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FROM AGRONOMIC DATA TO FARMER RECOMMENDATIONS

AN ECONOMICS TRAINING MANUAL

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CENTRO INTERNACIONAL DE MEJORAMIENTO DE MAIZ Y TRIGO

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PREFACE

This manual was prepared by the economics section of CIMMYT for use in its maize and wheat training programs. We hope that other agronomists will find it useful. We authorize and encourage the reproduction of any part of the manual. Comments from users which might improve the manual are solicited.

The idea of a manual was first presented to the CIMMYT Internal Review in 1972 by the economics section. A first version, written by J.R. Anderson, emerged from discussion between Anderson and Don Winkelmann. This version was substantially rewritten and expanded by Richard Perrin and Winkelmann. The second version was reviewed by Edgardo Moscardi while testing it with trainees. Moscardi and Perrin altered the draft and Winkelmann reviewed it. This version, the third, was sent out to agronomists and economists for comment. We're especially grateful to John Dillon, John Lindt, Torrey Lyons, Paul Marko, Matt McMahon, Robert Osler, Willem Stoop, Alejandro Violic, Pat Wall, and Delane Welch for helpful suggestions. Moscardi and Perrin incorporated many of these in this, the fourth version, which Winkelmann again reviewed.

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1 INTRODUCTION

This manual is intended for use by agronomists as they make farm recommendations from agronomic data. It is not necessarily difficult to make recommendations which fit farmers' goals and situations, but is certainly easy to make poor recommendations by ignoring factors which are important to the farmer; some of these factors may not be very evident.

The philosophy of this manual is that it is better to estimate an effect of a factor than to ignore it completely, even though it is sometimes difficult to estimate the effect of some factors on farmer choices. This manual provides lists of these factors and procedures for dealing with them from the farmer's point of view.

Successful farm recommendations

A good farm recommendation could be defined as a choice which the farmer himself would make if he had all the agronomic information available to the agronomist. Such a recommendation will be successful because farmers will adopt it and continue using it.

For successful farm recommendations, the agronomic data upon which your recommendations are based must fit the *farmer's agronomic conditions.* If not, the farmer will not obtain the results you predict. Also, your evaluation of these data must be consistent with the *farmer's goals* and with the factors that influence his ability to attain those goals. Let's look more carefully at these two aspects of farmers' circumstances.

Representative experimental conditions

It is impossible to conduct experiments on each farm to make recommendations tailored to each farm. Instead, you must define a target group of farmers, conduct experiments under conditions representative of their farms, and make recommendations which are applicable to the entire group. We shall call such a group of farmers a *recommendation domain.* Generally, a recommendation domain will consist of farmers within an agro-climatic zone whose farms are similar and who use similar practices.

While there are no clear rules for delineating recommendation domains and agro-climatic zones, you must have these concepts in mind to make successful farm recommendations. In practice the best rule is to seek out a group of farmers for whom you can expect a similar choice of variety, fertilizer level, etc. If the best level of fertilizer for all farmers in a large geographical area is 60 to 80 kg/ha of N, and if the best variety for virtually all farmers is variety Z, then for purposes of this crop the entire area could be considered a recommendation domain, even though there may be considerable variability in soils and climate across the area.

You need several representative experimental sites (not just the accessible ones, the productive ones, or the flat ones) to provide a sample of the results that farmers can expect in a given domain. If you have data from only one year and one site, they are better than none, but they are not very helpful even for making recommendations for the farm on which the experiment was conducted. To make good recommendations, you need to learn the range of agronomic results obtained from farm to farm and from year to year in the recommendation domain.

The cultural practices you use in the experiment must be similar to those which farmers can be expected to use, or the results from the trials may not represent the results which farmers will obtain when they try the recommendation. For example, it is not wise to use weed control techniques that farmers can not adopt or could not profitably adopt. You must take care that the plots are large enough to avoid border effects which would not occur in farmers' fields. Also, if most farmers in an area are dependent on rain for water supply, the results obtained from a well-irrigated fertilizer trial may have little relevance to the results which these farmers can expect to obtain.

These and other problems in the planning of a useful set of agronomic experiments are beyond the scope of this manual. We introduce them here to stress the point that the agronomic conditions under which the trials were conducted must be representative of farmers' agronomic conditions if recommendations based on the trials are to be good ones. But it is not enough that the agronomic data be representative of the farmer's agronomic conditions. The procedures used to derive recommendations from these data must be consistent with the goals of the farmer (who will decide whether to accept the recommendation).

Goals of the farmer

To make recommendations that farmers will use, you must be aware of the human element in farming, as well as the biological element. You must think in terms of farmers' goals and the constraints on attaining those goals.

In this manual, it is assumed that farmers think in terms of *net benefits* as they make farm decisions. For example, a weed-conscious farmer will recognize that he will likely benefit from eliminating weeds from his fields by harvesting more grain. On the other hand, he recognizes that he must give up some cash to buy herbicides and then give up some time and effort to apply them, or he must give up a lot of time and effort for hand weeding. The farmer 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. The net result of this weighing in the farmer's mind we refer to as the *net benefit* from a decision —the value of the benefits gained minus the value of the things given up.

Two factors complicate our understanding of this decision process. The first is that we cannot subtract hours of labor from kilos of grain to obtain a useful estimate of the net benefit which a farmer would perceive. The farmer can perhaps make such a judgement, but we must find a more systematic method of evaluating net benefits if we are to avoid the problem of adding and subtracting hours of labor, kilos of fertilizer, kilos of grain and tons of fodder. The second factor which complicates our understanding of the decision process is that the farmer is uncertain of the results which he will obtain from any given decision. In our weed control example, the farmer knows that in the case of severe drought or early frost, he may get no grain regardless of the amount of weeds in his fields. If this happens, there is no benefit at all from killing weeds. Unfortunately, it is difficult to know just how the farmer sees these risks, and how their existence affects his decision, but we know that they do affect the decision. In general, farmers attempt to protect themselves against risks of loss in benefits, and often avoid choices which subject them to these risks, even though these choices will on the average yield them positive net benefits.

In order to avoid the problem of subtracting hours of labor from kilos of grain, we estimate the value to the farmer of a kilo of grain and an hour of labor in terms of the common denominator, money. This gives us an estimate of net benefit measured also in terms of money. This does not necessarily imply that the farmer spends money for the labor, nor that he receives money for the grain. Neither does it imply that we think that farmers are concerned only with money. It is simply a device which we use to represent the process which we know goes on in the farmer's mind, the process of weighing the things gained and the things lost.

If our weed-conscious farmer is quite commercialized, that is, if he is contemplating hiring the labor, purchasing the herbicide, and selling the extra grain, then we can attach anticipated market prices to labor, herbicides and grain, and in this way represent quite accurately the net benefits which the farmer foresees. On the other hand, if he is a subsistence farmer we have to employ the concept of *opportunity cost* to represent the values he places on labor and grain, since there would be no money prices given up or received. *Opportunity cost* is the value of any resource in its best alternative use. Let's consider the opportunity cost of the farmer's time. If he has a job off the farm which he has to give up temporarily to weed his field, then we say that the opportunity cost of his time in weeding the field is the wage which he would have been earning if he had stayed in his job instead.

Suppose, however, that the best alternative use of his time is working on his tobacco, and that the day's work on tobacco will increase the value of the tobacco harvest by $5. (The $ symbol in this manual does not represent any particular national currency. Also, weights are in metric units). In this case, the opportunity cost of his time in weeding maize is $5 per day, since that is what he gives up by weeding the maize instead of tending the tobacco. Suppose the farmer would merely sit in the shade if he were not to weed his maize? Is the opportunity cost of his time zero? This is not very likely, since most people place some value on being able to sit in the shade rather than to work in the sun. But it is difficult to guess the value which a farmer places on leisure, if that is the highest-valued alternative use of his time.

We have suggested here the two main problems in evaluating agronomic alternatives from the point of view of net benefits to the farmer. The first is estimating the relative weights which farmers place on various kinds of goods, and we introduced the concepts of market prices and opportunity costs as ways to deal with this problem. The second problem is estimating the effect on farmers' decisions of uncertainty about net benefits. Much of this manual gives procedures which can be used to estimate prices, opportunity costs, and the effect of risk as they are viewed by farmers.

One further point is in order with respect to farmers. The conditions under which farmers live and work are diverse in almost every respect imaginable. They have different amounts of land and, to an extent, different kinds of land even within an agro-climatic zone; they have different degrees of wealth, different attitudes toward change, different attitudes toward risk, different marketing opportunities, and so on. Many of these differences influence the farmer's response to recommendations. Unfortunately, it is impractical to attempt to make a separate recommendation for each farmer. Instead, you must offer recommendations that will be approximately correct for large groups of farmers in recommendation domains.

The relationship between statistical and economic analysis of experiments

To this point we have not mentioned statistical analysis. Most agronomists are familiar with the techniques available to determine whether or not the mean yields from two treatments in an experiment are significantly different from one another. Some persons say that if treatment means are not significantly different, then there is no need for an economic analysis. This is not necessarily so, however. For one thing, most statistical tests are geared to the 0.05 or 0.01 levels of significance. But farmers may be willing to accept evidence that is much less persuasive than this. For instance of variety A yields 3 tons in an experiment, while variety B yields 4 tons, farmers may be quite happy to choose variety B even though this difference is statistically significant at, say only the 0.10 level.

Furthermore, it is quite possible that two treatment means are not significantly different at any of five trial sites, but the treatment means *are* different at the 0.01 level of significance when the data are pooled. Because of these considerations, we suggest that *both* statistical and economic analyses be conducted. If only one experiment is available, little can be said of the desirability of the treatment for farmers in the area, unless the results are overwhelming. When several experiments are available (from different sites or years or both), a statistical analysis of the pooled data should be conducted. The analysis of variance should include treatments, sites, and site-by-treatment interaction as sources of variation. If the treatment means are not significantly different, but an economic analysis shows that one treatment is a better recommendation than others, then a more careful analysis of the recommendation, using the procedures of Chapter 4 and 5 of this manual, is in order. In all other cases, the agronomist should be guided by the economic analysis in making his recommendations, for if he has done it well, his recommendation will indeed be in the best interest of the farmer.

This is not to say that statistical analyses are not useful. They are. However, their greatest value is not in deriving recommendations, but in determining what is happening, biologically, in the experiments. For example, only with statistical analyses can the agronomist determine with confidence whether there is an interaction between nitrogen response and phosphate level, or whether the response to nitrogen varies significantly from location to location. This type of information may be very valuable in planning further trials, and to some extent in interpreting the results of the trials already conducted. But statistical analyses are not necessary in deriving recommendations.

Aims of the manual

The goal of this is to show you how the elements described in the previous sections interact in the art of making recommendations. By use of the manual you will be able to:

1. Identify the benefits associated with treatment alternatives, and place values on them which match farmers' goals.
2. Identify which inputs change from treatment to treatment and place values on them which match farmers' goals.
3. Identify sources of variability which will make the farmer uncertain about the net benefits which he will get from each treatment.
4. Derive recommendations from cost, benefit and variability data, which are consistent with the farmer's desire to increase average income, with the farmer's desire to avoid risks, and with the scarcity of investment capital which is typical of most farm situations.

Our approach is deliberately non-mathematical and only a few concepts and special terms from economics are used. This is because we believe that such knowledge is not necessary for deriving successful farm recommendations.

2 PARTIAL BUDGET ANALYSIS OF EXPERIMENTS

We have stated that farmers are interested in net benefits and in protecting themselves against risk. We have also stated that if you want to make good recommendations, you must keep these goals in mind and evaluate alternative technologies from the farmer's point of view. Partial budgeting is a method of organizing experimental data and other information about the costs and benefits of various treatments. In this chapter we introduce the partial budget concepts. In later chapters we discuss in more detail some of the problems involved in estimating costs and benefits. In Chapter 4 we describe procedures for deriving recommendations from partial budget and risk information.

Basic concepts

The purpose of partial budgeting is to organize information in such a way as to help make a particular management decision. The types of decisions with which agronomists will usually be concerned are the choice of fertilizer level, the choice of variety, the choice of seeding data and rate, and so on, or perhaps the choice among alternative packages of such practices. Some of these are "yes or no" decisions and others are "how much" decisions, but all of them may be budgeted in the manner to be described.

To introduce these concepts, let's consider once again the case of the weed-conscious farmer. He has perhaps seen some experimental results across the fence, and knows that for the last two seasons, the plots without herbicide yielded an average of 2 tons per hectare and the herbicide plots averaged 2.5 tons. His own yields averaged about 2 tons, also, and he thinks he would realize about the same yield increase from herbicides on his own farm.

We don't know the exact sequence of steps the farmer would use to evaluate this choice, but in some fashion he weighs the benefits he would receive from each alternative with the costs which he must give up for each alternative. We can simulate the same process, and record the results as we go in Table 1. We will first look at benefits, then costs, and then net benefits.

The first concept used is:

> *Net yield*—the measured yield per hectare in the field, minus harvest losses and storage losses where appropriate.

Our farmer is satisfied that the yields obtained in the trials are the same as he would obtain, and since he sells his grain immediately after harvest, he need not consider storage losses. We can therefore record 2.0 and 2.5 in line one of Table 1 as a measure of the yields the farmer expects to receive. The next issue is the value which the farmer places on the yield, which we designate as:

> *Field price* (of output)—the value to the farmer of an additional unit of production in the field, *prior* to harvest. Farmers who sell all or part of their grain will be concerned with money field price while those who consume the entire crop will be concerned with opportunity field price. *Money field price* is the market price of the product minus harvest, storage, transportation and marketing costs, and quality discounts. *Opportunity field price* is the money price which the farm family would have to pay to acquire an additional unit of the product for consumption.

Our farmer always sells his grain to a trucker who comes by, and he expects to receive $1100 per ton. However, he also knows that it costs him about $100 per ton to harvest and shell the crop, so that the field price is $1000 per ton. Multiplying net yield by field price, we obtain an estimate of the total value or:

> *Gross field benefit*—net yield times field price for all products from the crop. In general, this may include money benefits or opportunity benefits, or both.

