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DERIVING OPTIMUM FERTILIZER LEVELS: THE NAIVE ECONOMIST VERSUS THE PRACTICAL FARMER

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Training Note

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1.0 Introduction

In establishing fertilizer recommendations for farmers, standard production function analysis has been widely applied to the analysis of fertilizer experimental data in order to derive optimal levels of fertilizer. That is, regression analysis is used to fit a suitable response function and then optimal levels are calculated by setting the marginal productivity of nutrients (given by differentiation of the function) equal to the ratio of the price of nutrients to the price of the crop.

Several methodological studies have focused in depth on questions of experimental design and statistics relating to the estimation of the function (e.g. Baum, Heady and Blackmore, Heady and Dillon, Colwell). However, none of these really addresses the practical questions of relating experimental results and prices to those faced by farmers. This note shows that, particularly for small farmers, the naive assumptions on yields and prices usually used by economists in this type of analysis may lead to unrealistically high levels of fertilizer recommendations which the farmer would never find practical (or profitable) to adopt.

2.0 The Fertilizer Experiments

Data for this example are taken from a series of on-farm fertilizer experiments conducted as part of CIMMYT's maize training program in the northern part of Veracruz State, Mexico. The experiments are based on a standard factorial design with four levels of nitrogen (0, 50, 100, 150 Kg/ha) and three levels of phosporous (0, 40, 80 Kg/ha) all applied at planting. For purposes of this analysis, data from experiments conducted between 1973 and 1977 in the winter cycle on flat vertisol soils are used to provide some homogeneity to the underlying conditions of the experiments. (Data are shown in Table 1.)

3.0 The Fitted Response Function

Polynomial functional forms were used to represent the data since they provide substantial flexibility and also facilitate computations. The quadratic form was chosen after testing other forms. Fitted functions are shown in Table 2.

The phosphorous response is rot statistically significant nor is there an economic response. The interaction between N and P is very small and contrary to expectations has a negative sign. For these reasons the P terms are dropped and the function re-estimated using only N. This has very little effect on the coefficients of the N terms. The R^2 in the fitted function is low indicating the substantial year to year and site to site variability in the area.

4.0 Derivation of Optimal Fertilizer Levels

Optimal fertilizer levels under various yield and price assumptions were derived from the fitted function. The first set of assumptions uses the unadjusted price ratios and actual experimental yields normally used by economists. These assumptions are then made more realistic by adjusting costs and benefits to reflect farmer circumstances following procedures outlined in CIMMYT's manual "From Agronomic Data to Farmer Recommendations" (Perrin et al, 1976).

The optimal level of nitrogen is easily derived from the equation in Table 2 by setting marginal productivity of nitrogen equal to the ratio of prices of nitrogen P_n and maize P_y, i.e.

$$13.0788 - (2.0 \times .045196N) = \frac{P_n}{P_y}$$

Representing this price ratio (P_n/P_Y) as r, we can obtain the optimal level of nitrogen, N*, as:

$$N^* = \frac{(13.0788 - r)}{.090392}$$

4.1 The Naive Assumptions and Price Adjustments

We begin by assuming the official prices for urea (46% nitrogen) and maize. In 1969 these were 2.7/kg of urea, or \$5.87/kg of N, bought from the official distributor of fertilizer and \$2.9/kg for maize bought by the official marketing agency, giving a price ratio, r, of 2.02 and and optimal level of nitrogen of 122 kg N/ha.

However, farmers rarely have an opportunity to buy fertilizer and sell maize at these prices. Fertilizer is usually distributed in the area through the official bank which charges \$3.20/kg urea. Moreover, most farmers do not sell maize through the official marketing agency because the net price received is lower than the official price due to quality and moisture discounts and because farmers must bear the cost of transportation to the official buying agency. For these reasons, the farmers usually sell to private buyers who pass through the village. A recent survey showed this price to average \$2.75/kg maize[1/]. Using prices farmers actually pay and received, we arrive at a price ratio of r = 2.53 and an N* of 117 kg/ha which is only slightly less than the optimum using official prices.

4.2 Adjustment to Costs

While the cost of purchasing fertilizer is one of the major costs in fertilizer use, there are also several other costs that the farmer incurs. These costs are the transport of fertilizer from the store to the farm, the extra labor required for fertilizer application, the cost of harvesting the extra yield gained from fertilizer use and finally the cost of the capital needed for purchasing fertilizer. Let's look at each of these costs in turn.

1/ In fact there is about a 30 percent seasonal fluctuation in maize prices. The price used reflects sales about two months after harvest when most farmers sell their maize.

