ECONOMIC ASPECTS OF FERTILIZER USE FOR MAIZE

(Met opsomming in Afrikaans)

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Abstract

An economic analysis of maize/fertilizer experimental data is demonstrated. Two different production functions are represented diagrammatically and points of maximum profit and maximum percentage return are found. The profit is estimated at these and other points in order to evaluate the usefulness of the analysis. It is concluded that the economic analysis is valuable but only practical if a suitable research team is available.

Introduction

As land prices increase it is becoming more and more important for farmers to adopt a businesslike approach to their farming. They should ensure that the capital that they employ in running their farms is achieving the maximum possible return. In the case of maize, where fertilizer costs can be more than fifty per cent of all other costs incurred, it is highly desirable that a farmer be aware of the profitability of his fertilizer applications; he should be asking "how much?" rather than "should I use this or that?". The purpose of this paper is to demonstrate how economic levels of application for maize can be estimated from the results of field trials and to demonstrate the possible attendant increase in profits.

At this stage it is worth noting that work on economic fertilizer applications has been carried out for some time in other parts of the world. In America such work started in 1950 (Heady & Dillon, 1961); in Britain the economics of fertilizer use was considered by Crowther & Yates (1941), and Colwell in Australia has been active in this field since about 1960 (Colwell, 1967). Our lack of progress in such research is noted by Skeen (1973).

The central methodological problems in determining economic optima are statistical and involve expressing maize yield in terms of fertilizer applied or, where possible, soil-test values and choosing suitable experimental designs that will supply practically useful results. While there are many practical difficulties in this work there is a considerable bank of information in various agronomic, economic and statistical journals which can be used. The two examples to be presented in this paper indicate that useful results can be obtained.

Economic considerations

Heady & Dillon (1961) describe the use of production functions to determine economic optima. Two points which are relevant in our context are (i) the point at which the profit is maximised and (ii) the point at which the percentage return on investment is maximised. These two points are now more explicitly described.

Suppose that we are dealing with N, P and K applications, then a common production function is

$$y = b_0 + b_1N + b_2P + b_3K + b_4N^2 + b_5P^2 + b_6K^2 + b_7NP + b_8NK + b_9PK$$

where y represents crop yield, N, P and K represented rates of fertilizer application and the b_i ($i = 0, 1, \ldots\ldots 9$) are regression coefficients. The cost (C) of producing a given yield of maize can be written as

$$C = F + p_nN + p_pP + p_kK$$

where F is the fixed cost which includes land preparation, harvesting costs etc and p_n, p_p and p_k are the prices per unit of N, P and K, respectively. If p_y is taken as the price a farmer gets per unit of yield the economic optimum (i) is attained at that level of fertilization for which $yp_y - C$ is maximum and (ii) is attained at that level of fertilization which yp_y/C is a maximum. These two points are suggested as upper and lower bounds respectively for fertilizer application. The calculation of the first is fairly simple (Heady & Dillon, 1961) but the calculation of the second is more difficult and involves the use of Lagrange multipliers and latent roots of matrices. Happily both sets of calculations are readily computerised and have in fact been programmed for an IBM 1130 (Mapham, 1975).

For the purposes of this paper the following costs and units will be used. Maize grain yield and amounts of N, P and K will be expressed as kilograms per hectare unless otherwise stated. The return per ton (1 000 kg) of maize will be taken as R56 and the price per kilogram of N, P and K as 34c, 66c and 26c respectively. Finally the fixed costs will be taken as R110 per hectare. Of course these costings may vary from place to place and particular situations may require particular analyses. For example the most profitable level of fertilization given some restriction on available capital may be required. Given a realistic production function such considerations are easily catered for.

Example A

During the 1971/72 season the research division of the Fertilizer Society ran twenty-nine field trials involving N, P and K. A San Cristobal design in three replicates was used and the experiments were laid down throughout the maize triangle. (Möhr, 1972). This example is the analysis of one of these experiments. A quadratic production function was fitted using ordinary least squares methods and came out as

$$y = 3648 + 40{,}8N + 11{,}3P + 45{,}3K - 0{,}35N^2 - 0{,}07P^2 - 1{,}20K^2 - 0{,}01NP - 0{,}26NK - 0{,}15PK$$

The multiple correlation coefficient, or the correlation coefficient between observed yields and yields estimated from the production function was R = 0,9107. This is an indication of the very good fit obtained. A diagramatic representation of this surface is given in Figures 1, 2 and 3. Contours of equal yield are plotted for varying levels for this type of investigation.

