.
Evaluate Possible Solutions

Because experimentation is the most costly phase of OFR, researchers must make sure that the possible solutions included in the experimental program have a high chance of success. In Step 5, many possible solutions to a given problem were considered. In Step 6, the list of solutions will be narrowed by evaluating each solution according to seven criteria:

1. **Probability that the technology will function**—Researchers must consider whether it is likely that the technology will function under the agroecological conditions and management practices of target farmers.

2. **Profitability**—Farmers will not be interested in a new technology unless it is profitable.

3. **Compatibility with the farming system**—Solutions to farmers' problems should be compatible with the other elements of the farming system—the socioeconomic and natural circumstances, management practices, and other crops, animals, and off-farm employment managed by farmers.

4. **Contribution to reducing risk**—Farmers will be most interested in solutions that help reduce risk in their farming operations.

5. **Need for institutional support**—Researchers should assess whether the proposed solution will require special support from extension services, the provision of new inputs, or a change in credit programs.

6. **Ease of testing by farmers**—There is a better chance of farmers using a technology if they can test it for themselves without a high initial investment of cash or labor.

7. **Ease of carrying out the experimental program**—All other things being equal, solutions that can be tested at low cost are preferable to those that require very expensive experimentation.

These criteria are presented in rough order of importance. Criteria 1 and 2 are the most crucial. If researchers have evidence that the proposed solution will not function or will not be profitable, then it should be eliminated from consideration. Criteria 3, 4, and 5 are also quite important. If solutions appear to be incompatible with the farming system, increase risks for farmers, or require much institutional support, researchers should consider whether it is likely that the solutions will be adopted. Unless a solution offers great advantages, it will be better to look for alternatives. Criteria 6 and 7 are rarely sufficient in themselves for eliminating a proposed solution, but in combination with other criteria they may suggest that another solution to the same problem deserves higher priority.

These seven criteria are presented only as suggestions; researchers may prefer to emphasize some others. But three important factors should be addressed when developing any criteria for evaluating possible solutions:

- The potential benefits of the solution to farmers (an issue addressed here by criteria 2 and 4);
- The ease with which farmers can adopt the solution (criteria 3, 5, and 6); and
- The ease of investigation (criteria 1 and 7).

Researchers should rank each potential solution using the set of criteria they have developed. Next, they should review the ranking and judge the value of conducting future research on the potential solution. Potential solutions should be reviewed each cycle. The experimental results of previous cycles will suggest whether certain solutions should be promoted, retained for further experimentation, or discarded.

An example of the evaluation of possible solutions is presented in Table 4.

1) Probability That the Technology Will Function
If a proposed solution has been included in on-farm experiments in previous years, researchers can judge its performance. But if it has not been tested before, researchers must ask themselves how certain they

are that it will work under farmers' circumstances and practices. Technologies that work in other areas or on the experiment station are not necessarily well adapted to the local situation.

Sometimes a technology may have unintended consequences, as when a new method of weed control increases erosion on hillside fields. Researchers want to take such factors into account. In other cases, they may conclude that a proposed solution will only be successful if additional changes are made (for example, the use of a herbicide may require changes in timing or type of cultivation). In such instances the additional factors should be listed as part of the proposed solution and included in the rest of the evaluation.

Occasionally the resolution of one problem may actually worsen another, as with plant population and anthracnose in beans: if plant population is increased, the severity of anthracnose will be greater. The problem of low plant population has not been passed to Step 5 because its causes are still being investigated. But researchers should be certain that they have some way to address the anthracnose problem before they resolve the problem of low plant population.

Each possible solution should be evaluated based on the probability that it will function in the local situation. A number of possible solutions in Table 4 get a high rating, either because of results in earlier on-farm experiments or because researchers are familiar with their performance in similar situations. Lack of experience with solutions 1b, 1c, 1d, 5c[12], and 6d gives them medium rankings. Fungicide Q (6c) has been found to be toxic for beans if the proper dosage is exceeded. In this case, a low rating is sufficient to elimitate fungicide Q from the experimental program.

12 There is some concern that solution 5c, rhizobium, may only function in the presence of added potassium, so it receives a medium ranking and researchers suggest that potassium be added to List A.

