another treatment, it may not matter if the first exhibits higher variability than the second. As long as marginal analysis shows that it gives an acceptable rate of return, and farmers are assured that even in the worst cases it gives higher net benefits than the alternative, then farmers will be interested in adopting it.

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

Prerequisites for a Minimum Returns Analysis

Minimum returns analysis

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

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

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

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

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

Minimum Returns Analysis

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

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

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

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

Net benefits = (Y x A x P)—TCV,

where

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

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

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

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

or 0.18 Y - 60.

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

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

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

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

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

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

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

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

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

Chapter Nine
Variability in Prices: Sensitivity Analysis

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

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

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

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

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

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

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

Sensitivity Analysis

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

The best way to test a recommendation for its ability to withstand price changes is through sensitivity analysis.

Sensitivity analysis

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

Table 9.1. Sensitivity analysis for nitrogen experiment

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

Marginal rates of return

Case A	Case B
0 kg N to 40 kg N = 287%	0 kg N to 40 kg N = 231%
40 kg N to 80 kg N = 133%	40 kg N to 80 kg N = 100%

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

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

Table 9.2. Calculation of maximum acceptable field price of nitrogen

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

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

or

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

Example

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

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

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

$$n = \$1.33/\text{kg}$$

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

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

Table 9.3. Sensitivity analysis for weed control experiment

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