In considering the costs associated with this decision, the farmer need only be concerned with those costs which are affected by the decision or *variable costs*.

TABLE 1.
Example of a per hectare partial budget

	Present practice	Use of herbicides
Benefits		
farmer's yield (net yield)	2.0 tons	2.5 tons
farmer's value (field price)	$1000	$1000
total benefit (gross field benefit)	$2000	$2500
Variable costs		
herbicide:		
amount	–	2 liters
value (money field price)	–	X$30
total (field cost of herbicide)	–	$60
labor for application:		
amount	–	2 days
value (opportunity field price)	–	X$10
total (field cost of application labor)	–	$20
labor for hand weeding:		
amount	10 days	3 days
value (opportunity field price)	X$10	X$10
total (field cost of weeding labor)	$100	$30
total variable costs	$100	$110
Net benefit	$1900	$2390

Note that the $ symbol in this manual represents no particular national currency. Weights are in metric units.

Costs which are not affected by the decision (such as plowing and planting costs in this case) are known as *fixed costs.* Since these costs will be incurred regardless of which decision is made, they cannot affect the choice and can be ignored for the purpose of this decision. The term "partial budgeting" is a reminder that not all production costs, and perhaps not all benefits are included in the budget—only those which are affected by the decision being considered.

If the farmer is to make a good decision, he must identify *all* the inputs which would change if he decides to apply the herbicide. In his case this includes only the herbicide and the labor required to apply it, plus the reduction in hand weeding labor (he already has a hand sprayer which can be used). The amount of herbicide required is two liters per hectare, and based on the amount of time it takes him to apply insecticide, he estimates that application will take two days of his time per hectare. The value of the herbicide can be simply expressed in terms of money, because it is money, $30 per liter, which he must give up to acquire it. This value concept we refer to as:

> *Field price* (of an input)—the total value which must be given up to bring an extra unit of input into the field. *Money field price* refers to money values such as purchase price or other direct expenses. *Opportunity field price* refers to the non-money value of inputs which must be given up. The opportunity price is the value of the input in its best alternative use. For farm family labor, the opportunity field price may be the wage which could be earned in off-farm employment, or the value of the time if spent on another farm enterprise, or the value which the worker places on leisure.
>
> *Field cost* (of an input)—is the field price of an input multiplied by the quantity of that input which varies with the decision. It may be expressed as money field cost or opportunity field cost, or perhaps both, depending on the input.

Thus for our farmer, the field cost of the herbicide is $60 per hectare. Regarding his labor, the farmer might perhaps note to himself that he would not do that kind of work for anyone else for less than $10 per day (otherwise he would rather sit in the shade). This means that he evaluates the opportunity cost of his time at

TABLE 2.
Maize yields (tons/ha of 14 percent moisture grain) by fertilizer treatment, 8 trials.

		Fertilizer treatment (kg/ha)												
	N:	0	50	100	150	0	50	100	150	0	50	100	150	
Trial	P_2O_5:	0	0	0	0	25	25	25	25	50	50	50	50	Avg.
1		0.40	1.24	3.63	3.76	0.79	2.58	4.23	4.72	1.67	2.51	3.28	3.66	2.71
2		1.53	2.60	5.14	5.32	1.67	3.79	5.10	6.83	1.41	4.13	5.89	6.27	4.14
3		4.15	4.86	4.80	4.87	4.44	5.00	4.97	5.28	5.12	5.66	6.36	6.62	5.18
4		2.42	3.82	5.23	4.48	2.36	4.54	6.26	7.17	1.61	4.41	5.38	6.58	4.52
5		1.64	1.92	2.08	2.19	2.04	3.21	3.12	2.93	1.44	3.44	3.32	3.62	2.68
6		1.61	2.94	4.14	4.34	1.81	3.92	3.61	3.81	1.18	3.89	5.38	4.92	3.46
7		4.74	5.41	4.29	4.92	4.91	5.22	5.38	5.14	5.10	4.88	4.54	5.28	4.98
8		1.21	2.33	1.97	2.23	1.53	2.78	2.49	2.80	1.37	3.51	3.75	4.35	2.53
Avg.		2.21	3.14	3.91	4.01	2.44	3.88	4.40	4.84	2.36	4.06	4.74	5.16	3.76

$10 per day, and therefore, the field cost of the labor for the herbicide treatment is $20 per hectare. He also observed that when herbicides were used, the time spent on hand weeding was reduced from 10 days per hectare to just 3. The cost of hand weeding was thus reduced from $100 to $30. The total of these values for each treatment is:

Total field cost or *Variable cost*—the sum of field costs for all inputs which are affected by the choice. In partial budgeting we refer only to those inputs which are affected by the decision, so that total field cost in fact refers to variable costs, i.e. those costs which vary with the choice. Variable cost can consist of either money costs or opportunity costs or both.

The total variable cost of the herbicide alternative is $110 per hectare. The total variable cost of the present practice is $100 per hectare. Subtracting these from the benefits received gives:

Net benefits—total gross field benefit minus total variable costs.

In the net benefit figure we want to represent the value which the farmer places on additional production minus the value he places on those things which he must give up to attain the extra production. In the case of the weed-conscious farmer, the net benefits from the herbicide alternative are $2390 per hectare, versus $1900 for his current practice. Remember that net benefits are not the same thing as profit, because we have left many costs out of the budget because they are irrelevant to this particular decision.

While it may appear that this farmer will choose to use herbicides, this is not clear since there is uncertainty surrounding his yields, and since money may be quite scarce. In later chapters we will deal with these matters. We now proceed to apply the concepts just described to make partial budget analyses of some fertilizer experiments.

Partial budget analysis of fertilizer experiments—an example

Table 2 presents the results of 8 maize fertilizer trials conducted in a rainfed recommendation domain. The purpose of these trials was to derive recommended fertilizer levels for farmers of the domain. Here we have presented the average yields obtained from three replications of the treatments. (We have averaged the replicates because these averages are the best estimate of the yield which would be obtained on the entire field in which the experiment was located).

Although it is obvious that there is considerable variability in yields and yield response from trial to trial, we shall postpone a discussion of the implications of the variability for farmers' decisions. For now, we'll consider only the *average yields* obtained for each treatment over the eight trials, and we will treat the data just as we would a single experiment. The yield curves in Figure 1 provide a graphic picture of the resulting average yield response.

Table 3 provides a convenient format for organizing the partial budget information. We show the alternative choices of fertilizer level as column headings, then the average yield for each, followed by net yield after adjusting down-ward 10%

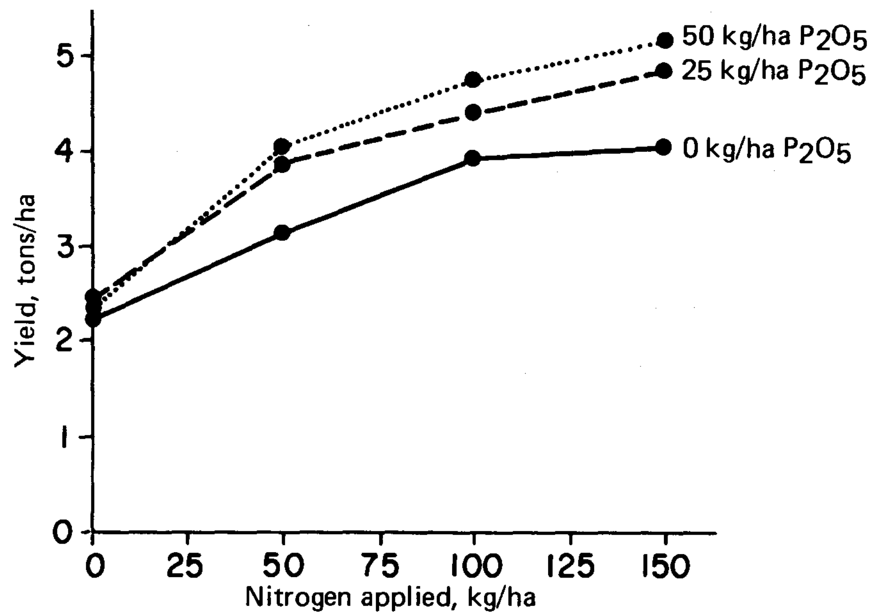

FIG. 1. **Average yield response to nitrogen.**

TABLE 3.
Partial budget of averaged data from fertilizer trials (per hectare basis)

Item		Fertilizer treatment (kg/ha)											
	N:	0	50	100	150	0	50	100	150	0	50	100	150
	P_2O_5:	0	0	0	0	25	25	25	25	50	50	50	50
(1) Average yield (ton/ha)		2.21	3.14	3.91	4.01	2.44	3.88	4.40	4.84	2.36	4.05	4.74	5.16
(2) Net yield (ton/ha)		1.99	2.83	3.52	3.61	2.20	3.49	3.96	4.36	2.12	3.64	4.27	4.64
(3) Gross field benefit ($/ha at $1000/ton)		1990	2830	3520	3610	2200	3490	3960	4360	2120	3640	4270	4640
Variable money costs:													
(4) Nitrogen ($8/kg N)		0	400	800	1200	0	400	800	1200	0	400	800	1200
(5) Phosphate ($10/kg P_2O_5)		0	0	0	0	250	250	250	250	500	500	500	500
(6) Variable money costs ($/ha)		0	400	800	1200	250	650	1050	1450	500	900	1300	1700
Variable opportunity costs:													
(7) Number of applications		0	1	2	2	1	1	2	2	1	1	2	2
(8) Cost per application (2 days at $25)		50	50	50	50	50	50	50	50	50	50	50	50
(9) Opportunity, cost ($/ha)		0	50	100	100	50	50	100	100	50	50	100	100
(10) Total variable costs ($/ha)		0	450	900	1300	300	700	1150	1550	550	950	1400	1800
(11) Net benefit ($/ha)		1990	2380	2620	2310	1900	2790	2810	2810	1570	2690	2870	2840

for assumed harvest and storage losses. The market price for maize in this area is \$1200 per ton, but after making corrections for harvest costs, transportation costs, and shrinkage, (see Chapter 7), we determine that the field price of additional yield is \$1000 per ton. Resulting *gross field benefit* is shown in line 3. Of course, the largest gross field benefit is obtained from the treatment with the highest yields, which in this case is also the highest level of fertilizer.

In considering the costs associated with each choice, we must be familiar with the cultural practices used by farmers if we are to determine which inputs are to be affected by the choice of fertilizer level. In this particular area, horse and plow technology is the dominant tillage method, and fertilizer is applied by hand. Therefore, the only inputs affected by this decision are the amounts of fertilizer and the labor required for application (the value of harvest labor has been deducted from field price—see Chapter 7). The price of nitrogen at the store is \$5 per kg of N and the price of phosphorus is \$7 per kg of P_2O_5 but after making adjustments for transportation (see Chapter 6), we determined the field price of N and P_2O_5 to be \$8 and \$10 per kilo, respectively.

In these experiments, nitrogen levels in excess of 50 kg were applied in two doses, and we estimate that two man days are required per hectare for each application. After visiting with farmers in the area we calculated that \$25 per man-day is a reasonable estimate of the average value of farmers' time, although we recognize that for some farmers in the area the amount should be closer to zero, while for others it should be more (see Chapter 6). In lines 7, 8 and 9 of Table 3, we have calculated the cost of labor for each treatment, and in line 10 we show the total of all variable costs associated with each treatment.

We have now completed the task of assessing the field benefits and variable costs associated with each of the alternative choices of fertilizer level. But the task of making a choice among them, from the farmers' point of view, is far from complete. Next we calculate *net benefit*, gross benefit minus variable costs, and record these amounts in line 11.

The listing of net benefit for each treatment, as shown in line 11 of Table 3, completes the *partial budget analysis* of the *average* yields from these experiments. One might be tempted at this point to choose treatment 100-50 as the fertilizer recommendation for this area. But this would be a poor choice, because we have so far ignored some crucial aspects of farmer conditions, namely capital scarcity, yield uncertainty and risk aversion. In the following three chapters, we consider these complicating factors and their effects on our recommendations.

3 CAPITAL SCARCITY AND THE COST OF INVESTMENT CAPITAL

In the previous chapter we were careful to include the costs of all inputs which change with a given production decision. These costs included the cash costs of purchased inputs but we did not include the cost of using investment capital. By *investment capital* we mean the value of inputs (purchased or owned) which are allocated to an enterprise with the expectation of a return at a later point in time. By the *cost of investment capital* we mean the benefits given up by the farmer due to having the investment capital tied up in the enterprise for a period of time. The cost of using investment capital (or, more simply, the *cost of capital*) may be a direct cost, as in the case of a person who borrows money to buy fertilizer and must pay an interest charge. It may also be an opportunity cost, the earnings which are given up by not using money, or an input already owned, in its best alternative use.

We suggested in the last chapter that the cost of capital may be very important to farmers' decisions. This is because the cost of investment capital for agricultural use is generally quite high, particularly in less developed countries. Interest charges by local money lenders often are in the vicinity of 100 % per year. This can effectively double the price of inputs purchased with such loans. Even in the case of a low cost government agricultural loan program, service charges and insurance fees can result in interest rates which are much higher than the interest rate announced by the loan agency. Furthermore, most small farmers have very little capital of their own, and they want to invest it in only those inputs which yield high returns. This means that the opportunity cost of capital, as well as the direct cost, is quite high for these farmers.

One way of incorporating the cost of investment capital into the budgeting procedure is to increase the cost of each input by an appropriate amount. Due to the critical importance of capital availability, however, we have rejected this approach in favor of another alternative. We charge no cost to capital in the budgeting process, but instead attribute net benefits as a return to investment capital. We can then compare this rate of return to capital with the rate which farm investment capital can realize in alternative activities. If the calculated rate of return for a production alternative is above the opportunity rate of return, i.e. its return in other alternatives, then we can judge the first to be desirable from the point of view of the farmer. This assumes that all alternatives are equally risky. This issue is considered further below.