Table 4
Evaluate possible solutions (Step 6)

	Possible solution	1 Probability that technology will function	2 Profitability	3 Compatibility with system	4 Contribution to reducing risk
1a	80 kg N/ha for maize, half at planting and half at 30 days, in hole	High (already tested)	High	High	Low
1b	Maize residues	Medium	(?)	Low (farmers use residues for fodder)	High
1c	Chicken manure	Medium	Low	Medium	High
1d	Leucaena	Medium	(?)	Medium	High
3a	Maize variety A	High (already tested)	High	High	High
3b	Leucaena (See 1d)				
4a	Pre-emergence herbicide C	High (but requires postponing hand weeding)	Medium	High	Medium
4b	Pre-emergence herbicide D	High (but requires postponing hand weeding)	Medium	Low (very toxic to humans)	Medium
4c	Pre-emergence herbicide E	High (but requires postponing hand weeding)	Medium	High	Medium

						List A	List C	List D
		x	Medium	High	Verify on large plots with farmer management	✓		✓
			Medium	Low	Postpone until other sources of fodder are developed		✓	
			Medium	Medium	Eliminate-not profitable			
x	x		Low	Low	Begin research to develop technology		✓	
	x		High	High	Demonstrations	✓		✓
x			Medium (need to postpone hand weeding)	High	Experiments-possible solution	✓		✓
x			Medium (need to postpone hand weeding)	High	Eliminate			
x	x		Medium (need to postpone hand weeding)	High	Experiments-possible solution	✓		✓

Table 4
Continued

5a Nitrogen fertilizer for beans	High	Medium	High	Low
5b Chicken manure (See 1c)				
5c Rhizobium inoculation	Medium (may need K)	(?)	High	Medium
5d Leucaena (See 1d)				
5e Maize residues (See 1b)				
5e† Bean varieties J, K, and L	High	Medium	Medium (only those farmers who do not market beans)	High
[illegible] Fungicides M, N	High	Medium	High	High
[illegible] Fungicides P, Q	Low - Q is very toxic to beans if dosage is exceeded	Medium	High	High
[illegible] Ten new bean lines	Medium	High	High	High

† Anthracnose severity is likely to be greater with high plant populations (see p. 76).

						List A	List C	List D
		x	Medium	High	Experiments-possible solution	✓		✓
x	x		Medium	High	Experiments (include K)	✓		✓
	x		High	High	Experiments-possible solution	✓		✓
			Medium	Medium	Experiments-possible solution	✓		
			Medium	Medium	Eliminate			
	x		High	High	Experiments-possible solution	✓		

2) Profitability

An estimate of the profitability of each proposed solution should be provided. If a solution has been tested in a previous cycle's experiments, the economic analysis of the results should give a good idea of its economic viability. If the proposed solution has never been tested on farmers' fields, an estimate of its profitability should still be attempted. Making the estimate involves assessing all of the changes in costs that the farmers must incur in using the new technology, and comparing those costs with an estimate of the yield difference that farmers can expect when using the technology under their conditions. Solutions that researchers believe have little chance of being profitable at present or in the future should not be tested on farmers' fields.

The profitability of each possible solution is presented in Table 4. Solutions 1a and 3a were included in on-farm experiments in previous cycles, and an economic analysis of the results provided a good estimate of profitability. For solutions that had not yet been tested, researchers estimated profitability by comparing an estimate of likely yield increases with the increase in costs that the new technology represents to farmers (see box, pp. 66-67). The analysis of profitability for the new bean varieties (6a) included the fact that although the new varieties yield more, their market value is not as high as that of the traditional varieties. In the case of herbicides for maize (4a, b, and c), yield changes are not expected, but lower production costs are anticipated. An economic analysis of the application of chicken manure (1c) showed that its profitability would be quite low and it was eliminated from further consideration. Finally, three possible solutions (1b, 1d, and 5c) presented so many technical uncertainties that researchers could not estimate profitability.

Estimates of profitability can sometimes be quite complicated and will require special assistance from economists. This is especially true for technologies that offer benefits over the long term, such as technologies to improve soil fertility or structure, or methods of controlling erosion. Researchers should consider the trade-offs involved in choosing experimentation aimed at providing solutions whose benefits will only be apparent after a number of

years over choosing to explore solutions that provide more immediate returns. In many instances a number of short-term opportunities will take precedence, whereas in other instances important long-term considerations, such as sustainability and/or a lack of available technologies, will dictate a different direction for the research program.

The proposal to experiment with planting leucaena strips is a good example. Although the effects of such a solution will probably not be evident for several years, it may make important contributions to improving soil fertility and moisture retention. Researchers believe that solution's potential impact is great enough to justify initiating some experimentation with leucaena.

3) Compatibility with the Farming System
In a diagnosis, researchers are interested in understanding the reasons for farmers' practices to better define the scope for proposing new technologies. As researchers form some ideas of possible solutions, each should be analyzed for compatibility with the farming system (see box, p. 69). During a survey, for example, farmers might be asked what they think of a particular technology, why they don't already use it, or what they think might happen if they did use it.

Thus an important aspect of planning involves a comparison of proposed solutions with what is known about farmers' circumstances. For example, a new variety is proposed for subsistence farmers. Is it acceptable for the family's food preparations? A change in planting methods is proposed that requires more labor. Is extra labor available at this time of the year? A new herbicide is proposed. Can it be used in the current rotation pattern? Researchers must review what they know of the management requirements of other crops and animals in the farming system, the land and labor resources available to the farm family, and the family's goals and preferences, to decide if a proposed solution is compatible.