Cost of Transport: To the small farmer who may buy just a few bags of fertilizer, the cost of transport often adds to 10 percent or more to the cost of fertilizer depending on the conditions of the local transport system and the network of distribution points. In this case we have estimated (from conversations with farmers) that it costs about $10 to transport a 50kg bag of urea by local buses from the distribution point to the farm; or about 6 percent of the fertilizer cost.[1/]

Application Labor: The recommended method for fertilizer application (and the one used in the experiments) is to make another hole at planting next to the planting hole, drop the fertilizer in the hole, and cover. This involves considerable extra labor at planting time which might be estimated conservatively as 4 days/ha for applying 100 kg N/ha. However, application labor does not increase proportionally with the amount of fertilizer applied, since operations such as making holes and covering fertilizer must be performed regardless of the amount of fertilizer used (except, of course, for zero levels). For convenience we assume that each 50 kg/ha extra of nitrogen applied requires one extra day of planting labor. Since planting time is a busy time for farmers, this labor can be realistically valued at the going wage rate for hired labor at this season of $50/day. That is, there is an additional cost of $1.0/kg of N applied for application labor.

Cost of Harvesting: The addition of fertilizer raises yields which requires additional labor for harvesting, transporting and shelling the extra maize. In conversations with farmers, these costs were estimated as follows:

Harvesting - 3 days/ton at $50/day	$150/ton
Transport from field to house - 2 days/ton	$100/ton
Shelling - 3 days/ton	$150/ton

1/ This is actually quite cheap. In one recent study, local transport and handling charges were estimated to add 30-50 percent to the cost of fertilizer to the farmers in their area. (Bruce et al, 1979) that is, each extra ton of maize harvested will incur about $400/ton in extra harvesting costs.

Cost of Capital: The farmer using fertilizer will make a considerable cash outlay for fertilizer purchase and application at the beginning of the season which he will not recuperate until after harvest. If the farmer is short of capital he must borrow this money, thus incurring direct costs of interest charges, or he must use his own money at an opportunity cost that the money would have in other operations on maize (e.g. weeding) or in other activities. Capital is usually in short supply to small farmers and interest rates on an annual basis in the informal money market are usually 50 - 100 percent or more, reflecting this scarcity. For the area in question, we will conservatively assume a 50 percent cost of capital.

Optimal Levels with All Costs Included: Including all of the above costs, we can now arrive at a new price relationship. The cost of fertilizer applied is equal to the price paid by the farmer plus cost of transport ($0.2/kg) plus cost of application ($1.0 /kg) plus cost of capital (50 percent), i.e.

$$\left[\left(\frac{3.2 + .2}{.46}\right) + 1.0\right] \times 1.50 = \$12.6/\text{kg}$$

The extra cost of harvesting which varies proportionally with yields is best subtracted from the price of maize to give a field price of maize. That is, the field prices of maize is 2.7 - .4 = $2.3/kg. The new price relationship is now r = 5.48 and the optimal level of N is 84/kg/ha, a reduction of about 40 kg/ha from the case in which the cost of purchasing fertilizer was naively assumed to be the only cost.

4.3 Adjustments to Yields

Difference Between Farmers' and Experimental Yields: Yields used in the above calculations were derived from experiments managed by researchers in farmers' fields. The question arises to what extent these yields would be obtained by farmers themselves. For several reasons we expect farmers to realize lower yields.

First, yields on small experiments plots are usually higher than on large commercial fields. One reason for this is simply border effects which are higher for small plots. In the current situation these effects are probably negligible because relatively large plots were used (20 m^2) and border rows were planted.

Another reason for higher experimental yields is that small plots can be managed carefully, by more precise spacing, more timely weeding, etc. than is possible or practical for farmers to use. In the present case, there are differences between experimental management and farmer management which we would expect to lead to yield differences. First experiments were planted at precise spacings and thinned to give the desired density. This is done because experimental error may be unacceptably high with irregular stands in small plots. Second, chemical weed control was used on the experiments while most farmers weed with hoes. However, since it is unlikely that fertilizer could be profitably adopted in the area without better weed control, it is assumed that we are developing fertilizer recommendations for farmers who have adopted the recommended chemical weed control technique.

Finally, the largest difference between experimental and farmer yields arises because of differences in harvesting technique. Experiments are harvested at physiological maturity or approximately 25-30% moisture content and yields converted to 15% moisture equivalent. Farmers who do not have mechanical driers must wait up to a month longer to allow the maize to dry to a moisture percentage of 15-20% in the field. During this period there is considerable loss of maize due to insects and birds. One recent study in the area estimated an average yield loss of from 15 to 30 percent between physiological maturity and when farmers harvest (Galt, 1977). Altogether then, we might conservatively expect farmers' yields to be about 20 percent less than experimental yields - 15 percent because of differences in harvesting technique and 5 percent due to other experimental management practices such as precise spacing and thinning.