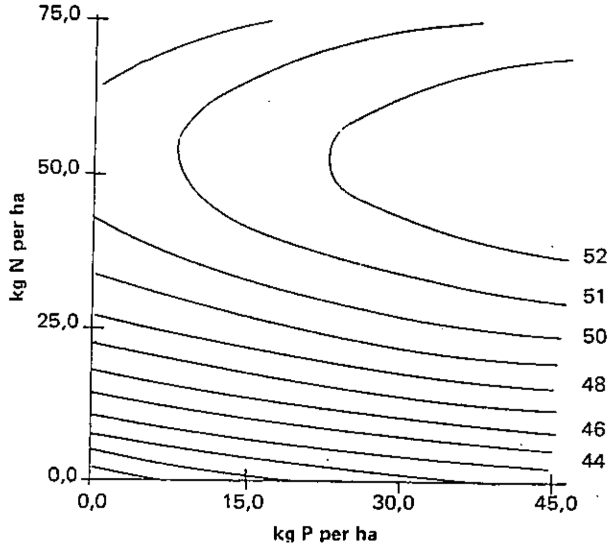

Fig 1 *Lines of equal yield in 100 kg units for levels of N and P restricted to the experimental range and K = 13 kg/ha*

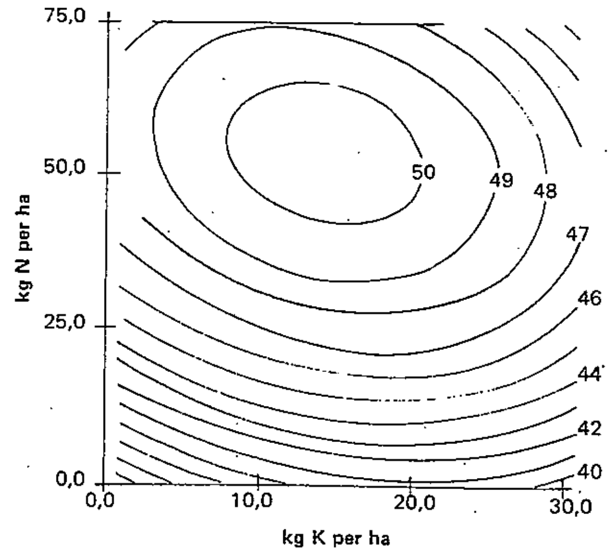

Fig 2 *Lines of equal yield in 100 kg units for levels of N and K restricted to the experimental area and P = 0.*

The production function gives us the following optimal fertilizer applications:

A1 *The maximum yield* within the experimental area if 5 296 kg per hectare at N = 54, P = 45 and K = 9kg/ha

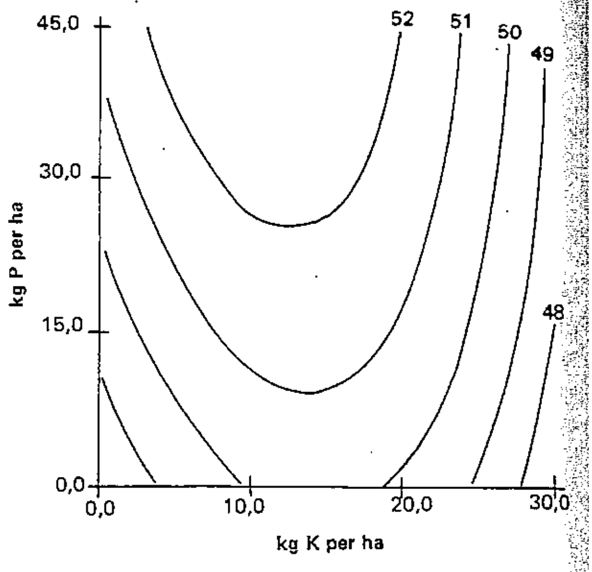

Fig 3 *Lines of equal yield in 100 kg units for levels of P and K restricted to the experimental range and N = 47 kg/ha*

The profit at this point is R136 per ha and the percentage of return to investment or costs is 184.

A2 *The maximum profit* within the experimental area is obtained at N = 45, P = 0 and K = 12 kg/ha
Here the yield is 5 006 kg/ha, the profit is R152 per ha and the percentage return is 218.

