A SIMPLE FORTRAN IV PROGRAM FOR THE ECONOMIC EVALUATION OF CROP RESPONSE TO TWO VARIABLE RESOURCES

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Abstract

The economic evaluation of crop response to fertilization is an important aspect of crop response studies, and should be presented in an easily-understood form to encourage the acceptance of sound fertilization practices by the farmer. A FORTRAN IV program was written to meet this aim, and data from a sunflower trial in which four rates each of N and P had been applied were used for illustrative purposes. Sunflower seed yield (Y)(kg/ha) over three seasons was satisfactorily estimated by the generalized power function of the form, $Y^{0,63} = -41{,}203 + 0{,}61884X_1^{0,67} + 76{,}395X_2^{0,47} - 0{,}016939X_1^{1,34} - 10{,}062X_2^{0,94} + 0{,}21294X_1^{0,67}X_2^{0,47}$ ($R = 0{,}835^{**}$), where X_1 = N applied (kg/ha) and X_2 = P soil test (ppm 0,025 mol/dm^3 H_2SO_4-extractable). The FORTRAN IV program was used to establish points on the response surface, thus enabling its graphical presentation. Thereafter, the program was used to compute input requirements, net profit and return on investment in fertilizer for points on selected yield isoquants. Upon inspection, the economically-optimum rate of the two inputs was determined for each isoquant. Yield levels ensuring maximum net profit and maximum return on investment in fertilizer were established by inspection. The ease was illustrated with which program output could be used to present a readily-understood form of the economic implications of fertilizer application.

Introduction

With the decreasing profit margins of crop farming in recent years, the practices promoting increased crop yields, and particularly the increased profits therefrom, have been subjected to increasing scrutiny. Fertilization is one facet of crop production which can be managed by the farmer to effect increased yields. But it is essential for continued, financially-sound crop production that the economic aspects of fertilizer application be evaluated. In the long term, the energy balance of crop production should be considered as Bruwer (1977) concluded that fertilizer accounted for one third of the cultural energy inputs on US farms. But in the short term, the economic implications of fertilizer application are of considerable significance to the crop farmer.

The importance of the study of crop response functions has been stressed by Heady (1956) who concluded that every fertilizer recommendation to farmers implies knowledge of the mathematical nature of the response function. Two general approaches have been used in developing mathematical relationships between crop yield and various factors. The first approach involves a knowledge of the basic laws of plant behaviour, but has the drawback in that biological processes are extremely complex and the mathematical form of the response function is usually unknown. With the second approach, experimental data are studied by statistical methods, and an empirical equation of best fit is developed. The latter approach is the more common in fertilizer response studies.

A great number of functions have been used in studies relating yield (Y) to two variable resources (X_1 and X_2), and an infinite number of functional forms are possible in productivity studies (Heady & Dillon, 1961). In spite of the numerous forms of response functions that might be used, it is essential that a reliable and functional mathematical relationship be established between crop yield and the variable inputs. Without a reliable prognosis of yield response, erroneous conclusions could be made regarding the economic implications of the inputs required.

The quadratic and square root functions have been widely used in fertilizer response studies (Heady & Dillon, 1961; Farina, Mapham & Channon, 1975), and have advantages in that they are relatively easy to fit by least squares procedures and are flexible, enabling data from various locations and years to be fitted (Mason, 1956). Furthermore, these functions are amenable to economic analysis, an important consideration in the interpretation of fertilizer response data (Heady & Dillon, 1961; Mapham & Nevin, 1976).

On the other hand, the quadratic and square root functions may not adequately estimate the relationship between crop yield and fertilization because of an asymetrical response. But the generalized power function, $Y^V = a + b_1X_1^W + b_2X_2^Z + b_3(X_1^W)^2 + b_4(X_2^Z)^2 + b_5(X_1^WX_2^Z)$, may accommodate both symetrical and asymetrical yield responses to two variable resources. (This has recently been demonstrated by Adams and Hills (1977) for a single factor response.) The advantage of response surfaces with power transformations has probably best been stated by Lindsey (1972) who concluded that 'the large portion of the variation due to the environmental variables, unexplained after fitting the quadratic surface, is often associated with departures of the true biologic response from that expressed by the quadratic approximation.' (The quadratic and square root functions are, of course, only two examples of the infinite number of response functions that may be accommodated by the generalized power function.) The generalized power function has been used to advantage with biological data (Lindsey (1972) used the function for relating the cruising speed of goldfish to two temperature variables), but no information could be found regarding the use of this function in fertilizer response studies. Nor could any information be found regarding the economic interpretation of crop response to fertilizer application using the relatively complex generalized power function.