There are two examples in Table 4 of solutions that are incompatible with farmers' circumstances. The first—incorporating maize residues to increase soil organic matter (1b)—would interfere with their use

as animal fodder. Unless researchers can propose an alternative source of fodder, or unless they feel that the extra yield from fields with more organic matter would compensate for the economic value of the fodder that is lost, it is not worthwhile to pursue that solution.

The second solution that is incompatible with farmers' circumstances is the use of herbicide D (4b). Researchers know that it is very toxic and because farmers in the research area do not have much experience managing chemicals it is felt best to eliminate this product from consideration.

A proposed solution may be compatible with the circumstances of some farmers but not others, a situation which should be noted. In such cases the particular group of farmers for whom the solution is intended should be described. For example, bean varieties J, K, and L (solution 6a) are acceptable for home consumption but receive a heavy discount in the market. Thus they are only appropriate for small-scale farmers who do not market their beans.

A low rating on compatibility with the farming system does not necessarily eliminate a possible solution from consideration. The basis for on-farm research, after all, is the conviction that farming systems can be improved. Rather than looking at the system as absolutely fixed, researchers should use their knowledge of its characteristics to ask, "Do we understand the trade-offs involved in choosing this solution?" In the example of incorporating maize residues to increase soil organic matter (1b), the trade-off can be described as weighing the rationale for the current practice (feed for animals, ease of land preparation) against possible gains from the alternative practice (improved soil fertility and structure, higher yields). In this case, the judgment is that the gains from the change will not compensate the losses to the current system, but if researchers find an alternative source of fodder that decision may change.

The new bean varieties (6a) are only a compatible solution for farmers who do not market beans, and research on the new varieties will depend on how many farmers do not market beans. If the number is very small, the solution may be abandoned.

However, researchers already know of anthracnose-tolerant bean lines that are acceptable in local markets. They know little about their adaptation to farm conditions and so decide to test 10 lines to increase the chances of success (solution 6d).

4) Contribution to Reducing Risk

Risk is an important determinant of farmers' practices: farmers may stagger planting dates to limit losses from drought, or plant several different varieties to reduce losses from disease. Such practices may indicate important problems that merit researchers' attention. Risk is also a concern when farmers consider adopting new practices.

Researchers should ask whether it is likely that farmers will face possible losses in some years if they adopt a proposed solution or if the solution is likely to increase the stability of farmers' incomes. If experimental evidence from previous cycles is available, the variability in results will help provide some indication of the risk involved in a proposed solution.

In Table 4, possible solutions that contribute to reducing risks caused by drought or disease (3a, 6a, b, c, d) get high rankings. An improvement in soil organic matter (1b, c, d) would certainly contribute to stability as well. Pre-emergence herbicides (4a, b, c) present a bit of risk because they require farmers to make most of their investment in weed control at the beginning of the season; as it is now, farmers adjust their hand weeding investment according to the rains and the growth of the crop. Finally, an analysis of previous experiments with fertilizer (1a, 5a) and a knowledge of drought risk in the study area lead researchers to exercise caution with respect to this solution, especially if it is used in the northern part of the area.

Profitability

If a proposed solution to a problem [illegible] costs than the farmer [illegible] see whether or not the [illegible] must be made. This [illegible] of analyzing on-farm [illegible] is to draw up a partial budget [illegible] marginal analysis for the costs [illegible] benefits of each treatment.[13] The partial budget includes:

- The gross benefits for each treatment (the yield multiplied by the farm [illegible]).
- The total costs that [illegible] for each treatment; and
- The net benefits (gross [illegible] that vary).

The marginal analysis [illegible] that vary and not be [illegible] the simple case of an [illegible] treatments (the farmer [illegible] the change in net benefits is [illegible] in costs that vary. [illegible] That rate of return must be [illegible] of return acceptable to farmers [illegible] 50%-100%) before the [illegible] recommended.

These same [illegible] solutions before [illegible] The additional costs [illegible] and the field price [illegible] calculate a marginal [illegible] farmers. Research [illegible] solution can [illegible] a yield increase.

Proposed solution [illegible] an example. First, [illegible] costs. In this case, [illegible] apply the checklist [illegible]

13 A method of [illegible] provided in CIMMYT [illegible]

fertilizer application. The additional [illegible] of the costs increased to [illegible] chicken manure:

- Cost of 3 tons of chicken manure [illegible]
- Cost of transporting chicken [illegible]
- Cost of applying the manure [illegible]
- Total increase in costs [illegible] for proposed solution

Second, remember that farmers [illegible] recover the extra costs they have [illegible] expect a return on their investment [illegible] rate of return is 50% [illegible], for every [illegible] farmers want to recover the [illegible] $0.50), then the minimum [illegible] farmers is 1.5 x $128, or $192.