Losses Due to Adverse Weather: It is common for both researchers and farmers to lose or almost lose a field of maize (or at least have years when yields are very low and there is no measurable response to fertilizer). This is the case in the study area where in the winter cycle under examination, it is common to have prolonged dry periods in the middle of the growing cycle. Farmers estimate that they completely lose or obtain very low yields in one year in five due to drought. Researchers have also experienced losses resulting in abandoning the experiment but less frequently than farmers because of better moisture retention under herbicide based zero tillage.

We assume then that in one year in five (not represented in the experimental data) yields are very low and there is no measurable response to nitrogen. Whether yields are assumed to be zero, 500 kg/ha or 750 kg/ha in these years will not affect the deriviation of optimal nitrogen levels which depend on marginal nitrogen response which can reasonably be assumed to be zero in these years.

Optimal Levels with Yields Adjusted: The optimum nitrogen level was re-computed with downward adjustments to experimental yields of 20 percent due to experimental management practices, particularly harvesting technique, and a further 20 percent adjustment to account for losses in drought years which are not reflected in the experimental data. This resulted in a final recommendation of 50 kg N/ha.

5.0 Conclusion

The simple example used in this note has shown that when realistic assumptions of farmers' costs and yields are used, the optimum level of fertilizer use can be substantially lower than would be predicted by the usual naive application by economists of marginal analysis. In the example used, optimal nitrogen application rates were reduced from 120 kg/ha when marginal response to nitrogen is equated to the nitrogen/maize price ratio to 50 kg/ha when realistic costs and yield figures were used. These costs and yield adjustments are particularly important in the case of small farmers, who often have poor access to inputs, a high opportunity cost of capital and who use management practices such as drying of maize in the field to improve storage which are substantially different to experimental procedures.

Of course, the assumptions used in adjusting costs and yields in the example are only approximate and the optimal level of nitrogen might vary between 40 kg/ha and 75 kg/ha depending on the yield adjustment and cost of capital assumed. In fact, farmers in the area who use nitrogen fertilizer were found in a recent survey to apply an average of 47 kg N/ha - very close to the predicted optimum.

Finally, we have used regression analysis in this example to compute optimal fertilizer use as this is the most common procedure used by economists in the analysis of data from fertilizer experiments. However, we could have more easily used partial budgeting procedures to compare the various treatments (0, 50, 100, 150 kg N/ha) following Perrin et al (1976). In fact, the partial budget analysis using the same cost and yield adjustment gives us the same recommended nitrogen level of 50 kg/ha. Although regression analysis is useful to smooth data and interpolate between points, partial budgeting of the treatments will usually give us very similar results - certainly at the general level of precision needed to make recommendations to farmers. The realism of cost and yield assumptions used in the analysis is more important than the analytical technique employed.

TABLE 1. YIELDS OBSERVED IN EIGHT NXP FERTILIZER IN NORTHERN WINTER CYCLE, 1973 - 1977

TREATMENT N (kg/ha)	P	1	2	3	4	5	6	7	8
0	0	1855	1495	2915	1895	2765	3690	2900	3600
0	40	2000	1785	2620	2205	2605	4430	2900	3300
0	80	2535	1550	3225	2080	2645	4015	2200	3700
50	0	3715	2930	3145	2875	2730	4185	3000	3400
50	40	3540	3205	3555	2410	2675	4717	4000	4100
50	80	3350	2785	3455	2325	3150	5390	3400	4500
100	0	3645	3635	3110	2890	2250	4130	3300	5300
100	40	3475	3080	3465	2965	2325	4190	3400	4300
100	80	4010	2760	3215	2840	2240	5705	2900	4000
150	0	3265	3120	3415	3110	2560	6250	3300	5200
150	40	4020	3670	3070	3105	2225	5570	2400	5500
150	80	3985	3800	3410	2790	2655	5290	3200	5000

TABLE 2. ESTIMATED RESPONSE FUNCTION FOR NITROGEN AND PHOSPHOROUS BASED IN RESULTS OF EIGHT EXPERIMENTS ON MAIZE IN NORTHERN VERACRUZ, MEXICO.a/

	Estimate with N & P	Estimate excluding P
Coefficient for:		
N	13.796 (6.105)	13.079 (5.732)
N^2	- .0452 (.0372)	- .0452 (.0368)
P	2.282 (10.948)	
P^2	.0006 (.1232)	
N x P	- .0179 (.0509)	
Constant	2660 (271)	2753 (178)
R^2	.15	.15

a/ All units in kg/ha. Standard errors are given in brackets.

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