This brings us to the difficult question of the minimum rate of return which will be acceptable to farmers. Let us consider two separate farmers to see why this is a difficult question and what we can do about it.

First let's consider Farmer A who can borrow money for production through his local credit cooperative. If he borrows money for a new production alternative, the cost of investment capital will be a direct cost, for he must pay interest at the rate of 12 % per year on the loan. Since he will be borrowing for only six months, the cost of the loan is 6 % of the amount of the loan. But he also must pay a service charge which amounts to 5 % of the amount of the loan. Thus the cost to him for a six-month loan is 11 % of the amount of the loan.

Now, if a production alternative promises an average return of just 11 %, then Farmer A will not want to adopt the alternative, because after paying the direct cost of capital he will have exactly zero gain in net benefits. For example, suppose this farmer can spend $100 on fertilizer and he expects an average increase in net benefits of $11. If he borrows the $100 from his co-op, he will have to pay $11 in interest and service charges in addition to his other costs, and his increase in net benefits will be reduced to nothing.

So we can safely conclude that Farmer A will not choose a production alternative unless the rate of return on capital is more than 11 %, the direct cost of his investment capital. But how much more? This will depend in part on the risk of the investment, the other important factor which we have not yet included in our discussion. Farmer A would be well aware that the net benefits as calculated in our partial budget analysis are based on average yield results. In some years, the net benefits from the investment may be very low. We will postpone to later a full discussion of how to evaluate this type of risk, but it should be clear that farmers, poor farmers particularly, do not want to place themselves in the position of losing what little capital they have.

Because of this aversion to risk, Farmer A may not want to accept a new production alternative unless the *average* returns (over time) to his scarce capital are considerably in excess of the direct cost of his capital. As a rule of thumb, we believe that most farmers of the less developed world will not invest in alternatives unless the average rate of return is at least 20 percent points per production cycle above the direct cost of capital. We do not claim any great accuracy for this estimate, but we are convinced it is better to make an estimate of this *risk premium* than to ignore it completely. For investment alternatives which are not very risky, we know that farmers would be willing to accept a smaller risk premium. For very risky alternatives, we are sure that the required risk premium can be much higher. Therefore, unless we had more information about Farmer A or about the riskiness of the alternatives he is considering, we would estimate that he would not adopt an alternative unless the rate of return for the average yield with that alternative is at least 31 %:

Farmer A, Cost of Capital

amount borrowed for fertilizer	$ 100
interest for 6 months (12 %/yr)	$ 6
service charge	$ 5
total amount of loan	$ 111
direct cost of capital (11/100)	11 %
risk premium	20 %
Farmer A cost of capital	31 %

Now let's consider Farmer B who will not be borrowing, but instead will be using his own funds to invest in alternative technologies. The opportunity cost of using his investment capital in a particular alternative is the rate of return which he would receive from his capital in its best alternative use plus the risk premium appropriate for that alternative use. We think that in general, a rough estimate of this opportunity cost is about 40% per production cycle. Again, we claim no great accuracy for this rule of thumb, but it is consistent with behavior that we have observed among farmers of both the developed and less developed agricultural areas, and again it is better to make an estimate, than to ignore the matter completely. Some people place the figure at 50% or even at 100%, and these levels will be appropriate in some cases, particularly for subsistence farmers in areas with high yield variability.

To summarize, we have argued that the cost of using investment capital is very high for most farmers of the world. While the cost of capital will vary from farm to farm, as a general rule we think that a technology should not be recommended unless the rate of return to the additional investment is at least 40% for the cropping season. When you have specific information regarding either the direct cost of capital, the opportunity cost of capital, or the riskiness of the alternatives, you may wish to use a different rate as a criterion. In Chapter 5 we will discuss further the measurement and implications of the riskiness of alternatives. In Chapter 6 we present a more thorough discussion of how to estimate the cost of capital.

4 THE USE OF NET BENEFIT CURVES AND MARGINAL ANALYSIS TO DERIVE RECOMMENDATIONS

In Chapter 2, we explained how to evaluate alternatives from the point of view of average net benefits to the farmer. We suggested that farmers will not necessarily choose the alternative with the highest average net benefits because of the scarcity of capital in agriculture and because of the risks that may be associated with the average net benefits from a given production alternative. In this chapter we bring these concepts together and show how to derive recommendations which are consistent with both capital scarcity and risks.

The net benefit curve

A very revealing device for summarizing the results of a partial budget is the net benefit curve. This curve shows the relationship between the variable costs of the alternatives and the average net benefits from the alternatives. We can best describe this by plotting the net benefit curve from the fertilizer experiments described earlier.

In Figure 2 we have plotted each of the fertilizer treatments from Table 3 according to the net benefit from the treatment and the variable costs of the treatment. Beside each of the 12 points plotted, we show in parentheses the nitrogen level and phosphate level. It is apparent from the points plotted that some of the fertilizer alternatives would not be chosen by any thoughtful farmer. For example, the phosphate-only treatments (0-25 and 0-50) have net benefits lower than the check treatment (0–0), yet require variable costs of $300 and $500 per hectare. No farmer is likely to choose these alternatives when he could receive a higher net benefit with zero variable cost. The same is true of treatments 100-0 and 50-50. The average returns from these two treatments are lower than the return from 50-25, and 50-25 has a lower variable cost. Fertilizer levels such as 0-25, 0-50, 100-0, and 50-50, we refer to as *dominated alternatives*, because for each of these there is another alternative with a higher net benefit and lower variable cost. In normal circumstances, we would never expect a farmer to choose one of these dominated alternatives.

The choices which are not dominated we have connected together with a solid line. This solid line is the *net benefit curve.* Two aspects of this net benefit curve are noteworthy. The first is that the curve rises steeply at first, then rises more slowly to a peak and begins to fall. The curve shows diminishing returns to fertilizer expenditures. This is important because it demonstrates clearly that we can reduce costs considerably from the point of maximum net benefits with little reduction in those benefits. Said another way, this demonstrates that the returns from expenditures on initial amounts of fertilizer are much greater than the returns to additional expenditures for larger amounts of fertilizer. Experience shows that this is often the case for fertilizer.

The second interesting aspect of the net benefit curve is its shape between the 0-0 point and the 50-25 point. The two solid line segments drop below the broken line connecting these two points, whereas we would normally expect a fertilizer response curve or net benefit curve to fall above the dotted line. In other words, we normally expect these curves to begin steeply, with the slope gradually falling as expenditure on inputs increases. The irregularity of the curve we observe here may be due to an interaction between nitrogen and phosphate at low fertilizer levels, or it may be due to chance (even though these are the combined results of many trials).

Whatever the cause of this unusual shape, the implications for further experimentation are clear. There is surely no reason to conduct any further trials with fertilizer costs in excess of $650, since it seems clear that net benefits increase little if any above that point. On the other hand, intuition suggests that there *may* be some fertilizer treatments which would result in points above the broken line between 0-0 and 50-25. Since it appears there might be an important interaction

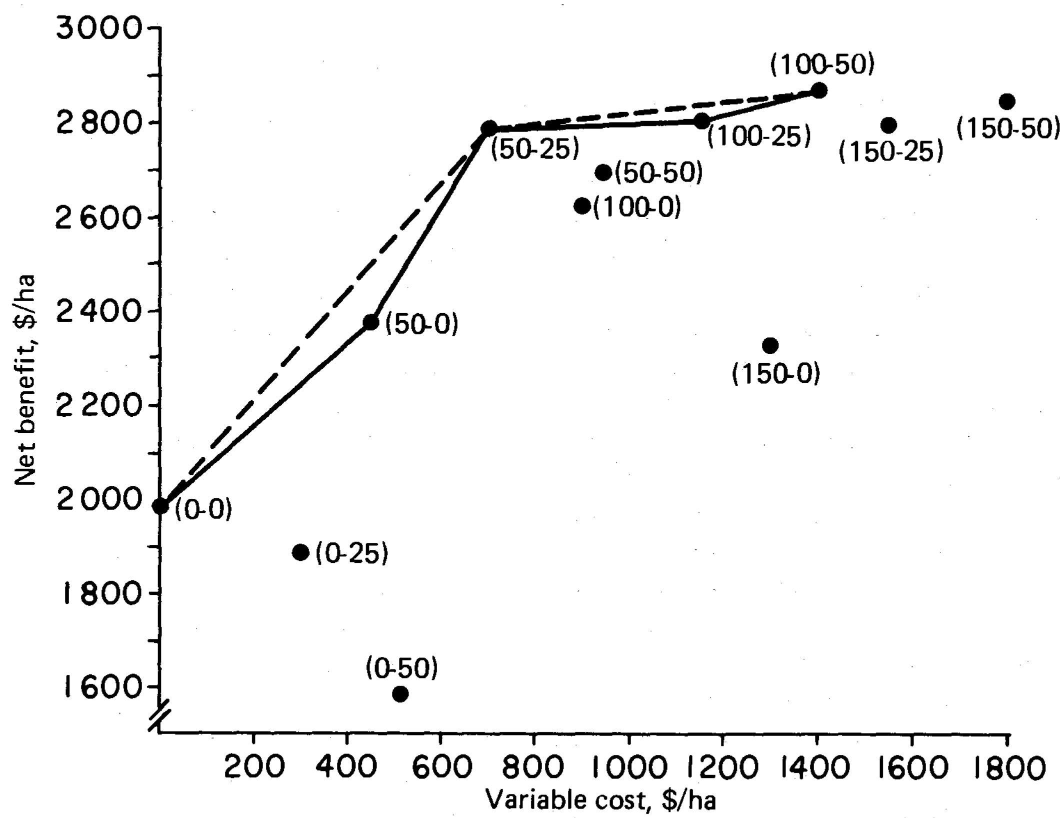

FIG. 2. **Net benefit curve for the fertilizer trials.** Numbers in parentheses represent kg/ha of N and P_2O_5 respectively.

between N and P_2O_5, it would seem wise to experiment further with treatments costing between \$300 and \$500, such as 40-15, 30-15, 25-25, etc. These treatments may result in the discovery of points above the broken line. If so, these are treatments which further reduce farmer costs without appreciably reducing net benefits.

Marginal analysis of net benefits

We have observed that the net benefit curve for the fertilizer data rises quite sharply at first and then more slowly to a maximum. We have found this to be true of most net benefit curves. It implies that the rate of return to the investment in the first units of fertilizer is much higher than the return to the additional units required to achieve the maximum net benefit. Look at figure 2. You may be tempted to conclude that not many farmers would want to invest more than \$700 per hectare for fertilizer (for 50 kg of N and 25 kg of P_2O_5). This is because the first \$700 provides an increase in net benefit of about \$800, while the second \$700 provides an increase in net benefit of only \$80. To explore this observation in more detail, we need to introduce the concept of marginal analysis.

The purpose of marginal analysis is to reveal just how the net benefits from an investment increase as the amount invested increases. *Marginal net benefit* is the increase in net benefit which can be obtained from a given *increment* of investment. In the fertilizer example, the marginal net benefit from \$450 invested in 50 kg of N (the smallest non-dominated investment included) is \$390. The next possible increment of expenditure is to spend an additional \$250 for 25 kg of P_2O_5 (taking us to the 50-25 treatment). The marginal net benefit from this increment in expenditure is \$410. *The marginal rate of return* to a given increment in expenditure is the marginal net benefit divided by the marginal cost (increment in expenditure). The marginal rates of return of the first two increments in fertilizer investment capital are determined as:

$$\frac{2380 - 1990 = \text{marginal net benefit}}{450 - 0 = 450 = \text{marginal cost}} = 0.87 = 87\%$$

The marginal rate of return of the second increment is:

$$\frac{2790 - 2380 = 410 = \text{marginal net benefit}}{700 - 450 = 250 = \text{marginal cost}} = 1.64 = 164\%$$

It is clear from the shape of the curve that the marginal rate of return on expenditures above \$700 per hectare is quite small. We verify this with later calculations.

It is possible to make a marginal analysis of the fertilizer data without reference to the net benefit curve itself. The first step is to list all the alternatives from the highest to the lowest net benefit. We have taken the information from Table 3 to make such a listing as shown in Table 4. Next, proceed from top to bottom down the list to identify and eliminate the dominated alternatives. For instance, the second-highest net benefit is obtained from treatment 150-50. But the variable cost for this treatment is higher than the variable cost for the treatment above it. Thus it is dominated, and can be eliminated (as indicated by italics in Table 4). Moving down the list, we eliminate any treatment which has a variable cost equal to or higher than the treatment above it. We are left with five non-dominated alternatives, which are of course the same as those represented by the solid net benefit curve of figure 2.

TABLE 4.
Dominance analysis of fertilizer response data.

Net benefit ($/ha)	Fertilizer treatment (kg/ha) N	P_2O_5	Variable cost ($/ha)
2870	100	50	1400
2840	*150*	*50*	*1800*
2810	100	25	1150
2810	*150*	*25*	*1550*
2790	50	25	700
2690	*50*	*50*	*950*
2620	*100*	*0*	*900*
2380	50	0	450
2310	*150*	*0*	*1300*
1990	0	0	0

To proceed with the marginal analysis, we take these five alternatives from Table 4 and place them in Table 5. Here we calculate and present the marginal cost, the marginal net benefit and the marginal rate of return for each increment of expenditure. Beginning at the bottom, the marginal cost of the first increment is $450, the marginal net benefit is $2380 – $1990 = $390, and the marginal rate of return is thus 390/450 = 87%. The marginal cost of the second increment is $700 – $450 = 250, the marginal benefit is $2790 – $2380 = $410, and the marginal rate of return is 410/250 = 164%. The next increment in expenditure, on an additional 50 kg of N for $450, returns only 4%, but the following increment of another 25 kg of P_2O_5 returns 24%.