Third, it is necessary to estimate [illegible] the maize—what an extra kilogram [illegible] to farmers. The field price [illegible] can receive for selling the maize [illegible] costs proportional to yield [illegible] harvesting and selling the grain [illegible] field price of maize was calculated [illegible]

Finally, the minimum return [illegible] price to determine the minimum [illegible] expected by farmers:

$$\frac{\$\ 192}{\$0.12/\text{kg}} = [illegible]$$

In this case, [illegible] of the quantity of chicken manure [illegible] give a yield increase of [illegible] per hectare. For that reason, they [illegible] eliminate this proposed solution from [illegible] consideration.

Although these calculations [illegible] clear answers about the [illegible] solutions, it is very important [illegible] good idea of the changes [illegible] the solutions that they are considering [illegible] them in on-farm experiments.

Low ratings on the contribution to reducing risk require careful consideration. Researchers will have to balance the gains of a new technology against the risks entailed, and ask if farmers are able to bear those risks. In the case of nitrogen fertilization (1a), a low rating must be weighed against the high (average) profitability observed in experiments. Researchers will have to analyze carefully the financial risks for farmers before making the nitrogen recommendation. Part of the risk of the technology is related to drought, and as researchers believe that they have identified some solutions to the drought problem, there is hope that nitrogen fertilization will not involve very high risks for farmers.

5) Need for Institutional Support

Extension should be a part of on-farm research activities and certain experiments may be used by the extension agency to demonstrate new technologies to farmers. Some proposed solutions will be accessible to farmers without any special institutional support, whereas others will require extra support from extension in training farmers. In the example, cases include: splitting the nitrogen application in maize (1a); incorporation of maize residues (1b); planting leucaena strips (1d); the use of pre-emergence herbicides to control weeds in maize (4a, b, c); and rhizobium inoculation in beans (5c).

Some proposed solutions may require inputs that are presently unavailable in the area. Researchers must decide if there are other options, or if it is worth communicating with those who are in charge of supplying inputs to assure that a particular input will be available to farmers. Recommending an input that farmers cannot obtain is a waste of time. Herbicide E is not currently available in the area, for instance. If initial experiments find it to be promising, then researchers will have to enquire about the possibility that it can be made available. If the new maize variety (3a) is to be taken further after successful trial results, researchers must make sure that seed production and distribution are being considered. If the bean varieties (6a) or lines (6d) prove successful, seed supply will be important as well. Researchers must also consider the availability of planting materials for leucaena (1d) and of rhizobium inoculants (5c).

Conceptualizing [illegible] Farming Systems

[illegible]

[illegible] constraints employed [illegible] system. Although [illegible] attention on [illegible] that farmers are aware of how [illegible] time, [illegible] and the management [illegible] of the system. When [illegible] evaluated, their [illegible] farming system must [illegible] follow.

In one study, [illegible] poor as a serious problem. A [illegible] that farmers [illegible] an analysis of the farming [illegible] was very [illegible] weeding would have to be [illegible] most farm families [illegible] neighboring [illegible] source of cash income [illegible] unlikely that the returns [illegible] in before crops [illegible] the weed problem [illegible]

In another study [illegible] deficiency [illegible] researchers to [illegible] moisture. But [illegible] farming system [illegible] before planting time. [illegible] therefore, not [illegible] system, and the [illegible] balanced against [illegible] farmers' management [illegible]

Occasionally a proposed solution may require that farmers have access to credit, and again researchers must determine if the solution is feasible and if it is worth talking to officials in charge of credit policy. In the study area some credit is available to farmers to obtain fertilizer for maize and beans. If more fertilizer is to be recommended, it might be helpful if more credit were available.

When a solution requires institutional support, its feasibility should be investigated before experimentation proceeds very far. If a certain input cannot be obtained, it should be discarded as a possible solution. None of the proposed solutions in the example is ruled out because of this factor, but several require that researchers investigate the availability of inputs, credit, or extension programs.

6) Ease of Testing by Farmers

Farmers are more likely to be interested in solutions that they can try out a little at a time, especially if a considerable investment is involved. For example, farmers will be less interested in trying a solution that requires the purchase of a new implement than in trying an input that they can buy in small quantities. However, this consideration should not be used to rule out possible solutions that require a large investment. With respect to machinery, for example, a few individuals may invest in a new implement and then develop a rental market.

Table 4 lists several possible solutions that farmers can easily test a bit at a time, including new varieties (3a and 6a, d). Other possible solutions are slightly more difficult to test gradually. Planting leucaena strips requires farmers to make a considerable commitment initially, and it gets a "low" rating. This is not sufficient to eliminate it from consideration, but researchers must be aware that it will be less easy for farmers to adopt this solution than some alternatives.