Despite the use of involved procedures in order to obtain a reliable, mathematical approximation of crop response, it is particularly important that the economic implications of fertilizer use be presented to the farmer in a simple, easily-understood form. In fact, complicated economic interpretation may be counter-productive to the adoption of financially-sound fertilizer practices. The aim of this paper is to present a simple FORTRAN IV program for the presentation of the economic evaluation of crop response to two variable resources in a readily understood form.

Materials and methods

In order to illustrate the application of the FORTRAN IV program, data were used from a sunflower field trial conducted for three seasons on a Doveton fine sandy clay at Dundee Agricultural Research Station. The cultivar, Kort Rus, was planted to ensure a population of 44 000 plants/ha. Four rates of N (0, 60, 120 and 180 kg N/ha) and four rates of P (0, 20, 40 and 60 kg P/ha) were applied annually in a 4^2 confounded factorial design with two replications. On average, an application of 6 kg P/ha increased the P soil test by 1 ppm (0,025 mol/dm^3 H_2SO_4-extractable) (Farina & Mapham, 1973).

In all seasons, there were highly significant yield reponses to N and P applied and highly significiant N x P interactions were recorded. Data from the three seasons were combined by expressing seed yield from each plot as a percentage of the mean maximum seed yield in each season. Yields were subsequently converted to kg/ha on the basis of 100 per cent = 2 520 kg/ha, this yield being the average of the mean maximum seed yields in the three seasons. (Since the data are from only three seasons, and no attempt has been made to establish the best P soil test method, the results are not presented as conclusive for prognostic purposes but solely to illustrate the procedures involved.)

A FORTRAN IV program was written in order to obtain estimated values of v, w and z, and the parameters, a and b_1 to b_5, for the generalized power function. After the method used by Adams and Hills (1977), the program calculates the values of v, w and z in stages using multiple regression analysis. The program user supplies minimum, incremental and maximum values of v, w and z. With v = 1 and w = 1, the optimum value of z is calculated as that which maximizes the correlation between the observed and fitted values of Y. The second and third stages involve a similar process in calculating the optimum values of w and v using previously established optimum values. The residuals (ie observed Y minus estimated Y) may be plotted against the estimated Y in order to ensure the absence of systematic deviations between the observed data and the fitted model. (A program listing is available on request.)

Using the combined data ($\underline{n}$ = 96) from the trial over three seasons for relating seed yield (Y) (kg/ha) to N applied (X_1) (kg/ha) and P soil test (X_2) (ppm), yields were satisfactorily predicted by the equation, $Y^{0,63} = -41,203 + 0,61884X_1^{0,67} + 76,395X_2^{0,47} - 0,016939X_1^{1,34} - 10,062X_2^{0,94} + 0,21294X_1^{0,67}X_2^{0,47}$ ($R = 0,835^{**}$), the fitted model accounting for 70 per cent of the observed variation in seed yield.

Economic interpretation of response data

The FORTRAN IV program for the economic interpretation of response data using the generalised power function is presented in Appendix 1. After reading and writing the heading and equation parameters, a decision is made regarding the plotting of the response surface. This is often desirable for the graphical illustration of crop response, but may not be required if the economics of crop response alone are being studied. This would be the case when the response surface has long since been established. The response surface for the sunflower data is presented in Figure 1.

In order that the results have greater economic interpretation and application, yield isoquants (ie contours of equal yield) should be calculated. Yield isoquants for the generalized power function may be presented as follows:

$$X_1 = [\ -(b_1 + b_5X_2^z) \pm (b_1 + b_5X_2^z)^2 - 4b_3(a - Y^v + b_2X_2^z + b_4(X_2^z)^2)^{0,05} / 2b_3]^{1/w}$$

In the study of a response function relating yield to two variable resources, the cost (C) of producing a certain yield (Y) may be calculated as, $C = F + X_1P_{X_1} + X_2P_{X_2}$, where