The question remains – what level of expenditure would the average farmer choose if he had all this information? We have previously stated that as a general rule, farmers will not want to make an investment unless the average rate of return is at least 40% per crop season. Thus in general, farmers would be willing to invest both the first $450 for 50-0 and the additional $250 for 25 kg of P_2O_5, for both increments have rates of return well over 40%. But farmers in general would *not* want to invest more. Clearly 4% is not a very attractive rate of return, although 24% might be for some farmers. But if a farmer were to go from 50-25 to 100-50 (two increments at once), the rate of return would be 80/700 = 11.4%. This is not a very good rate of return, and it is doubtful that very many farmers would be willing to make such an investment. Thus using this marginal analysis approach, we can feel quite comfortable in recommending a fertilizer rate of 50 kg N/ha and 25 kg P_2O_5/ha.

But there are other questions which should be asked before an agronomist can afford to be satisfied with this recommendation. The first question is whether 40% is the correct figure for the cost of capital. Suppose, for example, that farmers in the recommendation domain have access to government credit programs with an interest charge of 8% for the crop season. Recall that the cost of capital in this case can be approximated by adding a 20% risk premium to the direct cost of the capital. In this fertilizer example, this change would not result in an increase in the fertilizer recommendation, because the next increment in capital does not return more than 28%. But it is quite possible that a reduction in the cost of capital (interest charges plus risk premium or capital's opportunity cost) will increase the recommended level of fertilizer.

The second is the question of how risky this alternative is relative to no fertilizer at all or to, say, treatment 100-50. If these investment alternatives are not very risky, it is possible that farmers would be willing to accept a rate of return lower than 40%. Procedures for addressing this question will be considered in the following chapter.

The partial budget analysis and then the marginal analysis of these fertilizer data have involved considerable effort (though not much compared to the effort required to carry out the experiments). It is useful to review what we have gained by it. Had we based recommendations simply on maximum yields, we would have recommended 150-50, which would have subjected the farmer to very large costs ($1700) compared with the $700 expenditure which marginal analysis shows to be best. Had we based recommendations on maximum net benefit per hectare, we would have recommended 100-50 with an expenditure of $1400. But marginal analysis has shown us that the returns to the last $700 of this amount are much too low for most farmers. By reducing expenditures from $1400 to $700 per hectare, net benefit is reduced only $80. Even though yields for the recommended level are more than 1 ton per hectare less than the maximum attainable, this analysis has shown that it will not be in the interests of most farmers to approach this maximum.

Before leaving this topic, we wish to point out a mistake which we would probably have committed had we *not* used marginal analysis. We determined that the rate of return to the investment capital required to go from 50-25 to 100-50 was 11%. But what is the *average* rate of return to the entire $1400 (700 + 700) required for the 100-50 treatment? The net benefit is $880 higher than for the no fertilizer treatment, so the average rate of return is $880/$1400 = 63% By our criterion of 40%, this seems to be enough to warrant recommending it. But what we discovered in marginal analysis was that, while the farmer would earn 63% on this investment, he would in fact be earning 114% on the first $700 and only 11% on the second $700.

Clearly, we would have been misleading both ourselves and the farmer if we had recommended that he spend $1400 on 100-50 on the basis that the (average) rate of return, 63%, is very good. We are far more correct to recognize these marginal changes in rates of return and to make recommendations accordingly.

TABLE 5.
Marginal analysis of the undominated fertilizer response data (per ha).

				Change from next highest benefit		
Net benefit (1)	Fertilizer treatment N	P_2O_5	Variable cost (2)	Marginal increase in net benefit (3)	Marginal increase in variable cost (4)	Marginal rate of return (5)
(a) $2870	100	50	$1400	$ 60	$250	24%
(b) 2810	100	25	1150	20	450	4
(c) 2790	50	25	700	410	250	164
(d) 2380	50	0	450	390	450	87
(e) 1990	0	0	0	–	–	–

Examples of calculations: the amount in column 4, line a (4a) is the amount in column 2 line a (2a) minus the amount in column 2 line b (2b). Also, 3a = 1a - 2b, and 5a = 3a/4a.

5 VARIABILITY IN NET BENEFITS AND IMPLICATIONS FOR RECOMMENDATIONS

We have previously stated that farmers want to avoid the possibility of occasional high losses as they seek higher average net benefits. This is especially true of farmers near the subsistence level. For them an occasional net loss can have very serious consequences.

This view of the farmer has important implications for recommendations. Because risk aversion is important to the farmer, variability in yields and net benefits must be important to the agronomist. You cannot be content with recommendations which promise to increase *average* net benefits. You must recognize that the best choice will change from year to year and from field to field, and you must somehow estimate the risks which this variability causes. On the other hand, this variability means that you need not try to be very *precise* in deriving the recommendation from any one experiment.

We're *not* saying that care and attention to those trials which are made is unimportant. We're *not* saying that care in identifying and estimating costs is unimportant. We are saying that because of the role of risk aversion and because of variability there is a limit to how precisely recommendations can be made. In this sense, excess precision is pretense and a waste of time and funds.

What kind of variability should you look for? The variation that occurs in net benefits even when you administer the same treatment. This kind of variation emerges from several sources which can be grouped under two headings: yield variability and price variability. The purpose of this chapter is to discuss those sources of variability and what they mean for recommendations.

Sources of yield variability

Yields that farmers get from a particular treatment will not be the same as the yield that you get. There are several factors which cause this. There will be differences between the soils, the weather and the pest infestation at your site (or sites) and the soils, weather, and pest infestation at the farmers' sites. Because of this, you would obtain different yields at each of these sites even if you conducted identical trials at the same time. We call this site-to-site variability in yields.

Another type of yield variability is that which you will get from year-to-year at a given site even with the same treatment. This year-to-year variability may mean that the treatment which gives the highest net benefit in one year may give a disastrous loss the next year in the same experiment in the same location.

For examples of these two kinds of variability look at the data presented in Table 6. These are the data of the fertilizer trials discussed earlier. Though we did not mention it, the data from the first four trials are from one year and those for the second four trials are from a second year. Now compare trial 1 with trial 2. We've held prices constant in computing the net benefits in the table, so the difference in net benefits at the two sites is due to the site-to-site yield variability. You can see that no single treatment gave the same yield in one site as it did in another.

Now, compare trial 1 with trial 5, two trials conducted at the same site but in different years. The treatment which gave the biggest net benefit the first year (150-25) gave one of the smallest net benefits the second year. (You can also compare site 2 with 6, 3 with 7, or 4 with 8). These comparisons show that no single treatment gave the same yield at the same site in the two years. That is year-to-year variability.

These two kinds of variability are facts of life. They make it impossible to predict accurately what a particular treatment will yield in one place based on data from a different place *or* to predict accurately what will happen on a given site next year based on data from last year. You know that such variability exists. Farmers also know it. It is good to be skeptical about your ability to predict the results that a given farmer will obtain in a given year.

Let us for the moment suppose that the eight trials are representative of the kind of variability that a given farmer or the farmers of an area might expect from the treatment applied. That is, if a farmer were to apply (50-25), the net benefits he might expect on his farm in any given year are represented by the column of benefits under (50-25) in Table 6. Notice that the highest benefit is $4000 and the lowest is $1620. This is a wide range of variation, with an average net benefit of $2790. More importantly, notice that no single treatment consistently gives the highest net benefits across the trials.

There is still another source of yield variability which you should consider. That is the kind of variability that arises from farmers using different practices than you use in your experiments.

It is well known that the agronomist typically maintains more control over the environment of the crop than does the average farmer. This happens even when you are working on farmers' fields. You will probably take more care in the timing and thoroughness of planting, in weed control (herbicides are more often used

TABLE 6.
Net benefits to fertilizer treatments by site ($/ha).

		Fertilizer treatment (kg/ha)											
	N:	0	50	100	150	0	50	100	150	0	50	100	150
Trial	P_2O_5:	0	0	0	0	25	25	25	25	50	50	50	50
1		360	670	2370	2080	410	1620	2660	2700	950	1310	1550	1490
2		1380	1890	3730	3490	1200	2710	3440	4600	720	2770	3900	3840
3		3740	3920	3420	3080	3700	3800	3320	3200	4060	4140	4320	4160
4		2180	2990	3810	2730	1820	3390	4480	4900	900	3020	3440	4120
5		1480	1280	970	670	1540	2190	1660	1090	750	2150	1590	1460
6		1450	2200	2830	2610	1330	2830	2100	1880	510	2550	3440	2630
7		4270	4420	2960	3130	2120	4000	3690	3080	4040	3440	2690	2960
8		1090	1650	870	710	1080	1800	1090	970	680	2210	1980	2120
Avg.		1990	2380	2620	2310	1900	2790	2810	2810	1570	2690	2870	2840

on trials) and in insect and disease control.

The reasons for these differences in management intensity are many. In some cases it is because farmers are not aware of the techniques which you use. More often it is because farmers cannot wisely allocate as much time, thought, and money to their fields as you can and should. Regardless of the reasons, because of these differences the yields obtained by a farmer using a given treatment on a given field and in a given year might be different from the yields you would attain on the same field in the same year. Furthermore, because management intensity differs from farmer to farmer, different farmers will also get different yields from the same treatment, even if everything else is the same.

Unfortunately there seems to be no simple rule of thumb to correct for these management differences. We can say only that they can dramatically affect yields. Border effects, for example, can have a substantial effect on the absolute level of yields. CIMMYT trials comparing small and large plots suggest that the yields for small plots should be reduced by 20%, to compensate for border effects.

All in all, you will tend to get higher yields from any given treatment than will farmers. Some suggest that yields should be reduced by 20 to 30 % to account for the more intense management given the experiments.

But this isn't the entire problem. Management practices can cause changes in the ranking of treatments. For example, data from a trial undertaken in CIMMYT's wheat program shows that if the wild oat population is controlled (by spraying, for example), the 100 centimeter-high Jupateco variety outyields the taller durum variety Anhinga. But if the wild oat population is quite dense, the reverse is true. Yields for both varieties decline because of the wild oats, but that of the durum declines by far less. Another example is planting density and fertilizers in maize. With high plant densities heavy fertilizer applications can give higher net benefits than light applications. At lower plant densities the reverse can be true.

You are probably aware of other examples. The examples we have presented stress the importance of still another source of variability. They also warn that you should be quite familiar with the standard practices of farmers before you organize your experiments. You should also try to understand why these practices are used so that you will know whether farmers will find it difficult to change them.

There is still another source of variability that we could discuss but it really isn't necessary. This is the variability that occurs among replications, often called experimental error but better called "within-site variability." This variability just signals that the fields are not homogeneous. Farmers know this and they tend to think in terms of the whole field. When differences are really notable they tend to make two fields or more where they had one. In any case, you need not regard within-site variation as another source of variability.

To summarize, there are three sources of yield variability which you must recognize when you attempt to predict what will be farmers' yields based on data from trials. They are:

1. Site-to-site variability under the same management conditions;
2. Year-to-year variability under the same management conditions;
3. Management level variability on a given site in a given year.

Adjustment of recommendations for yield variability (minimum returns analysis). In the analysis of the net benefits in the previous chapter, we considered only the average yields for each of the treatments. In this chapter we have pointed out the sources of variability in yields, and examined the variability in net benefits which resulted from the variability of yields in the fertilizer data. We have already suggested one procedure for incorporating risk aversion into the process of deriving recommendations. This was to add a 20 % "risk premium" onto the direct cost of capital. This is because farmers (and others, too) want a margin of protection. In general, an alternative which offers an average 20 % risk premium will be less likely to lead to ruin from a bad year than will an alternative which offers only a 10 % risk premium.

But the idea of a 20 % risk premium is a general rule of thumb. There may be some new technology options which are basically no more risky than traditional technology, or perhaps even less risky. But even in this case, farmers would be likely to insist on a small risk premium because the new option entails the risks of the unknown. On the other hand, a new option may be much more risky than the traditional options. This will be true if the new option calls for a large investment and crop failure is likely to occur.

To examine the relative risks of "disaster" among the alternatives, we use minimum returns analysis. Of all the experimental trials available, we look at the worst 25 % or so of the outcomes of each treatment. A comparison of these worst results will give us some idea of the relative riskiness of the various treatments. If the recommended practice (from marginal analysis) appears to be very little more risky than the current farmer practice, you can be even more confident that this recommendation is a good one for the farmer. If, on the other hand, the recommended practice has "worst" results which are worse than the poorest from current farmer practice, then you need to reconsider the recommendation. One way to reconsider is to use an opportunity cost of capital higher than 40 %. The exact level depends upon the riskiness which is observed, but risk premiums of 50 % or even 100 %, (added on to the direct cost of capital) might realistically represent farmer circumstances.

A minimum returns analysis such as this will be meaningless unless you have at least five or six experiments. It will also be misleading if you don't include *all* of the experimental (or demonstration) sites in the analysis. It is common practice to abandon agronomic trials if weather or other factors damage the site to the extent that the agronomist is satisfied that he will observe no significant yield differences between treatments. Thus if 20 sites are planted, it might be that 5 are abandoned because of drought, flood, severe insect or disease infestation or other factors. It is common practice to analize only the results from the 15 "successful" trials. But this is a mistake, because the farmer must accept unsuccessful as well as successful results. It is just as important for you to know what results the farmer will obtain in unfavorable circumstances as it is to know the results for the successful circumstances.

Therefore, it is very important for you to consider carefully the reasons why a particular trial has been abandoned. If the cause was an obvious error on your part (you applied the wrong chemical, broke the plants with a machine, etc.), then the site could properly be deleted as being unrepresentative of farmers' re-

TABLE 7.
Minimum net benefits from eight fertilizer trials ($/ha).

