Vol XVII
No. 4

OCTOBER-
DECEMBER
1962

ISSN 0019-5014

INDIAN JOURNAL OF AGRICULTURAL ECONOMICS

INDIAN SOCIETY OF
AGRICULTURAL ECONOMICS,
BOMBAY

THE ECONOMICS OF FERTILIZER USE—A CASE STUDY IN PRODUCTION ECONOMICS[1]

W. David Hopper

To a plant, fertilizer is a source of nutrients that are essential for its vigorous development. To the farmer, it is a productive input which like labour and seed, must return more than it costs him. The first relation is one of plant response to nutrients—an agronomic matter; the second is one of costs and returns—an economic matter. Therefore, both the agronomist and the economist must bring their relevant specialities to bear when the farmer asks: "How much fertilizer should I use?"

The present exercise is an economic analysis relating to this query of the farmer. It begins where the agronomist finishes his work. It cannot begin before this point because it is only when the economist has the basic data on plant response to fertilizer (and/or other productive inputs) that he can bring his tools to bear on the problem. In this case, I have used some data from an experiment conducted at the Wheat Experiment Station, Powerkheda, Hoshangabad, (M.P.), given me by Robert Engle, fertilizer advisor, U.S.A.I.D. As an economist I am not in a position to judge the agronomic merits of the data, and only to the extent of these is my analysis valid. Also, in view of the limitations of the data, I would prefer that this analysis be regarded as an example wherein some of the tools of the production economist are marshalled to answer practical questions in agriculture. Only by the careful study of many such experiments can the economist accumulate sufficient background to confidently extend his results to farmers.

The experimental data used in this example involved per acre wheat yields that resulted from two, three, and four irrigations each with two, three, and four inches of water, and each of these with three levels of nitrogen and superphosphate (0, 30, and 60 pounds of N and P_2O_5 per acre), alone and in combination. Thus the datum for each experimental plot was associated with a unique level of water application, water amount, and pounds of nitrogen and P_2O_5. In all, 81 observations were available.

To be most useful to the economist, plant response information should be presented as a mathematical equation—this form is usually obtained by fitting a function to the experimental data by the technique of least squares. If the levels of inputs (treatments) used in the experiment go high enough, the function should reveal diminishing returns, *i.e.*, yield increasing at a decreasing rate. Probably the simplest such function for this experiment is a quadratic of the type:

---

1. This paper was originally prepared for non-economists as an introduction to the thinking and methods of the economist. It is with some hesitation that I accepted the suggestion that it be published in this Journal. I have agreed to do so in hopes that teachers of agricultural economics will find it useful for their courses. Professional economists will find much of the text elementary, but those interested in fertilizer response functions may find the analysis useful. The paper was first issued in mimeographic form as IADP Staff Working Paper No. 6201 ; the present revision has benefited from the comments of my colleagues on the "Package" Programme staff, and especially from the editorial suggestions of Mr. Bert Johnson.

$$Y = a_0 + a_1N + a_2P + a_3W + a_4A + a_{11}N^2 + a_{22}P^2 + a_{33}W^2 + a_{44}A^2$$

where Y is yield of wheat in pounds per acre, N is pounds of nitrogen per acre, P is pounds of P_2O_5 per acre, W is amount of irrigation water in inches, A is the number of irrigations, and the a's are the parameters (numerical constants) of which the last four (the quadratic terms) should be negative if the experiment reveals the area of diminishing returns.

However, a function of the above type does not include possible interactions between the different inputs—that is, the effect each may have in improving the performance of the others when they are used together. A complete interaction quadratic would take the following form :

$$Y = a_0 + a_1N = a_2P + a_3W + a_4A + a_{11}N^2 + a_{22}P^2 + a_{33}W^2 + a_{44}A^2$$

$$+ a_{12}NP + a_{13}NW + a_{14}NA + a_{23}PW + a_{24}PA + a_{34}WA$$

$$+ a_{123}NPW + a_{124}NPA + a_{234}PWA + a_{1234}NPWA$$

where the variables and parameters are as before. In practice such a function is rarely, if ever, used. An analysis of variance of the original data is usually done to determine which of the terms are statistically significant. Then a function that includes only these terms is fitted by least squares.