A3 *The maximum percentage return* within the experimental area is at N = 35, P = 0 and K = 11 kg/ha
where the yield is 4 900 kg/ha, the profit is R150 per ha and the percentage return is 220.

A4 If costs and relative fertilizer prices are not taken into consideration a *recommendation* of N = 50, P = 20 and K = 0 kg/ha could easily be made for which the yield is estimated as 5 001 kg/ha, the profit is R140 per ha and the percentage return is 200.

It is obvious that the level of fertilization which gives maximum yield A1 is not the most economic. Most agriculturists recognise this of course, but what is just as important is the comparison between the 'recommendations' with no P and some K (A2) and (A3), and the 'recommendation' with some P and no K (A4). It can be seen that although the yield is much the same there is a fairly substantial difference in profit. Previous fertilization has in fact so built up the P status of this soil that further applications are not economic.

A restriction on the usefulness of the above analysis is the fact that yield is expressed in terms of levels of fertilizer applied. Thus the conclusions hold only for that particular site and so as a tool for prediction fertilizer requirements some intuition and experience must be relied on. If on the other hand yield is related to soil test values then soil tests can be used to determine the optimum levels of fertilization.

Example B

This example is the economic analysis of a 4^3 fertilizer trial with N, P and K run in the Natal Midlands (Farina, 1974). For this experiment a soil test on each of the plots in the trial was made before and two weeks after fertilization. A highly significant linear relationship between P applied (P_A) and increase in soil test for P (P_{ST}) was observed; the equation was $P_{ST} = -0{,}14 + 0{,}263P_A$ where P_{ST} is in parts per million and P_A is in kg per hectare, and the correlation coefficient between observed and fitted values was 0,869. This relationship can be used to determine the amount of P that is neeeded to raise the soil test value by 1 ppm. Hence the cost of raising the soil test by 1 ppm can be estimated. The same can be done for K but for this experiment the effect of K was negligible and it will not be considered further. We can now proceed to find a suitable production function in terms of N applied and P soil test and calculate our optimum points as before. However for this data a square root function (R = 0,9322) fitted the data better than the quadratic function (R = 0,9161) used in example A. This square root function was estimated as

$$y = 57 - 0{,}267N - 309P + 12{,}78N^{\frac{1}{2}} + 2833P^{\frac{1}{2}} + 24{,}14N^{\frac{1}{2}}P^{\frac{1}{2}}$$

with y the estimated yield in kg/ha, N in kg/ha and P in ppm according to the soil test. A diagrammatical representation of this surface is given in Figure 4.

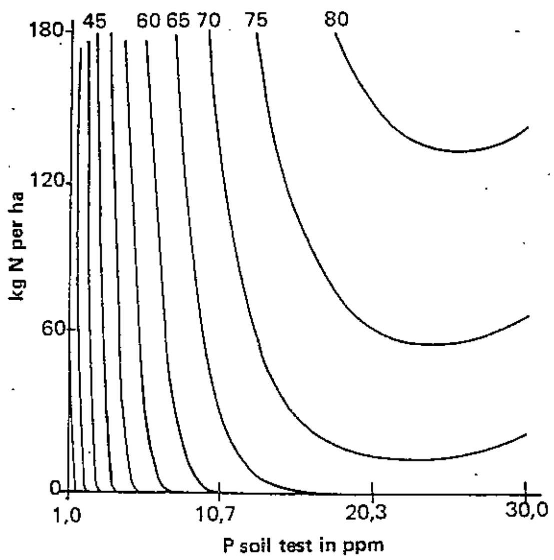

FIG 4 Lines of equal yield in 100 kg units for N and P within experimental range

The use of the square root function for calculating economic optimum points involves different techniques to the quadratic function. These techniques have also been computerised and the optimal fertilizer 'recommendations' are as follows:

B1 *The maximum yield* within the experimental area is 8 243 kg/ha at N = 180 kg/ha and P = 26 ppm (75* kg applied)
At this nutrient level the estimated profit is R225 per ha, and the percentage return is 195.

B2 *The maximum profit* is obtained at
N = 86 kg/ha and P = 19 ppm (53* kg)
for which the yield is 7 606 kg/ha, the profit is R239 per ha and the percentage return is 228.

B3 *The maximum percentage return* is at
N = 10 kg/ha and P = 12 ppm (31* kg)
Here yield is 6 465 kg/ha, the profit is R219 per ha and the percentage return is 252.