Farmers also prefer to change their practices in steps. Whenever possible, technologies should be tested so that a series of changes rather than an "all-or-nothing" package can be offered to farmers. Nevertheless, sometimes there is no alternative but to propose a combination of changes, as when a new tillage method also requires changes in weeding

practices, or a new variety requires a different planting density. But the more complex the recommendation, the more difficult it will be for farmers to adopt quickly. Three proposed solutions in Table 4 imply some complexity. The change in fertilizer practices (1a) includes both a change in dosage and method of application. The use of pre-emergence herbicides (4a, b, c) requires farmers to postpone their traditional weeding from 30 days to 40 days to avoid breaking the herbicide film. Neither solution is so complex as to be unacceptable, but each is an example of the factors that have to be taken into account when considering an innovation's acceptability to farmers. As for rhizobium inoculation (5c), researchers are concerned that it may only function in combination with the application of potassium. If this were to be the case, it might have to be eliminated.

7) Ease of Carrying Out the Experimental Program
Some proposed solutions are more costly than others to investigate and therefore may receive lower priority in the experimental program. Long-term experiments with rotations, or experiments that require frequent monitoring and measurement, are examples of research that may be quite costly. If that research seems to offer the best possibility for resolving a particular production problem, then it should certainly be considered. But if there are less costly alternatives, they will probably be given higher priority. Especially in the first years of on-farm research in an area, very complex experiments may distract researchers' attention from establishing a solid record of collaboration with farmers and extension agents. As researchers gain more experience with the area and the difficulties of managing on-farm experiments, more complicated experiments can be considered.

In Table 4, several possible solutions present some questions with respect to ease of experimentation. The fungicide experiments (6b, c) are rated to be of medium difficulty because they require large plots. Incorporating maize residues (1b) and planting leucaena (1d) get low ratings because they require several years of experimentation. In the case of leucaena, researchers believe that going ahead with investigation is worthwhile despite the fact that a fairly elaborate experimental program is required. The

incorporation of maize residues was already eliminated because of incompatibility with the farming system.

Final Evaluation of Possible Solutions

The last column in Table 4 presents tentative decisions on the future of each possible solution. The decisions are tentative because other factors (such as the importance of each particular problem) must be considered, as well as the decisions that will have to be taken later regarding the number and types of experiments. Nevertheless, it is important to summarize the analysis that has taken place in Step 6.

The overall evaluation can be done in several ways. It is possible to assign scores to each ranking for the various categories and then add the scores. If a large number of possible solutions are being considered, scoring them is often a good way to begin. As only a small number of possible solutions are being considered in Table 4, the evaluation was made on a qualitative basis.

Two solutions included in previous experiments have performed well enough that work with them will continue: nitrogen fertilization (1a) in maize will be verified on large plots under farmer management in preparation for a recommendation, and the new maize variety (3a) will be part of demonstrations by the extension agency. The low rating for stability given to nitrogen fertilization means that researchers will have to pay particular attention to an analysis of risk before making a final recommendation. The evaluation of other solutions (4a, c; 5a, c; 6a, b, and d) is high enough that they can be considered for the experimental program. They are all included in List A. Leucaena (1d) is considered to be worth pursuing as part of a longer term research effort, and it is included in List C. The idea of incorporating maize residues is abandoned until other fodder sources are developed, a suggestion also included in List C. Serious doubts about possible solutions 1c, 4b, and 6c cause them to be set aside. Solutions that are to be included in experiments and require institutional support are noted in List D.

Summary

The sixth and last step in identifying factors for experimentation is to evaluate solutions proposed in Step 5. The proposed solutions must be considered in light of their technical characteristics, the farmers' ability to adopt the proposed solution, and the research expense involved. Researchers must develop a clear set of criteria to evaluate each proposed solution; seven criteria are suggested here.