In the present case the following function was found to best fit the data from the wheat experiment.

$$Y = 413.32 + \underset{(2.63)}{12.98N} + \underset{(2.63)}{26.72P} + \underset{(20.41)}{136.60A} + \underset{(.0278)}{.196NP} - \underset{(.0393)}{.104N^2} - \underset{(.0393)}{.319P^2}$$

Standard error of estimate: 149.98 lbs. $R^2 = .924$

The figures in parentheses below each coefficient are standard errors which indicate that all the coefficients except that for N^2 are significant beyond the 1 per cent level and that the one for N^2 is significant above the 5 per cent level. The function indicates that variations in the levels of N, P, and A weighted according to the numerical constants, account for 92.4 per cent of the variation observed in the output of pounds of wheat per acre. Also, given the amounts of each variable (within the range of the experiment), it indicates that wheat yield per acre could be determined with a standard error of $\pm$ 149.98 lbs.

It is noteworthy that the *quantity* of water applied is not statistically important in these data, whereas the fact that *some* water was applied, and applied with increasing frequency, did add significantly to yields. Because rainfall data were not included with the experimental report, it is impossible to generalize about water requirements. The size and sign of the application parameter

(+136.60) must be taken to indicate that on those plots irrigated only two or three times the lack of water did affect yields, but that very little extra water, not over 2 inches, was actually needed for additional output. The quadratic term ($a_{44}A^2$) was not significant, implying that the experiment did not include a sufficient number of water applications (albeit small in the quantity of water applied) to indicate at what point diminishing returns to additional applications would occur. From the data at hand, it appears that each water application would add 136.60 $\pm$ 20.41 lbs. of wheat to the per acre yield.

Aside from the irrigation question, the most important use of the function is in exploring the production potentials and the economics of the use of nitrogen and superphosphate. In this case the function indicates diminishing returns to both nutrients, and a significant and positive interaction between them. Table I indicates the total wheat yield per acre (in lbs.) that would result from various levels of N and P_2O_5 in lbs. per acre (holding irrigation at one application, *i.e.*, A=1.0).

TABLE I—TOTAL POUNDS OF WHEAT/ACRE (Y)* AT DIFFERENT LEVELS OF N AND P_2O_5

Pounds of N/acre (N)									
140	329	838	1285	1666	1984	2239	2456	2557	2620
120	610	1080	1487	1830	2108	2324	2475	2563	2588
100	808	1244	1612	1915	2155	2331	2443	2492	2477
80	923	1315	1643	1907	2108	2245	2318	2327	2273
60	954	1307	1597	1821	1983	2080	2114	2085	1991
40	903	1216	1467	1652	1774	1833	1827	1759	1626
20	768	1042	1253	1400	1438	1502	1457	1349	1178
0	550	785	957	1064	1108	1088	1004	857	646
Pounds of P_2O_5/acre (P)	0	10	20	30	40	50	60	70	80

*From : $Y = 413.32 + 12.98N + 26.72P + 136.60A + .196\,NP - .104N^2 - .319P^2$ holding A constant at 1.0

Diagram I was derived from Table I by plotting the lines of equal output for various levels of each input. These "contour" lines define the "production surface." Clearly the farmer should never use combinations of N and P_2O_5 that lie outside the two straight lines F and H because higher production could be obtained by using smaller quantities of either input in combination with a given level of the other. For example, referring to Table I, if 20 lbs. of N is used it would be foolish to use 60 lbs. of P_2O_5 as this combination would produce only 1457 lbs. of wheat per acre when 20 lbs. of N and *50 lbs.* of P_2O_5 would produce a large amount—1502 lbs. per acre. Thus the economic decision of how much fertilizer to use lies inside the space bounded by the two lines.

