ECONOMIC ANALYSIS OF 2^4 FACTORIAL AGRONOMIC EXPERIMENTS

L. Harrington*

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* Economist at CIMMYT, Mexico. The views expressed are not necessarily those of CIMMYT.

TRAINING NOTE

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1.0 Introduction

The 2^4 factorial experiment has become increasingly popular in on-farm agronomic experimentation, in part due to the efforts of CIMMYT's maize training program. This experiment is used to examine main effects and interactions for four different factors, each of which is set at two levels. If the two levels for each factor are respectively set at the farmer's level and at a high, non-limiting level, the experiment is useful in identifying those factors that limit crop yield (Palmer et al, 1980). If the levels are respectively set at the farmer's level and at a higher level that appears to be possible for target farmers, the experiment can also serve as a basis for formulating recommendations for farmers.

The 2^4 factorial experiment has been used to study several arrangements of factors (Maize Training Program, 1981), including variety, N level, insect control, density, weed control, timing and placement of N and P, and so on.

However, the very characteristic that makes this experiment useful - the simultaneous testing of multiple factors - creates complications in the economic analysis of results. The major complication is that not all treatments in a given experiment are necessarily included in the partial budget used in economic analysis. Sometimes data from individual treatments are used in analysis; at other times averages for main effects are used, depending on the results of statistical analysis. The purpose of this note, then, is to address this complication and to provide guidelines for dealing with it when economic analysis of 2^4

factorial experiments is to be conducted.

2.0 Partial Budgets - An overview

Before examining the difficulties in planning economic analysis for 2^4 experiments, a brief review of budgeting concepts, and the relationships between statistical and economic analysis of agronomic data, is in order.

2.1 Review of Concepts

Partial budgets are useful and appropriate in the economic analysis of experimental data (Byerlee, 1980). In their simplest form, partial budgets merely compare the changes in benefits with the changes in costs that are due to changes in treatments. A more complete form of partial budgets is used in this note, following Perrin et al (1976) who propose the following steps:

1) Budgets are planned on a treatment by treatment basis, using data either from individual experiments or (preferably) from experiments pooled by recommendation domain.

2) Average yields for each treatment are adjusted downwards by a constant percentage to reflect the difference between experimental and farmer yields due to differences in management, and differences in yield loss due to earlier harvest by researchers or different harvest techniques.

3) "Adjusted yields" are multiplied by a "field price" of the product (sales price less harvest cost, shelling cost and transport cost from the field to the point of sale) to obtain a "gross benefit" for each treatment.

4) "Costs that vary" due to treatment changes are subtracted from "gross benefits" to obtain "net benefits" for each treatment.

5) "Dominated" treatments are eliminated from further consideration. A treatment is considered "dominated" if simultaneously its "net benefit" is lower and its "costs that vary" are higher than those corresponding to any other treatment.

6) "Marginal rates of return" to increased expenditure (MRR) are calculated for undominated treatments, as follows:

$$MRR = \frac{NB_2 - NB_1}{VC_2 - VC_1} \times 100$$

where

NB = net benefits

VC = costs that vary

and when treatments 1 and 2 are two alternative treatments in an experiment, treatment 1 being associated with a lower level of net benefits and costs.

7) A recommended treatment is selected as follows: increase expenditure by going from less to more expensive treatments, until the MRR has been reduced to a level just greater than the "cost of capital" to farmers.

8) Risk analysis (See Perrin et al, 1976).

2.2 Statistical versus Economic Analysis

In the budgeting procedures described above, increased "costs that vary" are compared with increased "net benefits" to calculate a "marginal rate of return". Clearly, the analysis assumes that net benefits and gross benefits are calculated on the basis of yield changes that really exist, and that are really due to treatment effects, i.e., not due to random variation. If yield changes do not exist (or are not due to treatment effects), then the procedures for partial budgets do not entirely apply. In the absence of yield changes (and hence, in the absence of change in net benefits) preference is normally given to the least-cost treatment.

Whether or not yield changes really exist is determined by statistical analysis. Perrin et al, however note two cautions.

"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 if 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 analysis 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 year 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".

The above two points refer to ways in which the search for "significance" may be facilitated. Nonetheless, research programs frequently find themselves forced to analyze one or few experiments, to focus future experimental work and/or make preliminary farmer recommendations. Such is the case when research is begun in a new study area. In these cases, "significance" may be elusive for some factors. Even in those cases where researchers have access to several cycles of data, not even pooled analysis will lead to "significant" differences between treatment means if none exist in the universe under study.

Researchers must be ready, then, to deal with situations in which some factors demonstrate "significant" differences between treatment means while other factors do not. As noted, this possibility creates special complications in such multiple-factor experiments as 2^4 factorials.