	Fertilizer treatment (kg/ha)											
N:	0	50	100	150	0	50	100	150	0	50	100	150
Net benefit P_2O_5:	0	0	0	0	25	25	25	25	50	50	50	50
Worst	360	670	870	670	410	1620	1090	970	510	1310	1550	1460
Second worst	1090	1280	970	710	1080	1800	1660	1090	680	2150	1590	1490
Average of worst two	725	975	920	690	745	1710	1375	1030	595	1730	1570	1475

sults. If a part of the plot was damaged by livestock, this could be dismissed as not representative of results that a farmer would get on his entire parcel. Otherwise, the data should be included as being representative of farmers' conditions and therefore, very relevant. In some cases you will collect no yield data from such a site, even though you want to include the site in the analysis. This is an unfortunate situation, but if it should occur, you should estimate the harvestable yield from the entire plot, and assume that this yield occurred on all treatments. This way the calculated net benefits will reflect the loss in variable costs. This is a relevant measure of the worst results which farmers could expect from a given treatment (the loss of the variable costs).

We have suggested that you consider the worst net return, but this is not entirely satisfactory. Due to random chance, this level of return may be a lot lower than the remaining outcomes. Furthermore, the farmer may be able to survive just one bad outcome, if the others are relatively more favorable. So in addition to the worst possible outcome, we suggest that you look at the average of the worst 25% or so of the outcomes for each treatment.

In table 7 we show the worst net return from the eight trials for each treatment (taken from Table 6). For this set of experiments we are lucky, for the treatment which we chose using marginal analysis (50-25) is also the treatment which has the highest net return in the worst of the eight situations ($1620). Therefore, a farmer who is concerned about occasional low returns could not do better than to choose 50-25.

The last line in Table 7 shows the average net returns for the worst two outcomes of each treatment. Again, the previously selected treatment, 50-25, provides nearly the highest average (50-50 provides an average which is $20 higher, but this cannot be a very important difference to the farmer).

This analysis of minimum net benefits has provided a check on the riskiness of the treatment chosen by marginal analysis as compared with other alternatives. In this case, the previously chosen treatment has less down-side risk than do the others, so it seems to be a good choice for risk averters. Often, however, the alternative selected by marginal returns analysis will prove to be inferior to others in minimum net return. In such a case, you will need to assess the importance of risk aversion to the farmers in the recommendation domain before you can decide whether or not to alter the recommendation because of the result of minimum returns analysis.

A further comment is in order with respect to the minimum net returns realized from a particular treatment. Ocassionally, something goes wrong in an experiment and one or more of the applications of a treatment may have very low yields *relative* to other replications or other treatments. If this is the case, that yield figure may result in a "worst" return for that treatment that is misleading. Thus in examining the array of outcomes as in Table 7, you should view with suspicion any net returns which are far below both other net returns for that treatment and net returns for other treatments. You should go back to the field book to determine whether or not some extraneous factor was lowering the yields for just one of the treatment plots.

Price variability and sensitivity analysis

In making a partial budget, you will be unable to accurately estimate prices or costs. This is especially true of the prices estimated for the product and for labor. Variability from year-to-year and farmer-to-farmer in prices paid or received is a fact of life which you must somehow consider.

With product prices it is sometimes tempting to use guaranteed prices. We all know, however, that the prices which farmers actually receive often differ from guaranteed prices. Sometimes they are higher. Often they are lower. This is why it is essential for you to find out what prices farmers are actually receiving. Even so, your estimates of product prices are apt to be in error because of season-to-season or year-to-year variability which you cannot anticipate.

Your estimates of labor prices are apt to be in error because some farmers will have a higher or lower opportunity cost for their time than do other farmers.

The implications of these difficulties in estimating prices may or may not be serious. Fortunately, it is usually easy for you to determine whether this is the case. This can be done by using a technique called *sensitivity analysis.* The object of this procedure is to change the product (or labor) price within reasonable bounds of the original estimate to determine if the ranking of alternatives is affected.

To demonstrate this technique we will first apply it to the question of whether errors in estimating labor price could have an important effect on our fertilizer recommendation example. Look again at Table 5, the undominated treatments. Note that of the five treatments listed, the first two require 4 extra days of labor, the second two require 2 extra days of labor, and the last, the check plot, requires no extra labor. What effect would a change in labor price have on the ranking of the treatments?

Using the previously established field price of labor, $25 per day, treatment 100-50 returns a net benefit $80 higher than treatment 50-25. Note however, that if we increased the field price of labor to $65 per day, both would return about the same net benefit.

	50-25	*100-50*
gross field benefit	$3490	$4270
variable money costs	650	1300
variable labor costs (at $65/day)	130	260
total variable costs	780	1560
net benefit	$2710	$2710

We have already noted that the alternative 100-50 does not quite offer enough extra net benefit to warrant the extra expenditure of fertilizer over 50-25. For farmers whose opportunity cost for labor approaches $65, it would offer no increase in net benefits whatsoever. This is one more reason for being reluctant to recommend 100-50, even though it has the highest estimated net benefit. The marginal return from the additional investment falls rapidly with higher labor prices.

Comparing 50-25 with 0-0, however, we can determine that for any labor field price up to $212 per day, the former alternative would still offer a higher net benefit. Since this figure is far above our estimate, we can be confident that errors in estimating the field price of labor will not affect our recommendation of 50-25.

Suppose now we were interested in whether maize price changes of up to 20% would effect the fertilizer recommendation. One could complete the entire budget analysis again using field prices of $800 and $1200 per ton, but this is not really necessary. We know that if the maize price rises the return to all levels of fertilizer will increase, and the main question of interest is whether the returns to 100-50 increase enough to warrant its recommendation for poorer farmers. Given a field price of $1200 per ton, the net benefit for 100-50 would increase from $2870 to $3724:

	at a field price of $1200		*at a field price of $800*	
	50-25	*100-50*	*0 - 0*	*50-25*
gross field benefit	$4188	$5124	$1592	$2792
variable costs	– 700	–1400	– 0	– 700
net field benefit	$3488	$3724	$1592	$2092
marginal net benefit	$236		$500	
marginal rate of return	34%		71%	

The net benefit from 50-25 would be $3488, and the rate of return of the extra fertilizer would be 236/700 = 0.34 = 34%, compared with 24% at the old price. This is nearly a high enough return to warrent its recommendation to farmers. If there were a good chance that a field price of more than $1200 would prevail, we would want to reconsider the recommendation.

At a maize field price of $800, on the other hand, the question is whether 50-25 remains profitable enough to be recommended. At this field price, the increase in net benefit over the check plot is about $500, compared with $800 at the original price, and the rate of return falls from 114% (800/700) to 71% (500/700). This is still adequate to warrant recommendations of 50-25.

So the result of this maize price sensitivity analysis is that the recommendation for most farmers does not change for maize prices within 20% of our best estimate price, $1000 per ton, though it might for prices in excess of $1200. Sensitivity analysis with respect to maize price and labor price has given us further confidence that the 50-25 recommendation will indeed be in the farmers' interest, even if prices should differ from what we expect.

6 MORE ON ESTIMATING COSTS

In Chapter 2 we discussed the general procedures for reporting gross benefits and variable costs, but we said very little about the problems and procedures involved in estimating costs and benefits. In this and the following chapter we discuss in more detail how these estimates are made, and provide check lists which can help you to insure that you do not overlook significant costs or benefits.

The first task in estimating costs is to identify which input items are changed in any way by changing from one treatment to another. These inputs are called *variable inputs*. They include changes in chemicals, seed, amount or type of labor, and amount or type of machinery. The second task is to determine *field price* of that input - the money cost or opportunity cost per unit of the input.

Identifying and measuring variable inputs

To identify which inputs are affected by the alternatives included in an experiment, you must be familiar with local practices as well as the practices used on the experiment. You must then ask yourself which operations change from treatment to treatment, and which operations are different from those used by the farmers in the recommendation domain.

Following is a check list of operations which should be considered:

Land preparation
is it the same for all treatments and on farms?

Planting
is the same seed used for all treatments?
is the same amount of seed used?
is the planting technique the same?

Weeding/cultivating
is there reason to think the amount of time required
for this chore will differ from treatment to treatment?
is the technique the same for all treatments and on farms?

Thinning
is it required for all treatments?
is the amount of time required the same?
do farmers do it?

Application of pesticides and fertilizer
are these practices identical for all treatments?

If the practices for the above operations are not identical for all treatments and for the farms in the recommendation domain, one must then consider which of the following types of inputs might be affected by the differences, and by how much.

Chemicals–(fertilizer, insecticide, herbicide)
do they differ in either type or amount?

Seed
does it differ in type or amount?

Equipment
are the kinds of equipment needed the same?
is the amount of equipment time required the same?

Labor
how much does labor differ due to differences in operations
–weeding practices, thinning practices, irrigation practices, planting density, land preparation, etc.
does the amount of labor required vary significantly with type or amount of seed applied or fertilizer applied?
is the type of labor required different between treatments?

For inputs such as labor and equipment time, it is usually difficult to make estimates of the differences in the amount required for each treatment. Information about labor use from the experimental plots, even if they are conducted on farmer fields, is not very useful because of the small size of the plots. The best way to get this information is to visit with several different farmers. Each will have his own opinion as to the time required for various operations, but a number close to the average of these opinions will provide a good estimate. For activities with which farmers are completely unfamiliar, a guess will have to suffice. Remember, not all farmers take the same amount of time for a given job, so your

TABLE 8.
Assessing variable field costs for a particular treatment (per hectare).

			Field cost ($/ha)				
			Money		Opportunity		
Operation	Input	Number of units	price per unit	cost	price per unit	cost	Total cost
Planting	seed	15 kg	1	15	–	–	15
	labor	2 days	–	–	25	50	50
Fertilizer	N	50 kg	8	400	–	–	400
	P_2O_5	25 kg	10	250	–	–	250
	labor	2 days	–	–	25	50	50
Total variable costs				665		100	765

estimate cannot be precise. The danger is that you will overlook an important change in labor requirements.

Once *variable inputs* for each operation have been identified and their amounts estimated, it is sometimes useful to record them in an orderly manner such as the first three columns of Table 8. We say sometimes, because in relatively simple experiments such as fertilizer trials, only fertilizer and application labor are variable inputs, and they may be recorded directly in a partial budget table such as Table 3. But for experiments with a larger number of variable inputs, such as a trial demonstrating technological packages, a table such as Table 8 will be very helpful to you in organizing *field cost* information. Differences in field cost from treatment to treatment can then be quickly determined by comparing the total costs from the table for each treatment.

To this point we have discussed only the identification and measurement of variable inputs, the first three columns of Table 8. We now turn to some considerations related to assessing the cost of each of these.

Determining the field prices of purchased inputs

How can you estimate the *field price* of inputs which are purchased and used up during the season? (This would include such items as seed, pesticides, fertilizer, and irrigation water.) It's very easy. Go to the local retail outlets or wherever the farmers must buy the inputs, and check the retail price for the appropriate size of package.

Then find out how the farmers get the input to the farm. In the case of non-bulky inputs such as insecticides and herbicides, the item can be carried by the person and transportation costs are insignificant. But for fertilizer, and perhaps seed, this is not the case. Usually the farmer must use a truck or perhaps a pack animal to get the input home. If this is so, a transportation charge must be added to the retail price. If the farmer pays others to transport the item for him, it is not difficult to learn what the normal charges are. If he transports it himself, one may want to include the opportunity cost of his own time and for his own truck. When budgeting for farmers in general, one will have to be guided by the practice which would be followed by the majority of the farmers in the recommendation domain.

In some situations, the farmer will be selecting seed from his previous crop, rather than buying the seed. This seed is not costless either, as he has other alternatives for it. In general, the opportunity cost of this seed should be the local market price, less transportation and marketing costs, plus cost of storage and seed treatment (if any).

Determining the field price of equipment

Some treatments or alternatives may require the use of small hand equipment not required by other treatments. Then for the types of budgets we are describing, you must derive a *field price* per hectare for the use of the equipment.

The retail price of the equipment is the appropriate starting point in determining *field price* per hectare of use. To obtain a pro-rated cost per hectare of use, one can first divide the retail price by the approximate life of the piece of equipment (in years). This provides a pro-rated annual cost, which must then be divided by the average number of hectares per year grown by farmers in the area to obtain the pro-rated per hectare field price of the piece of equipment.

For example, suppose you are considering recommending a herbicide which is applied with a knapsack sprayer which costs \$500. You might estimate that most farmers could use this for 5 years, and that the average farmer has 5 hectares of the crop. You can calculate the per hectare cost as

\$500/5 years = \$100 per year
\$100/5 hectares = \$20 per hectare per year

In rare cases you may be considering alternatives which differ in their use of tractor-drawn implements or perhaps small self-powered implements. The above procedure can be used for this type of equipment also, but there are other factors involved in the cost, such as repair costs, fuel costs and the possibility that the equipment would have other uses on the farms. Thus for these larger pieces of equipment, it is best to seek the advice of an agricultural engineer or an agricultural economist who is familiar with the equipment and costing techniques.

The above approach to estimating equipment field price may seem a bit crude, and it is true that more sophisticated costing techniques could be used. But one cannot hope for much precision in estimating these costs per hectare, as they may vary widely from farm to farm. Once again, precision can be a waste of time and money. And it is far better to use a crude method of estimating the costs then to ignore them altogether.

Thoughtful readers might have noticed that we have included no interest charges in this procedure for determining the field price of equipment. This is because we are using the rate of return to investment capital as a decision criterion (Chapter 4). If the rate of return is not at least as high as the interest rate, we will not recommend the treatment which requires the equipment.

Determining the field price of labor

For farmers who hire labor for the operations in question, the *field price* of labor is the going wage rate for day laborers in the area, plus the value of non-monetary payments normally offered, such as lunch. (The value of such non-monetary payments may not be trivial. In parts of Pakistan for example, the value of lunch represents a fourth of the wage.) There are two problems with using this price. First, it may be that most farmers for whom the recommendations are intended do not hire outside labor and will do the work themselves with family labor. Second, it may be that the operation in question is of such a critical nature that the farmer would not want to entrust the task to anyone other than himself.

Where the farmers or members of his family will in general be doing the work, we must use the concept of opportunity cost to determine labor's *field price*. Opportunity cost represents value which is given up in order to do the work and thus represents a real cost. For example, if the farmers must take a day off from his job in town to do the extra work, he will give up at least a day's wages, and this opportunity cost is just as real as if he had paid someone else to do the work for him.