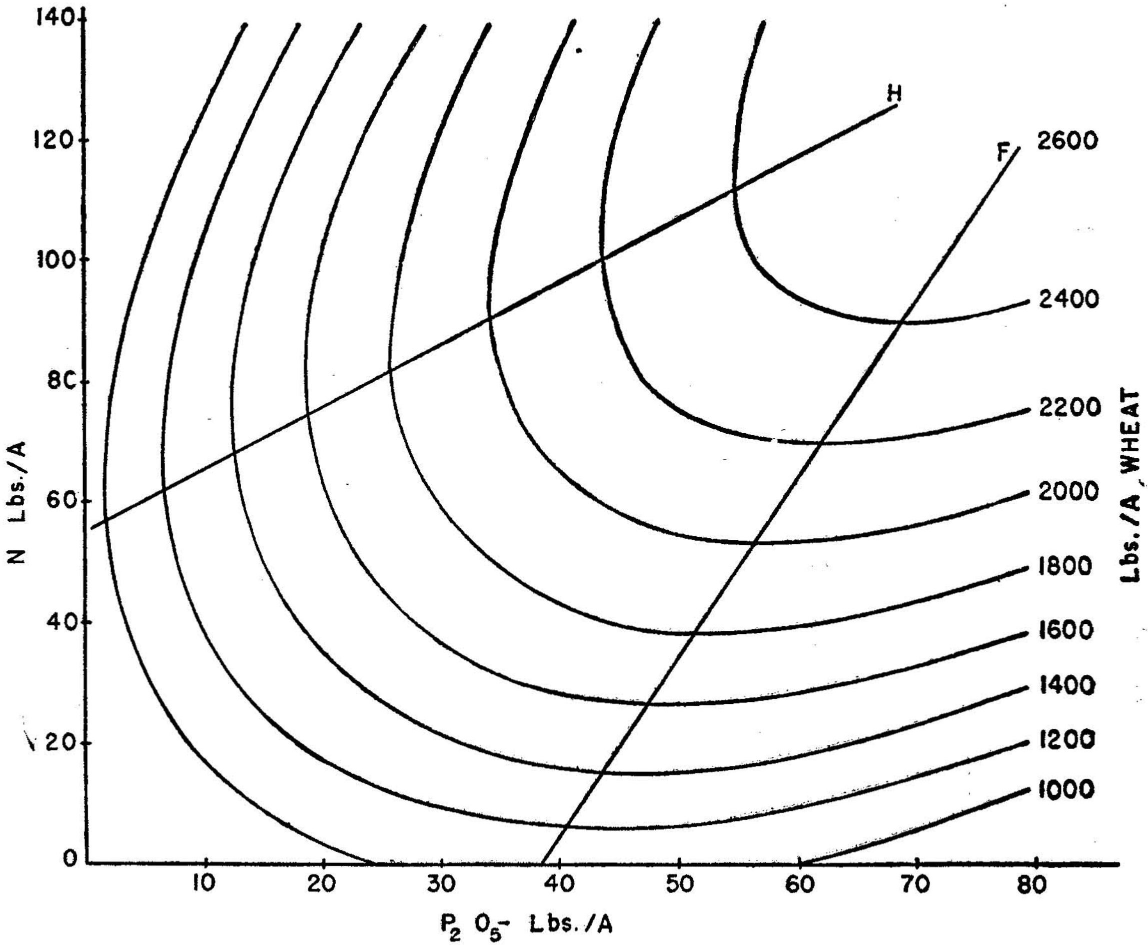

DIAGRAM 1

Within this space we can restrict our concern much more closely. Suppose the farmer had Rs. 30.00 to spend per acre for N and P_2O_5. If he spent it all on N which sells for Rs. 0.75 per lb. he could purchase 40 lbs. of nutrient. If he bought nothing but P_2O_5 at Rs. 0.50 per lb. he could buy 60 lbs. of phosphate. The straight line connecting these two points on the N and P axis in Diagram I would show all the combinations of N and P_2O_5 that can be purchased at these prices with Rs. 30.00. Similar lines may be drawn for Rs. 20.00, Rs. 40.00, etc., and if the prices of the two nutrients remain constant these lines will be parallel to each other, Diagram II-A. Superimposing this diagram on the lines of equal production plotted in Diagram I, it can be seen that each equal expenditure line will cut several equal product lines at two points (within the relevant range of decision-making) and will just touch the highest product line at one point. Obviously, it is this point of touch, or tangency, which is of the most interest to the farmer for it is at this point that he gains the highest yield of product of his given expenditure. Once this point is found, the optimum quantity of N and P_2O_5 to be used per acre may be read off the appropriate axis. In Diagram II-B the optimum points lie along line R, and for each expenditure line the best quantities of N and P are respectively N_1P_1, N_2P_2, etc.