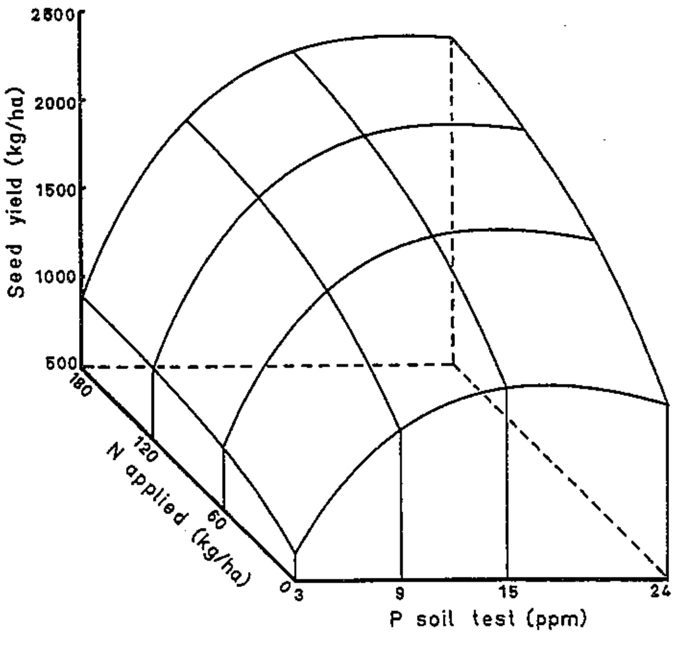

FIG 1 Response surface relating sunflower seed yield to N applied and P soil test over three seasons as estimated by the generalized power function

F are the fixed costs, X_1 and X_2 are the quantities of the two resources required to realize Y, and P_{X_1} and P_{X_2} are the unit prices of X_1 and X_2, respectively. A commonly-used optimum fertilizer rate is that at which net profit, $\pi = YP_Y - C$, is maximized (P_Y being the price received per unit of yield). On the other hand, where capital is limiting, the optimum level of fertilization more nearly approaches that point where return on investment in fertilizer, $R = YP_Y/C$, is maximized (Mapham & Nevin, 1976). The estimated production costs per hectare and producer prices averaged over three seasons at Dundee that will be used for illustrative purposes were as follows: F = R119-57; P_{X_1} = R0-36 per kg N applied; P_{X_2} = R3-67 per 1 ppm increase in P soil test; P_Y = R0-14 per kg sunflower seed.

The continued operation of the program after the calculation of points on the response surface is dependent on the decision being made whether or not to calculate the various economic parameters discussed above. (In preliminary studies on the shape of the response surface, it may not be necessary to investigate the economics of crop response.) Should this be required, the program user is called upon to supply the unit price of Y, the fixed cost and the unit prices of X_1 and X_2. The minimum, incremental and maximum values of the isoquant yields and X_2, as well as the maximum value of X_1, are also required.

With the use of this information, net profit and return on investment in fertilizer are computed for each selected point on each isoquant in turn. The isoquants may thus be plotted, as has been conducted for the data from the sunflower field trial (Figure 2). Using the information generated by the program, the economically optimum ratios of X_1 and X_2 for each yield level may be established by inspection. These optima lie on the isocline (ie the least cost combination of X_1 and X_2) as described by Heady and Dillon (1961). The isocline for the economic conditions prevailing at Dundee during the period of the trial is presented in Figure 2, the maximum net profit (π_{max}) and maximum return on investment in N and P fertilizer (R_{max}) being established by inspection. These two points on the isocline would represent the limits of the zone of rational production (Farina *et al*, 1975).

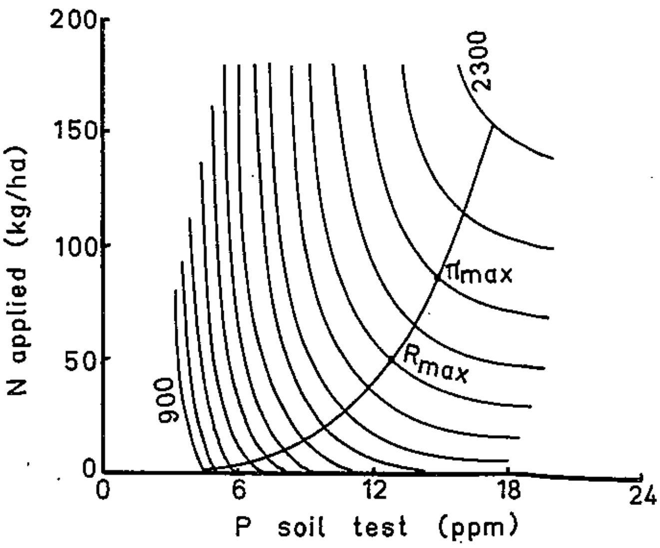

FIG 2 Sunflower seed yield isoquants in 100 kg/ha increments and the isocline of optimum economic return with the mean economic conditions at Dundee over three seasons

In order that the economic implications of crop response to fertilizer application have greater impact on the farmer, it is probably necessary that the data be presented in a slightly different form. To begin with, it would be advisable to illustrate the effect of changing X_1:X_2 ratios on the economics of crop production at a single yield level. This has been presented for the 1 600 kg/ha yield isoquant for sunflowers in the present study (Table 1), and it was interesting to note the marked differences in the profitability of production at the same yield level with variation in N and P applied.

