An Economics Training Manual

From Agronomic Data to Farmer Recommendations

CIMMYT

ECONOMICS PROGRAM

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The International Maize and Wheat Improvement Center (CIMMYT) is an internationally funded, nonprofit scientific research and training organization. Headquartered in Mexico, the Center is engaged in a worldwide research program for maize, wheat, and triticale, with emphasis on food production in developing countries. It is one of 13 nonprofit international agricultural research and training centers supported by the Consultative Group on International Agricultural Research (CGIAR), which is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Programme (UNDP). The CGIAR consists of 40 donor countries, international and regional organizations, and private foundations.

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Preface

This document is a completely revised version of the CIMMYT Economics Program manual, *From Agronomic Data to Farmer Recommendations: An Economics Training Manual*, written by Richard Perrin, Donald Winkelmann, Edgardo Moscardi, and Jock Anderson. Since its publication in 1976 that manual has been through six printings and has been translated into six languages. The manual has been used by countless students and researchers for learning a straightforward method of analyzing the results of on-farm agronomic experiments and making farmer recommendations.

We approach the revision of such a successful manual with considerable caution. Our work over the past decade has given us a chance to present this material, in the classroom and in the field, to agricultural researchers in a wide variety of settings all over the world. This experience has led us to propose and test some new ways of explaining and presenting key concepts. We gradually began to consider the possibility of incorporating some of those ideas in a revised manual.

One of the first steps in the process was to introduce a set of exercises for classroom teaching, developed by Larry Harrington. Later, Robert Tripp and Gustavo Sain developed further exercises and methods of presentation which they tested in training courses. Tripp and Sain wrote the first draft of the present document and guided its review by the entire staff of the CIMMYT Economics Program.

Just as this revised manual has built on the experience of hundreds of researchers with the original version, we hope that those who use this new version will provide suggestions for its improvement. We believe it will be useful in the classroom as well as for individual study and reference. A book of exercises has been developed to accompany this manual and can be obtained from CIMMYT. We hope that the new version of the manual will find an acceptance as wide as that of its predecessor.

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The document passed through several drafts, which would not have been possible without the superb organization and typing of Maria Luisa Rodriguez. Editing was in the very competent hands of Kelly Cassaday and design was skillfully directed by Anita Albert. Typesetting, layout, and production were carefully managed by Silvia Bistrain R., Maricela A. de Ramos, Miguel Mellado E., Rafael De la Colina F., Jose Manuel Fouilloux B., and Bertha Regalado M.

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Chapter One
Overview of Economic Analysis

This manual presents a set of procedures for the economic analysis of on-farm experiments. It is intended for use by agricultural scientists as they develop recommendations for farmers from agronomic data. Developing recommendations that fit farmers' goals and situations is not necessarily difficult, but it is certainly easy to make poor recommendations by ignoring factors that are important to the farmer. Some of these factors may not be very evident.

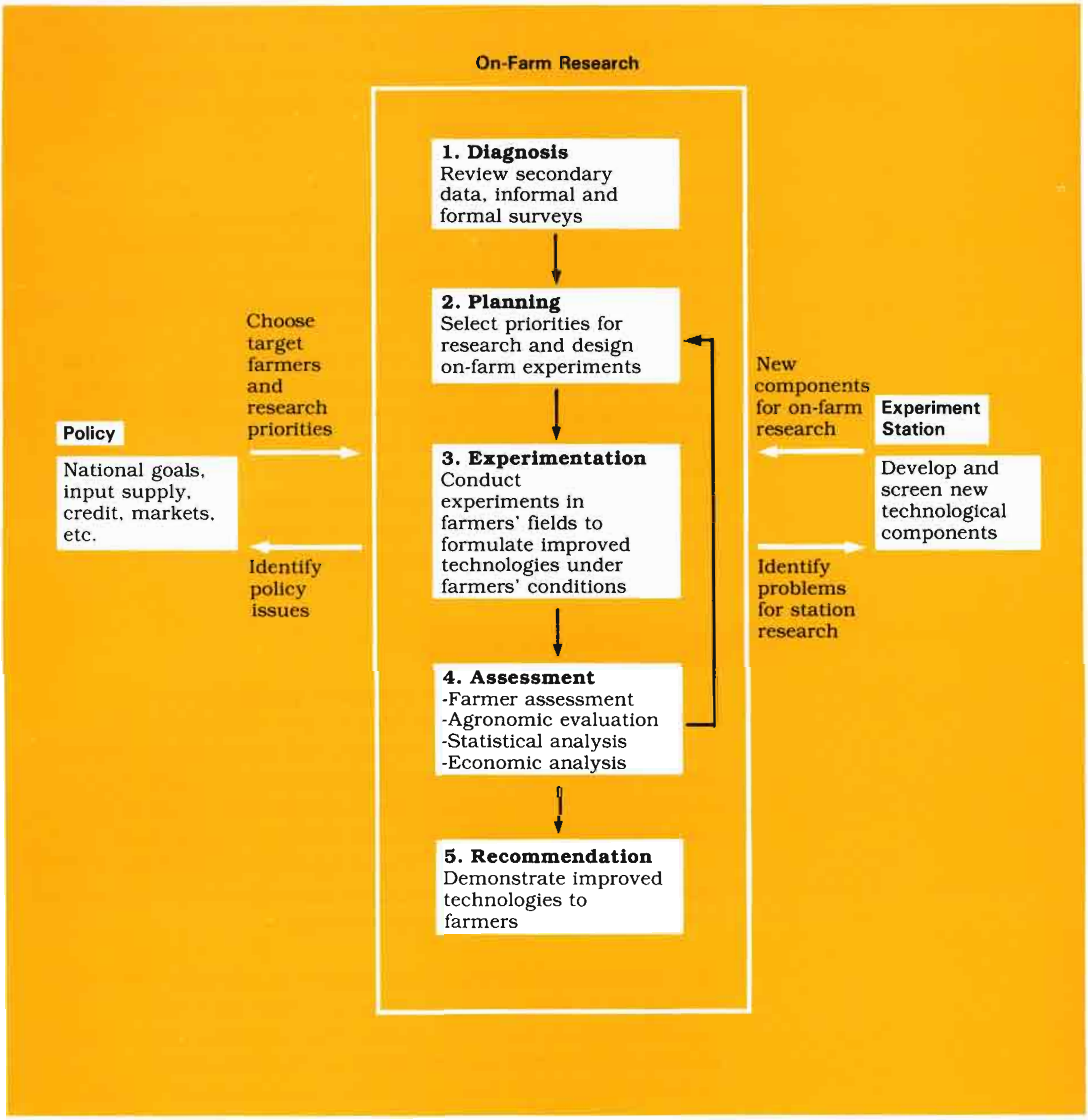
A recommendation is information that farmers can use to improve the productivity of their resources. A good recommendation can be thought of as the practices which farmers would follow, given their current resources, if they had all the information available to the researchers. Farmers may be able to use a recommendation directly, as in the case of a particular variety. Or they may adjust it somewhat to their own conditions and needs, as in the case of a fertilizer level or storage technique. The agronomic data upon which the recommendations are based must be relevant to the farmers' own agroecological conditions, and the evaluation of those data must be consistent with the farmers' goals and socioeconomic circumstances.

On-Farm Research

The stages of an on-farm research program are shown in Figure 1.1. The first step is diagnosis. If recommendations are to be oriented to farmers, research should begin with an understanding of farmers' conditions. This requires some diagnostic work in the field, including observations of farmers' fields and interviews with farmers. The diagnosis is used to help identify major factors that limit farm productivity and to help specify possible improvements.

The information from the diagnosis is used in planning an experimental research program that includes experiments in farmers' fields. The on-farm experiments should be planted on the fields of representative farmers. After the first year, the experimental results form an important part of the information used for planning research in subsequent crop cycles. Other diagnostic work continues during the management of the experimental program as researchers continue to seek information about farmers' conditions and problems which will be useful in planning future experiments.

Figure 1.1. Stages of on-farm research



The results of the on-farm experiments must be assessed. There are several elements in such an assessment. First, researchers must discuss the results with farmers to get their opinions of the treatments they have seen in their fields. The farmers' assessment is very important. The experimental results must also be subjected to both an agronomic evaluation and a statistical analysis. Finally, an economic analysis of the results is essential. The economic analysis helps researchers to look at the results from the farmers' viewpoint, to decide which treatments merit further investigation, and which recommendations can be made to farmers. The procedures for carrying out such an economic analysis are the subject of this manual.

The results of an assessment of on-farm experiments can be used for several purposes. First, they may be used to help plan further research. Some experiments will have as their goal the clarification of production problems: Is production limited by the availability of phosphorus? Will improved weed control give an important increase in yields? The answers to such questions provide researchers with information for further work. As Figure 1.1 shows, that information can be used to plan subsequent experiments. It also may help orient work on the experiment station.

Second, the results may be used to make recommendations to farmers. Some experiments will compare possible improvements to farmers' current practices: Which level of phosphorus should be applied? Which weed control method gives the best results? The answers to these questions provide information to guide farmers in their management decisions.

Finally, the results of on-farm experiments may sometimes be used to provide information to policymakers regarding current policy toward such matters as input supply or credit regulations. Experimental results can be used to help analyze policy implementation: Given a significant response to phosphorus, is the appropriate fertilizer available? Do local credit programs allow farmers to take advantage of new weed control methods? Although the emphasis in this manual will be on the economic analysis of on-farm experiments for guiding further research and making recommendations to farmers, at several points links between on-farm research and policy implementation will be mentioned.

Goals of the Farmer

In order to make recommendations that farmers will use, researchers must be aware of the human element in farming, as well as the biological element. They must think in terms of farmers' goals and the constraints on achieving those goals.

In the first place, many farmers are primarily concerned with assuring an adequate food supply for their families. They may do this by producing much of what their family consumes, or by marketing a certain proportion of their output and using the cash to obtain food. Farm enterprises also provide other necessities for the farm family, either directly or through cash earnings. In addition, the farm family is usually part of a wider community, towards which it may have certain obligations. To meet all of these requirements, farmers often manage a very complex system of enterprises that may include various crops, animals, and off-farm work. Although the procedures of this manual concentrate on the evaluation of improvements in particular crop enterprises, it is essential that these new practices be compatible with the larger farming system.

Second, whether farmers market little or most of their produce, they are interested in the economic return. Farmers will consider the costs of changing from one practice to another and the economic benefits resulting from that change. Farmers will recognize that if they eliminate weeds from their fields they will likely benefit by harvesting more grain. On the other hand, they will realize that they must give up a lot of time and effort for hand weeding, or that alternatively they must give up some cash to buy herbicides and then expend some time and effort to apply them. Farmers will weigh the benefits gained in the form of grain (or other useful products) against the things lost (costs) in the form of labor and cash given up. What farmers are doing in this case is assessing the difference in *net benefits* between practices—the value of the benefits gained minus the value of the things given up.

As farmers attempt to evaluate the net benefits of different treatments, they usually take risk into account. In the weed control example just mentioned, farmers know that in the case of drought or early frost they may get no grain, regardless of the type of weed control. Farmers attempt to protect themselves against risks of loss in benefits and often avoid choices that subject them to these risks, even though such choices may on average yield higher benefits than less risky choices do. That farmers may prefer stable returns to the highest possible returns is referred to as risk aversion.

Another factor in farmers' decision making, related to risk aversion, is the fact that farmers tend to change their practices in a gradual, stepwise manner. They compare their practices with alternatives, and seek ways of cautiously testing new technologies. It is thus more likely that farmers will adopt individual elements, or small combinations of elements, rather than a complete technological package. This is not to say that farmers will not eventually come to use all the elements of a package of practices, but simply that in offering recommendations to farmers it is best to think of a strategy that allows them to make changes one step at a time.

Characteristics of On-Farm Experiments

What are the characteristics of agronomic experiments that will allow an appraisal of alternative technologies in a way that parallels farmer decision making? The following are five requirements of on-farm experiments that must be fulfilled if the procedures described in this manual are to be useful:

1. The experiments must address problems that are important to farmers. It may be that farmers themselves are not initially aware of a particular problem (e.g., a nutrient deficiency or a disease), but if research does not lead to possibilities for significantly improving farm productivity, it will neither attract the interest of farmers, nor merit assessment. Thus the experiments demand a good understanding of farmers' agronomic and socioeconomic conditions.

2. The experiments should examine relatively few factors at a time. An on-farm experiment with more than, say, four variables will be difficult to manage and may be inappropriate given farmers' stepwise adoption behavior.

3. If researchers are to compare the farmers' practice with various alternatives in order to make a recommendation, then the farmers' practice should be included as one of the treatments in the experiment. The farmers will want to see this comparison in any case.

4 The nonexperimental variables of an experiment should reflect farmers' actual practice. It is sometimes tempting to use higher levels of management for the nonexperimental variables to increase the chances of observable responses to the experimental variables. This type of experiment may certainly be justified in some cases, but the results usually cannot be used to make recommendations to farmers.

An example may be useful. Assume that researchers wish to carry out a fertilizer experiment in an area where insects cause crop losses but farmers do not control insects. There are four possibilities:

- Carry out the fertilizer experiment with good insect control. The experiment will give interesting information on fertilizer response but will probably not provide a relevant fertilizer recommendation for farmers who do not use insect control. An analysis of this experiment using the procedures in this manual will give misleading results.

- Carry out the fertilizer experiment without insect control (the farmers' practice). The results can be analyzed, using the procedures in this manual, to decide what level of fertilizer is appropriate, given farmers' current insect control practices.

- If insects are indeed a very serious problem, it may be better to experiment first with insect control methods before experimenting with fertilizer. The diagnosis and planning steps of on-farm research are meant to help set these priorities. The methods of this manual could then be used to help identify an appropriate insect control method for recommendation to farmers.[1/]

- If insects and fertility are both serious problems, then an experiment can be designed which takes both insect control *and* fertilizer as experimental variables. As long as one treatment represents the farmers' practice with respect to both insect control and fertility, the experiment can be analyzed using the procedures in this manual.

5 Finally, not only must the management of nonexperimental variables be representative of farmers' practice, but the experiments must be planted at locations that are representative of farmers' conditions.

1/ Once this work has been done, and there is evidence that farmers will adopt the new insect control method, it could be used as a nonexperimental variable in the fertilizer experiments, as long as it is understood that the fertilizer recommendation to be developed from such trials depends on the farmers first adopting the insect control method.

If most of the farms are on steep slopes, the results of experiments planted on an alluvial plain will probably not be relevant. Similarly, if most farmers plant one crop in rotation with another, experiments from fields that have been under fallow may provide little useful information. More will be said in the following section about selecting locations.

Experimental Locations and Recommendation Domains

The development of recommendations for farmers must be as efficient as possible. The conditions under which farmers live and work are diverse in almost every respect imaginable. Farmers have different amounts and kinds of land, different levels of wealth, different attitudes toward risk, different access to labor, different marketing opportunities, and so on. Many of these differences can influence farmers' responses to recommendations. But it is impossible to make a separate recommendation for each farmer.

Recommendation domain

As a practical matter, researchers must compromise by identifying groups of farmers who have similar circumstances and for whom it is likely that the same recommendation will be suitable. In this manual such a group of farmers is called a *recommendation domain.* Recommendation domains may be defined by agroclimatic and/or by socioeconomic circumstances. The definition of the recommendation domain depends on the particular recommendation. For example, a new variety may be appropriate for all farmers in a given geographical area, whereas a particular fertilizer recommendation may be appropriate only for farmers who follow a certain rotation pattern or whose fields have a certain type of soil. Thus the recommendation domain for variety would be different from the recommendation domain for fertilizer.

Recommendation domains are identified, defined, and redefined throughout the process of on-farm research. They may be tentatively described during the first diagnosis. Experimentation adds precision to the definition of domains. The final definition may not be developed until the recommendation is ready to be passed to farmers.

When interpreting agronomic data to make their recommendations, researchers must have a fairly clear idea of the group of farmers who will be able to use this information. Researchers must consider not only the agroclimatic range over which the results will be relevant, but also whether such factors as different management practices or access to resources will be important in causing some farmers to interpret the results differently from others.

For the purposes of this manual, it is important that the on-farm experiments be planted at locations that are representative of the recommendation domain. The economic analysis is done on the *pooled data* from a group of locations of the same domain. The economic analysis of results from a single location is not very useful because, first, researchers cannot make recommendations for individual farmers, and second, one location will rarely provide sufficient agronomic data to be extrapolated to a group of farmers. Thus all of the examples in this manual will represent data from several locations of one recommendation domain.

Introduction to Basic Concepts

To make good recommendations for farmers, researchers must be able to evaluate alternative technologies from the farmers' point of view. The premises of this manual are:

1. Farmers are concerned with the benefits and costs of particular technologies.

2. They usually adopt innovations in a stepwise fashion.

3. They will consider the risks involved in adopting new practices.

These concerns will be treated in subsequent sections of the manual. Part Two describes the construction of a partial budget, which is used to calculate net benefits. Part Three presents the techniques of marginal analysis. This is a way of evaluating the changes from one technology to another by comparing the changes in costs and net benefits associated with each treatment. Part Four describes ways of dealing with the variability that is characteristic of farmers' environments. Variability in results from location to location and from year to year, and in the costs of the inputs and prices of crops, is of concern to farmers as they make production decisions. Part Five summarizes the first four sections and provides general guidelines for reporting research results.