As we mentioned earlier, it may be that the extra work is required at a time which is critical in the care of some other crop, such as tobacco. If taking a day from the more important crop results in a reduction in earnings from that crop, then that loss is the opportunity cost of the labor. Again it is a very real cost, even though it does not directly involve money.

It is all very well for us to give you the opportunity cost principle as the approach to estimating the field price of labor, but how can you discover what the opportunity costs are for the average person for whom the recommendation is to be made? The point of departure is the going agricultural wage rate for the season in the area, which can be discovered by talking to several farmers. Remember that it is not unusual to find the going rate higher during some periods of the year than during others.

Then you must call upon your familiarity with farming practices to determine whether the extra labor will be required at a time when the family labor will be fully occupied, or if it will occur at a time when there is likely to be slack labor available. If the extra labor is to occur during a relatively slack period, we suggest an opportunity price of about 50 to 75 % of the going wage rate. We suggest this lower price because the farmer will have the opportunity, if he wishes, to work off his farm, in which case he could have earned the going rate for the season. But since it is probably some trouble for him to obtain outside work, and since he probably prefers to work for himself, we think most farmers are willing to work at home for somewhat less.

We have suggested the figure of 50 to 75 % but this is, of course, a rough estimate of values which probably vary from farm to farm. We want to caution you not to be swayed by the possible fact that the farmer would be sitting around doing nothing if he were not doing the extra work. For if jobs are available, and he does not choose to take them, this is evidence that he values his leisure time more than the amount which he could obtain by working. Of course, if no off-farm work is available for most farmers, it may well be that the opportunity cost of most farmers' time is very much closer to zero. In this case, the opportunity cost of labor can be set even lower than 50 % of the going wage, but in no case should it be set at zero.

On the other hand, if the extra labor is to occur during a very busy time, when the farmer is likely to be able to earn more in another enterprise, then we suggest using an opportunity cost of about 125 % of the going wage rate for that season. While the opportunity cost of the farmer's time may be more than this, he usually has the opportunity of hiring in workers to assist him. Since it is some bother to him to do this, the true cost of hiring in the labor would be more than the going wage rate, and this is why we suggest the figure of 125 %. (While the busy farmer may not actually hire the labor, the fact that he does not do so indicates that he does not feel that the value of labor in the alternative uses is worth more than 125 % of the wage rate.)

Summarizing what we have said about the *field price* of labor, we point out that the going agricultural wage rate (including lunches, etc.) in the area for the season of the year in question is the starting point for estimating the opportunity price of labor. If the farmers for whom the recommendations are being made will be very busy at this time of year, then we suggest a figure of 125 % of the wage rate (for that season) as the opportunity cost. If the farmers can be expected to be less than fully employed at the time in question, we suggest a figure of 50 to 75 % of the wage rate for that season. In Chapter 5 we described a way to see how important the estimated field price of labor is in choosing a treatment to recommend.

Determining the cost of investment capital

The opportunity rate of return is the concept which we use to estimate the cost of using capital, and though we do not use it in calculating field costs, we do use it to derive recommendations as described in Chapter 4. We now want to discuss in more detail how the opportunity rate of return may be estimated.

Suppose a partial budget analysis of a $100/hectare investment in fertilizer shows an average net benefit of $25 per hectare. This is a rate of return of 25% per 6 months. We now need to estimate the opportunity rate of return to investment capital if we are to decide whether or not this 25 % is satisfactory.

If the farmers will be borrowing money to finance the investment, the rate of interest which they must pay on their loan is a first approximation to the opportunity rate. But you must not forget service charges and insurance premiums associated with the loans but not included in the interest rate. These charges will often cost more than interest charges, thus perhaps doubling the effective interest rate which the farmer must pay. Also, one must consider that the loan interest rate is expressed in percent per year, while the period of investment in fertilizer may be only six months. Perhaps we can best show how to account for these factors with an example.

Suppose the farmers can borrow from the agricultural bank to buy this $100 worth of fertilizer. The annual interest rate is 12%, there is a $5 service fee, and a charge for loan insurance. The bank makes a loan for $121, determined as follows:

$ 100	cost of fertilizer
x0.12	interest rate per year
$ 12	annual interest charge
x 0.5	fraction of year
$ 6	interest charge
$ 100	cost of fertilizer
6	interest charge
5	service fee
10	insurance premium
$ 121	

But this bank, like most others, actually gives to the farmer only the value of the fertilizer, $100, and asks the farmer to pay back $121 at the end of 6 months. The cost of investment capital is the total charges for the loan divided by the amount received, or

21/100 = 0.21 = 21%, the cost of capital.

The effective loan rate which this farmer pays is 21 % per 6 months (42 % per year). The fertilizer investment returns 25 % per 6 months (a total of $125), a little more than enough to repay the loan. But most farmers would require a risk premium of 20 % or more above the effective loan rate to provide an income safety margin, given the risks of production. This would increase the cost of capital from 21 % to 41 %. The 25 % rate of return on this fertilizer investment would probably not be sufficient for most farmers. The greater the yield and price uncertainty, the larger average return over loan costs will be required to convince the farmer to invest.

Now let's consider those *farmers who will invest their own money* in fertilizer. The opportunity rate of return to their own capital is (1) the rate at which they could loan their capital to others (with comparable risks as for investment in fertilizer) or (2) the rate which they could earn by investing their capital in alternative enterprises of similar riskiness. Unfortunately it is much easier to conceive of these two rates than it is to measure them. However, our experience with poorer farmers around the world suggests that local (private) interest rates are generally quite high, up to 100% as we mentioned earlier, and that available investment opportunities on farms generally promise rates of return of 30% and more. Thus we have suggested a figure of 40% (per crop season) as a minimum opportunity rate of return. Where the variability of net benefits is high, the figure should be 50% or more. In areas where the private money-lending trade is active, the rate of interest for these loans can be used as the opportunity rate of return.

Let's summarize what we have said about capital charges and rates of return. We have not made any charge for the use of capital for inputs in our partial budget approach. Rather, we have calculated marginal net returns as a percentage of marginal variable costs, and have compared this rate of return with the opportunity rate of return to determine if the rate of return is sufficiently greater to warrant undertaking the risk involved. Where loans are widely available for financing the investment, the rate of return should be around 20% above the *effective* loan rate for investments with average risk. Where farmers will generally be financing the investment themselves, we have suggested an opportunity capital use cost of 40% per crop season for investments with average risk.

Summary

We have presented many details which you should consider in estimating variable costs. These details may appear tedious, but they will not seem so once you incorporate them into your way of thinking about the value of your research to farmers. The details are important. Failure to recognize all of the important costs associated with a treatment can destroy the credibility of your recommendations. To assist you in identifying these important costs, we offer the following check list.

Check list for estimating field costs

1. Identify all operations which will be performed differently from treatment to treatment, including:
   - land preparation
   - planting (density, technique, seed)
   - weeding/cultivating
   - thinning
   - application of pesticides and fertilizers
   - other?
2. For each of these operations, note which inputs are different, and estimate the quantities required, including:
   - chemical inputs (fertilizer, insecticide, herbicide of the correct kind)
   - seed (kind and amount required)

equipment (kind and amount required)
labor
other?

3. Determine the field price of each of the above inputs
    - purchased inputs
        - retail price (for appropriate size of package)
        - transportation costs
    - equipment
        - retail price
        - average years of life
        - average crop hectares for farmers of area
    - labor
        - going agricultural wage during relevant season
        - full employment or slack employment period
    - capital
        - effective loan rate if loans are generally available
        - information about private credit rates

7 MORE ON ESTIMATING BENEFITS

In Chapter 2 we presented an overview of how to assess the benefits and costs of alternative recommendations using partial budgeting. Here we will look more closely at some of the problems that can arise in assessing benefits. We will discuss the identification of sources of benefits and the assignment of values to benefits, and conclude with a check list for easy reference.

Identifying and assessing benefits

Recall our earlier statements about the need for completeness. What that means for benefits is that you must identify all items which:

1. have a positive value to the farmer
2. which change from one treatment to another

Let's return to the example of maize production presented in Chapter 2. Maize grain has value to the farmer and the data presented in Table 1 show maize yields changing as the application of fertilizer changes. But the farmer will not salvage the entire harvest, as some grain will be lost in the harvest, shelling and storage process. For this case, we estimated that the farmer will lose 10%of the grain in these operations. The *net yields* (90 % of the measured yields) represent the quantities which the farmer will benefit from.

Should we distinguish between maize sold and maize consumed on the farm? One could argue that sales provide income while maize used on the farm does not, hence that only the maize sold is a source of the benefits. Clearly that is a short sighted view as the maize used on the farm has value in satisfying nutritional requirements. Indeed it also has potential value in the market – it could be sold for cash and the cash used to buy something else which could satisfy the requirements of food and feed.

Let's agree, then, that we want to value the total production of maize whether sold or consumed on the farm. Notice here that maize can be used on the farm in three ways: as seed, as animal feed, and as human food.

We are now left with the problem of valuing the maize produced.

A first approximation of the value is the market price. From this you must deduct certain costs associated with getting the maize from the field –the point at which the farmer makes agronomic decisions– to the market.

Which costs must be deducted? The rule we suggest is to deduct from the market price all of those costs which will vary directly with the quantity of maize produced. To see what these costs are, suppose yields were zero. Then there are no harvest costs, no costs for storage, no costs for bagging the grain, no costs for transporting grain to market. Alternatively, for a harvest of 2 tons, the cost of harvesting, shelling, storing, bagging, and transporting 2 tons is almost exactly twice the cost of performing the same activities for a harvest of 1 ton. These costs, harvesting, shelling, storing, bagging, and transporting, are the costs which vary in direct proportion to production and should be deducted from market price. The remaining value is the *field price* of maize.

Before continuing, we need to describe what we mean by market prices. These are *not* the retail prices in central cities. They *are* the prices which farmers can expect to receive in local markets. Because prices vary over the course of the year, it is a good idea to get an average price. If you want to be conservative, you can use the price expected at harvest time. Again the price to use is *not* necessarily the official price. We all know of cases where prices to farmers have been higher or lower than official prices. We want the price our decision-making farmer anticipates, whatever it is.

It might be asked why the cost of, say, weeding isn't also deducted from market price. This is because the cost of weeding is *not* a constant proportion of yields. It is this distinction which differentiates those costs which can be subtracted from the market price and those which can better be treated separately.

Returning now to the costs, you'll recall that in the previous chapter we distinguished between money costs and opportunity costs. We must do the same thing here. Consider Table 9.

If payments are to be made in cash –for buying bags, for hiring custom shelling or threshing, for transportation– then one need only write in that cost per ton. If it is contemplated that an activity or several activities will be done with family labor, then the concept of opportunity cost must again be used. In the example we've assumed that the farm family will harvest the maize. Again, all such costs must be assigned in per-ton terms. If for example, a day's labor is valued at $25 and if in one day a worker can harvest 0.3 tons, then the cost per ton is $25/0.3 = $83.30.

Storage needs special consideration. The items which figure in costs are fumigants and insecticides along with a charge for the cost of constructing the space which the grain occupies. It is likely that the cost of storing grain will be small on a per ton basis. We include it for completeness and because, while small, it is still greater than zero.

Storage losses create another complication in calculating proportional costs. Suppose you pay $135 (= 83 + 17 + 35) to harvest and store a ton of grain. Suppose further that 20 % of the grain is lost in storage. The cost per ton of grain remaining after storage is then $135/0.8 tons or $169/ton, rather than $135/ton. The storage loss of 20 % has increased these proportional costs by 25%. In situations where storage losses are large, you should make this correction in determining proportional costs.

Subtracting proportional market costs from the market price of maize gives the *fieldprice* of maize, $1200 – 200 = 1000. This is the value to the farmer of a ton of maize standing in the field. Notice how much lower it is than the market price. These costs will normally be ***at least*** 10% of the market price, and you should not ignore them.

It is now time to reconsider the problem of identifying sources of value which will vary among alternative treatments. Maize for grain has been discussed above. Does anything else vary? Clearly yes, the production of fodder varies. If fodder has a value, as it so often has in poor countries, then you should estimate its gross field benefit also.

The procedure for estimating the gross field benefit for fodder is exactly the same as that for estimating the value of grain. First you must estimate production and deduct anticipated losses to get net production. Then follow each step outlined above for assessing costs. Of course "harvesting" becomes "collecting", "shelling" becomes "baling" and it seems likely that the costs of storage and of bagging will be virtually zero. The important thing to remember however, is to consider each potential activity – will "chopping" be included? – and follow the procedure laid out for maize to estimate the proportional cost per ton of processing the fodder from field to market.

Once the per ton proportional cost is estimated, all that remains to do is to subtract that amount from the market price to get *field price* and then multiply field price by adjusted production. The result is the *gross field benefit* from fodder.

Adding the two benefits together – that from grain and that from fodder – gives the estimated *gross field benefit* from the treatment. It then remains to continue with the cost categories as described earlier.

Now, it is unlikely that calculations for maize or wheat will show potential benefits from more than two sources, grain and fodder. For other crops or for crop mixtures more than two sources of benefits might well emerge. Again the procedure for treating each potential source of benefits is the same as the procedure described above for handling maize.

Tenancy

So far our discussion has assumed that the farmer is an owner-operator of his farm. However, in many farm communities considerable numbers of farmers are tenant farmers. The form of tenancy varies widely from country to country and from region to region. It is common for the landlord and tenant to share the crop according to some formula with the tenant supplying all the cash inputs such as

TABLE 9
Assigning costs (per ton) to activities proportionally related to production.

	Money	Opportunity	Total
Harvest	–	$83	$83
Shelling/threshing	$17	–	17
Storage	35	–	35
Bagging	25	–	25
Transport	40	–	40
Total proportional costs per ton	117	83	200

fertilizer, seeds, etc. If we assume that the (tenant) farmer wants to reap as much net benefit as he can, then such crop-sharing arrangements may exert a very significant influence on the choice of practices.