3.0 Planning Partial Budgets for 2^4 Factorial Experiments

3.1 Individual Treatments versus Pooling by Factors

In the procedures and examples used by Perrin *et al*, experimental treatments are analyzed one by one. In the case of the 2^4 factorials, each of the sixteen treatments included in a given experiment would be analyzed: net benefits calculated, dominated treatments excluded, etc. Table 1 shows the economic analysis for a tillage systems experiment, arranged as a 2^4 factorial.

It is clear that the only undominated treatments are the following: 0111, 0100 and 0101. Calculating marginal rates of return, we find that 0101 (zero till, urea, N in the hole but P broadcast) is the most profitable treatment. (See table 2).

However, the statistical significance of differences in treatment means has not been taken into account. Indeed, the profitability of the final change in the marginal analysis, from 0100 to 0101, is based on an apparent yield

Table 1. ECONOMIC ANALYSIS OF A TILLAGE SYSTEMS EXPERIMENT, NORTH VERACRUZ 1981A

Treatment[1/] A B C D	Yield kg/ha	Adjusted[2/] Yield kg/ha	Gross[3/] Benefit $/ha	N[4/] Cost $/ha	Applic.[5/] Cost $/ha	Tillage[6/] Cost $/ha	TCV $/ha	Net Benefit $/ha
0 0 0 0	2.55	2.04	8,772	975	150	1,820	2,945	5,827
1 0 0 0	2.74	2.19	9,426	975	150	3,050	4,175	5,251
0 1 0 0	3.53	2.82	12,143	880	150	1,820	2,850	9,293
1 1 0 0	3.64	2.91	12,522	880	150	3,050	4,080	8,442
0 0 1 0	2.62	2.09	9,012	975	200	1,820	2,995	6,018
1 0 1 0	2.82	2.26	9,701	975	200	3,050	4,225	5,476
0 1 1 0	2.43	1.94	8,359	880	200	1,820	2,900	5,459
1 1 1 0	2.62	2.10	9,013	880	200	3,050	4,130	4,883
0 0 0 1	3.09	2.47	10,630	975	200	1,820	2,995	7,635
1 0 0 1	3.21	2.57	11,042	975	200	3,050	4,225	6,817
0 1 0 1	4.00	3.20	13,760	880	200	1,820	2,900	10,860
1 1 0 1	2.98	2.38	10,251	880	200	3,050	4,130	6,121
0 0 1 1	2.19	1.75	7,534	975	50	1,820	2,845	4,688
1 0 1 1	1.92	1.54	6,605	975	50	3,050	4,075	2,530
0 1 1 1	2.62	2.10	9,013	880	50	1,820	2,750	6,263
1 1 1 1	2.90	2.32	9,976	880	50	3,050	3,980	5,996

1/ A0 = Zero tillage
A1 = Conventional tillage with chemical weed control
B0 = Ammonium Sulphate
B1 = Urea
C0 = N in a hole, near the seed
C1 = N broadcast
D0 = P in a hole, near the seed
D1 = P broadcast

2/ 20% yield adjustment

3/ Sales price of maize = $5.50/kg; harvest, shelling and transport cost = $1.20/kg and field price of maize = $4.30/kg

4/ Ammonium sulphate = $1.70/kg; plus $0.30/kg transport; urea = $3.75/kg; plus $0.30/kg transport

5/ Placement in a hole requires 1.5 man-days/ha, broadcast requires 0.5 man-day/ha, wage = $100/man-day

6/ Zero tillage includes 5 man-days/ha chopping, followed by 2 lt Gramoxone ($520/ha) and 1 kg Gesaprim 50 ($250/ha), using a backpack sprayer ($50/ha). Application labor does not change over treatments. However, planting labor does increase from 3 to 5 man-days/ha with zero tillage.

Cont'd. Table 1

Conventional tillage with chemical weed control requires tractor land preparation (plowing and 2 diskings = $2000/ha), followed by 2.5 kg Gesaprim Combi ($700/ha). Costs/ha, then, are as follows:

	CONVENTIONAL TILL	ZERO TILL
	($/ha)	
Tractor	2,000	0
Sprayer	50	50
Gramoxone	0	520
Gesaprim Combi	700	0
Gesaprim 50	0	250
Planting cost	300	500
Chopping	0	500
T O T A L	3,050	1,820

Table 2. MARGINAL ANALYSIS, TILLAGE SYSTEMS EXPERIMENT[1/]

Treatment A B C D	Change Net Benefits $/ha	Change TCV $/ha	MRR
0 1 0 1	1567	50	313%
0 1 0 0	3030	100	303%
0 1 1 1	--	-	--

1/ Treatment definitions and data from Table 1.

change of 470 kg/ha of maize, which statistical analysis of the experiment indicates does not really exist! That is, form of P application does not affect yields in the experiment under study. (See Table 3.) Therefore, 0100 is the correct recommendation.