The following sections offer a brief overview of these topics.

The Partial Budget

Partial budgeting is a method of organizing experimental data and information about the costs and benefits of various alternative treatments. As an example, consider the farmers who are trying to decide between their current practice of hand weeding and the alternative of applying herbicide. Suppose that some experiments have been planted on farmers' fields, and the results show that the current farmer practice of hand weeding results in average yields of 2,000 kg/ha, while the use of herbicides gives an average yield of 2,400 kg/ha.

Table 1.1. Example of a partial budget

	Hand weeding	Herbicide
Average yield (kg/ha)	2,000	2,400
Adjusted yield (kg/ha)	1,800	2,160
Gross field benefits ($/ha)	3,600	4,320
Cost of herbicide ($/ha)	0	500
Cost of labor to apply herbicide ($/ha)	0	100
Cost of labor for hand weeding ($/ha)	400	0
Total costs that vary ($/ha)	400	600
Net benefits ($/ha)	3,200	3,720

Table 1.1 shows a partial budget for this weed control experiment. There are two columns, representing the two treatments (hand weeding and herbicide). The first line of the budget presents the average yield *from all locations in the recommendation domain* for each of the two treatments. The second line is the *adjusted yield*.

Although the experiments were planted on representative farmers' fields, researchers have judged that farmers using the same technologies would obtain yields 10% lower than those obtained by the researchers. They have therefore adjusted the yields downwards by 10% (yield adjustment will be discussed in Chapter 3).

The next line is the *gross field benefits*, which values the adjusted yield for each treatment. To calculate the gross field benefits it is necessary to know the field price of the crop. The *field price* is the value of one kilogram of the crop to the farmer, net of harvest costs that are proportional to yield. In this example the field price is $2/kg (i.e., 1,800 kg/ha x $2/kg = $3,600/ha).[2]

Farmers can now compare the gross benefits of each treatment, but they will want to take account of the different costs as well. In considering the costs associated with each treatment, the farmers need only be concerned by those costs that differ across the treatments, or the *costs that vary*. Costs (such as plowing and planting costs) that do not differ across treatments will be incurred regardless of which treatment is used. They do not affect the farmers' choices concerning weed control and can be ignored for the purpose of this decision. The term "partial budget" is a reminder that not all production costs are included in the budget—only those that are affected by the alternative treatments being considered.

In this case, the costs that vary are those associated with weed control. Table 1.2 shows how to calculate these costs. Note that they are all calculated on a per-

Table 1.2. Calculation of costs that vary

Price of herbicide	$250/l
Amount used	2 l/ha
Cost of herbicide	**$500/ha**
Price of labor	$50/day
Labor to apply herbicide	2 days/ha
Cost of labor to apply herbicide	**$100/ha**
Price of labor	$50/day
Labor for hand weeding	8 days/ha
Cost of labor for hand weeding	**$400/ha**

[2] The use of the $ sign in this manual is not intended to represent any particular currency, and several different currencies are assumed in the examples that follow. Additional abbreviations used in this manual are: hectare (ha), kilogram (kg), and liter (l).

hectare basis. The *total costs that vary* for each treatment is the sum of the individual costs that vary. In this example, the total costs that vary for the present practice of hand weeding is $400/ha, while the total costs that vary for the herbicide alternative is $600/ha.

The final line of the partial budget shows the *net benefits*. This is calculated by subtracting the total costs that vary from the gross field benefits. In the weed control example, the net benefits from the use of herbicide are $3,720/ha, while those for the current practice are $3,200/ha. Net benefits are not the same thing as profit, because the partial budget does not include the other costs of production which are not relevant to this particular decision. The computation of total costs of production is sometimes useful for other purposes, but will not be covered in this manual.

A partial budget, then, is a way of calculating the total costs that vary and the net benefits of each treatment in an on-farm experiment. The partial budget includes the average yields for each treatment, the adjusted yields and the gross field benefit (based on the field price of the crop). It also includes all the costs that vary for each treatment. The final two lines are the total costs that vary and the net benefits.

Marginal Analysis

In the weed control example, the net benefits from herbicide use are higher than those for hand weeding. It may appear that farmers would choose to adopt herbicides, but the choice is not obvious, because farmers will also want to consider the increase in costs. Although the calculation of net benefits accounts for the costs that vary, it is necessary to compare the extra (or marginal) costs with the extra (or marginal) net benefits. Higher net benefits may not be attractive if they require very much higher costs.

If the farmers in the example were to adopt herbicide, it would require an extra investment of $200/ha, which is the difference between the costs associated with the use of herbicide ($600) and the costs of their current practice ($400). This difference can then be compared to the gain in net benefits, which is $520/ha ($3,720-$3,200).

In changing from their current weed control practice to a herbicide the farmers must make an extra investment of $200/ha; in return, they will obtain extra benefits of

$520/ha. One way of assessing this change is to divide the difference in net benefits by the difference in costs that vary ($520/$200 = 2.6). For each $1/ha on average invested in herbicide, farmers recover their $1, plus an extra $2.6/ha in net benefits. This ratio is usually expressed as a percentage (i.e., 260%) and is called the *marginal rate of return*.

The process of calculating the marginal rates of return of alternative treatments, proceeding in steps from the least costly treatment to the most costly, and deciding if they are acceptable to farmers, is called *marginal analysis*.

Variability

In addition to being concerned about the net benefits of alternative technologies and the marginal rates of return in changing from one to another, farmers also take into account the possible variability in results. This variability can come from several sources, which researchers need to consider in making recommendations.

Experimental results will always vary somewhat from location to location and from year to year. An agronomic assessment of the trial results will help researchers decide whether the locations are really representative of a single recommendation domain, and can therefore be analyzed together, or whether the experimental locations represent different domains. This type of agronomic assessment helps refine domain definitions and leads to more precisely targeted recommendations.

Another source of variability in experimental results derives from factors that are impossible to predict or control, such as droughts, floods, or frosts. These are risks that the farmers have to confront, and if the experimental data reflect these risks, they should be included in the analysis.

Finally, farmers are also aware that their economic environment is not perfectly stable. Crop prices change from year to year, labor availability and costs may change, and input prices are also subject to variation. Although such changes are difficult to predict with accuracy, there are techniques that allow researchers to consider their recommendations in view of possible changes in farmers' economic circumstances.

Chapter Two
Costs That Vary

Costs that vary

The first step in doing an economic analysis of on-farm experiments is to calculate the costs that vary for each treatment. ***Costs that vary* are the costs (per hectare) of purchased inputs, labor, and machinery that vary between experimental treatments.** Farmers will want to evaluate all the changes that are involved in adopting a new practice. It is therefore important to take into consideration all inputs that are affected in any way by changing from one treatment to another. These are the items associated with the experimental variables. They may include purchased inputs such as chemicals or seed, the amount or type of labor, and the amount or type of machinery. These calculations should be done before the experiment is planted, as part of the planning process, to get an idea of the costs of the various treatments that are being considered for the experimental program.

In developing a partial budget, a common measure is needed. It is of course not possible to add hours of labor to liters of herbicide and compare these with kilograms of grain. The solution is to use the value of these factors, measured in currency units, as a common denominator. This provides an estimate of the costs of investment measured in a uniform manner. It does not necessarily imply that farmers spend money for labor or receive money for grain. Neither does it imply that farmers are concerned only with money. It is simply a device to represent the process that farmers go through when comparing the value of the things gained and the value of the things given up.

Opportunity cost

An important concept in these calculations is that of ***opportunity cost*.** Not all costs in a partial budget necessarily represent the exchange of cash. In the case of labor, for instance, farmers may do the work themselves, rather than hire others to do it. **The opportunity cost can be defined as the value of any resource in its best alternative use.** Thus if farmers could be earning money as laborers, rather than working on their own farms, the opportunity cost of their weeding is the net wage they would have earned had they chosen not to stay on the farm and weed. The concept of opportunity cost will be discussed at several points in the following sections.

Field price (of an input)

The *field price* of a variable input is the value which must be given up to bring an extra unit of input into the field. The field price is expressed in units of sale (e.g., $ per kilogram of seed, liter of herbicide, day of labor, or hour of tractor time).

Field cost

The *field cost* is the field price multiplied by the quantity of the input needed for a given area. Thus field costs are usually expressed in $ per hectare. If the field price of herbicide is $10/l, and if 3 l/ha are required, then the field cost of the herbicide is $30/ha. In both cases, the emphasis is on the *field*, i.e., what the farmers pay to obtain the input and to transport it to their farms. Such field prices may be quite different from official prices.

Identifying Variable Inputs

To identify which inputs are affected by the alternative treatments included in an experiment, researchers must be familiar with farmers' practices as well as the practices used in the experiment. They must then ask themselves which operations change from treatment to treatment and make a list of these.

For example, consider an experiment in which two different fungicides (A and B) are being tested, along with the farmers' practice of no fungicide application. There are thus three treatments in the experiment. The list of variable inputs is as follows:

- Fungicide A
- Fungicide B
- Labor to apply each fungicide
- Labor to haul water for mixing with each fungicide
- Rental of sprayer to apply each fungicide

This list includes purchased inputs (the fungicides), labor, and equipment (a sprayer). The following sections explain how to calculate the costs for all of these.

Purchased Inputs

Purchased inputs include such items as seed, pesticides, fertilizer, and irrigation water. The best way to estimate the field price of a purchased input is to go to the place where most of the farmers buy their inputs and check the retail price for the appropriate size of package. For instance, if farmers normally purchase their insecticide in 1-kg packets in a rural market, that is the price that should be used, rather than the price of insecticide in 25-kg sacks in the capital city.

In some situations, the farmers will be selecting seed from their previous crop, rather than buying seed. This seed is not without cost. The best way to estimate the opportunity field price of the farmers' own seed is to use the price that farmers pay if they buy local seed, either from each other or at the market.

The next step is to find out how the farmers get the input to the farm. Such inputs as insecticides and herbicides, which are not bulky, can be carried by the farmers and transportation costs are probably not important. But for fertilizer and perhaps seed, this is not the case. Usually the farmers must use a truck or an animal to get the input to the farm. If this is so, a transportation charge must be added to the retail price. As many farmers pay others to transport such items for them, it is not difficult to learn what the normal charges are. In general, it is best to be guided by the practice that is followed by the majority of farmers in the recommendation domain.

For example, if a 50-kg sack of urea costs $375 in the market, and it costs $25 to transport the 50 kg to the farm, then the field price of urea is calculated as follows:

$375	cost of 50 kg urea in market
+ $ 25	cost of transporting 50 kg to farm
$400	field price of 50 kg urea

or $\frac{\$400}{50 \text{ kg}} = \$8/\text{kg}$, field price of urea

Very often fertilizer experiments, especially those in the early stages of investigation, use single-nutrient fertilizers. The treatments are usually expressed in terms of amounts of the nutrient (e.g. 50 kg N/ha or 40 kg P_2O_5/ha). In these cases, it is useful to go one step further and calculate the field price of the nutrient. This can be done by simply dividing the field price of the fertilizer by the proportion of nutrient in the fertilizer. In the case of urea, which is 46% nitrogen,

$$\frac{\$8/\text{kg urea}}{0.46 \text{ kg N/kg urea}} = \$17.4/\text{kg N, field price of N}$$

The field cost of 50 kg N in a particular treatment using urea would be 50 x $17.4, or $870/ha.

This should be done only when working with single-nutrient fertilizers, and it presumes that the field price of nitrogen (for instance) is roughly the same in any nitrogen fertilizer available. If it is not, researchers should of course be aware of this and take these differences into account when considering which fertilizer to experiment with and recommend.

A final point about purchased inputs is in order. This discussion has assumed that the inputs in the experiments are available in local markets, or can be made available. If this is not the case, then the economic analysis of experiments involving such inputs may be of little immediate use to farmers. The results may be used, however, to communicate to policymakers the possible benefits of making a particular input available.

Equipment and Machinery

Some experimental treatments may require the use of equipment not required by other treatments. It is then necessary to estimate a field cost per hectare for the use of the equipment.

The easiest way to estimate the per-hectare field cost of equipment is to use the average rental rate in the area. For example, if farmers rent their sprayers for $20/day and if the sprayer can cover 2 ha in one day, then the field cost may be taken as $10/ha. When estimating the field cost of tractor-drawn or animal-drawn implements, or small self-powered implements, the average rental rate in the area can also be used. This is especially appropriate if most farmers are renting the implements anyway, but even for farmers who own their equipment, the rental rate is a good estimate of the opportunity field cost. In certain cases a pro-rated cost per hectare can be calculated, using the retail price of the equipment and its useful lifetime, but this calculation involves factors such as repair costs, fuel costs, and the possibility that the equipment will have other uses on the farm. If a pro-rated field cost is to be calculated, it is best to consult an agricultural economist who is familiar with the equipment and costing techniques.

Labor

It is very important to take into consideration all of the changes in labor implied by the different treatments in an experiment. Estimates of labor time should come from conversations with farmers and perhaps direct observation in their fields. Information about labor use derived from the experimental plots is not very useful, however, if small plots are used in the experiments. The best way to get this information is to visit with several different farmers. Each will have an opinion as to the time required for a given operation, but a number close to the average of these opinions will provide a good estimate. Not all farmers take the same amount of time for a given task, so the estimates will only be approximate. For new activities with which farmers are completely unfamiliar, some educated guesses will have to be made until more reliable estimates can be developed.

If farmers hire labor for the operations in question, the field price of labor is the local wage rate for day laborers in the recommendation domain, plus the value of nonmonetary payments normally offered, such as meals or drinks. This wage rate can be estimated by talking to several farmers. The field cost of labor for a particular treatment is then the field price of labor multiplied by the number of days per hectare required.

When members of the farm family will do the work, it is necessary to estimate the opportunity cost of family labor. This is the value which is given up to do the work and thus represents a real cost. For example, if farmers must take a day off from working in town to do extra weeding, they will give up a day's wages in town. This opportunity cost is just as real as paying a laborer to do the work. And even if the farmer has nothing to do but sit in the shade, the opportunity cost is not zero, as most people put some value on being able to sit in the shade rather than work in the sun.

The best place to start in estimating an opportunity field price for family labor is the local wage rate (plus nonmonetary payments). It is not unusual to find the rate higher during some periods of the year than others, and this must be taken into account.

It is sometimes difficult to estimate an opportunity cost of family labor, especially if local labor markets are poorly developed. Labor availability may vary seasonally, or across different types of farm households. Labor availability and labor bottlenecks are two of the most important types of diagnostic information that aid in selecting appropriate treatments for experiments and in defining recommendation domains. If labor is scarce at a particular time, extreme caution must be used in experimenting with technologies that further increase the labor demand at that time. In cases such as this, it is reasonable to set the opportunity cost of labor above the going wage rate. On the other hand, if additional labor is to be used during a relatively slack period, an opportunity cost below the going wage rate might be appropriate. But in no case should the opportunity cost of labor be set at zero.

In situations where most farm labor is provided by the family, and where the new technologies being considered change the balance between cash expenditures (i.e., for inputs) and labor, special care must be taken in estimating labor costs. If a particular treatment involves a large change in labor input, relatively small differences in the opportunity cost of labor will have significant effects on the estimation of the cost of the treatment.

Total Costs That Vary

Total costs that vary

Once the variable inputs have been identified, their field prices determined, and the field costs calculated, the total costs that vary for each treatment can be calculated. **The *total costs that vary* is the sum of all the costs that vary for a particular treatment.** A description of a weed control by seeding rate experiment is provided in Table 2.1; the calculation of costs that vary is shown in Table 2.2; and the calculation of the *total* costs that vary is shown in Table 2.3.

Table 2.1. Weed control by seeding rate experiment (wheat)

Treatment	Weed control	Seeding rate
1[a]	No weed control	120 kg/ha
2	Herbicide (2 l/ha)	120 kg/ha
3	No weed control	160 kg/ha
4	Herbicide (2 l/ha)	160 kg/ha

[a] Farmers' practice

Data

Field price of seed	$20/kg
Field price of herbicide	$350/l
Field price of labor	$250/day (local wage rate)
Field price of sprayer	$75/day (rental rate)
Labor to apply herbicide	2 days/ha
Labor to haul water	One laborer can haul 400 l/day (200 l water/ha are required for the herbicide)

Table 2.2. Calculation of costs that vary

Cost of seed	Treatments 1 and 2: 120 kg/ha x $20/kg = $2,400/ha
	Treatments 3 and 4: 160 kg/ha x $20/kg = $3,200/ha
Cost of herbicide	Treatments 2 and 4: 2 l/ha x $350/l = $700/ha
Cost of labor to apply herbicide	Treatments 2 and 4: 2 days/ha x $250/day = $500/ha
Cost of labor to haul water	Treatments 2 and 4: $\frac{\text{200 l required}}{\text{400 l/day}}$ x $250/day = $125/ha
Cost of sprayer	Treatments 2 and 4: 2 days/ha x $75/day = $150/ha

Table 2.3. Total costs that vary for weed control by seeding rate experiment

	Treatment			
	1	2	3	4
Seed ($/ha)	2,400	2,400	3,200	3,200
Herbicide ($/ha)	0	700	0	700
Labor to apply herbicide ($/ha)	0	500	0	500
Labor to haul water ($/ha)	0	125	0	125
Sprayer ($/ha)	0	150	0	150
Total costs that vary ($/ha)	2,400	3,875	3,200	4,675

The perceptive reader will have noticed that not all of the costs that vary have been treated in this chapter. There are two important exceptions. Costs associated with harvest and marketing are discussed in the next chapter, where they are included in the field price of the crop. Costs associated with obtaining working capital, such as interest rates, are discussed in Chapter 5.