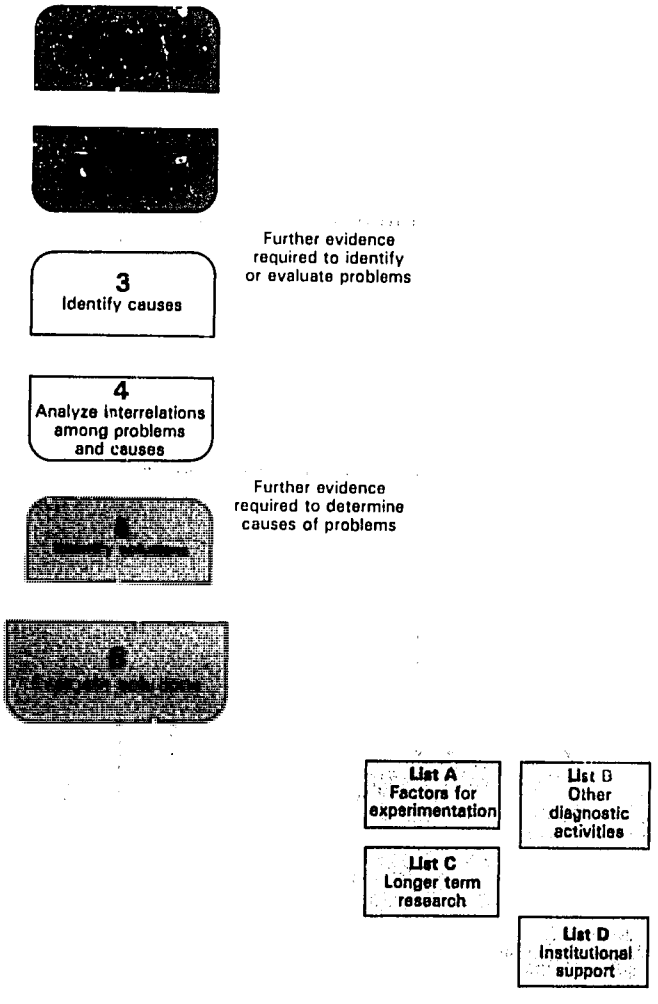
The first criterion for evaluating proposed solutions is the probability that the technology will function under farmers' agroecological conditions and management practices. The second criterion is the estimated profitability of the solution. If either of these two criteria gets a low rating, the solution will almost certainly be eliminated from further consideration.

The third criterion is whether or not the proposed solution is compatible with the farming system, i.e., with the natural and socioeconomic circumstances under which farmers operate. The fourth criterion is the extent to which the solution helps reduce risks for farmers. The fifth criterion is the need for support from extension, credit, or input suppliers to ensure that the solution can be adopted. If researchers have doubts about any of these criteria then the proposed solution should be examined very carefully before work proceeds.

The sixth criterion is the ease with which farmers can test the proposed solution. The seventh is the ease of carrying out the experimental program to test the proposed solution, including the time and expense required. Neither of these two criteria is sufficient in itself to eliminate a solution from consideration, but each is important in deciding between solutions whose potential is otherwise similar.

Once researchers have rated each proposed solution on the basis of these criteria, they must come to a decision regarding the future of the solutions. If a proposed solution is thought to be acceptable for on-farm experimentation, it is included in the list of experimental factors (List A). If a proposed solution has potential but requires more research before it

can be tested on farms under farmers' conditions, it is included in the list of themes for longer term research (List C). If the proposed solution requires special consideration by extension, credit, or input suppliers (the fifth criterion above), a note is made in List D regarding suggested interactions with appropriate institutions.



Summarizing the Six Steps: Lists of Conclusions

The work described in the six planning steps usually requires several days of discussion and is based on many months or years of research. It is therefore important to summarize conclusions from these discussions and record them in a form that researchers can use. One way to summarize conclusions is through a set of lists. Four lists are suggested here. List A contains all of the experimental factors discussed in the six steps. In particular, it lists the exploratory factors that have been suggested for examining problems (Step 1) and causes (Step 3), and the possible solutions to well-defined problems that received a favorable evaluation in Step 6. List B contains suggestions for other diagnostic activities that are useful for obtaining more information on problems or their causes. List C summarizes suggestions for longer term research derived from the evaluation of possible solutions carried out in Step 6. List D summarizes conclusions from the evaluation (also done in Step 6) of institutional support necessary for promoting adoption of proposed solutions.

List A: Experimental Factors
The principal goal of the planning process is to develop a list of experimental factors for on-farm experiments (an example is presented in Table 5). Those experimental factors will come from three sources.

1) **Exploratory Factors**—Some problems (Step 1) or causes (Step 3) require further experimental information. The experimental factors will help researchers explore the importance or the cause of a problem.

   Broad-leaf weed control in beans (using herbicide Z) is an exploratory factor for better understanding a possible *problem*. Phosphorus placement for maize is an exploratory factor for examining the *cause* of phosphorus deficiency in maize. Exploratory factors do not necessarily represent possible solutions; a higher than economic dose of phosphorus may be examined

simply to see if there is a response. But as much as possible, decisions about which exploratory factors are appropriate should be guided by the criteria listed in Table 4 for evaluating solutions.

2) **Possible Solutions**—If the problem and its cause(s) are clear, experimental factors are the inputs, varieties, or techniques specified as possible solutions in Step 6. They may have been tested in previous experiments.

   Nitrogen fertilizer application in maize is in the final stages of testing, and the early maturing maize variety A is ready for recommendation (Table 4). Other possible solutions (e.g., herbicides C and E or bean varieties J, K, and L) will be tested for the first time to see if they give acceptable results. For each possible solution the group of farmers for whom the solution is appropriate should be identified. Small-scale farmers who do not market a high proportion of their beans will be a target group for testing bean varieties J, K, and L, but other farmers will not be interested because those varieties receive a lower price in the market. However, all farmers will be interested in products M and N to control anthracnose. Early maturing maize variety A is mostly intended for farmers in the north of the research area.