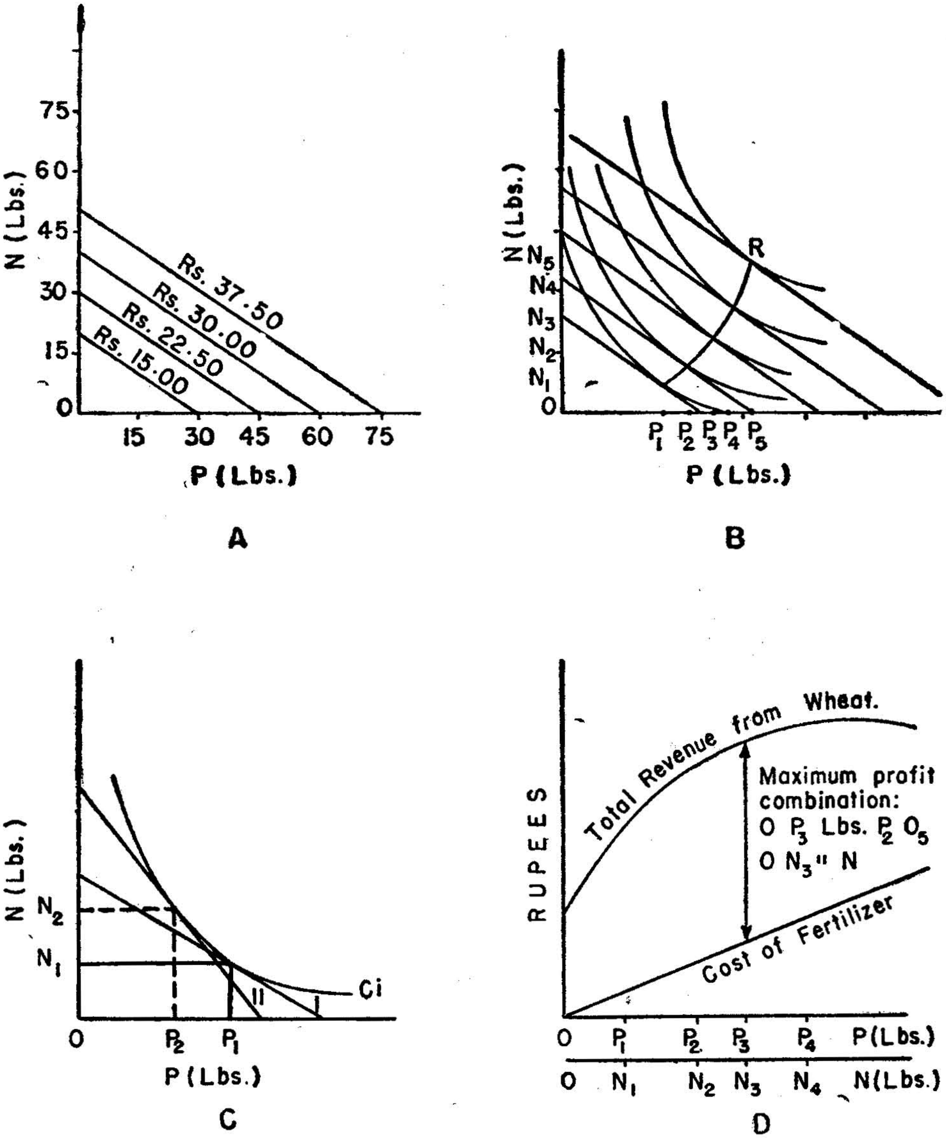

DIAGRAM II

We have now restricted our area of concern from the rather wide band in Diagram I to the line R in Diagram II-B. The exact location of this line is dependent upon the prices the farmer must pay for N and P_2O_5, their relative price determines the slope of the expenditure line. This is shown in diagram II-C where two lines I and II indicate two different sets of prices for N and P_2O_5 and

C_1 is any equal product contour. In the case of the first price set a given expenditure will buy less N than P and the optimum quantity of fertilizer to use is ON_1 and OP_1. In the second case the price of N is lower (so more can be bought) and the price of P is higher (so less can be purchased). Under these new prices the amount of N would increase to ON_2 because it is cheaper, and the amount of the relatively more expensive P would decrease to OP_2. This is just common sense. What it says is that, as prices change, the cheaper goods will be substituted for the expensive one, and its consumption will rise while the other falls.

So far we have not needed to refer to the price the farmer gets for his wheat. In fact if the farmer chooses beforehand how much he will spend on fertilizer, he will seek the combination of N and P_2O_5 which exhausts his budgeted amount and gives him the largest amount of grain regardless of its price. But our question was: "How much fertilizer should I use?" not: "If I want to spend Rs. x per acre, how much fertilizer should I use?". To answer this question we must find the *point* where the difference between the revenue from the sale of the wheat produced and the cost of the fertilizer is largest, *i.e.*, where profit is maximized. This point will be on line R (Diagram II-B) but its determination is difficult to demonstrate on a two-dimensional diagram of the II-B type. However, if the combinations of N and P_2O_5 on line R are plotted on matching horizontal axes (their scales will be different), the total revenue from the use of each combination could be plotted against the vertical axis by multiplying the total quantity of wheat associated with the combination by the price of wheat. Because of diminishing returns to added increments of fertilizer, this total revenue curve will increase at a decreasing rate. Plotting the total rupee costs of the fertilizer combination (which will rise as a straight line if the horizontal scale is adjusted correctly) on the same diagram, one could determine by inspection the location of the widest gap between the two lines and read off the combination of N and P_2O_5 that is most profitable. This is illustrated in Diagram II-D.

