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

Tillage Experiment

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

Figure 6.3. Yields from tillage experiment

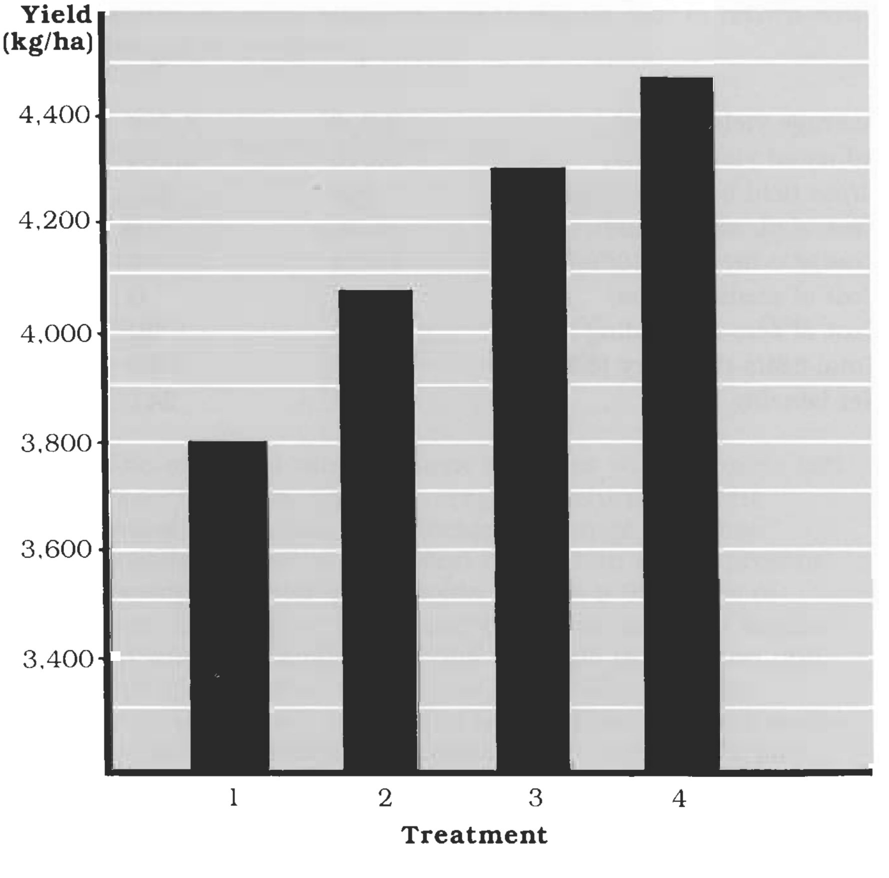


Table 6.4. Tillage experiment data

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

a/ Farmers' practice

Data

Tillage costs:

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

Table 6.5. Partial budget, tillage experiment

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

Figure 6.4. Net benefit curve, tillage experiment

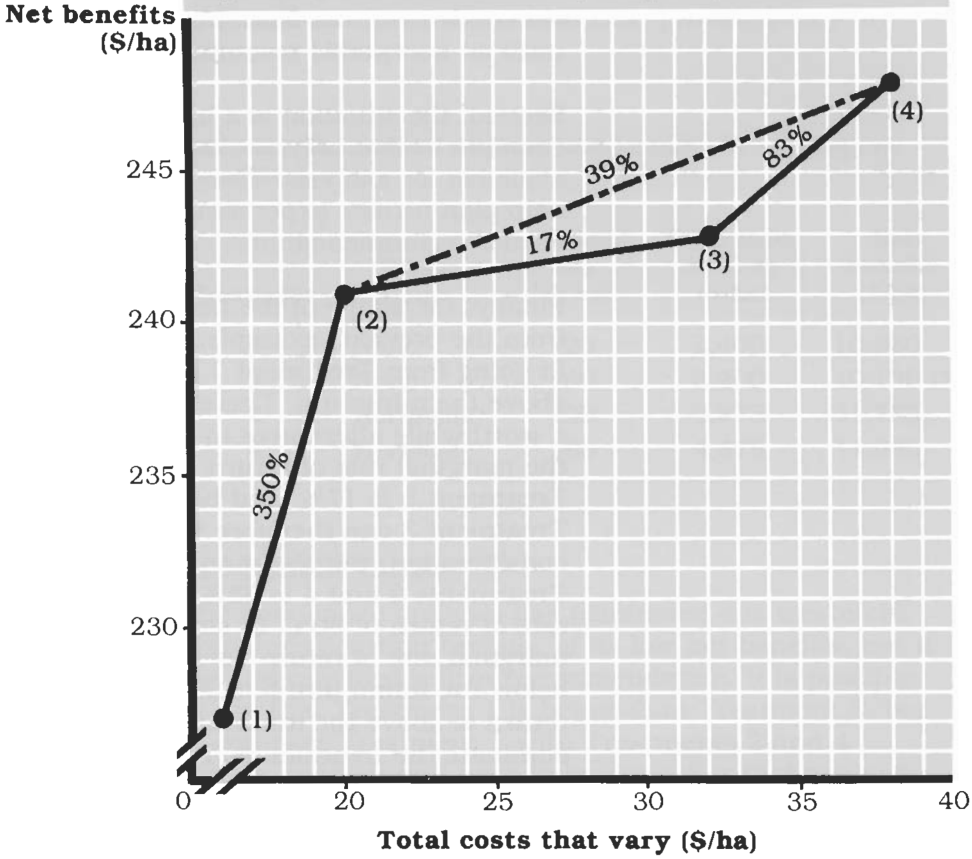


Table 6.6. Marginal analysis, tillage experiment

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

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

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

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

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

Analysis Using Residuals

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

Table 6.7. Analysis of nitrogen experiment using residuals

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

[a] Maximum residual

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

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

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

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

Table 6.8. Analysis of tillage experiment using residuals

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

[a] Maximum residual

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

SOME QUESTIONS ABOUT MARGINAL ANALYSIS

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

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

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

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

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

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

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

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

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

Partial budget	1	2
Gross field benefits ($/ha)	500	650
Total costs that vary ($/ha)	100	200
Net benefits ($/ha)	400	450

Marginal rate of return $= \frac{450 - 400}{200 - 100} = 50\%$

Complete budget	1	2
Gross field benefits ($/ha)	500	650
Total costs that vary ($/ha)	100	200
Total of costs that do not vary ($/ha)	300	300
Total costs ($/ha)	400	500
Net benefits ($/ha)	100	150

Marginal rate of return $= \frac{150 - 100}{500 - 400} = 50\%$

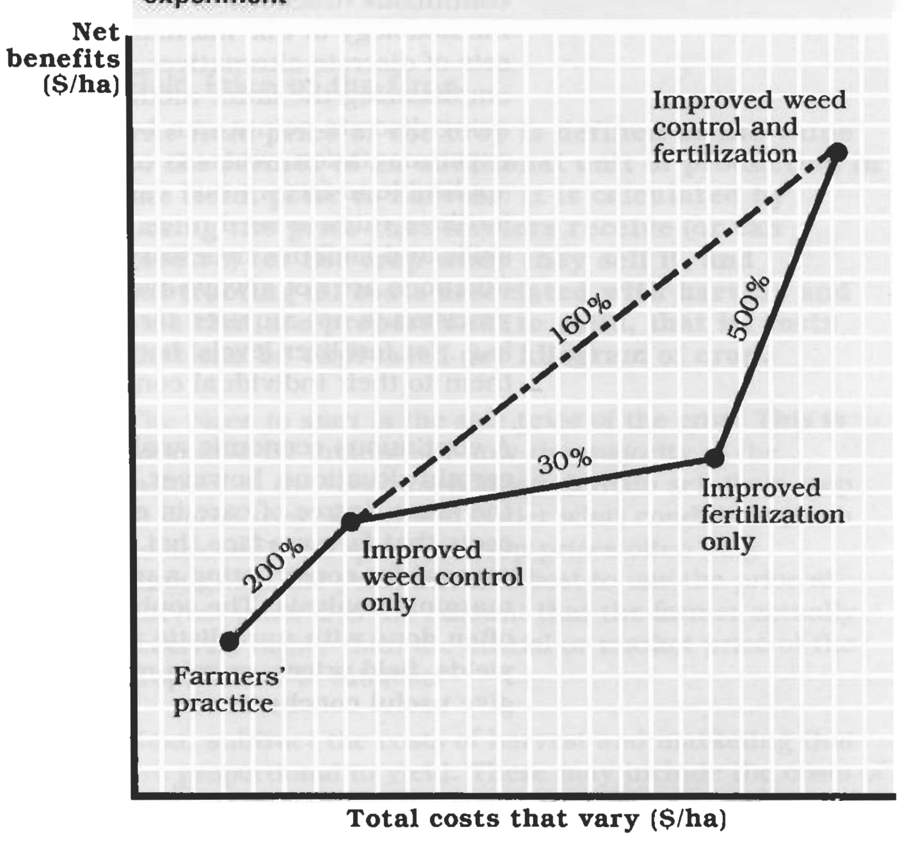
calculated using benefits and total costs, the result is the same.

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

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

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

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



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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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