Chapter Three
Gross Field Benefits, Net Benefits, and the Partial Budget

There are several steps involved in calculating the benefits of the treatments in an on-farm experiment:

Step 1. Identify the locations that belong to the same recommendation domain. The economic analysis is done on the pooled results of an experiment that has been planted in several locations for one recommendation domain.

Step 2. Next, calculate the average yields across sites for each treatment. If the results of these experiments are agronomically consistent and understandable, do a statistical analysis of the pooled results. If there is no reasonable evidence of differences among treatment yields, researchers need only consider the differences in costs among the treatments. But if there are real yield differences, then researchers should continue with the partial budget.

Step 3. Adjust the average yields downwards, if it is believed that there are differences between the experimental results and the yield farmers might expect using the same treatment.

Step 4. Calculate a field price for the crop and multiply by the adjusted yields to give the gross field benefits for each treatment.

Step 5. Finally, subtract the total costs that vary from the gross field benefits to give the net benefits. With this calculation the partial budget is complete.

Pooling the Results From the Same Recommendation Domain

The first line of a partial budget is the average yield for each treatment for a particular experiment for all locations for a recommendation domain. Recall that a recommendation domain is a group of farmers whose circumstances are similar enough that they will all be eligible for the same recommendation. Tentative identification of recommendation domains begins during the diagnostic and planning stages of on-farm research. This tentative identification is used for selecting locations for planting experiments. The recommendation domain for a fertilizer experiment, for example, might be defined in terms of farmers who plant the target crop, whose fields have certain types of soil, and who follow a particular crop rotation. Locations for the experiments are chosen to represent farmers with those particular circumstances. Upon analyzing the results it may be found that a factor not previously considered, such as the slope of the field, is responsible for different results between locations. In such a case, the experiments from the tentative domain would not all be combined for economic analysis. Instead, they would be divided into two domains (further defined by slope, in this case), and two separate analyses would be carried out. More detail on how and when to pool experimental results is presented in Chapter 7.

It should be noted here that although locations can be eliminated from analysis if it can be demonstrated that they do not belong to the recommendation domain in question, this does not hold for locations where trials were severely damaged by drought, flooding, or other environmental factors that are not predictable. Such locations must be included in the economic analysis because they are outcomes that farmers will experience, too. Further discussion of risk analysis is to be found in Chapter 8.

Assessing Experimental Results Before Economic Analysis

Before doing an economic analysis of the pooled results of an experiment for a particular recommendation domain, researchers must assess the experimental data to verify that the observed responses make sense from an agronomic standpoint. Researchers must also review the statistical analysis of the experimental data. Performing an economic analysis on experimental data that researchers do not understand, or do not have confidence in, is a misuse of the techniques presented in this manual.

If statistical analysis of the results of an experiment indicates that there are no relevant differences between two treatments, then the lower cost treatment would be preferred. If researchers have evidence that treatment yields are probably about the same, the gross benefits for these treatments will also be similar, and the lowest cost method of achieving those benefits should be chosen. If two methods of weed control give equivalent results, for instance, the method with the lower costs that vary should be chosen (for further experimentation or for recommendation) and no further economic analysis is needed.

More details on the relation of statistical analysis to economic analysis are given in Chapter 7.

Average Yield

When the recommendation domain for a particular experiment has been established and agronomic and statistical assessments have indicated that it is worthwhile to proceed with a partial budget, the average yields of each treatment are entered on the first line of the partial budget.

Table 3.1 shows the results from five locations in one recommendation domain of the weed control by seeding rate experiment described in Tables 2.1-2.3. There were two replications at each location. Note that the results from location 5, which was affected by drought, are included in the average.[3/]

Table 3.1. Yields (kg/ha) for weed control by seeding rate experiment

	Treatment 1 No weed control 120 kg seed/ha (farmers' practice)		
	Replication		
Location	**1**	**2**	**Avg.**
1	2,180	2,220	2,200
2	2,800	2,640	2,720
3	1,720	1,880	1,800
4	2,680	2,620	2,650
5[a/]	530	670	600
Average yield			**1,994**

a/ Affected by drought

3/ Note that the individual treatment yields are reported to the nearest 10 kg/ha, to reflect the reliability of the data. It should be remembered that neither the average yields nor any of the results of calculations done with them can be more precise than the original yield data on which they are based. Thus the final digit reported in the average yields is *not significant* and is maintained in the partial budget for convenience only.

The average yields for the four treatments are reported on the first line of the partial budget (Table 3.2, p. 27).

Adjusted Yield

Adjusted yield

The next step is to consider adjusting the average yields. **The *adjusted yield* for a treatment is the average yield adjusted downward by a certain percentage to reflect the difference between the experimental yield and the yield farmers could expect from the same treatment.** Experimental yields, even from on-farm experiments under representative conditions, are often higher than the yields that farmers could expect using the same treatments. There are several reasons for this:

1. **Management.** If they manage the experimental variables, researchers can often be more precise and sometimes more timely than farmers in operations such as plant spacing, fertilizer application, or weed control. Further bias will be introduced if researchers manage some of the nonexperimental variables.

2. **Plot size.** Yields estimated from small plots often overestimate the yield of an entire field because of errors in the measurement of the harvested area and because

in one recommendation domain

Treatment 2 Herbicide (2 l/ha) 120 kg seed/ha			Treatment 3 No weed control 160 kg seed/ha			Treatment 4 Herbicide (2 l/ha) 160 kg seed/ha		
Replication 1	Replication 2	Avg.	Replication 1	Replication 2	Avg.	Replication 1	Replication 2	Avg.
3,030	2,570	2,800	2,440	2,180	2,310	3,200	3,060	3,130
3,090	3,410	3,250	2,790	3,010	2,900	3,410	3,510	3,460
2,200	2,180	2,190	1,820	1,680	1,750	2,410	2,230	2,320
3,270	3,090	3,180	2,950	2,770	2,860	3,400	3,480	3,440
860	740	800	700	500	600	620	680	650
		2,444			**2,084**			**2,600**

the small plots tend to be more uniform than large fields.

3 **Harvest date.** Researchers often harvest a crop at physiological maturity, whereas farmers may not harvest at the optimum time. Thus even when the yields of both researchers and farmers are adjusted to a constant moisture content, the researchers' yield may be higher, because of fewer losses to insects, birds, rodents, ear rots, or shattering.

4 **Form of harvest.** In some cases farmers' harvest methods may lead to heavier losses than result from researchers' harvest methods. This might occur, for example, if farmers harvest their fields by machine and researchers carry out a more careful manual harvest.

Unless some adjustment is made for these factors, the experimental yields will overestimate the returns that farmers are likely to get from a particular treatment. One way to estimate the adjustment required is to compare yields obtained in the experimental treatment which represents farmers' practice with yields from carefully sampled check plots in the farmers' fields. Where this is not possible, it is necessary to review each of the four factors discussed earlier and assign a percentage adjustment. As a general rule, total adjustments between 5 and 30% are appropriate. A yield adjustment of greater magnitude than 30% would indicate that the experimental conditions are very different from those of the farmers, and that some changes in experimental design or management might be in order. Many of these problems regarding yield adjustment are eliminated if the farmers manage the experiment. Decisions regarding experimental management will depend on several factors, but where possible the farmers should certainly manage the nonexperimental variables. As the experimentation moves into later stages, farmers should also manage the experimental variables.

In the case of the weed control by density experiment in wheat, researchers estimated that their methods of seeding and of herbicide application were more precise than those of the farmers, and so estimated a yield adjustment of 10% due to management differences. Plot size was also judged to be a factor, and a further 5% adjustment was suggested. Since the plots were harvested at the same time as those of the farmers, no adjustment was needed to account for differences in harvest date. However, the plots were harvested with a small combine harvester, while the farmers used larger machines, and the difference in harvest loss was judged to be about 5%. Thus the total yield adjustment for this experiment was estimated to be 20%. The second line of the partial budget (Table 3.2) thus adjusts the average yields downwards by 20%. For instance, the average yield for Treatment 1 is 1,994 kg/ha and the adjusted yield is 80% x 1,994 or 1,595 kg/ha.

It is obvious that this type of adjustment is not precise, nor does it pretend to be. The point is that it is much better to estimate the effect of a factor than to ignore it completely. As researchers gain more experience in an area they will have better estimates of the differences between farmers' fields and the experiments, and yield adjustments will become more accurate. The yield adjustment, although approximate, should not be looked upon as a factor to be applied mechanically. Each type of experiment, each year, should be reviewed before deciding on an appropriate adjustment. If this is done, researchers will be able to make decisions about new technologies with a realistic appreciation of farmers' conditions.

Field Price of the Crop

Field price (of output)

The *field price of the crop* is defined as the value to the farmer of an additional unit of production in the field, prior to harvest. It is calculated by taking the price that farmers receive (or can receive) for the crop when they sell it, and subtracting all costs associated with harvest and sale that are proportional to yield, that is, costs that can be expressed per kilogram of crop.

The place to start is the sale price of the crop. This is estimated by finding out how the majority of the farmers in the recommendation domain sell their crop, to whom they sell it, and under what conditions (such as discounts for quality). Crop prices often vary throughout the year, but it is best to use the price at harvest time. It is the amount that the farmer actually receives, rather than the official or market price of the crop, that is of interest.

Next, subtract the costs of harvest and marketing that are proportional to yield. These may include the costs of harvesting, shelling, threshing, winnowing, bagging, and transport to the point of sale. These costs have to be estimated on a per-kilogram basis. In the case of harvesting or shelling, for instance, this may require collecting data on the average amount of labor necessary to harvest a field of defined size and yield, or shell a given quantity of grain. Again, these may be cash costs or opportunity costs.

- If farmers sell maize to traders for $6.00/kg,
- and they incur harvesting costs of $0.30/kg,
- shelling costs of $0.20/kg,
- and transport costs of $0.20/kg,
- then the field price of an additional unit of maize is: $6.00 - ($0.30 + 0.20 + 0.20) = $5.30/kg.

It is important to account for these costs because they are proportional to the yield; the higher the yield of a particular treatment, the higher the cost (per hectare) of harvesting, shelling, and transport. That is, the cost of harvesting, shelling, and transporting 200 kg is almost exactly twice the cost of performing the same activities for a harvest of 100 kg. As these costs will differ across treatments (because the treatment yields are different), they must be included in the analysis. It is convenient to treat these costs separately from the costs that vary (described in Chapter 2) because, although they do vary across treatments, they are incurred at the time of harvest and thus do not enter into the marginal analysis of the returns to resources invested. That is, farmers have to wait perhaps five months to recover their investment in purchased inputs, but only a few days to recover harvest-related costs.

If there are costs associated with harvest or sale that do not vary with the yield, then these should *not* be included in the field price, nor in the partial budget. In the example of the weed control by seeding rate experiment, the farmers sell their wheat in town for $9/kg. The harvesting is done by combine, and the operators charge on a per-hectare basis (regardless of yield), so harvest cost is *not* included in the calculation of field price.

- There is a bagging charge of $0.10/kg,

- transport charge of $0.50/kg,
- and a market tax of $0.40/kg,
- so the field price of the wheat is: $9.00 - ($0.10 + 0.50 + 0.40) = $8.00/kg.

Gross field benefits

The *gross field benefits* for each treatment is calculated by multiplying the field price by the adjusted yield. Thus the gross field benefits for Treatment 1 is 1,595 kg/ha x $8/kg = $12,760/ha.

Although the field price is based on the sale price of the crop, the concept can normally be used even in situations where farmers do not produce enough for their own needs. An alternative would be to calculate an *opportunity field price* for the crop, based on the money price the farm family would have to pay to acquire an additional unit of the product for consumption (see note 5, p. 35). But under most conditions use of the field price is adequate for estimating the value of the product to farmers, even when the product is not sold, and this is the approach that will be followed in this manual.

Table 3.2. Partial budget, weed control by seeding rate experiment

	Treatment			
	1	2	3	4
Average yield (kg/ha)	1,994	2,444	2,084	2,600
Adjusted yield (kg/ha)	1,595	1,955	1,667	2,080
Gross field benefits ($/ha)	12,760	15,640	13,336	16,640
Cost of seed ($/ha)	2,400	2,400	3,200	3,200
Cost of herbicide ($/ha)	0	700	0	700
Cost of labor to apply herbicide ($/ha)	0	500	0	500
Cost of labor to haul water ($/ha)	0	125	0	125
Cost of sprayer rental ($/ha)	0	150	0	150
Total costs that vary ($/ha)	2,400	3,875	3,200	4,675
Net benefits ($/ha)	10,360	11,765	10,136	11,965

Net Benefits

Net benefits

Table 3.2 is a partial budget for the weed control by seeding rate experiment. **The final line of the partial budget is the *net benefits*. This is calculated by subtracting the total costs that vary from the gross field benefits for each treatment.**[4]

Including All Gross Benefits in the Partial Budget

The examples discussed above have assumed that a single product is the only thing of value to the farmers from their fields. This is often not the case. In many regions crop residues have considerable fodder value, for instance. The procedure for estimating the gross field benefit for fodder is exactly the same as that for estimating the value of grain. First estimate production (by treatment) and adjust the average yields. Then calculate a field price. Of course "harvesting" becomes "collecting," "shelling" becomes "baling," and so forth. It is important to consider each activity that is performed (for instance, is maize fodder chopped?). Multiplying the field price of the fodder by the adjusted fodder yield gives the gross field benefit from fodder, and this should be added to the gross field benefit from grain.

Another important example is that of intercropping. If the majority of farmers in the recommendation domain intercrop, then experiments should reflect that practice. (Intercropping experiments may of course include individual treatments with a single crop as well, if that is considered a possible alternative.) It may be that the experimental variables affect only one crop, but if farmers intercrop maize and beans, for instance, then a fertilizer experiment on maize should include beans, or a disease control experiment on beans should be planted with maize. The yields of both crops should be measured, since treatments may have a direct or indirect effect on the associated crop. The partial budget would then have two average yields, two adjusted yields, and two gross field benefits.

The total costs that vary would be subtracted from the sum of the two gross field benefits to give the net benefits. Table 3.3 gives an example.

4/ It is important to remember that the net benefits do not have greater precision than the original yield data (which in this case were reported to three significant digits in Table 3.1). When using a calculator for further operations (such as calculating the marginal rates of return), it is convenient to take the numbers as they appear in the partial budget, but for final reporting researchers may wish to round the net benefits (e.g., $11,800 instead of $11,765 in Treatment 2).

Table 3.3. Partial budget for an experiment on bean density and phosphorus application in a maize-bean intercrop

	Treatment			
	1	2	3	4
Bean density (plants/ha)	40,000	60,000	80,000	80,000
Phosphorus rate (kg P_2O_5/ha)	30	30	30	60
Average bean yield (kg/ha)	650	830	890	980
Average maize yield (kg/ha)	2,300	2,020	1,700	1,790
Adjusted bean yield (kg/ha)	553	706	757	833
Adjusted maize yield (kg/ha)	1,955	1,717	1,445	1,522
Gross field benefits, beans ($/ha)	17,143	21,886	23,467	25,823
Gross field benefits, maize ($/ha)	14,663	12,878	10,838	11,415
Total gross field benefits ($/ha)	31,806	34,764	34,305	37,238
Cost of bean seed ($/ha)	900	1,350	1,800	1,800
Cost of labor for planting beans ($/ha)	450	675	900	900
Cost of fertilizer ($/ha)	1,050	1,050	1,050	2,100
Total costs that vary ($/ha)	2,400	3,075	3,750	4,800
Net benefits ($/ha)	29,406	31,689	30,555	32,438

Chapter Four
The Net Benefit Curve and the Marginal Rate of Return

In the previous chapter a partial budget was developed to calculate the total costs that vary and the net benefits for each treatment of an experiment. This chapter describes a method for comparing the costs that vary with the net benefits. This comparison is important to farmers because they are interested in seeing the increase in costs required to obtain a given increase in net benefits. The best way of illustrating this comparison is to plot the net benefits of each treatment versus the total costs that vary. The net benefit curve (actually, a series of lines) connects these points. The net benefit curve is useful for visualizing the changes in costs and benefits in passing from one treatment to the treatment of next highest cost. The net benefit curve also clarifies the reasoning behind the calculation of marginal rates of return, which compare the increments in costs and benefits between such pairs of treatments. Before proceeding with the net benefit curve and the calculation of marginal rates of return, however, an initial examination of the costs and benefits of each treatment, called dominance analysis, may serve to eliminate some of the treatments from further consideration and thereby simplify the analysis.