3) **Other Factors**—Factors may not come directly from the identification of problems, causes, or solutions but should nevertheless be considered for the experimental program. Such factors are derived from researchers' knowledge of possible agronomic interactions with factors being tested. One example is researchers' belief that rhizobium should be tested in the presence of potassium. Another is the fact that experimentation to control anthracnose should take account of bean plant density.

It should be emphasized that not all of the factors that appear in Table 5 may end up in the experimental program. Their inclusion will depend on the resources available and the number and types of experiments that the research team can manage.

Table 5
List A: Summary of Factors for Experimentation

1	**Exploratory Factors**	**Sources**
	Herbicide Z for beans	To explore whether broad-leaf weeds are a problem—Step 1, No. 9
	Phosphorus placement in maize	To explore lack of economic response to phosphorus—Step 3, No. 2
2	**Possible solutions**	
	1a 60 kg N/ha in split applications	
	3a Maize variety A (particularly for north of research area)	
	4a Herbicide C	
	4c Herbicide E	
	5a Nitrogen fertilizer for beans	Step 6 (Summary of Table 4)
	5c Rhizobium inoculation	
	6a Bean varieties J, K, and L (for farmers who do not market beans)	
	6b Mixture of fungicides M,N	
	6d 10 new bean lines	
3	**Other factors**	
	Potassium	Step 6, No. 5c (Note in column 1, Table 4) Possible interaction with rhizobium
	Bean plant density	Step 6, No. 6 a,b,c,d (Note in column 1, Table 4) Possible interaction with anthracnose

List B: Data Needs for Continuing Diagnosis
Some diagnostic activities take place before experiments begin, but diagnosis should also continue during experimentation. As researchers debate the importance of particular problems (Step 1) and seek their causes (Step 3), they may find that certain diagnostic tools would be helpful and should be noted. List B (Table 6) gives examples that summarize the needs for nonexperimental data suggested in Steps 1 and 3. Diagnostic tools may include a wide range of data-gathering techniques such as reviews of secondary data, farmer interviews, field observations, and laboratory tests. These techniques require additional time from researchers, and their use should be carefully planned and integrated as much as possible with the on-farm experimental program.

Table 6. List B: Data needs for continuing diagnosis of problems and causes

Data needed	Source
Examine meteorological data to determine frequency of drought	Step 1, No. 3. Needed for an analysis of the problem of drought stress in maize.
Interview farmers who are beginning to use herbicides in maize	Step 1, No. 4. A simple informal survey of herbicide users will give a better understanding of the problem of the high cost of weeding maize.
Field sampling and laboratory tests to confirm the species of organism causing root rots	Step 1, No. 7. To further describe the problem of root rots.
Germination tests for farmers' bean seed	Step 3, No. 8. To see if seed quality is the cause of low plant populations.
Observation of emergence rates of beans under farmers' soil conditions and land preparation practices	Step 3, No. 8. To see if soil and tillage conditions are causes of low plant populations.

List C: Suggestions for Longer Term Research

The analysis carried out during planning is useful not only for identifying short-term goals for on-farm experimentation, but also for helping guide longer term research. As researchers consider possible solutions to problems in Step 6, they will often encounter items that may require attention on the experiment station or through other types of research. Those items should be noted and discussed with the appropriate researchers. Examples are given in Table 7.

Table 7. List C: Suggestions for longer-term research

Research	Source
Alternative sources of fodder	Step 6, Nos. 1b, 5e. Farmers do not incorporate maize residues because they are used for fodder; other sources of fodder appropriate to the region should be investigated.
Leucaena	Step 6, Nos. 1d, 3b, 5d. Planting leucaena strips is proposed as a possible solution for problems related to soil fertility and moisture retention; initial research needs to be done to identify appropriate varieties of leucaena, investigate how they might be planted, and analyze their economic viability.

List D: Suggestions for Improving Institutional Support

The evaluation of possible solutions in Step 6 may produce suggestions for improving institutional support. A review of column 5 in Table 4 should help summarize issues to be discussed with extension agents or policymakers (Table 8).

Extension agents should be involved in all stages of OFR and should assume responsibility for much of the work in verifying and demonstrating new technologies. In addition, they should be particularly involved in experiments with possible solutions that will require special extension programs, which can be noted in List D.

The availability of inputs cannot be overlooked. If new varieties are recommended, researchers should make sure that a seed supply system is in place. Researchers are responsible for discussing with both public and private input suppliers the implications of research results for input availability and quality. It should be emphasized that proposals to change the supply of inputs may take considerable preparation as well as a study of the rationale for current policy. It should not be assumed that simply informing policymakers of the advantages of new inputs will be sufficient to bring about change.

