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

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

Reviewing the Purpose of the Experiment

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

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

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

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

Tentative Recommendation Domains

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

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

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

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

Reviewing Experimental Results

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

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

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

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

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

Statistical Analysis

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

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

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

Table 7.1. Yield data for a nitrogen by tillage experiment

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

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

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

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

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

Chapter Eight
Variability in Yields
Minimum Returns Analysis

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

Dealing with Risk in On-Farm Research

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

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

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

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

Risk and Data From On-Farm Experiments

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

The Farmers' Point of View

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

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

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

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

But variability *per se* is not the only factor that farmers will take into account when deciding among treatments. If one treatment always gives higher net benefits than