Dominance Analysis

Table 4.1 lists the total costs that vary and the net benefits for each of the treatments in the weed control by seeding rate experiment from the previous chapter.

Notice that the treatments are listed in order of increasing total costs that vary. The net benefits also increase, except in the case of Treatment 3, where net benefits are lower than in Treatment 1. No farmer would choose Treatment 3 in comparison with Treatment 1, because Treatment 3 has higher costs that vary, but lower net benefits. Such a treatment is called a *dominated treatment* (marked with a "D" in Table 4.1), and can be eliminated from further consideration. **A *dominance analysis* is thus carried out by first listing the treatments in order of increasing costs that vary. Any treatment that has net benefits that are less than or equal to those of a treatment with lower costs that vary is dominated.**

Dominance analysis

This example illustrates that to improve farmers' incomes it is important to pay attention to net benefits, rather than yields. Notice (from Table 3.2) that the yields of Treatment 3 are *higher* than those of Treatment 1, but the dominance analysis shows that the value of the increase in yield is not enough to compensate for the increase in costs. Farmers would be better off using the lower seed rate, provided they are not using herbicide.

Table 4.1. Dominance analysis, weed control by seeding rate experiment

Treatment	Weed control	Seeding rate (kg/ha)	Total costs that vary ($/ha)	Net benefits ($/ha)
1	None	120	2,400	10,360
3	None	160	3,200	10,136 D
2	Herbicide	120	3,875	11,765
4	Herbicide	160	4,675	11,965

Net Benefit Curve

The dominance analysis has eliminated one treatment from consideration because of its low net benefits, but it has not provided a firm recommendation. It is possible to say that Treatment 1 is better than Treatment 3, but to compare Treatment 1 with Treatments 2 and 4 further analysis will have to be done. For that analysis, a net benefit curve is useful.

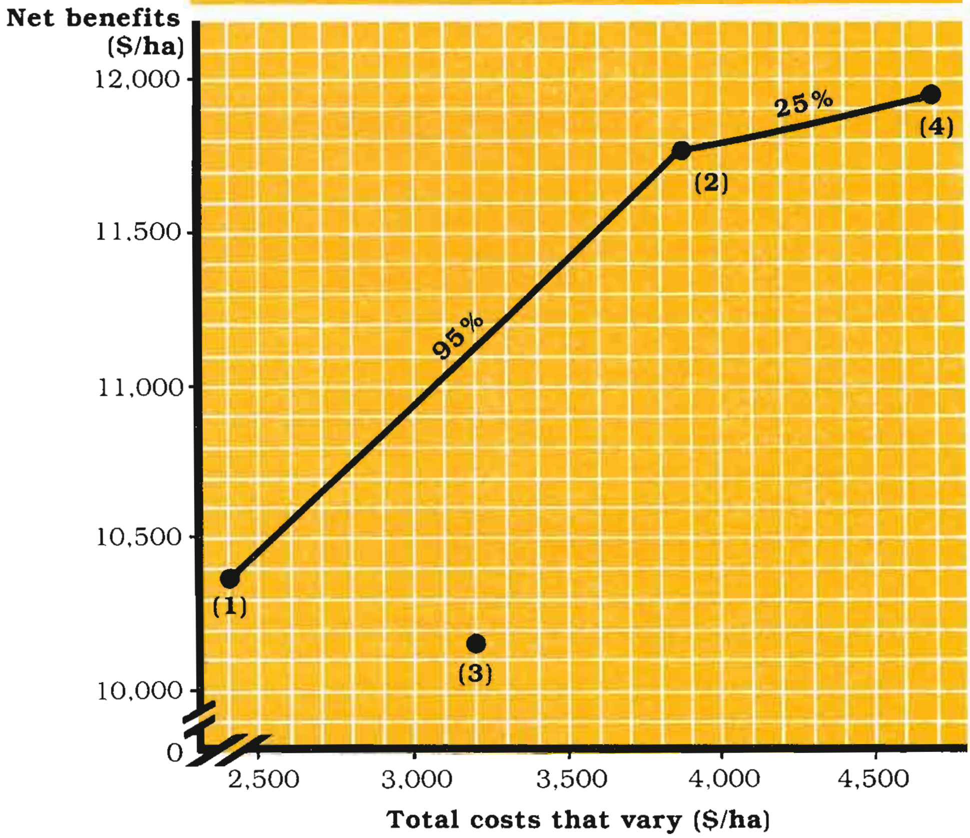
Net benefit curve

Figure 4.1 is the net benefit curve for the weed control by seeding rate experiment. **In a *net benefit curve* each of the treatments is plotted according to its net benefits and total costs that vary. The alternatives that are not dominated are connected with lines.** The dominated alternative (Treatment 3) has been graphed as well, to show that it falls below the net benefit curve. Because only nondominated treatments are included in the net benefit curve, its slope will always be positive.

Marginal Rate of Return

The net benefit curve in Figure 4.1 shows the relation between the costs that vary and net benefits for the three nondominated treatments. The slope of the line connecting Treatment 1 to Treatment 2 is steeper than the slope of the line connecting Treatment 2 to Treatment 4.

Figure 4.1. Net benefit curve, weed control by seeding rate experiment



The purpose of marginal analysis is to reveal just how the net benefits from an investment increase as the amount invested increases. That is, if farmers invest $1,475 in herbicide and its application, they will recover the $1,475 (remember, the costs that vary have already been subtracted from the gross field benefits), plus an additional $1,405.

Marginal rate of return

An easier way of expressing this relationship is by calculating the *marginal rate of return*, which is the marginal net benefit (i.e., the change in net benefits) divided by the marginal cost (i.e., the change in costs), expressed as a percentage. In this case, the marginal rate of return for changing from Treatment 1 to Treatment 2 is:

$$\frac{\$11{,}765 - \$10{,}360}{\$\ 3{,}875 - \$\ 2{,}400} = \frac{\$1{,}405}{\$1{,}475} = 0.95 = 95\%$$

This means that for every $1.00 invested in herbicide and its application, farmers can expect to recover the $1.00, and obtain an additional $0.95.

The next step is to calculate the marginal rate of return for going from Treatment 2 (*not* 1) to Treatment 4.

$$\frac{\$11{,}965 - \$11{,}765}{\$\ 4{,}675 - \$\ 3{,}875} = \frac{\$200}{\$800} = 0.25 = 25\%$$

Thus for farmers who use herbicide and plant at a rate of 120 kg seed/ha, investing in the higher seed rate would give a marginal rate of return of 25%; for every $1.00 invested in the higher seed rate, they will recover the $1.00 and an additional $0.25.

The two marginal rates of return confirm the visual evidence of the net benefit curve; the second rate of return is lower than the first. It is possible to do a marginal analysis without reference to the net benefit curve itself (Table 4.2). Note that the marginal rates of return appear *in between* the two treatments. It makes no sense to speak of the marginal rate of return of a particular treatment; rather, the marginal rate of return is a characteristic of the *change from one treatment to another*. Because dominated treatments are not included in the marginal analysis, the marginal rate of return will always be positive.

Table 4.2. Marginal analysis, weed control by seeding rate experiment

Treatment	Costs that vary ($/ha)	Marginal costs ($/ha)	Net benefits ($/ha)	Marginal net benefits ($/ha)	Marginal rate of return
1	2,400		10,360		
		1,475		1,405	95%
2	3,875		11,765		
		800		200	25%
4	4,675		11,965		

The marginal rate of return indicates what farmers can expect to gain, on the average, in return for their investment when they decide to change from one practice (or set of practices) to another. In the present example, adopting herbicide implies a 95% rate of return, and *then* increasing seed rate implies a further 25%. As the analysis in this example is based on only five experiments in one year, it is likely that the conclusions will be used to select promising treatments for further testing, rather than for immediate farmer recommendations. Nevertheless, a decision cannot be taken regarding these treatments without knowing what rate of return is acceptable to the farmers. Is 95% high enough? What about 25%? The next chapter explains how to estimate a minimum rate of return.

Chapter Five
The Minimum Acceptable Rate of Return

Working capital

Cost of capital

In order to make farmer recommendations from a marginal analysis, it is necessary to estimate the minimum rate of return acceptable to farmers in the recommendation domain. If farmers are asked to make an additional investment in their farming operations, they are going to consider the cost of the money invested. This is a cost that has not been considered in previous chapters. Because of the critical importance of capital availability it is treated separately. ***Working capital*** **is the value of inputs (purchased or owned) allocated to an enterprise with the expectation of a return at a later point in time. The cost of working capital (which in this manual will simply be referred to as the *cost of capital*) is the benefit given up by the farmer by tying up the working capital in the enterprise for a period of time.** This may be a direct cost, as in the case of a person who borrows money to buy fertilizer and must pay an interest charge on it. Or it may be an opportunity cost, the earnings of which are given up by not putting money, or an input already owned, to its best alternative use.

It is also necessary to estimate the level of additional returns, beyond the cost of capital, that will satisfy farmers that their investment is worthwhile. After all, farmers are not going to borrow money at 20% interest to invest in a technology that returns only 20% and leaves them with nothing to show for their investment. In estimating a minimum acceptable rate of return, something must be added to the cost of capital to repay the farmers for the time and effort spent in learning to manage a new technology.

There are several ways of estimating a minimum acceptable rate of return (or, more simply, a minimum rate of return).

A First Approximation of the Minimum Rate of Return

Experience and empirical evidence have shown that for the majority of situations the minimum rate of return acceptable to farmers will be between 50 and 100%. If the technology is new to the farmers (e.g., chemical weed control where farmers currently practice hand weeding) and requires that they learn some new skills, a 100% minimum rate of return is a reasonable estimate. If a change in technologies offers a rate of return above

100% (which is equivalent to a "2 to 1" return, of which farmers often speak), it would seem safe to recommend it in most cases.

If the technology simply represents an adjustment in current farmer practice (such as a different fertilizer rate for farmers that are already using fertilizer), then a minimum rate of return as low as 50% may be acceptable. Unless capital is very easily available and learning costs are very low, it is unlikely that a rate of return below 50% will be accepted.

This range of 50 to 100% is rather crude but it should always be remembered that the other agronomic and economic data used in the analysis will be estimates or approximations as well. This range should serve as a useful guide in most cases for the minimum rate of return acceptable to farmers. It is important to note that this range represents an estimate for crop cycles of four to five months. If the crop cycle is longer, the minimum rate of return will be correspondingly higher[5/]. In areas where the inflation rate is very high, this range should be adjusted upward by the rate of inflation over the period of the crop cycle as well. (For more information on inflation, see pp.71-72.)

The Informal Capital Market

An alternative way of estimating the minimum rate of return is through an examination of the informal capital market. In many areas, farmers do not have access to institutional credit. They must either use their own capital, or take advantage of the informal capital market, such as village moneylenders. The interest rates charged in this informal sector provide a way of beginning to estimate a minimum rate of return. Informal conversations with several farmers who are part of the recommendation domain should give researchers a good idea of the local rates of interest. "If you need cash to purchase something for the farm, to whom do you go?" and "How much does this person charge for the loan of the money?" are examples of relevant questions.

If it turns out that local moneylenders charge 10% per month, for instance, then a cost of capital for five months would be 50%. To estimate the minimum rate of return in this case, an additional amount would have to be added to represent what farmers expect will repay their effort in learning about and using the new

5/ In cases where the *opportunity* field price is used to calculate gross field benefits, the estimation of the minimum rate of return should be based on the period from planting to the time when the household makes its principal purchase of the commodity. This is generally much later than harvest, and thus the minimum rate of return in these cases will be higher than when the field price is used to calculate gross field benefits.

technology. This extra amount may be approximated by doubling the cost of capital (unless the technology represents a very simple adjustment in practices). Thus in this example, the minimum rate of return would be estimated to be 100%. Again, it should be emphasized that this is simply a way of deriving a rough estimate of the level of returns that farmers will require.

The Formal Capital Market

It is also possible to estimate a minimum rate of return using information from the formal capital market. If farmers have access to loans through private or government banks, cooperatives, or other agencies serving the agricultural sector, then the rates of interest charged by these institutions can be used to estimate a cost of capital. But this calculation is relevant only if the majority of the farmers in fact have access to institutional credit. If they do not, then they will probably face a cost of capital different from that offered through relatively cheap institutional credit. In some cases, it may be that farmers with otherwise similar circumstances must be divided into two groups according to their access to one or the other type of credit. These two groups of farmers would face different minimum rates of return and may well represent two separate recommendation domains.

In other cases, institutional credit may be available to farmers, but only for certain crops or in the form of rigidly defined credit packages. If institutional credit is not likely to be available for the recommendations being considered, then the cost of capital in these credit programs is not relevant to the estimation of a minimum rate of return. This is another example of how on-farm research can provide information to policymakers, in this case by interacting with credit institutions to assure that their services are directed to farmers in as efficient a manner as possible.

If farmers do have access to institutional credit, the cost of capital can be estimated by using the rate of interest charged over the agricultural cycle. That is, the rate of interest should cover the period from when the farmers receive credit (cash or inputs) to when they sell their harvest and repay the loan. In addition, it is necessary to include all charges connected with the loan. There are often service charges, insurance fees, or even farmers' personal expenses for things like transport to town to arrange the loan, that must be included in the estimate of the cost of capital.

Once the cost of capital on the formal market has been calculated, an estimate of the minimum rate of return can be obtained by doubling this rate. This will provide a rough idea of the rate of return that farmers will find acceptable if they are to take a loan to invest in a new technology.

Summary

It is necessary to estimate a minimum rate of return acceptable to the farmers of a recommendation domain. In most cases it will not be possible to provide an exact figure, but experience has shown that the figure will rarely be below 50%, even for technologies that represent only simple adjustments in farmer practice, and is often in the neighborhood of 100%, especially when the proposed practice is new to farmers. If the crop cycle is longer than four to five months, these minimum rates will be correspondingly higher. Where farmers have access to credit, either through the informal or formal capital markets, it is possible to estimate a cost of capital (or an opportunity cost of capital) and use it to estimate a minimum rate of return. But even in these cases, it must be remembered that the figure will be approximate. The next chapter explains how to use the estimates of the minimum rate of return to judge which changes in technology will be acceptable to farmers.

Chapter Six
Using Marginal Analysis to Make Recommendations

Marginal analysis

Chapter 4 demonstrated how to develop a net benefit curve and calculate the marginal rate of return between adjacent pairs of treatments. Chapter 5 discussed methods for estimating the minimum rate of return acceptable to farmers. The purpose of this chapter is to describe ***marginal analysis*, which is the process of calculating marginal rates of return between treatments, proceeding in steps from a lower cost treatment to that of next higher cost, and comparing those rates of return to the minimum rate of return acceptable to farmers.** It should be emphasized again that this type of analysis is useful both for making recommendations to farmers, where there is sufficient experimental evidence, and for helping select treatments for further experimentation. Three examples of marginal analysis follow.

Weed Control by Seeding Rate Experiment

It might be best to start by returning to the example of the weed control by seeding rate experiment summarized in Figure 4.1. After the dominance analysis there were only three treatments left for consideration, and the marginal rates of return were calculated. If Treatment 1 represents the farmers' practice, will farmers be willing to adopt Treatment 2 or Treatment 4?

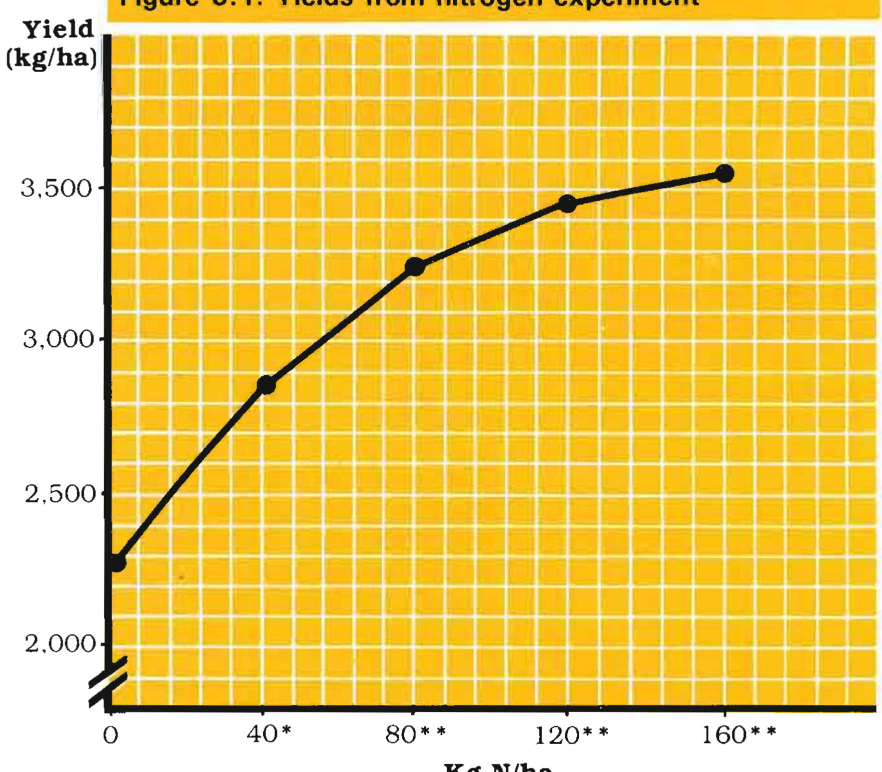
Farmers should be willing to change from one treatment to another if the marginal rate of return of that change is greater than the minimum rate of return. In this case, if the minimum rate of return were 100%, the farmers would probably not be willing to change from their practice of no weed control, represented by Treatment 1, to the use of herbicide, represented by Treatment 2, because the marginal rate of return (95%) is below the minimum. If the minimum rate of return were 50%, then farmers would be willing to change to Treatment 2. Only if the minimum rate of return were below 25% (which is unlikely) would the farmers be willing to change from Treatment 2 to Treatment 4. As long as the marginal rate of return between two treatments exceeds the minimum acceptable rate of return, the change from one treatment to the next should be attractive to farmers. If the marginal rate of return falls below the minimum, on the other hand, the change from one treatment to another will not be acceptable.