To demonstrate the importance of this, let's assume that the maize fertilizer recommendation discussed previously is to be made for tenant farmers who pay all the costs of inputs, but receive only half of the production. We need to calculate the net benefits again under this assumption. For the 0-0 treatment, for example, the net benefit would be 0.995 tons x $1000 = $995, exactly half of the previously calculated figure. For the 50-25 treatment, the net benefit is:

1.745	tons
x$ 1000	field price per ton
$ 1745	gross field benefit
– 700	total variable costs
$ 1045	net benefit

instead of $2790 as calculated for an owner-operator. If you proceed with these calculations for all treatments, you will find that *none* of the other fertilizer treatments give a net benefit as high as the $995 from the 0-0 check plot. Then treatments 0-0 and 50-25 are the only undominated alternatives for the tenant farmer. The marginal rate of return on the $700 investment for 50-25 is:

$ 1095 – $ 995 = $100 marginal net benefit
$ 100 / $700 = 0.14 = 14% marginal rate of return

This is not an adequate rate of return to warrant recommendation of any fertilizer to tenant farmers who must pay all the fertilizer costs and receive only half the crop. This is a drastic change from our previous conclusion. It demonstrates that you cannot afford to overlook the effect of tenancy arrangements when you calculate net benefits.

And what about tenants who pay a fixed rent for their land? A little thinking about our earlier discussion – where we said that things which don't change with treatments can be eliminated – argues that we needn't worry about cash rents.

Summary

Some persons might regard the foregoing discussion of costs and returns as being unduly concerned with detailed aspects of accounting. While there may be an element of truth in such a point of view, we contend that disregard for some of these "little details" has been an important factor in explaining the non-adoption of technology which was thought to be "profitable." People who make recommendations and who desire not to be surprised by low rates of adoption should recognize these little-but-important details. They should also bear in mind the likelihood and impact of high opportunity costs of farm labor and scarce financial resources.

Check list for benefits

1. Identify all sources of potential benefits which can be expected to vary from one treatment to another –for cereals these are likely to include only grain and fodder.
2. For each potential source of benefits, estimate harvest and storage losses and calculate net yield. Make adjustments for tenancy if appropriate.

3. For each potential source of benefits estimate a market price or opportunity price, with proper attention to quality discounts.
4. Identify all activities whose costs vary proportionately with production per hectare. These are usually the processing activities from harvest to market, including harvest, shelling/threshing, bagging, storage, and transportation.
5. Estimate the unit cost, for example per ton, of each of the activities identified in (4). Adjust for storage losses if appropriate.
6. Add the adjusted costs per unit of the activities identified for each potential source of benefits (e.g. for grain and for fodder) and subtract each total from the relevant market price. The resulting values are the *field prices* of grain, of fodder, etc.
7. For each potential source of benefits, multiply the *field price* times the net yield and sum over all potential sources of benefits. This is the *gross field benefit* of the treatment.

8 SUMMARY OF PROCEDURES FOR DERIVING RECOMMENDATIONS FROM EXPERIMENTAL DATA

I. Calculate average net benefits for each treatment.

A. Estimate benefits for each treatment (see check list, Chapter 7)

1. Calculate *average yields* for each treatment including grain and fodder if appropriate. Adjust yields first for differences between experimental management levels and farmer management levels (0-50%). Then adjust for normal harvest and storage losses (at least 10%).

2. Estimate the *field price* of grain and fodder. For sellers, this will be the local farmer market price less cost of harvest, shelling/threshing, storage, transportation and marketing. These costs will generally total *at least* 10% of the market price, sometimes much more. For subsistence farmers, local market price plus transportation and marketing costs may be more appropriate.

3. Multiply field price times adjusted average yield for each product and sum to obtain *gross field benefit* for each treatment. Correct for tenent's share if appropriate.

B. Estimate variable costs for each treatment (see check list, Chapter 6).

1. Identify the *variable inputs,* those items which are affected by the choice of treatment. Include chemicals, seed, labor and equipment. Estimate the quantity of each of these inputs used for each treatment. To estimate the quantity of labor and equipment required under farmer conditions, familiarity with farmers' practices is required.

2. Estimate the *field price* of each input. Normally this will be retail price plus transportation costs for purchased inputs. Field price of labor will normally be an *opportunity cost.* Start with the farm labor wage rate and adjust if the labor is needed at a very busy season or a very slack season.

3. Multiply the field price of each input by the quantity and sum over inputs to obtain the *variable cost* for each treatment. This will include a money cost component and an opportunity cost component.

C. Subtract variable costs from gross field benefit to obtain the *net benefit* for each treatment.

II. Choose a recommended treatment using marginal analysis.

A. Array treatments from high to low net returns. Eliminate dominated treatments. Calculate the *rate of return* to each increment in capital. Graph the net returns curve if several treatments are involved.

B. Select as the recommendation the treatment which offers the highest net benefit *and* a marginal rate of return of at least 40 % on the last increment of capital.

III. Check the suitability of the recommendation from the point of view of yield and price variability.

A. Use *minimum return analysis* to compare the minimum returns from the selected treatment to those from all other treatments. If it compares unfavorably, a different recommendation may be more consistent with local farmers' circumstances.

B. Use *sensitivity analysis* to determine whether the choice of recommendation is sensitive to product or input prices which are particularly subject to estimation error. If the recommendation is sensitive to these changes, consider changing the recommendation or obtaining more information about the prices in question.

9 TWO EXAMPLES

Our purpose here is to describe two more examples in which we use procedures of the manual to derive farmer recommendations from agronomic data. These two examples are different from the fertilizer example we used in the text in that they are more nearly "yes-no" problems rather than "how-much" questions. The first involves a choice between two treatments, the second involves a choice among six. As we have mentioned, the procedures of the manual are useful in both "yes-no" and "how much" situations.

In the first example we examine a series of on-farm maize trials with two treatments: The "current" technology package and an "intensive" technology package. The question is whether or not to recommend the intensive package. In the second example we examine a series of wheat trials in which there were six treatments: three varieties, each with and without fertilizer. The question here is which of the treatments should be recommended to farmers.

Maize technology packages

A series of demonstration/research trials were conducted in three high tropical valleys. The intensive technology package included fertilizer at the rate of 100 kg/ha of N and 40 kg/ha of P_2O_5, one soil insecticide application, two foliar insecticide applications, and herbicide. The current technology package, which was designed to represent current farmer practice, included half the amount of fertilizer, no soil insecticide, and hand weeding rather than herbicides. In all other respects the two packages were identical. The purposes of the trials were to demonstrate to the farmers the results they could obtain with the two packages, and to evaluate the desirability of the intensive package over a number of locations (26) in the recommendation domain. (Other trials were being conducted simultaneously to examine components of the package – fertilizer response, insecticide response, variety comparision, etc.)

In Table 10 we show the calculations of variable costs for the two treatments (following the format of Table 8). Agricultural labor in the area is commonly hired by the day for $3 per day, and the rental of hand sprayers is common at the rate of $4 per day. Labor estimates for applying fertilizer, insecticides and herbicides and for hand weeding were based on discussions with farmers. Fertilizer and chemicals are available from both private and government-sponsored stores at the prices indicated (including a delivery charge for fertilizer).

Maize is marketed by most farmers through independent truckers who regularly pass through the villages offering to buy grain. It is not usually stored before being sold. Prices the last two seasons have been about $250 per ton. The official government price is higher, but since the government buys only a limited amount, and since farmers must accept quality discounts and pay delivery costs, the price from truckers is taken to be relevant to most farmers. The field price per ton was determined as:

Price offered by truckers	$250.00
Less:	
picking	−5.25
husking	−3.50
shelling	−8.75
field price	$232.50

The cost of picking was determined by dividing the number of man-days per hectare by the average yield in the area, multiplied by the going wage. The costs of husking and shelling were estimated from contract rates reported by various farmers in the area.

The partial budget of these trials can now be completed as shown in Table 11 (which follows the format of Table 3). Notice that the average yields as measured have been reduced by 10% to account for losses from shelling and other factors not reflected in the experimental harvest and measurement procedures. The marginal cost of the intensive technological package is $150 per hectare, and the rate of return to this investment is 77% (last line, Table 11).

TABLE 10

Variable cost calculations for the current and intensive technologies (per hectare).

			Field cost ($/ha)				
			Money		Opportunity		
Operation	Input	Amount	Price	Cost	Price	Cost	Total
Current technology package							
fertilization	46-0-0	65 kg	0.54	35.10	–	–	35.10
	20-20-0	100 kg	0.54	54.00	–	–	54.00
	labor	6 days	–	–	3.00	18.00	18.00
				89.10		18.00	107.10
weed control	weeding	10 days	–	–	3.00	30.00	30.00
insect control (2 applications)	insecticide	24 kg	1.60	38.00	–	–	38.00
	sprayer	2 days	4.00	8.00	–	–	8.00
	labor	2 days	–		3.00	6.00	6.00
				46.00		6.00	52.00
Intensive technology package							
fertilization	46-0-0	130 kg	0.54	70.20	–	–	70.20
	20-20-0	200 kg	0.54	108.00	–	–	108.00
	labor	9 days	–	–	3.00	27.00	27.00
				178.20		27.00	205.20
weed control	herbicide	2 kg	17.00	34.00	–	–	34.00
	sprayer	3 days	4.00	12.00	–	–	12.00
	labor	3 days	–	–	3.00	9.00	9.00
				46.00		9.00	55.00
insect control (3 applications)	insecticide	36 kg	1.60	58.00	–	–	58.00
	sprayer	3 days	4.00	12.00	–	–	12.00
	labor	3 days	–	–	3.00	9.00	9.00
				70,00		9.00	79.00

TABLE 11
Partial budget of the maize technology trials.

Item	Treatment: Current technology	Treatment: Intensive technology
Average yield, (ton/ha)	2.78	4.04
Adjustment for harvest loss (10%)	X .9	X .9
Net yield (ton/ha)	2.50	3.64
Gross field benefit ($/ha at $232.50/Ton)	581	846
Variable costs (from Table 10):		
fertilization ($/ha)	107	205
weed control ($/ha)	30	55
insect control ($/ha)	52	79
Total variable cost ($/ha)	189	339
Net benefit ($/ha)	392	507

Rate of return = (507 – 392)/(339 – 189) = 115/150 = 0.77 = 77%

A rate of return of 77% is adequate to warrant its recommendation to farmers unless the risks are unusually high. (Similar trials elsewhere in the same country showed rates of return too small to be recommended). The risk analysis procedure suggested in Chapter 5 is to list the net benefits from each treatment at each location. In this case we suggest a modification of this procedure which is quite useful where only two treatments are included.

In Table 12 we present the yields for each treatment at each of the 26 sites, as well as the yield gain offered by the intensive technology as compared with current technology. Notice that four of the 26 trials were lost due to drought. Since drought is a hazard which farmers must consider, we must include these results in the analysis.

What size yield gain is required in order to pay for the cost of the extra inputs? This is determined as follows:

marginal cost in money	$150
marginal cost in grain ($150/$230.50)	0.65 ton
marginal yield required to give 40 % rate of return (0.65 x 1.40)	0.90 ton

We now know that if a farmer is to receive a 40%rate of return to his investment, the intensive technology package must yield 0.9 ton/ha more than the current technology.

We see in Table 12 that this occurs in 14 of the 26 trials. Furthermore, we see that in three more cases, the farmer would have got his investment back, but at a lower rate of return than 40%. This leaves nine trials of the 26 in which the gain in yield was not enough to pay for the additional inputs.

The above approach offers a convenient way to present the range of results from a two-treatment experiment. But it does not directly help us to assess the down-side risks of the two alternatives. To do this, we again turn to a minimum returns analysis as described in Chapter 5. First, look down the column of yields for the current technology. The worst eight of these (the worst 25%, including the four drought trials and the four yields in italics) average 0.36 tons. To get net benefits, expressed as grain, we can subtract from these figures 0.81 tons (variable cost of $189 divided by $232.50 per ton of grain), giving the results in Table 13. Similarly, subtract 1.46 tons from the worst yields in the complete technology column ($339 divided by $232.50).

It is clear from Table 13 that the complete technology is more risky only when there is a complete crop loss. In these cases (15% of the trials in this year) the farmer would lose the equivalent of 0.65 tons of grain more with the intensive technology than with the current technology. This is a serious risk, and will discourage many subsistence farmers from applying the extra inputs, even though the average return on the investment is 77%. It is probably not wise to recommend this investment to farmers close to the subsistence level, because of the probability that a crop failure in the first or second year would put the family in a very bad debt situation. In the recommendation domain of this study, however, the number of subsistence farmers is small, and the intensive technology is an appropriate recommendation despite the risks.

Wheat variety trials

The set of wheat variety trials which will be analyzed were conducted at six different sites in a rainfed area. Varieties were tested under conditions of no fertilizer and 60 kg of N plus 20 kg of P_2O_5 per hectare. The results (replication means, again) are presented in Table 14. Figure 3 also helps show the relationship

TABLE 12.
Yields (ton/ha) from 26 trials with two levels of maize technology.

Trial	Technology: Intensive	Current	Gain
1	6.98	5.17	1.81 **
2	6.24	6.34	–0.10
3	5.49	3.25	2.24 **
4	5.84	4.97	0.87 *
5	5.26	4.04	1.22 **
6	*3.00*	3.01	–0.10
7	6.07	2.51	3.56 **
8	7.81	7.11	0.70 *
9	5.25	3.14	2.11 **
10	6.10	1.15	–0.05
11	*3.04*	*0.21*	2.83 **
12	4.86	1.36	3.50 **
13	*3.33*	*0.39*	2.94 **
14	*2.06*	*1.01*	1.05 **
15	4.63	1.47	3.16 **
16	3.43	3.81	–0.38
17	3.71	2.99	0.72 *
18	3.41	*1.24*	2.17 **
19	5.43	3.76	1.67 **
20	3.67	2.64	1.03 **
21	5.19	3.84	1.35 **
22	4.26	4.05	0.21
23 (drought)	0	0	0
24 (drought)	0	0	0
25 (drought)	0	0	0
26 (drought)	0	0	0
Avg	4.04	2.78	1.26 **

**Yield gain sufficient for rate of return of 40% or more. *Yield gain sufficient for rate of return between 0% and 40%.

TABLE 13
Minimum net benefits (ton/ha) from the 26 trials.