The treatment by treatment analysis of 2^4 factorials is complex due to the large number of treatments included in the budgets, and can be misleading due to the relative difficulty of combining statistical and economic results.

An alternative to a treatment by treatment approach to economic analysis is to pool data, using yield averages for main effects. Further disaggregation would only be needed in the presence of significant interactions. Thus, instead of a single budget with 16 treatments, there may be several budgets, each with two or possibly four treatments. The exact form of the budgets, however, depends on the results of statistical analysis.

3.2 Case I - No significance

At times, statistical analysis indicates that there is no significant difference in yields for either main factors or interactions. Such a case is illustrated in Table 4. In this case, there is no need to use partial budget analysis because yields (and therefore gross benefits) are the same for all treatments. A comparison of costs is all that is needed to select a recommendation: the least-cost treatment[1/]. As Table 5 indicates, this may be performed on a factor by factor basis.

From Table 5 it is clear that, given the experimental results, farmers should broadcast N and P together in a single application at planting time, using ammonium nitrate as the source of N.

3.3 Case II - Some Main Effects Significant - No Significant Interactions

Normally, some of the factors in a 2^4 experiment will demonstrate significant yield differences between the selected levels. This is especially the case when the selected factors are serious limitations to increased production by representative farmers, when the two levels for each factor are set "far apart", and when the experiment is reasonably precise.

1/ This is a form of dominance analysis. If yields and gross benefits are identical for all treatments, a high cost (TVC) automatically implies a low net benefit. The least-cost treatment will dominate all other treatments.

Table 3. Statistical Analysis of Tillage Systems Experiments, North Veracruz, 1981A

Source of Variation	Observed[2/] F
A (tillage)[1/]	0.025
B (source of N)	8.045
C (form of N application)	19.868
D (form of P application)	0.001
AB	0.282
AC	0.616
AD	1.616
BC	1.494
BD	0.217
CD	1.803

1/ For full treatment description see Table 1.
2/ Tabular F for 0.05 level = 4.6.

Table 4. Statistical Analysis of Systems of Fertilizer Application Experiment, North Veracruz 1980 A

Source of Variation[1/]	Observed F[2/]
A	1.178
B	0.096
C	0.221
D	0.016
AB	0.503
AC	2.535
AD	7.169[3/]
BC	1.012
BD	0.044
CD	1.567
ABC	0.754
ABD	2.309
ACD	0.545
BCD	0.954

1/ A = source of N (ammonium nitrate vs ammonium sulphate)
B = time of N application (all at planting versus split application)
C = method of N application (hole vs broadcast)
D = method of P application (hole vs broadcast)

2/ Tabular F for 0.05 signifcance level = 4.60

3/ This interaction is statistically significant but agronomically inexplicable, especially in the absence of main factor significance.

Table 5. Comparison of Costs for Main Factors: System of Fertilizer Application Experiment

FACTOR	TREATMENT	COST 1/
A0	Am Sulphate 2/	975
A1	Am Nitrate 2/	910
B0	N all at planting 3/	50
B1	N split Application 3/	100
C0	N in hole 4/	150
C1	N broadcast 4/	50
D0	P in hole 5/	0
D1	P broadcast 5/	0

1/ Only those costs are included that vary with changes in the two levels with a given factor, e.g. when comparing A0 with A1, N application cost is not included.

2/ A0: $\frac{\text{Price of ammonium sulphate plus transport cost}}{\text{\% N in ammonium sulphate}} \times \text{dose}$

$$= \frac{1.7 + 0.3}{.205} \times 100 = \$\ 975/\text{ha}$$

A1: $\frac{\text{Price of urea plus transport cost}}{\text{\% of N in urea}} \times \text{dose}$

$$= \frac{3.75 + 0.3}{-46} = \$\ 910/\text{ha}$$

3/ Assuming broadcast application, the least cost method.

4/ Assuming a single application, the least cost method.

5/ If P is mixed with N, there is no additional cost for P application.

When some main effects are significant - but there are no significant interactions - it is possible to conduct economic analysis by means of separate budgets for each significant factor. (Factors without significant yield differences between the two chosen levels are treated as in section 3.2 - the least-cost level is chosen for each such factor.)

An example of this case (some significant main effects, no significant interactions) is the tillage systems experiment first analyzed in Table 1, in which all sixteen possible treatments were included in a single budget. Table 3 indicated that factors B (source of N) and C (form of N application) were significant, whereas factors A (tillage) and D (form of P application) were not significant, nor were any interactions significant. Consequently, we must choose the least cost level for factors A and D, and we must construct two budgets, one each for factors B and C. This analysis is shown in Table 6. The result is the same: Zero tillage, urea, with N and P applied together in a hole, near the seed, is recommended. However, the form of analysis used in Table 6 incorporated statistical results from the very beginning, and was considerably more simple.