Fertilizer Experiment

Figure 6.1 shows the results of a nitrogen experiment in maize. Table 6.1 gives details on the experimental design and costs that vary. The yield data are the average of 20 locations from three years of experimentation. Table 6.2 is a partial budget for the experiment. Figure 6.2 shows the net benefit curve and Table 6.3 shows the marginal analysis (one of the treatments is dominated).

For the recommendation domain where these experiments were planted, researchers estimated that the minimum rate of return for the crop cycle was 100%. With 20 experiments over three years, researchers felt that they were ready to make a nitrogen recommendation to farmers, who are currently not using nitrogen fertilizer on their crop. What should be the recommendation? Or, in other words, if farmers are considering investing in nitrogen fertilizer and the labor to apply it, what should be the recommended level of investment?

Figure 6.1. Yields from nitrogen experiment



* = single application, ** = split application

Table 6.1. Nitrogen experiment data

Treatment	Nitrogen (kg/ha)	Number of applications of N	Average yield (kg/ha) for 20 locations over 3 years
1[a/]	0	0	2,222
2	40	1	2,867
3	80	2	3,256
4	120	2	3,444
5	160	2	3,544

a/ Farmers' practice

Data

Field price of N = $0.625/kg
Field price of maize = $0.20/kg
Cost of one fertilizer application = $5.00/ha
Yield adjustment = 10%
Minimum rate of return = 100%

Table 6.2. Partial budget, nitrogen experiment

	Treatment				
	1 0 kg N/ha	2 40 kg N/ha	3 80 kg N/ha	4 120 kg N/ha	5 160 kg N/ha
Average yield (kg/ha)	2,222	2,867	3,256	3,444	3,544
Adjusted yield (kg/ha)	2,000	2,580	2,930	3,100	3,190
Gross field benefits ($/ha)	400	516	586	620	638
Cost of nitrogen ($/ha)	0	25	50	75	100
Cost of labor ($/ha)	0	5	10	10	10
Total costs that vary ($/ha)	0	30	60	85	110
Net benefits ($/ha)	400	486	526	535	528

This analysis should always be done in a stepwise manner, passing from the treatment with the lowest costs that vary to the next. If the marginal rate of return of the change from the first to the second treatment is equal to or above the minimum rate of return, then the

Figure 6.2. Net benefit curve, nitrogen experiment

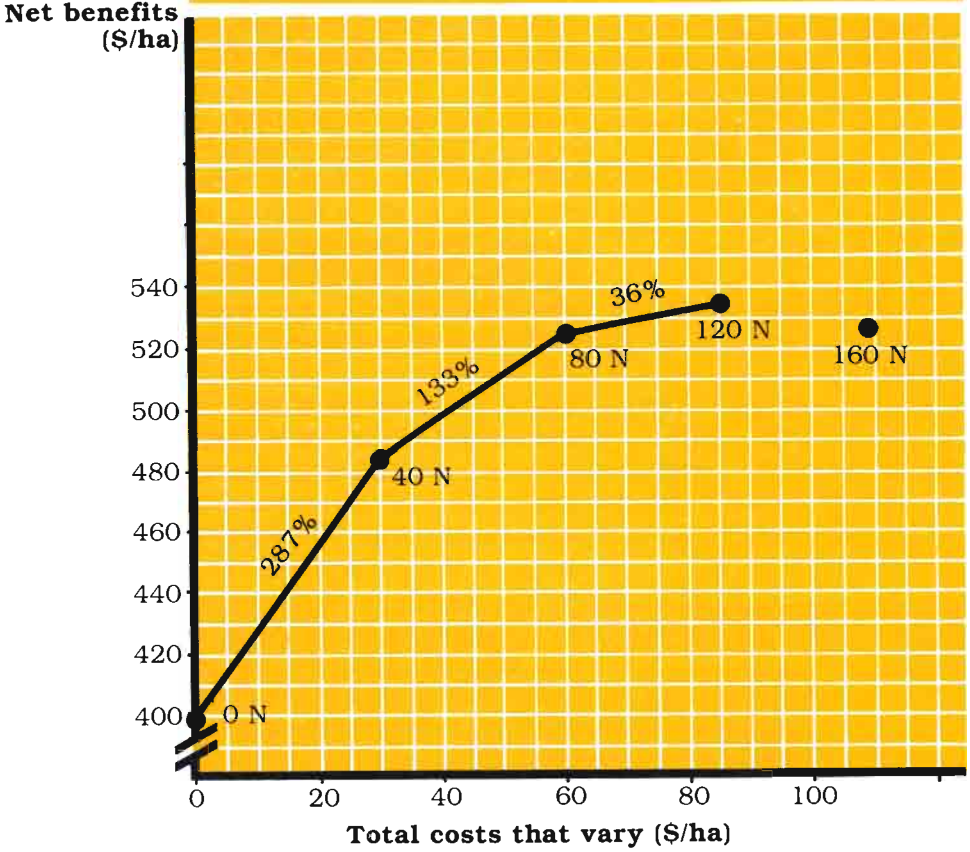


Table 6.3. Marginal analysis, nitrogen experiment

Treatment	Total costs that vary ($/ha)	Net benefits ($/ha)	Marginal rate of return
1 0 kg N/ha	0	$400	
			287%
2 40 kg N/ha	$ 30	$486	
			133%
2 80 kg N/ha	$ 60	$526	
			36%
4 120 kg N/ha	$ 85	$535	
			X
5 160 kg N/ha	$110	$528 D[a]	

[a] Treatment 5 is dominated

next comparison can be made, between the second and third treatments (not between the first and third). These comparisons continue (i.e., increasing the level of investment) until the marginal rate of return falls below the minimum rate of return. If the slope of the net benefit curve continues to fall, then the analysis can be stopped at the last treatment that has an acceptable rate of return compared to the treatment of next lowest cost. If the net benefit curve is irregular, then further analysis must be done. (See the next example, p.43).

In the nitrogen experiment, the marginal rate of return of the change from 0 kg N/ha to 40 kg N/ha is 287%, well above the 100% minimum. The marginal rate of return from 40 kg N/ha to 80 kg N/ha is 133%, also above 100%. But the marginal rate of return between 80 kg N/ha and 120 kg N/ha is only 36%. So of the treatments in the experiment, 80 kg N/ha would be the best recommendation for farmers.

There are a couple of things to notice about this conclusion. First, the recommendation is not (necessarily) based on the highest marginal rate of return. For farmers who use no nitrogen, investing in 40 kg N/ha gives a very high rate of return, but if farmers stopped there, they would miss the opportunity for further earnings, at an attractive rate of return, by investing in an additional 40 kg of nitrogen. Farmers will continue to invest as long as the returns to each extra unit invested (measured by the marginal rate of return) are higher than the cost of the extra unit invested (measured by the minimum acceptable rate of return).

The second thing to notice is that the recommendation is not (necessarily) the treatment with highest net benefits (120 kg N/ha). If instead of a step-by-step marginal analysis, an average analysis is carried out, comparing 0 kg N/ha with 120 kg N/ha, the rate of return looks attractive (i.e., (535-400)/(85-0) = 159%), but this is misleading. The *average* rate of return of 159% hides the fact that most of the benefits were already earned from lower levels of investment. This average rate of return lumps together the profitable and the unprofitable segments of the net benefit curve. The marginal analysis indicates acceptable rates of return up to 80 kg N/ha. If the farmers are to apply 120 kg N/ha, the analysis shows they would only get a marginal rate of return of 36% on their investment of the last $25. It is likely that they would be willing to invest their money in nitrogen up to 80 kg N/ha, and then ask if there is not some other way of investing that final $25 (a little extra weeding, fencing for animals, etc.) that would give a better rate of return than 36%.

In summary, the recommendation is not necessarily the treatment with the highest marginal rate of return compared to that of next lowest cost, nor the treatment with the highest net benefit, nor the treatment with the highest yield. The identification of a recommendation requires a careful marginal analysis using an appropriate minimum rate of return.

Tillage Experiment

This example illustrates some additional aspects of marginal analysis and the selection of recommendations. Figure 6.3 presents yield data from a tillage experiment in wheat. Table 6.4 gives details of the design and the costs that vary. The yield data are the average of six locations from one year of experiments. Table 6.5 shows the partial budget. Figure 6.4 shows the net benefit curve and Table 6.6 shows the marginal analysis.

Figure 6.3. Yields from tillage experiment

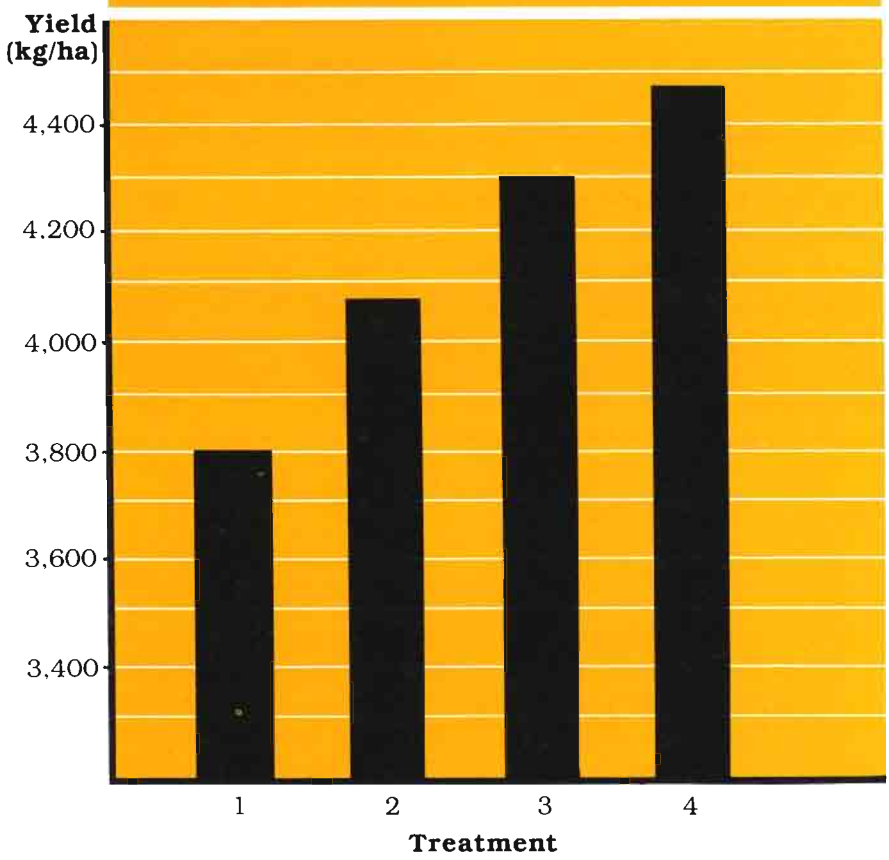


Table 6.4. Tillage experiment data

Treatment	Type of plow	Number of cultivations	Seeding method	Average yield (kg/ha) for 6 locations
1[a]	None	2	By hand	3,800
2	None	0	Zero-till planter	4,080
3	Chisel	2	By hand	4,300
4	Mold board	2	By hand	4,470

a/ Farmers' practice

Data

Tillage costs:

Cultivator	$7/ha	Cost of seeding by hand	$2/ha
Chisel plow	$16/ha	Field price of wheat	$0.08/kg
Mold board plow	$22/ha	Yield adjustment	20%
Zero-till planter	$20/ha	Minimum rate of return	80%

Table 6.5. Partial budget, tillage experiment

	Treatment			
	1	2	3	4
Average yield (kg/ha)	3,800	4,080	4,300	4,470
Adjusted yield (kg/ha)	3,040	3,264	3,440	3,576
Gross field benefits ($/ha)	243	261	275	286
Cost of plowing ($/ha)	0	0	16	22
Cost of cultivation ($/ha)	14	0	14	14
Cost of seeding ($/ha)	2	0	2	2
Cost of zero-till seeding ($/ha)	0	20	0	0
Total costs that vary ($/ha)	16	20	32	38
Net benefits ($/ha)	227	241	243	248

Figure 6.4. Net benefit curve, tillage experiment

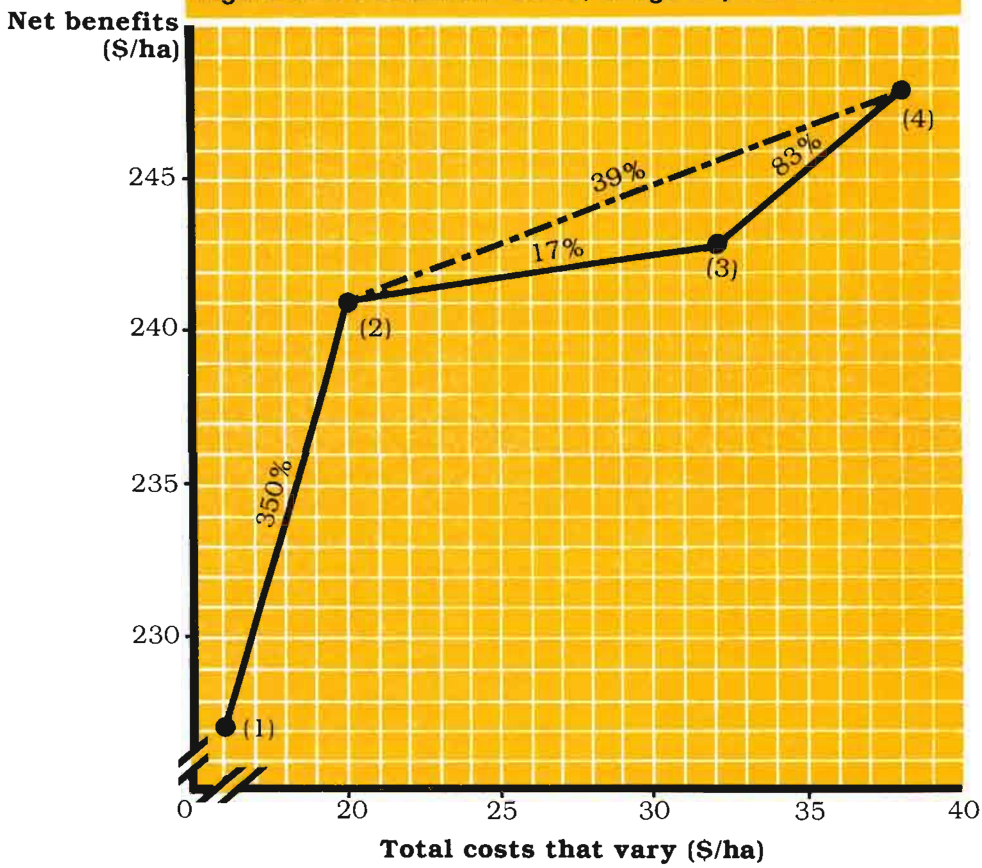


Table 6.6. Marginal analysis, tillage experiment

Treatment	Total costs that vary ($/ha)	Net benefits ($/ha)	Marginal rate of return
1	16	227	
			350%
2	20	241	
			17% ⎤
3	32	243	⎬ 39%
			83% ⎦
4	38	248	

First, it should be noted that this tillage experiment is different from the nitrogen experiment in that it tests four distinct treatments, rather than the continuous increase of one factor. It is impossible to use 80 kg of nitrogen without using 40 kg of nitrogen, but using one tillage method does not require first using a lower cost method. There are four different options, arranged on the net benefit curve in order of increasing costs. The marginal analysis is simply a way of examining various alternatives for tillage (in this case). The comparisons are made, as always, in a stepwise manner between one alternative and the next, in order of increasing costs, until an acceptable recommendation is identified.

Second, the situation is a bit different from the previous example in that only six locations from one year are available for analysis. Thus the analysis will be used to help plan further experiments, rather than to make farmer recommendations.