In addition to the presentation of data on the profitability of production at a single yield level, the presentation of data for the economically-optimum levels of X_1 and X_2 at each yield level would probably assist in the acceptance of sound fertilization practices by the farmer. This has been

TABLE 1 Effect of changing N and P inputs on the economic returns at a single yield level

N applied (kg/ha)	P soil test (ppm)	Seed yield (kg/ha)	Gross income (R)	Production costs (R)	Net profit (R)	Investment return
110	7	1 600	224	184	40	1,22
54	8	1 600	224	168	56	1,33
31	9	1 600	224	164	60	1,37
18	10	1 600	224	163	61	1,38
10	11	1 600	224	164	60	1,37
6	12	1 600	224	166	58	1,35
3	13	1 600	224	168	56	1,33
2	14	1 600	224	171	53	1,31
1	15	1 600	224	175	49	1,28
0	16	1 600	224	178	46	1,26

TABLE 2 *Economic returns at various production levels with optimum N and P inputs*

N applied (kg/ha)	P soil test (ppm)	Seed yield (kg/ha)	Gross income (R)	Production costs (R)	Net profit (R)	Investment return
1	3	800	112	134	– 22	0,84
1	4	900	126	136	– 10	0,93
2	5	1 000	140	139	1	1,01
2	6	1 100	154	142	12	1,09
3	7	1 200	168	145	23	1,16
5	7	1 300	182	148	34	1,23
8	8	1 400	196	152	44	1,29
13	9	1 500	210	157	53	1,34
18	10	1 600	224	163	61	1,38
27	11	1 700	238	169	69	1,41
38	12	1 800	252	176	76	1,43
51	13	1 900	266	184	82	1,45
67	14	2 000	280	194	86	1,45
87	15	2 100	294	205	89	1,43
117	16	2 200	308	219	89	1,41
153	17	2 300	322	238	84	1,35

presented using program output for the response of sunflowers to N and P inputs (Table 2). It is noteworthy that marked differences were recorded in the profitability of sunflower production at different yield levels.

Furthermore, marked differences were recorded between the economically-optimum N:P ratios at the different yield levels. This emphasized the contention that nutrient interactions are important in nutrient response studies. As Farina *et al* (1975) concluded, 'it is significant that in present practice little or no cognisance is taken of nutrient interaction and it is not uncommon to find different quantities of the same fertilizer mixture being recommended for both high and low yield targets.' Output from the FORTRAN IV program emphasized the necessity of recognizing nutrient interactions because of their economic implications.

Summary and conclusions

The response of sunflowers to N applied and P soil test was used to illustrate the application of a simple FORTRAN IV program for the economic evaluation of crop response to two variable resources. In order to assess the economic implications of fertilizer use, it was necessary first of all to establish a mathematical estimate of crop response to the two inputs. The generalized power function was found to be satisfactory for this purpose, the fitted model accounting for 70 per cent of the observed variation in seed yield. There appeared to be no systematic deviations between the observed data and the fitted model.

With the generalized power function as an estimate of crop response to two variable resources, the FORTRAN IV program was used to plot points on the response surface which could then be illustrated. The next step was the computation of the input requirements, and the economic implications thereof, of points on the yield isoquants. Upon inspection, it was possible to determine the economically optimum rates of the two inputs at each yield level. Further inspection of the program output established the yields and the input rates ensuring maximum net profit and maximum return on investment in fertilizer.

Since a number of commonly-used production functions (eg the quadratic and square root functions) are individual applications of the generalized power function, the FORTRAN IV program could be used for the economic evaluation of crop response as estimated by these functions. Slight modification of the program could result in further sophistication of the economic evaluation of fertilizer response data. For example, the variable cost of harvesting and transporting different yields could be included in the cost function. The generalized power function may also be used to estimate crop response to more than two variable resources. Should this occur, a modification of the FORTRAN IV program could be effected for evaluating the economic implications of crop response to more than two variable resources.

It was considered important that the economic evaluation of crop response to fertilizer application be presented in an easily-understood form to ensure the adoption of sound fertilizer practices by the farmer. It was possible with the use of the program output to present economic data in a simple form in spite of the use of a relatively complex response function.

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