B4 Using *no fertilizer* at all the yield is estimated as 3 513 kg/ha, the profit is R87 per ha and the percentage return is 179.

The closeness of the recommendations in B1 and B2 is due to the recommendation for maximum yield being restricted to lie within the experimental area. For this production function recommendations would lie in the range of 15 to 144 kg N per hectare and 34 to 56 kg P per hectare as given in B2 and B3. Applications above the upper limit will tend to decrease profits while if it is worth growing maize at all it is worth fertilizing to the lower limit (Bishop & Toussaint, 1958, p 40). Using no fertilizer at all (B4) is obviously irrational. The advantage of using soil test values in the production function is that fertilizer recommendations can be predicted at the beginning of a season taking into account the nutrient status of the soil as measured by a soil test.

Discussion

The economic importance of recommendations based on response surface analysis is clearly demonstrated in the two examples. If agriculture in South Africa develops similarly to agriculture in America and Australia a demand for these more sophisticated recommendations by farmers and extension agencies is likely to develop (Dillon, 1968, p 114). However results based on field experimentation can be criticised. Responses can vary a great deal from region to region and also from season to season. Also crop yields under experimental conditions tend to be somewhat higher than yields achieved under ordinary farm conditions.

*The relationship between P applied and soil test takes into account a residual effect from the previous year's experiment.

Results from one or two large experiments can not in general be applied reliably to large areas which may include different ecological zones for example.

Hartley (1965) recognises these problems and suggests conducting survey-experiments where trials are laid down over a range of sites in any particular region. If an area is classified according to soil form and bioclimatic characteristics and homogeneous sub-areas are investigated then there is a good chance that practically usable results will be obtained. By choosing experimental designs which are smaller than conventional factorials, a larger number of sites can be included in the sample from the sub-area for the same amount of effort. Hartley *op cit* suggests using composite designs although there are several designs available which might also be suitable. Thus information on the reproducibility of the production function can be obtained. That this approach is practical is demonstrated by Möhr (1972) who has actually applied this sort of survey-experimentation.

Heady & Dillon (1961) suggest either the above approach or the use of real-life data (ie data from actual farm activities). They give a comprehensive account of the respective advantages and shortcomings of both methods. For fertilizer production functions they prefer data obtained from controlled experiments although they point out that the two approaches are to a certain extent complimentary. In conclusion then, the production function approach to fertilizer recommendations may give valuable results but a team involving statisticians and agronomists or soil scientists is essential for a successful investigation.

Opsomming

EKONOMIESE ASPEKTE BY BEMESTING VAN MIELIES

'n Ekonomiese ontleding van data van mielie/kunsmis proewe word gedemonstreer. Twee verskillende produksiefunksies word diagramaties aangedui en punte van maksimum wins en maksimum persentasie omset word bepaal. Om die waarde van die ontleding te evalueer word die wins by hierdie en ander punte beraam. Die gevolgtrekking word gemaak dat die ekonomiese ontleding waardevol is maar slegs prakties uitvoerbaar waar 'n geskikte navorsingspan beskikbaar is.

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References

BISHOP, C.E. & TOUSSAINT, W.D., 1958. Agricultural economic analysis. Wiley, New York.

COLWELL, J.D., 1967. The calibration of soil tests. J. Austr. Inst. Agric. Sci., 33, 321–330.

CROWTHER, E.M. & YATES, F. 1941. Fertilizer policy in war-time. Emp. J. Exp. Agric., 9, 77–97.

DILLON, J.L., 1968. The analysis of response in crop and livestock production. Perganon press.

FARINA, M.P.W., 1974. Natal regional research project No NCe 106/21.

HARTLEY, H.O., 1965. Experimental designs for estimating the characteristics of production functions. OECD, Documentation in agriculture and food, 65, 163–175.

HEADY, E.O. & DILLON, J.L., 1961. Agricultural productions. Iowa State University Press, Ames, Iowa.

MAPHAM, W.R., 1975. Some biometrical aspects of soil calibration. M.Sc. (Agric) Thesis, Univ of Natal, Pietermaritzburg.

MÖHR, P.J., 1972. Die Misstofvereniging van Suid-Afrika navorsingsafdeling, aanhangsel tot navorsingsverslag nr. iv.

SKEEN, J.B., 1973. Evaluating the P-status of soils. Fert. Soc. S. Afr. J. 2, 69–74.