Finally, the shape of the net benefit curve is different from the previous example. The marginal rate of return in going from Treatment 1 to Treatment 2 is 350%, well above the minimum. Therefore Treatment 2 is certainly a worthwhile alternative to the farmers' practice. Next, the marginal rate of return in going from Treatment 2 to Treatment 3 is 17%, and below the minimum. Treatment 3 can therefore be eliminated from consideration. But the marginal rate of return between Treatments 3 and 4 is 83%, and above the minimum rate of return of 80%. In such cases as this, where the marginal rate of return between two treatments falls below the minimum, but the following marginal rate of return is above the minimum, it is necessary to eliminate the treatment(s) that are unacceptable and *recalculate* a new marginal rate of return. In this example, it is necessary to calculate a marginal rate of return between Treatment 2 and Treatment 4. The result is 39% $\left(\frac{248\text{-}241}{38\text{-}20} = 39\%\right)$, which is below the minimum rate of return. Thus Treatment 4 is also rejected. If this last marginal rate of return had been above 80%, however, Treatment 4 would have been the best treatment.

In this case researchers should continue to experiment with Treatment 2 (the zero-till planter), which seems to be a promising alternative to the farmers' practice of two cultivations before seeding. Treatments 3 and 4 give higher yields, but their costs are such that they do not provide an acceptable rate of return. Researchers must decide if there is sufficient evidence to eliminate these treatments from future experimentation, or if another year of testing is worthwhile.

Analysis Using Residuals

The conclusions of a marginal analysis can be checked by using the concept of "residuals."[6] Residuals (as the term is used here) are calculated by subtracting the return that farmers require (the minimum rate of return multiplied by the total costs that vary) from the net benefits. Table 6.7 illustrates this method, using the data from the nitrogen experiment (Table 6.3).

Table 6.7. Analysis of nitrogen experiment using residuals

Treatment	(1) Total costs that vary ($/ha)	(2) Net benefits ($/ha)	(3) Return required [100%x(1)] ($/ha)	(4) Residual [(2) - (3)] ($/ha)
1 0 kg N/ha	0	400	0	400
2 40 kg N/ha	30	486	30	456
3 80 kg N/ha	60	526	60	466[a]
4 120 kg N/ha	85	535	85	450

a/ Maximum residual

The treatments are listed, as usual, in order of total costs that vary. Column 1 gives the total costs that vary and column 2 gives the net benefits. Column 3 is the minimum acceptable rate of return multiplied by the costs that vary, and represents the return that farmers would require from their investment in order to change their practice. For instance, if 40 kg N/ha has costs that vary of $30/ha, and if the minimum rate of return is 100%, this means that farmers would ask for returns of at least an additional $30/ha before investing in 40 kg N/ha. Finally, the residual (column 4) is the difference between net benefits (column 2) and the return that farmers require (column 3). Of course this residual is not the profit, and it is the comparison between the residuals, rather than their absolute value, that is of interest.

Farmers will be interested in the treatment with the highest residual. In this case, the treatment with the highest residual is 80 kg N/ha, which is the same conclusion that was reached in the previous analysis. Stopping at 40 kg N/ha denies the farmers the possibility to earn more money per hectare. Going on to 120 kg N/ha implies a loss, after accounting for the return that farmers require.

6/ For the purposes of this manual the term "residual" is used in a special way, to indicate the difference between the net benefits and the cost of the investment. The reader should note that the term has other meanings, both in economics and in other fields.

Residuals can also be used to check the conclusions of the marginal analysis of the tillage experiment (Table 6.6). Table 6.8 shows the results; Treatment 2 is the one with the highest residual.

Table 6.8. Analysis of tillage experiment using residuals

Treatment	(1) Total costs that vary ($/ha)	(2) Net benefits ($/ha)	(3) Return required [80% x (1)] ($/ha)	(4) Residual [(2) - (3)] ($/ha)
1	16	227	13	214
2	20	241	16	225[a]
3	32	243	26	217
4	38	248	30	218

a/ Maximum residual

This method of calculating and comparing residuals will always give the same conclusion as the graphical method of marginal analysis shown earlier. The method of using residuals, however, requires an exact figure for the minimum rate of return, whereas the graphical method allows comparison of the marginal rates of return with various assumptions about the minimum rate of return. Thus it is advisable to use the graphical method first and then, if necessary, check the conclusions with respect to a particular minimum rate of return by calculating residuals.

SOME QUESTIONS ABOUT MARGINAL ANALYSIS

1 Is marginal analysis the "last word" for making a recommendation?

Marginal analysis is an important step in assessing the results of on-farm experiments before making recommendations. But agronomic interpretation and statistical analysis are also part of the assessment, as well as farmer evaluation. As researchers conduct on-farm experiments, they must constantly solicit farmers' opinions and reactions. Alternatives that seem to be promising both agronomically and economically may have other drawbacks that only farmers can identify. To the extent possible, screening treatments for compatibility with the farming system should take place before experiments are planted. But farmer assessment of the experiments is also essential. It is the farmers who have the last word.

2 How precise is the marginal rate of return as a criterion?

It is important to bear in mind that the calculation of the marginal rate of return is based on yield estimates derived from agronomic experiments and on estimates of various costs, often opportunity costs. Furthermore, the marginal rate of return is compared to a minimum rate of return which is only an approximation of the investment goals of the farmers. Discretion and good judgment must always play an important part in interpreting these rates and in making recommendations. If the marginal rate of return is comfortably above the minimum, the chances are good that the change will be accepted. If it is close to the minimum rate of return then caution must be exercised. In no case can one apply a mechanical rule to recommend a change that is a few percentage points above the minimum rate, or reject it if it is a few points below. Making farmer recommendations requires a thorough knowledge of the research area and the problems that farmers face, a dedication to good agronomic research, and the ability to learn from previous experience. Marginal analysis is a powerful tool in this process, but it must be seen as only a part of the research strategy.

3 Can the marginal rate of return be interpreted if the change in costs that vary is small?

Certain experiments, such as those that look at different varieties or perhaps modest changes in seeding rate, involve changes in costs that may be quite small. If the yield differences are at all substantial, the resulting marginal rate of return can be very large, sometimes in the thousands of percent. In these cases the marginal rate of return is of little use in comparing treatments. Thus it is usually not worthwhile calculating marginal rates of return for variety experiments, unless there are significant differences in cost between varieties (e.g., local maize variety versus a hybrid), or in the market value of the varieties (e.g., because of consumer preference).

4 Is it really possible to make recommendations, using marginal analysis, without considering all the costs of production?

Remember that the starting point in on-farm research is the assumption that it is much better to consider relatively small improvements in farmers' practices, rather than propose large-scale changes. The idea is thus to ask what changes can be made in the present system, and to compare the change in benefits with the change in costs. Because the focus is on the *differences* between two treatments, rather than their absolute values, costs that do not vary between treatments will not affect the calculation of the marginal rate of return. Table 6.9 shows two cases, both using the same yields and costs that vary. For the partial budget, the marginal rate of return is calculated in the usual way. The complete budget includes all of the costs of production; they are of course constant ($300/ha) for each treatment. When the marginal rate of return is

Table 6.9. Marginal analysis using a partial budget and a complete budget

Partial budget	1	2	Complete budget	1	2
Gross field benefits ($/ha)	500	650	Gross field benefits ($/ha)	500	650
Total costs that vary ($/ha)	100	200	Total costs that vary ($/ha)	100	200
Net benefits ($/ha)	400	450	Total of costs that do not vary ($/ha)	300	300
			Total costs ($/ha)	400	500
			Net benefits ($/ha)	100	150
Marginal rate of return $= \frac{450 - 400}{200 - 100} = 50\%$			Marginal rate of return $= \frac{150 - 100}{500 - 400} = 50\%$		

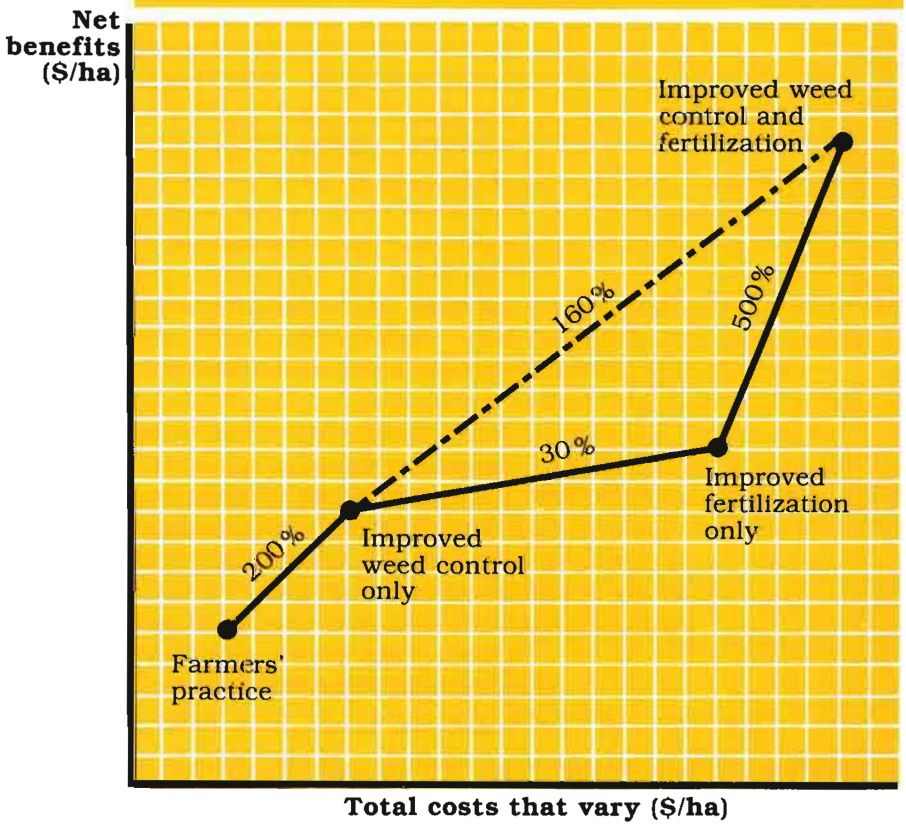
calculated using benefits and total costs, the result is the same.

5 Is the correct strategy always to consider small changes in farmers' practices?

Experience has shown that farmers are much more likely to adopt new practices in small steps rather than in complete packages. But in following this strategy it should be realized that farmers can (and do) eventually adopt a new set of practices over a period of several years of testing. The complexity of the individual steps depends on the nature of the agronomic interactions among the elements being tested and on the resources available to farmers.

It is often possible to take advantage of this sequential adoption pattern in making recommendations. Initial steps may be intermediate between farmers' practice and the recommendation that would be selected by marginal analysis. Figure 6.5 is the net benefit curve for

Figure 6.5. Net benefit curve, weed control by fertilizer experiment



a weed control by fertilizer experiment. The curve shows that a combination of improved weed control and fertilization should be the recommendation.

Nevertheless, it is possible to first promote an intermediate recommendation of improved weed control only and then add fertilization later. The curve allows researchers to trace out an efficient set of technologies for recommendation as farmers increase expenditure levels. In this case, further analysis would indicate that adopting fertilizer first, without improved weed control, would not be a worthwhile option.

More complex changes, such as the introduction of new crops or cropping patterns, are of course possible as well. But such changes require extremely careful planning and analysis which are beyond the scope of this manual.

6 What is the difference between a marginal analysis and a continuous analysis of data?

Agronomists often estimate response functions for factors such as nutrients, and economists use similar continuous functions to select economic optima. Yet the methodology of this manual uses a marginal analysis for sets of discrete alternatives. There are three reasons for emphasizing the latter method. First, marginal analysis, using discrete points, can be used for any type of experimentation, whereas continuous analysis is only applicable to factors that vary continuously, such as fertilizer rates or seed rates. Second, the computational skills and facilities necessary for estimating response functions are not always available. Finally, great precision is not required for farmer recommendations (e.g., for fertilizer levels) because farmers will adjust them to their individual conditions.

A continuous economic analysis may be very useful in certain situations, however. But if it is done, it requires the same degree of care in estimating the benefits and costs that farmers face that has been emphasized in this manual for constructing a partial budget and conducting marginal analysis. The sophisticated analyses that are often done with unrealistic assumptions about farmers' yields, field prices, or minimum rate of return do not give useful conclusions.

7 Does the marginal analysis assume that capital is the only scarce factor for farmers?

In the marginal analysis, all factors are expressed in monetary units. This does not necessarily mean that farmers think of all costs and benefits in monetary terms, or that cash is necessarily the limiting factor. Marginal analysis may be used, for instance, in an experiment that compares treatments which differ only in the amount of (unpaid) family labor utilized on a crop which is not sold. To decide whether extra amounts of labor would be effectively invested to produce extra amounts of the crop, opportunity costs and prices can be assigned and the comparison made.

Nevertheless, in cases where family labor is the predominant source of labor, and experimental treatments involve significant changes in labor use, care must be taken in valuing labor. If, for instance, a change from one treatment to another implies a reduction in family labor and an increase in cash expenditure, a modest increase in total costs that vary may in fact represent a significant increase in cash outlay (balanced to some extent by a reduction in labor "costs"). In cases where family labor is a particularly important factor in farmer decision making regarding new technologies, a careful analysis must be undertaken. This is complicated by the fact that the opportunity cost of labor is sometimes difficult to estimate. Different members of the household (men, women, children) will likely have different opportunity costs of labor, and the time of the year (slack season, peak season) will also affect the estimate.

One possibility is to do a sensitivity analysis (Chapter 9), which involves doing several marginal analyses using different estimates of the opportunity cost of labor. Another technique involves estimating the returns to labor for the treatments and comparing the marginal returns to labor between two treatments with various estimates of the opportunity cost of labor. This is a reminder that there are often alternative analytical techniques, beyond the scope of this manual, which may be useful in making decisions about the appropriateness of a particular technology.

8 Can the concept of marginal analysis be used for planning experiments?

It is common to consider a change in farmers' practice by doing a quick calculation of how much additional yield would be needed to pay for the extra costs of the new practice. If an extra 100 kg of fertilizer costs \$1,000, and wheat is selling for \$5/kg, then the estimate might be that the farmers would need an extra 200 kg of wheat (\$1,000/\$5) in order to "repay the fertilizer." However, there are three errors in this kind of calculation.

The first error is in using market prices for fertilizer and wheat, rather than field prices. The second is not including the labor or machinery costs associated with the use of fertilizer. The third is in not including the minimum rate of return. The following formula corrects those errors, and provides a useful way for helping to consider practices that are proposed for experimentation.

$$\Delta Y = \frac{\Delta TCV\ (1 + M)}{P}$$

where
ΔY = minimum change in yield required
ΔTCV = change in total costs that vary
P = field price of product
M = minimum rate of return (expressed as a decimal fraction)

In the example just mentioned, if the additional fertilizer plus the labor to apply it is worth \$1,200, the field price of wheat is \$4/kg, and the minimum rate of return is 50%, then:

$$\Delta Y = \frac{\$1{,}200\ (1 + 0.5)}{\$4}$$
$$= 450 \text{ kg of wheat}$$

Thus, given current prices, the minimum yield increase required by farmers from the addition of an extra 100 kg of fertilizer is 450 kg of wheat, not the 200 kg in the original calculation. The use of this type of calculation before designing an experiment helps ensure that the treatments include an economically realistic range of levels.

9 Can marginal analysis be used when yields are variable or prices change?

Yields in agronomic experiments are usually quite variable, and prices often change. Methods for accommodating this kind of variability to marginal analysis are discussed in Chapters 7, 8, and 9.

Chapter Seven Preparing Experimental Results for Economic Analysis: Recommendation Domains and Statistical Analysis

Marginal analysis for a particular experiment should be done on the pooled results from at least several locations over one or more years. To prepare the experimental results for this type of analysis, several steps must be taken. First, researchers must review the purpose of the experiment in order to decide whether the results of the analysis are to be used for making recommendations for farmers or for guiding further research. Second, a review of results from the different locations will indicate whether all of the locations belong to the same recommendation domain and can therefore be analyzed together. Finally, a combination of agronomic judgment and statistical analysis will lead to a decision regarding the yield differences among treatments in the experiment. If researchers have little confidence that there are real differences in yields, then the total costs that vary of each treatment can be compared; the treatment with the lowest costs will generally be preferred. If, on the other hand, researchers believe that the differences observed represent real differences among treatments, then a marginal analysis should be done.

Reviewing the Purpose of the Experiment

Each experimental variable in an experiment has a purpose, and researchers should review the objectives of the experiment before thinking about an economic analysis. Some experimental variables are of an exploratory nature; they are meant to provide answers regarding response (e.g., is there a response to phosphorus?) or to elucidate particular production constraints that have been observed (e.g., is the low tillering observed in the wheat crop due to a nutrient deficiency or to the variety?). These variables are meant to provide information that can be used in specifying production problems and designing solutions for them. The treatments in these exploratory experiments are chosen to detect the possibility of responses, and thus need not be designed to represent economically viable solutions to a particular problem. Researchers must bear this in mind when considering the economic analysis of experiments with this type of exploratory variable. If the experimental results provide clear evidence that a particular production problem exists, the economic analysis may help to select possible solutions for testing. If a high level of an insecticide in an exploratory experiment provided evidence of a response, but if the marginal analysis then showed an unacceptable rate of return, researchers would want to examine lower levels of insecticide or less expensive insect control methods in subsequent experimentation.