Data from on-farm experiments may also be used to suggest changes in the composition or requirements of a credit program, as is the case with fertilizer in the example.

Table 8.

List D: Improving institutional support

Extension

Extension agents should be included in the testing of nitrogen fertilizer in maize (1a), pre-emergence herbicides (4a, c), and rhizobium inoculation (5c), so that they can begin to consider possible extension strategies for those technologies.

Inputs

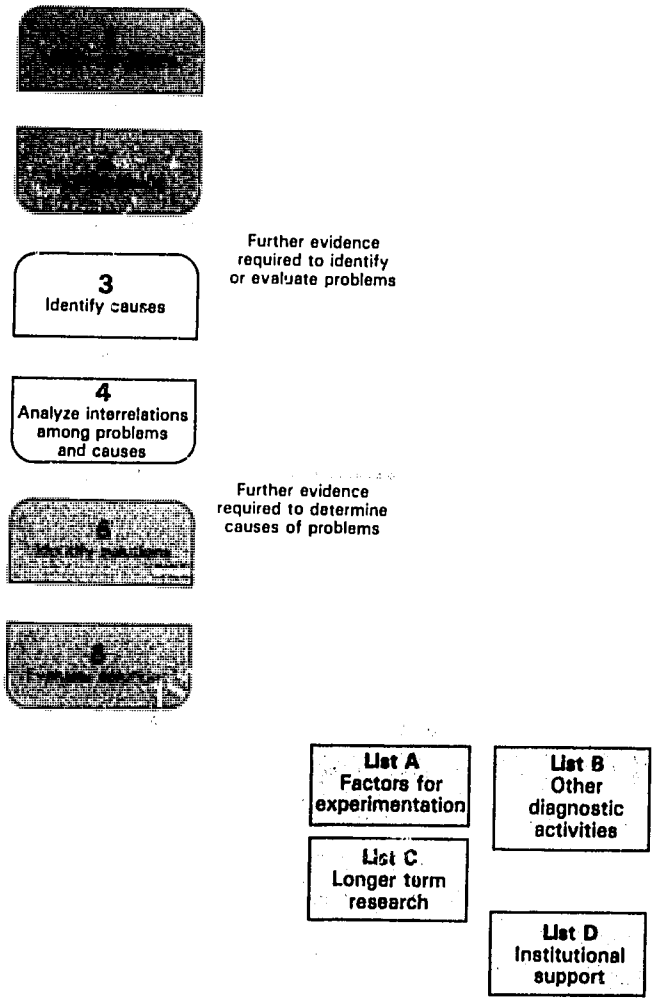
Researchers need to be sure that a seed production system is in place for maize variety A, which is being demonstrated to farmers (3a), and they must also investigate the possibility of seed production for bean varieties J, K, and L (6a). In addition, researchers must talk to input distributors to examine whether supplies of herbicide E (4c) can be assured.

Credit

Credit officials should be made aware of the experiments with fertilizer on maize (1a) and beans (5a). If those solutions prove to be acceptable, it would be helpful if more credit were available.

Summary

The conclusions of the planning steps are summarized in four lists. The first contains all the factors that are to be considered for on-farm experiments, including exploratory factors that help develop information on problems and their causes, as well as possible solutions to problems that are well-defined. The second list includes suggestions for further diagnostic activities related to the problems or their causes. The third list summarizes proposals for longer term research related to the possible solutions, and the fourth contains suggestions for ensuring that institutional support is available for the solutions under discussion.



A Final Word on Priorities

The steps presented in this document are a guide to setting priorities for on-farm experimentation. The results of that analysis are summarized in four lists, and the items listed may be subject to further scrutiny. Even after much debate and the elimination of many research themes suggested during the planning session, the final lists may still contain more items than the research program can manage, and further decisions will have to be made. Planning to do more research than the resources and personnel of the program can accommodate results in half-done studies, unanalyzed or even unharvested experiments, and much wasted effort.

The experimental factors in Summary List A have already been subjected to two reviews in which decisions were made about the importance of the problems and their interrelations. The experimental factors will be subjected to further analysis when decisions are taken about experimental design: how many types of experiments can be managed and how many factors should be placed in one experiment?[14] The items in Summary Lists B, C, and D should also be examined carefully. Which diagnostic activities are most important and can be managed by the research team? What are the priorities for longer-term research? Which issues merit the special analysis and preparation that discussions with policymakers require?

Those are difficult decisions. The steps presented in this document are only a guide to setting priorities. They are not formulas for decision-making, but rather suggestions for managing the debate, and their real utility depends very much on the energy and imagination of the researchers who use them.

[14] Exactly which factors can be accommodated in an experimental program depends on which of them fit together in efficiently designed experiments, as well as on the resources available for the experimental program. See Woolley (1987).

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