Net benefit	Current Technology	Intensive Technology
Worst	–0.81	–1.46
Second worst	–0.81	–1.46
Third worst	–0.81	–1.46
Fourth worst	–0.81	–1.46
Fifth worst	–0.60	0.60
Sixth worst	–0.42	1.54
Seventh worst	0.20	1.58
Eighth worst	0.43	1.87
Average of eight trials	–0.45	–0.03

TABLE 14
Yield data from a set of wheat variety trials (ton/ha).

Trial	Variety local 0-0	Variety local 60-20	Variety V1 0-0	Variety V1 60-20	Variety V2 0-0	Variety V2 60-20
1	0.84	1.67	1.08	2.25	1.46	2.58
2	0.72	1.50	0.98	2.00	0.76	1.94
3	1.23	1.38	1.68	2.33	0.95	2.27
4	1.22	1.51	1.34	2.31	1.67	2.58
5	1.36	1.30	1.10	2.24	1.40	2.68
6	1.58	1.99	1.53	2.01	1.74	2.97
Avg.	1.16	1.56	1.28	2.19	1.33	2.50

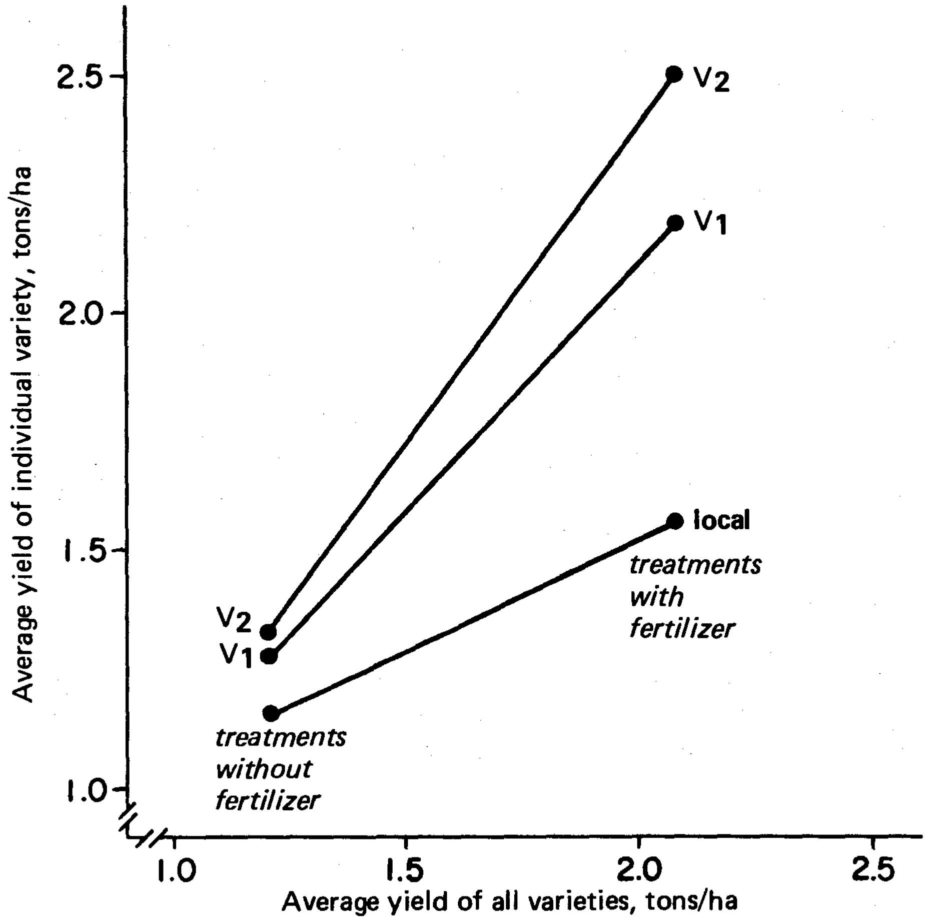

FIG. 3. **Wheat variety yields and fertilizer levels.**

TABLE 15

Partial budget of wheat variety trials (per hectare).

Item		Variety local		Variety V1		Variety V2	
	N:	0	60	0	60	0	60
	P_2O_5:	0	20	0	20	0	20
(1) Average yield (ton/ha)		1.16	1.56	1.28	2.19	1.33	2.50
(2) Net yield (ton/ha)		1.02	1.37	1.13	1.92	1.17	2.20
(3) Field price ($/ton)		1000	1000	900	900	1000	1000
(4) Gross field value ($/ha)		1020	1370	1017	1728	1170	2200
Variable money costs							
(5) Seed (75 kg at $1/kg)		–	–	75	75	75	75
(6) Fertilizer ($ 5/unit)		–	400	–	400	–	400
(7) Variable money costs ($/ha)		0	400	75	475	75	475
Variable opportunity costs:							
(8) Days per application		–	2	–	2	–	2
(9) Cost of application ($50/day)		–	100	–	100	–	100
(10) Total variable costs ($/ha)		0	500	75	575	75	575
(11) Net benefit ($/ha)		1020	870	942	1153	1095	1625

TABLE 16
Marginal analysis of the wheat data (per hectare).

Net benefit	treatment: variety	N	P_2O_5	variable cost	change from next highest: increase in variable cost	increase net benefit	rate of return
$1625	V2	60	20	$575	$500	$530	106%
1153	*V1*	*60*	*20*	*575*	–	–	–
1095	V2	0	0	75	75	75	100%
1020	local	0	0	–			

between variety yields and fertilizer levels. For each fertilizer level the average yield of each variety is plotted against the average yield of all varieties. Such a diagram is useful in visualizing variety-environment interactions. In this case there are only two environments represented, the fertilized environment and the non-fertilized environment.

It is clear that V2 is the variety most responsive to fertilizer, V1 is about average, and the local variety is least responsive.

Only an economic analysis such as the one which follows can indicate the implications of these data for farmer recommendations.

The first step is to adjust average yields for harvest and storage losses, which we estimate at 12%. After appropriate inquiries among farmers and merchants in the area, we determine that the *field price* of the local variety is $1000 per ton. Variety V1 is a new variety which had been previously introduced, and merchants state that local people will not buy it because of its color, though it can be shipped out of the area and sold. Because of this, the price of V1 has been 8 to 10 lower than the local variety, which means a field price of $900 per ton. The other new variety, V2, has not previously been released, but the grain is virtually indistinguishable from the local variety, so the field price is assumed to be the same, $1000 per ton. The gross field values, based on the *average* yields for each variety, are shown in line 4 of Table 15.

Most farmers would have to purchase seed of the two new varieties at a field price of $2 kg, so at a seeding rate of 75 kg/ha the new varieties would require a cash outlay of $150/ha. Seed for the local variety costs only $1.00 kg, so the increase in seed costs above the local variety is $1.00/kg. The field price of both N and P_2O_5 were determined to be $5/kg of nutrient, and it was estimated that 2 man-days were required to apply fertilizer to 1 hectare, at a field price of $50 per man-day. The resulting estimates of total variable cost by treatment are shown in lines 7 and 10 of Table 15.

Finally, in line 11 of Table 15, we present the resulting net benefit for each of the alternatives. Variety V2, when fertilized, offers clearly the highest average net benefit, but again due to considerations of capital scarcity and risk aversion, we will need to examine these results using the procedures described earlier to be sure which alternatives to recommend.

The first task is a marginal analysis of the partial budget results. To this end, we rank the alternatives by net benefit as shown in Table 16, omitting those treatments which gave net benefits smaller than the check plot (the local variety without fertilizer).

The treatment V1 with fertilizer is dominated by V2 with fertilizer, since both have the same variable cost, but the latter has a higher net benefit. Only V2 without fertilizer and V2 with fertilizer remain as reasonable alternatives by this criterion. The smallest investment alternative available to the farmer is to spend $75/ha on the seed for the new variety. In exchange for this he can expect to receive a net return of $75/ha (the first year), for a rate of return of 100%. This is an adequate rate to warrant farmers' investment, and morevoer, the farmer can expect to receive additional benefits in the future without the necessity of again investing in seed. The actual rate of return is then underestimated by this figure. However, the absolute amount of increase in net benefits ($75/ha) is quite small, being only 7 % or so higher than net returns attainable from the local variety. Thus farmers might not be too enthusiastic about making this change, even though the rate of return on the investment in seed is quite high.

What about the alternative of investing an additional $500/ha to apply fertilizer to variety V2? The expected increase in net benefits is $575/ha, for a rate of return of 106%. This rate is acceptable (if the risks are not unusually great), and the size of the increase in net returns is quite significant, being about 50 % of the net benefits from the local variety without fertilizer. Thus we can assume that the recommendation of variety V2 with fertilizer would be consistent with farmers' circumstances.

As a check on the riskiness of these alternatives compared with the others, we need to examine the returns in the worst of the six outcomes and the worst two of the six. These are presented in Table 17 (along with the average of all six for reference). Here we find, as we did in the case of the fertilizer trials, that the treatment chosen by marginal analysis of the average yields is also the treatment with the highest minimum returns. The minimum return analysis again supports the recommendation.

However, the minimum returns analysis does reveal something which was not evident from the marginal analaysis of the average yield data. Suppose that there are some farmers in the area who are unable or unwilling to invest in fertilizer. The marginal analysis suggests that for these farmers, V2 would be a good recommendation, or perhaps they could as well stay with their old variety. However, Table 17 shows that these two alternatives have minimum returns much lower than the alternative V1. Then very risk-averse farmers who cannot or will not apply fertilizer might prefer V1, even though on the average they would receive lower returns than from either of the other varieties when grown without fertilizer. The variety V1 appears to be more stable across environments than the other two. Furthermore, it outyields the local variety on the average under unfertilized conditions, and yields almost as much as V2 without fertilizer. The reason that it shows up as a relatively unattractive alternative in the marginal analysis is because of the price discount. It is therefore appropriate to use sensitivity analysis to examine the implications of possible changes in this discount.

We can ask ourselves at what price discount V1 without fertilizer would provide higher net benefits than the local variety without fertilizer. The answer is a discount of about 3%. With such a discount (a price of $970), the net benefits would be $1020/ha, the same as for the local variety. In order to provide a rate of return equal on the average to that from investing in V2 seed, variety V1 would have to have an even higher price than the local variety.

What then are we to conclude? First, the recommendation of V2 with ferti-

TABLE 17
Minimum returns analysis of the wheat data (per hectare).

Treatment variety	N	P_2O_5	worst net return	average of worst two net returns	average of all six net returns
local	0	0	$ 633	$ 686	$1020
local	60	20	640	677	870
V1	0	0	701	740	942
V1	60	20	1008	1012	1153
V2	0	0	594	678	1095
V2	60	20	1131	1276	1625

lizer is a good one, as it is verified by both marginal analysis and minimum returns analysis. If there are some farmers who will not be applying fertilizer regardless of the recommendation, one might want to recommend that they plant V1 because of its high minimum net returns. The judgement must be made on the agronomist's judgement of the size of this group of farmers and the seriousness with which they might view the differences in minimum net returns between the local variety and V1.

Since six observations are not many, the agronomist might be wise to wait another season before making any recommendation with respect to V1 versus the old variety under unfertilized conditions. Additional observations may show that the difference in minimum returns is not so great as is estimated here on the basis of just six outcomes.

GLOSSARY

Cost of capital–benefits given up by the farmer due to having investment capital tied up in an enterprise for a period of time.

Dominance–one alternative is said to dominate another when the first has higher net benefits and equal or lower variable cost than the second.

Field cost(of an input)–the field price of an input multiplied by the quantity of the input which varies with the decision.

Field price (of an input)–the total value which must be given up to bring an additional unit of input into the field.

Field price (of output)–the value to the farmer of an additional unit of production in the field, prior to harvest.

Gross field benefit–net yield times field price for all products from the crop.

Investment capital value of inputs (purchased or owned) which are allocated to an enterprise with the expectation of a return at a later point in time.

Marginal cost–the increase in variable cost which occurs in changing from one production alternative to another.

Marginal net benefit–the increase in net benefit which can be obtained by changing from one production alternative to another.

Marginal rate of return– the marginal net benefit divided by the marginal cost. (Calculated for non-dominated alternatives only).

Money field price (of an input)–refers to purchase price plus other direct expenses such as transportation costs.

Money field price (of output)–the market price of a unit of product minus harvest, storage, transportation and marketing costs, and quality discounts.

Minimum returns analysis–a process on each production alternative which features examining net returns to the individual treatments and selecting that alternative whose lowest return or whose lowest average return is highest among the alternatives being considered.

Net benefits–the value of the benefits less the value of the value of the things given up in achieving the benefits, total gross field benefit minus total variable cost.

Net yield–the measured yield per hectare in the field, minus harvest losses and storage losses where appropriate.

Opportunity cost–the value of any resource in its best alternative use.

Opportunity field price (of an input)–refers to the non-money value of the input in its best alternative use.

Opportunity field price (of output)–the money price which the farm family would have to pay to acquire an additional unit of the product for consumption.

Proportional cost–costs which vary directly and proportionally with yield.

Recommendation domain–a group of farmers within an agro-climatic zone whose farms are sufficiently similar and who follow sufficiently similar practices that a given recommendation is applicable to the entire group.

Risk premium–an amount, given as a percentage, which a farmer requires before exposing himself to a variable income.

Sensitivity analysis–a process which features changing a price or a cost within reasonable bounds of the original estimate to determine if the original ranking of alternatives is affected.

Total field cost/variable cost–the sum of field costs for all inputs which are affected by the choice.

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