Other experimental treatments test possible solutions to well-defined production problems. The solutions will have been selected for testing not only because they promise economically acceptable returns, but because they are compatible with the farming system and do not represent special risks to farmers. When there are yield differences among treatments in these cases, the marginal analysis should be more rigorous, because a recommendation may be made to farmers.

The marginal analysis should be done on the pooled results of a number of locations, usually over more than one year. No strict rules can be given here, but the number of locations should be sufficient to give researchers confidence that the results fairly represent the conditions faced by farmers in the recommendation domain. A very rough rule of thumb might be to include at least 20 experimental locations (in relatively homogeneous environments) over two years for each recommendation domain. The exact number of test sites required will depend on the variability (across sites and across years) in the recommendation domain and on the technology being tested. For instance, fertilizer recommendations usually require a fairly large number of locations to adequately sample the range of response by soil type, rotation, and so forth. Insect control recommendations may require several years of evidence to sample year-to-year variability in insect populations, especially in the case of routine preventive treatments.

Once recommendations are derived they are often presented to farmers through demonstrations, which may involve one or more large plots showing various alternatives next to a similar plot with the farmers' practice. As a way of following up on the recommendation the results of these demonstration plots should also be subjected to an economic analysis, preferably as part of the demonstration.

Tentative Recommendation Domains

Whether the experiments are of an exploratory nature or are testing possible solutions, they should be planted in locations that represent the tentative definition of the recommendation domain. Recall that a recommendation domain is a group of farmers whose circumstances are similar enough that members of the group are eligible for the same recommendation.

An example may help. In a particular research area there is experimental evidence of a response to nitrogen in maize. Farmers currently use no fertilizer, and an experiment is designed to test various levels of nitrogen. Most of the farmers plant maize under rainfed conditions, although a few have access to irrigation. Because the response to nitrogen may differ under rainfed and irrigated conditions, and because of the small number of farmers with irrigation, only farmers with rainfed fields are considered. (If there were more farmers with irrigation, experiments might be planted with them as well, but they would almost certainly be a separate recommendation domain.) Most of the farmers with rainfed fields have land with sandy to sandy-loam soils. Locations are chosen to represent this range of soil types, and careful note is taken in the field book of the soil type at each location. The tentative definition of the recommendation domain includes the range of soil types, but the experimental results may distinguish separate domains. Nonexperimental variables, such as variety, planting date, and weed control are left in the hands of the farmers. A certain range in these practices is present in the recommendation domain, and the actual practices at each location are noted in the field book. The researchers do their best to reject locations that represent very unusual practices or conditions (such as a few farmers who plant a special maize variety to sell as green maize.)

The tentative definition of the recommendation domain for the fertilizer experiment is thus: "All farmers in the area who plant maize under rainfed conditions on sandy to sandy-loam soils." This definition allows for some variability in conditions and practices, and the selection of experimental sites tries to represent this range, but avoids obvious extremes.

Notice that the recommendation domain is defined for the particular experimental variable. A different experimental variable (say, a disease-resistant variety) might be tested in a domain of a different definition. In this case, the variety might be tested on both irrigated and rainfed fields, if no difference in its disease resistance capacity were expected.

Reviewing Experimental Results

The results of each experiment at each location in the tentative recommendation domain must be reviewed. Inconsistencies in results between locations can be due to one of three causes:

1 **Redefinition of the recommendation domain.** In the above example, soil type was being considered as a possible means of subdividing the recommendation domain. If the responses are very different at locations with sandy soils and those with sandy-loam soils, then there may be two separate recommendation domains (and two separate economic analyses). Or it may be that an unexpected characteristic is of importance. Suppose, in this same example, that some farmers plant a maize-maize rotation, while others rotate their maize with fallow. If the responses to nitrogen are different on these two types of fields, the original recommendation domain may be refined (by eliminating the rotation that represents a minority of the farmers) or divided (by rotation, if both rotations are of importance in the area).

The important point is that researchers must have a clear and consistent definition of the recommendation domain whose experiments will be submitted to economic analysis. Domain definitions are reviewed and refined during the experimental process. As the number of possible defining characteristics for domains is greater than the number of locations to be planted, careful selection of experimental locations is important. The routine collection of information adequate to describe each location (e.g. elevation, soil, cropping history, management practices) is a most important activity, without which across-location interpretation is impossible.

2 **Improper experimental management.** At times the experimental results at a location may differ from the others because of problems in experimental management. This may include errors by the researchers (such as applying the wrong dosage of a chemical), or factors related to the farmer (such as a cow destroying part of the experiment, or the farmer failing to weed because of a misunderstanding). In such cases the location can be eliminated from the analysis and the researchers will gain a bit more experience—in the management of chemicals, in locating experiments where there is little chance of animal damage, or in carefully discussing with farmers their responsibilities in the management of an experiment. Part of experimental management includes the selection of locations. If locations have to be eliminated because they have characteristics well outside the normal range of the recommendation domain (such as very late planting dates) this too is an indication of the necessity to improve experimental management.

3 **Unexplained or unpredictable sources of variation.** After eliminating locations from the analysis because they do not represent the recommendation domain, and eliminating sites where the management of the experiment is responsible for unrepresentative results, there may still be considerable variation in the results from the remaining locations. This may be due to factors that are not understood (and may be the focus of further agronomic investigation and/or discussion with farmers). Or it may be due to factors that are understood but not predictable, and hence not eligible for defining a recommendation domain, like drought or frost. These sites must be included in the economic analysis, unless researchers are able to identify particular areas where the factor is more likely to occur. It may be, for instance, that the research area can be divided into more and less drought-prone domains. But if drought (or frost or insect attack) cannot be associated with particular areas, then the results of the affected locations must enter the analysis. More will be said about treating these risk factors in Chapter 8, but it is important to emphasize that locations that have been affected, or even abandoned, because of these factors must be included in the marginal analysis.

Statistical Analysis

In Chapter 3 it was pointed out that the economic analysis of an experiment should be done only after reviewing the agronomic assessment and statistical analysis. If after reviewing the statistical analysis researchers do not have confidence that there are real differences among treatments, then they need to take another look at the experiment. If the average differences among treatments are large relative to the yields obtained by farmers (e.g., 5-10% or more of average farmer yields), but there is insufficient evidence that these differences are real, then researchers may want to review the design or management of the experiment and perhaps repeat it the next cycle. If the differences among treatments are small in relation to farmers' yields, and researchers have no confidence that the differences are real, then they need consider only the differences in costs among treatments and choose the one with lowest costs.

Cases where no significant yield differences exist and no marginal analysis is required are not necessarily trivial. If experimentation leads to recommendation of a practice that lowers the costs of production while maintaining yields, the gains in productivity of farmer resources are as legitimate as those from a higher yielding (and higher cost) treatment. One common example is that of substituting some form of reduced tillage for mechanical tillage. This often results in considerable cost savings, although yields may not be affected.

In experiments with factorial designs, an examination of the statistical and agronomic analyses will help point the way to the most appropriate type of economic analysis. For example, in an experiment with two factors, one factor may be responsible for yield differences although the second factor is not (and there is no interaction between them). In that case, the yields for levels of the first factor should be the average for each level over all levels of the second factor. Such a case occurs in a nitrogen by tillage experiment in which there is a response to nitrogen, but not to tillage (Table 7.1). The tillage method to be chosen for further experimentation is the one that costs the least. The partial budget for such an experiment will then have

Table 7.1. Yield data for a nitrogen by tillage experiment

Treatment	Nitrogen (kg/ha)	Tillage method	Average yield (kg/ha)
1	50	"A"	2,560
2	50	"B"	2,300
3	100	"A"	3,120
4	100	"B"	3,200

Average yield:	50 kg N/ha	2,430 kg/ha
	100 kg N/ha	3,160 kg/ha
Average yield:	tillage method "A"	2,840 kg/ha
	tillage method "B"	2,750 kg/ha

only two columns, corresponding to the two nitrogen levels (50 kg/ha and 100 kg/ha). The yields for the two nitrogen levels will be the average yields *across tillage treatments* (to take advantage of all the data available, which should give a better estimate of real differences in yields between nitrogen levels). The first line of the partial budget ("Average yield") will thus have 2,430 and 3,160 kg/ha. The costs that vary will include those associated with the change in nitrogen level (fertilizer, application costs), but *not* those associated with tillage. The marginal analysis of the partial budget will examine the marginal rate of return of changing from one nitrogen level to another.

The economic analysis of factorial experiment is concerned only with factors that exhibit responses or are involved in interactions. Therefore the interpretation of experiments including several factors is often simplified because some factors may be dropped from the analysis. In the example above, for instance, tillage was not included in the analysis. But if there had been an interaction between tillage and nitrogen, the partial budget would have had four columns (with all possible combinations of tillage and nitrogen) and the costs that vary would have reflected both factors.

In the early stages of on-farm experimentation there are often experiments with a large number of treatments (12 to 15 or more) examining several variables. The statistical analysis of such experiments may be quite complex, and its relation to an economic analysis at first sight may be unclear. The point to remember is that the purpose of those experiments is to characterize as quickly as possible the responses and the interactions of several factors. Once that is accomplished, a small number of possible solutions can be tested. If the results of such an exploratory experiment are agronomically clear (and the statistical analysis can only help in making this decision), then the next year's experiments will certainly be simpler, and a marginal analysis will help to select a reasonable range of treatments for those experiments. If the results are not clear agronomically, then further exploratory work is needed, and there is less that a marginal analysis can contribute to the selection of treatments for future experiments.

Chapter Eight
Variability in Yields: Minimum Returns Analysis

Assigning experimental locations to different recommendation domains and reviewing the management of the experiments (Chapter 7) help account for some of the variability in experimental yields. After doing this, however, some variability will certainly remain, and farmers and researchers will take this into account when making decisions about alternative practices. Some variability in the performance of particular treatments will be unexplained, whereas some may be due to identifiable factors such as drought, frost, or flooding. In either case, farmers will want to know how this variability might affect their welfare, and what undesirable outcomes are possible if they adopt a recommendation. One method for analyzing experimental data in this way is known as minimum returns analysis.

Dealing with Risk in On-Farm Research

Recall that the objective of an on-farm research program is to improve the productivity of farmers' resources. Besides improving the production of target crops or animals, this may also include lowering the costs of production or increasing the stability of production. The latter is an important factor for many farmers, whose practices often reflect attempts to reduce the risks of failure. Common examples of such practices include staggering planting dates to minimize the risk of losing an entire crop to drought, or investing extra labor to double over the maize plants before harvest in areas where there are strong winds.

Risk has three important implications for an on-farm research program. First, new technologies that are proposed for testing should be compatible with farmers' practices to reduce risk. Before proposing a technology that relies on a uniform planting date, for instance, researchers should take account of farmers' rationale for staggered planting dates. Technologies that do not take account of farmers' attempts to reduce risk have little chance of being adopted.

The second implication is that the risks faced by farmers may suggest opportunities for developing recommendations to help stabilize farm production. Drought risk may be reduced with moisture conservation techniques, and losses from high winds may be reduced with shorter varieties. Thus in setting priorities for an experimental program, researchers should include the possibility of testing alternatives that may not necessarily increase average benefits, but instead help to reduce their year-to-year variability.

The third implication is that researchers will want to be careful in evaluating how new recommendations modify the risks currently borne by the farmers in a recommendation domain. The amount that farmers are willing to give up (in terms of average net benefits) to reduce the effects of an uncertain environment is a measure of their degree of risk aversion. The degree of farmers' risk aversion may depend on several factors, but in general it can be said that most farmers in developing countries are moderately averse to risks. It is not easy to specify the degree of risk aversion, but it is something that should be considered when proposing new recommendations.

Risk and Data From On-Farm Experiments

The source of risk is often thought of as being susceptible to quantification. Thus it is possible to say that the probability of less than 400 mm of rainfall in the growing season is 0.2 (i.e., one year in five). If researchers have information about the probability of occurrence for a particular event, then those data may be used in interpreting experimental results. If, for instance, it is known that there is a drought on the average of one year in five, causing a certain percentage of crop loss, that information can be factored into an analysis of the results of the on-farm experiments, whether or not they were conducted during a drought year. But this type of precise data is not usually encountered, and researchers need a more useful way of looking at the variability in their own experimental data. Even if the source of variability is well specified (e.g., midseason drought), probabilities may not be available. Often the variability observed in experimental results and in farmers' fields is due to several sources. Thus the minimum returns analysis presented here is not, strictly speaking, a method of risk analysis, but rather a way of assessing the variability due to unpredictable and at times unexplained causes.

The Farmers' Point of View

Before minimum returns analysis is done to look at variability the way that farmers do, it is useful to consider how in fact farmers approach this problem.

First, recall that the marginal analysis is based on the *average* yields from a number of locations. If a proposed recommendation gives an average yield of 3,000 kg/ha, it is certain that it will have yielded more than 3,000 kg/ha in some locations and less in others. If the farmers' practice yields an average of 2,000 kg/ha, it too will exhibit some variation. And if the marginal analysis indicates that the proposed recommendation has an acceptable marginal rate of return, when compared to the farmers' practice, it is a rate of return based on these average yields. Minimum returns analysis will not look at averages, but rather at the results from individual sites. Looking at across-location and across-year variability is one way of estimating the risks for farmers associated with the proposed recommendation. The careful definition of recommendation domains attempts to eliminate across-location variability as much as possible. Across-year variability, on the other hand, is estimated here based on the results of only two or three years, and tends to underestimate the year-to-year variability that farmers face. Nevertheless, a careful minimum returns analysis is a useful way of examining the variability associated with different technological alternatives.

Second, note that farmers are more interested in variability in benefits than variability in yields. A minimum returns analysis looks at variability in net benefits.

If the results of a set of on-farm experiments show that two treatments have the same average net benefits, but one treatment's results are more variable than the other's, it is likely that farmers will prefer the treatment that is more consistent, rather than the one that sometimes gives very high net benefits but at other times gives very low net benefits.

But variability *per se* is not the only factor that farmers will take into account when deciding among treatments. If one treatment always gives higher net benefits than another treatment, it may not matter if the first exhibits higher variability than the second. As long as marginal analysis shows that it gives an acceptable rate of return, and farmers are assured that even in the worst cases it gives higher net benefits than the alternative, then farmers will be interested in adopting it.

The most difficult decisions must be taken when the average net benefits for one treatment are higher than those for another, but in some locations the net benefits are lower than those of the alternative. The marginal analysis (on average results) shows the treatment to be acceptable, but there are some individual cases where the benefits are lower than those of the alternative treatment. Should the farmers choose the treatment that is better on average, or the one that offers less chance of low net benefits? It is here that a minimum returns analysis is most helpful.

Prerequisites for a Minimum Returns Analysis

Minimum returns analysis

A minimum returns analysis is a way of screening data from on-farm experiments in order to give farmers (and researchers) additional information about the variability in returns implicit in a proposed recommendation in comparison with the farmers' practice. **A *minimum returns analysis* compares the average of the lowest net benefits for each nondominated treatment.** For the analysis to be relevant, several prerequisites must be met:

1. The marginal analysis must have been done on all locations for a given experiment and for all years. It should include all locations deemed to belong to the recommendation domain, including locations with poor results or those that have been abandoned. A marginal analysis done only on locations with "good" results will not be of much use to farmers. At times it is tempting to remove a particularly poor location from the analysis. If ten locations were planted in the recommendation domain, and one location had poor results because of frost damage, the analysis of the remaining nine will give farmers an idea of what returns they can expect *if there is no frost*. This may not be very useful information. If nine locations were damaged by frost, no one would propose analyzing only the single good one! Thus minimum returns analysis assumes that all locations have been included in the marginal analysis done previously.

2 A minimum returns analysis should be done only on experimental treatments that are being considered for recommendation. That may include not only the farmers' practice and the treatment that has been judged acceptable *on the average* by marginal analysis, but also other nondominated treatments that may provide alternatives if the tentative recommendation proves unsatisfactory.

3 Minimum returns analysis presumes that researchers have tried to explain the reasons for the variability they observe, rather than assuming it is simply bad luck. The more precise an idea of the sources of observed variability, the more useful the information from the minimum returns analysis will be for farmers.

4 Minimum returns analysis is most useful when recommendations are being considered. Although it does not pretend to be mathematically precise, it does try to assess the effects of variability, and this is best estimated from a large number of results. Minimum returns analysis is most relevant when done on the results of at least 20 locations from at least two years. The results should be from enough locations and years to fairly represent the variability that farmers in the recommendation domain are likely to face.