3.4 Case III - Some Main Effects and Some Interactions Significant

When some main effects and some interactions are significant, the factor-by-factor approach discussed in Section 3.3 is no longer valid. Nonetheless, it is not necessary to return to the long, complicated treatment-by-treatment approach illustrated in Table 1. A middle ground does exist, in which budgets are constructed for significant main factors and factors with which a significant interaction exists. (In the same experiment if a main factor is not significant and does not interact with other factors, the approach of section 3.2 is used: choose the least cost treatment. If a main factor is significant but does not interact with other factors, use the approach of section 3.3 - construct a budget with two treatments) Table 7 illustrates this case, using data from a 2^4 fertilizer experiment in which only factor A (N) and the AB interaction (N by P) are significant (See Table 8 for the statistical analysis of this experiment). It is clear that neither boron (Factor C) nor zinc (Factor D) should be applied, that

Table 6. Factor by Factor Economic Analysis of a Tillage Systems Experiment, North Veracruz 1981 A[1/]

a) Factor A (not significant: choose least-cost level)

LEVEL	DESCRIPTION	COST
A0	Zero tillage	1,820
A1	Conventional tillage with chemical weed control	3,050

b) Factor B (significant: construct partial budget)

VARIABLE	B0 (Am Sulphate)	B1 (Urea)
Average yield (kg/ha)	2,640	3,090
Adjusted yield (kg/ha)	2,112	2,472
Gross benefits ($/ha)	9,082	10,630
TCV ($/ha)	975	880
Net benefits ($/ha)	8,107	9,750

c) Factor C (significant: construct partial budget)

VARIABLE	C0 (N hole)	C1 (N broadcast)
Average yields (kg/ha)	3,220	2,520
Adjusted yields (kg/ha)	2,576	2,016
Gross benefits ($/ha)	11,077	8,669
TCV ($/ha)	150	50
Net benefits ($/ha)	10,927	8,619

MRR = 2,308%

d) Factor D (not significant: choose least-cost level)

The least-cost level is to apply P mixed with N; in this case there is no additional cost for P application.

1/ Data from Table 1

Table 7. Economic Analysis of 2^4 Fertilizer Experiment, North Veracruz 1980 A

a) Factor A (significant and interacts with factor B)

VARIABLE	A0 B0[1/]	A1 B0	A0 B1	A1 B1
Yield (kg/ha)	2.21	3.36	2.05	3.67
Adjusted yield[2/] (kg/ha)	1.77	2.69	1.64	2.94
Gross benefits[3/] ($/ha)	7,602	11,558	7,052	12,625
TCV[4/] ($/ha)	0	1,030	915	1,795
Net benefits ($/ha)	7,602	10,528	6,137	10,830
MRR		284%		39%

1/ A0 = no N; A1 = 100 kg/ha N; B0 = no P; B1 = 80 kg/ha P

2/ 20% adjustment

3/ field price of maize = $4.30/kg

4/ N costs $8.80/kg in the field; P costs $9.56/kg in the field; application labor for fertilizer = $150/ha

b) Factor B (included with factor A due to interaction with that factor)

c) Factor C (not significant and no significant interaction - choose least-cost level)

LEVEL	TREATMENT	COST
C0	No Boron	0
C1	1 kg/ha Boron	>0

d) Factor D (not significant and no significant interaction - choose least-cost level)

LEVEL	TREATMENT	COST
D0	No Zinc	0
D1	2 kg/ha Zinc	>0

Table 8. Statistical Analysis of Fertilizer Experiment, North Veracruz 1980A

Source of Variation	Observed F[1/]
A	135.27
B	0.44
C	1.61
D	0.29
AB	4.24
AC	1.04
AD	2.30
BC	0.29
BD	0.02
CD	2.43
ABC	2.18
ABD	1.40
ACD	0.11
BCD	0.33

1/ Tabular F for 0.05 significance level 4.60

100 kg/ha N is highly profitable (MRR = 284%) and that the addition of 80 kg/ha P to the N dose is only profitable when capital is abundant (cost of capital must be less than 39% per cycle). The analysis by which these conclusions were obtained was far simpler than a complete treatment by treatment analysis, in which all 16 individual treatments would be compared.

4.0 Conclusions

The 2^4 factorial experiment have become more popular in on-farm agronomic research, but the economic analysis of these experiments is somewhat complicated. The purpose of this paper was to describe a method of economic analysis that focuses on factors, not on individual treatments, and that uses the result of statistical analysis to help plan economic analysis.

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