Minimum Returns Analysis

For simplicity, the steps in the minimum returns analysis will be illustrated for a comparison between only two treatments. Table 8.1 lists the yield data from 20 locations over three years of the "0 kg nitrogen" (farmers' practice) and "80 kg nitrogen" treatments in a fertilizer experiment. The 80 kg N/ha treatment gives, on the average, higher yields than the 0 kg N/ha, although there is considerable variability for both treatments. The marginal analysis of the average yield data showed 80 kg N/ha gives an acceptable rate of return (see Table 6.3).

Table 8.1. Yields by location for Treatments 0 kg N and 80 kg N

Location	Yield (kg/ha) 0 kg N	80 kg N
1	2,450	3,970
2	2,840	3,930
3	2,130	1,870
4	2,170	3,720
•	•	•
•	•	•
•	•	•
20	2,570	1,780
Average of 20 locations	2,222	3,256

The first step is to calculate the net benefits at each one of the locations for each one of the treatments. This is not as time consuming as it sounds. In the case of the 80 kg N treatment, the necessary calculations are shown below:

Net benefits = (Y x A x P)—TCV,

where

Y = yield at one location
A = 1—the yield adjustment
P = field price of crop
TCV = total costs that vary for the treatment

If A = 0.90, P = $0.20/kg, TCV = $60/ha

then the net benefits for treatment 80 kg N for each location will be:

(Y x 0.9 x $0.20) - ($60)

or 0.18 Y - 60.

Because Treatment 0 kg N has no costs that vary, the formula for calculating the net benefits is even easier (0.18 Y). The net benefits for each location are shown in Table 8.2.

To do the minimum returns analysis, select the (approximately) 25% lowest net benefits for one treatment and compare their average with that of the

Table 8.2. Net benefits by location for Treatments 0 kg N and 80 kg N

Location	Net benefits ($/ha) 0 kg N	80 kg N
1	441	655
2	511	647
3	383	277
4	391	610
5	250	593
6	322	619
7	490	660
8	458	600
9	180	162
10	250	612
11	542	562
12	512	681
13	285	291
14	387	578
15	375	230
16	494	661
17	485	660
18	295	480
19	485	683
20	463	260
Average	400	526
Average of five lowest	252	244

25% lowest net benefits for the alternative. The five lowest net benefits representing the 25% worst cases for each treatment are marked in yellow in Table 8.2.

If the average of the lowest net benefits for the tentative recommendation is higher than the average of the lowest net benefits for the farmers' practice, then the recommendation should be made, because even in the worst cases the recommendation does better than the farmers' practice.

But if the average for the tentative recommendation is lower than that for the farmers' practice, then a decision must be made. The average of the five lowest net benefits for 0 kg N is $252, whereas the average for the five lowest for 80 kg N is $244. The absolute value of these net benefits has little meaning but the difference between the two should be examined. If the difference is small, then farmers will probably be willing to accept this risk, knowing that over the long run they will come out ahead with the recommendation. In this case, the difference is only $8, and is small in relation to the average increase in net benefits ($126). So it is likely that farmers will be willing to accept this risk. But if the difference is large, representing a sum equivalent to a significant part of farmer income or a quantity that would put farmers in serious debt to a bank or a moneylender, then it would be best to reconsider the recommendation. Perhaps an alternative could be found (in this case it would be worth doing the minimum returns analysis on 40 kg N as well). If no less risky alternative is available, then the farmers' practice is to be preferred.

It is important to emphasize that this type of analysis assumes that all locations are representative of a single recommendation domain, and that there is nothing special about any individual location. The poor results for one treatment may or may not be in the same location as the poor results for another treatment. Thus in Table 8.2 the farmers' practice does much better than the recommendation in location 3, whereas in location 5 the reverse is true. But it is assumed that these locations passed through the analysis described in Chapter 7. The explanation for these peculiar results may be a specific factor, such as flooding, or it may be an undetermined cause. But the decision has been taken that they both fairly represent the recommendation domain, should be included in the marginal analysis, and then included in the minimum returns analysis.

Finally, it should be noted that the minimum returns analysis is done with actual location by location data. No attempt is made to fit the data to standard frequency distributions. The rule of thumb of looking at the worst 25% of cases for each treatment is a guideline only. Experimental results unfortunately do not always give smooth curves and normal distributions. The key to minimum returns analysis, as with the other analytical techniques described in this manual, is a commonsense examination of the data from the farmers' point of view.

Chapter Nine
Variability in Prices: Sensitivity Analysis

Experimental yields are not the only element of the partial budget that is likely to vary. Input and product prices are subject to change as well. Researchers need some way of deciding which prices to use in a partial budget when making recommendations. At times it is difficult to predict where prices might be a year or several years in the future, or difficult to estimate the opportunity cost of a particular input such as labor. In these cases, researchers need a way of estimating the range of prices under which a given treatment may be recommended. A method for doing this is called sensitivity analysis.

Which Costs and Prices Should Be Used in the Partial Budget?

Chapters 2 and 3 emphasized that the partial budget should use the costs and prices that farmers actually face, rather than those announced in the newspaper or set by the government. But beyond this rule there are still a number of questions that may be asked about how to select the appropriate price. The price of the crop may vary considerably within one year, or between years. Both crop and input prices may be subject to inflation. And both may be affected by government policies. What prices should be used in these cases?

It is not uncommon for crop prices to vary within a year, rising just before harvest and then falling after harvest. Even if all the farmers in a recommendation domain store their crop after harvest to sell it at a later date, it is usually most convenient to base the field price of the crop on the market price immediately after harvest.

If crop (or input) prices vary from year to year, it is possible to use the average price over the past, say, three to five years as a basis for calculating field prices. If researchers have access to price data from ten years or more, a trend price may be estimated. Very often, however, these "trends" are due to inflation. Although inflation is a serious problem for any country, it need not be an impediment to the marginal analysis. If the calculations of the costs that vary are based on the input prices that the farmers will face at the *beginning* of the cycle, and if the field price of the crop used for calculating gross field benefits is based on the crop price the farmers will receive at the *end* of the cycle, and if the minimum rate of return includes the rate of inflation (which it should if it is based on the rate of interest in the informal capital market, or in the unsubsidized formal capital market), then the comparison of the marginal rate of return to the minimum rate of return is valid. Alternatively, if input prices and product prices are taken at one point in time, then the inflation rate does not have to be included in the minimum rate of return.

In some cases, prices are controlled by the government, either directly or through certain policies that affect the operation of market forces. If input prices are maintained at low levels through subsidies of some kind (or if crop prices are maintained at high levels), care must be taken in using these prices in the economic analysis of experimental results. If the analysis is to be used for making recommendations to farmers for future years, a judgment must be made as to whether the government can maintain such subsidies. If it seems unlikely, then it will be better to use more realistic prices in the calculations.

If, on the other hand, farmers are adversely affected by government policy, if crop prices are controlled (and farmers have no alternative markets) or inputs are sold at higher than world market prices, then there are two possible lines of action. First, over the short term, recommendations will have to be based on the prices that farmers face under these policies. But second, if it is felt that there is something to be gained by providing policymakers with information about the consequences of their current policies and the possible advantages of a change, the same analysis can be done using estimates of undistorted prices and be presented to policymakers. Thus the same set of experiments can be analyzed in two different ways, for two different audiences; using current prices for short-term farmer recommendations, and using alternative prices for contributing to the consideration of policy options.

Sensitivity Analysis

Markets, inflation, and policies are often unpredictable enough that, short of access to a crystal ball, there is no way for researchers to predict prices with any certainty a few years in the future. Recommendations often involve an investment in extension agents' time, field days, pamphlets, or radio programs, and researchers would like to feel that a recommendation will be able to withstand any likely changes in prices of inputs or crops for at least a few years.

Sensitivity analysis

The best way to test a recommendation for its ability to withstand price changes is through sensitivity analysis. ***Sensitivity analysis* simply implies redoing a marginal analysis with alternative prices.** If, for instance, a fertilizer recommendation is made using current fertilizer prices, but there are indications that those prices may increase, a reasonable estimate of the new prices may be substituted in the analysis. Table 9.1 illustrates such a situation. In the original analysis (case A), a field price for nitrogen of $0.625/kg was used. The recommendation of 80 kg N was made, assuming a minimum rate of return of 100%. If the field price of nitrogen increases to $0.75/kg, would the same recommendation hold? Redoing the partial budget (case B) with the higher price of nitrogen shows that the recommendation of 80 kg N is now in doubt, because the marginal rate of return of changing from 40 kg N to 80 kg N is just equal to the minimum rate of return. Any higher nitrogen prices would necessitate lowering the fertilizer recommendation.

Table 9.1. Sensitivity analysis for nitrogen experiment

	Case A (Current field price of N = $0.625/kg)			Case B (Future field price of N = $0.75/kg)		
	0 kg N	40 kg N	80 kg N	0 kg N	40 kg N	80 kg N
Adjusted yield (kg/ha)	2,000	2,580	2,930	2,000	2,580	2,930
Gross field benefits ($/ha)	400	516	586	400	516	586
Cost of fertilizer ($/ha)	0	25	50	0	30	60
Cost of labor ($/ha)	0	5	10	0	5	10
Total costs that vary ($/ha)	0	30	60	0	35	70
Net benefits ($/ha)	400	486	526	400	481	516

Marginal rates of return	
Case A	Case B
0 kg N to 40 kg N = 287%	0 kg N to 40 kg N = 231%
40 kg N to 80 kg N = 133%	40 kg N to 80 kg N = 100%

If the minimum rate of return does not change, and the price of labor and the field price of maize remain constant, how high can the field price of nitrogen go before even 40 kg N ceases to be a viable recommendation? Such questions can be answered by the formula in Table 9.2. (This is the same formula used in Chapter 6, p. 54, to help in selecting economically viable treatments for experimentation). The change in the total costs that vary will depend on the field price of N (n) and the labor costs of applying 40 kg N/ha ($5). The calculation shows that the nitrogen field price can rise to $1.33/kg before 40 kg N ceases to be a profitable practice for farmers.

Sensitivity analysis can also be used to examine assumptions about opportunity costs, particularly those of labor. At times a partial budget is developed which uses an opportunity cost of labor that is only a rough estimate. If the treatments involve significant changes in labor, an inaccurate estimate of the opportunity cost of labor may lead to erroneous conclusions. Other opportunity costs of labor can be substituted in the partial budget to give an idea of the range over which a given recommendation would be acceptable to farmers.

Table 9.2. Calculation of maximum acceptable field price of nitrogen

ΔY = change in adjusted yield
ΔTCV = change in total costs that vary
M = minimum rate of return (expressed as a decimal fraction)
P = field price of product

$$\Delta Y = \frac{\Delta TCV\ (1 + M)}{P}$$

or

$$\Delta TCV = \frac{P \times \Delta Y}{1 + M}$$

Example

Increase in adjusted yield between
0 kg N and 40 kg N = 580 kg/ha
Cost of labor to apply fertilizer = $5/ha
Minimum rate of return = 100%
Field price of maize = $0.20/kg

To calculate the maximum acceptable field price of nitrogen (n) in order for the application of 40 kg nitrogen to be economic:

$$40\ n + 5 = \frac{0.2 \times 580}{2}$$

$$n = \$1.33/kg$$

Suppose experimental evidence shows that a certain herbicide gives the same average yield as the farmers' hand weeding. A comparison of costs that vary is thus the only economic analysis necessary for making the recommendation. Table 9.3 shows these calculations. In case A, the researchers have assumed an opportunity cost of labor of $1/day. The total costs that vary of using the herbicide are lower than those of hand weeding, and therefore the herbicide should be recommended. But if the opportunity cost of labor is only $0.50/day, then hand weeding is the preferred alternative. (Calculations show that as long as the opportunity cost of labor is above $0.56/day, the herbicide is to be recommended.) This illustrates the necessity of carefully studying the availability and utilization of labor before making recommendations for something like weed control.

The discussion of sensitivity analysis serves as a reminder that farmer recommendations may change as prices change. Agronomic data regarding responses to a factor are valid as long as the biological environment and farming practices do not change. The economic interpretation of that data will depend on changes in prices. There is thus the need to continually review farmer recommendations, based on past agronomic experiments, in the light of present (and future) economic circumstances.

Table 9.3. Sensitivity analysis for weed control experiment

	Case A (Opportunity cost of labor = $1.00/day)		Case B (Opportunity cost of labor = $0.50/day)	
Costs that vary	**Hand weeding**	**Herbicide**	**Hand weeding**	**Herbicide**
Herbicide ($/ha)	0	8	0	8
Sprayer ($/ha)	0	1	0	1
Labor cost ($/ha)	20	4	10	2
Total costs that vary ($/ha)	20	13	10	11

Chapter Ten
Reporting the Results of Economic Analysis

This manual has presented a set of procedures for doing an economic analysis of on-farm agronomic experiments. The careful use of these procedures will help in selecting treatments for further experimentation and for developing farmer recommendations. When researchers report the results of on-farm experiments, a summary of the results of the economic analysis should be included. The following points are a checklist for organizing a report of the economic analysis.

1 Review Objectives of Experiment

Before beginning any analysis, review the objectives of the experiment. Include a review of the previous diagnostic and experimental evidence that was used in planning the experiment and a review of the tentative definition of the recommendation domain. The purpose of each variable in the experiment should also be reviewed. Does it represent a possible alternative to the farmers' practice, or is it meant to provide initial evidence about the importance, interactions or causality of particular production constraints? In other words, do treatments represent possible farmer recommendations, or are they being used to help design further experiments which will lead to such recommendations?

2 Review Experimental Design and Management

Review the design and management of the experiment. The marginal analysis presented in this manual is useful only when applied to on-farm experiments with particular characteristics. The nonexperimental variables must be at levels representative of farmers' practice in the recommendation domain, and one treatment must represent the farmers' practice with respect to the experimental variable(s).

3 Calculate Total Costs That Vary

Identify the variable inputs for each treatment in the experiment. Make sure that all inputs that vary across treatments are included, paying particular attention to changes in labor. Calculate the costs that vary for each treatment, on a per-hectare basis. For purchased inputs, base the costs on realistic field prices that farmers in the recommendation domain must face. For nonpurchased inputs, develop realistic opportunity costs. Sum the total costs that vary for each treatment. (A preliminary calculation of these costs should have been done when the experiment was being planned.)

4 **Calculate Average Yields**

Review the results of the experiment at each location. These may be the results of a single year, or of several years. Decide if all the locations represent a single recommendation domain. Decide if any locations should be eliminated because of errors in experimental management. Report the reasoning behind these decisions. Use statistical analysis to help decide if there are any differences in response among the treatments. Locations with results that were affected by unexplained or unpredictable factors must be included in the statistical analysis.

5 **Decide If a Partial Budget Should Be Presented**

a) If there are no yield differences among treatments, the one with lowest total costs that vary should be chosen for further experimentation or, if there is sufficient evidence, for recommendation.

b) If there are yield differences among treatments, then a partial budget will have to be developed.

6 **Calculate Adjusted Yields**

The first line of the partial budget should show the yields for each treatment averaged over all locations in the recommendation domain. The second line shows adjusted yields based on differences between the experiments and the farmers' fields with respect to trial management, plot size, or time or method of harvest.

7 **Calculate Gross Field Benefits**

Calculate the field price of the crop. Remember, an experiment may involve more than one crop, and/or may involve crop by-products, such as fodder, which are of importance to farmers. The field price of a crop is the price that farmers receive, less all costs of harvesting and marketing that are proportional to the yield. The gross field benefits for each treatment are the adjusted yields times the field price.

8 **Calculate Net Benefits**

List the costs that vary, and the total, for each treatment. Calculate the net benefits for each treatment. The partial budget should contain only yield, cost, and benefit figures. Assumptions about field prices, yield adjustments, etc. should be presented beneath the partial budget as footnotes. Details on experimental treatments should be clearly presented elsewhere in the report, in the discussion of the experiment.

9 Do a Dominance Analysis

Arrange treatments in order of ascending total costs that vary, with corresponding net benefits. Eliminate dominated treatments.

10 Estimate a Minimum Acceptable Rate of Return

Estimate a minimum rate of return for a crop cycle. In most cases the minimum rate of return will probably be between 50% and 100% for a crop cycle.

11 Do a Marginal Analysis

A marginal analysis presents the nondominated treatments on a net benefit curve and calculates the marginal rates of return between pairs of adjacent treatments. Compare the marginal rates of return to the minimum rate of return in order to select acceptable treatments. Present the results of the marginal analysis in the report.

12 Draw Conclusions From the Marginal Analysis

a) If the results of the experiment are being used to help plan further experimentation, then the results of the economic analysis should be discussed in the report in light of the choice of appropriate treatments for experiments in the next cycle.

b) If the economic analysis is being done to develop a recommendation, then the report should contain a discussion of the evidence that has been used to make the recommendation.

13 Before Making a Recommendation, Do a Minimum Returns Analysis

If data from enough locations and years are available, do a minimum returns analysis on all the experimental results to examine the implications of the variability in the results for farmer welfare.

14 Before Making a Recommendation, Do a Sensitivity Analysis

If variability in prices or costs is expected, carry out the relevant sensitivity analysis and include the results in the report.

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References to definitions of terms are printed in boldface type.

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