Once the basic diagrams are found several questions may be answered. One can determine how the optimum combinations of plant nutrients would vary with changes in prices of wheat, in N, and/or in P_2O_5. By discounting the response, say 20 or 30 per cent, as farmers might to allow for weather and other risks, one could determine the new optimum quantities of nutrients to be used. Such discounts, of course, would lower the total revenue curve and change the position of the maximum profit point. We can also determine how much a farmer could profitably pay for extra quantities of a scarce nutrient if he can purchase the other one in the market place and can sell his output for a known price.

In practice the economist uses the techniques of differential calculus to determine these optimum combinations of inputs and outputs. The logic behind these mathematical operations is precisely the logic of our diagrams, but the calculus is easier to use and more precise than graphical methods. This seeming precision, however, can be misleading. Though an "optimum" combination can be calculated to any number of decimal places, the statistical accuracy of the original data seldom provides the required foundation for such precision. Also, it is a rare farmer who can accurately differentiate in using .30 and 32 lbs, of N per acre let alone in using 30.6 and 30.8 lbs.

The basic relation from the experimental data is:

$$Y = 413.32 + 12.98N + 26.72P + 136.60A + .196NP - .104N^2 - .319P^2$$

which is purely a physical relation that reaches a maximum with respect to N at $\frac{\partial Y}{\partial N}=0$ and with respect to P_2O_5 at $\frac{\partial Y}{\partial P}=0$.[2] Solving these two differential equations simultaneously we find the maximum[3] physical production of wheat is 2499 + 136.60A lbs. per acre. This is reached when 143 lbs. of N and 86 lbs. of P_2O_5 are applied. These values are considerably beyond the range of the experiment and therefore should be treated with great caution. It will be noticed that the levels of N and P_2O_5 are jointly determined. This is because of the NP interaction—that is, the effect on yield of N depends not only on the plant's need for nitrogen, but also upon the level of P_2O_5 available tc work with the N. The more P_2O_5, the greater the effective utilization of N, and vice-versa. This is so regardless of how many applications of water are made within the range of the experiment.

Maximum profit from fertilizer will occur where $\frac{\partial Y}{\partial N} = \frac{P_n}{P_y}$ and $\frac{\partial Y}{\partial P} = \frac{P_p}{P_y}$ where P_y is the price of wheat per pound, P_n the price of N per pound, and P_p the price of P_2O_5 per pound. Assuming P_n=Rs. 0.75, P_p=Rs. 0.50 and P_y=.1585 (Rs. 13.00 per maund), the optimum rates of fertilization would be 103 lbs. of N and 68 lbs. of P_2O_5.

Using these same prices, the optimum combinations under other assumptions would be:

1. The farmer feels he must discount the experimental results by 20 per cent *i.e.*, he feels he can make only 80 per cent of the yield made at the experiment station. Optimum combination: N=94 lbs., P_2O_5=64 lbs.

2. The farmer makes a response discount of 20 per cent as before, and wants a 15 per cent return on the last rupee of his investment in fertilizer, *i.e.*, he feels that he can lend his money at 30 per cent per annum and asks that the six month crop season return him 15 per cent on his fertilizer investment. Optimum combination: N=87 lbs., P_2O_5 = 61 lbs.

3. Farmer is a share crop tenant who discounts his yield at 20 per cent, asks for a 15 per cent return on the last rupee of his money, but must pay his landlord one-half the crop although as tenant he must pay for all the fertilizers used. Optimum combination: N=32 lbs., P_2O_5 = 37 lbs.

2. I have chosen to use the basic calculus, necessary to derive the various answers that can be obtained from the experimental equation. For the reader unfamiliar with calculus, the logic has already been outlined. For the reader familar with calculus it should provide an interesting exercise to check my results. For those interested in the basic formulas any standard text on mathematical economics will indicate their proofs. Actually the derivations are very simple using only elementary maxima and minima operations.

3. This may be a maximum or minimum (or even an inflection point) depending upon the sign of the second derivation $\left(\frac{\partial^2 Y}{\partial N^2}\right)$. Because the second derivation of Y = f (N, P, A) is negative it will be a maximum. Indeed as both a_{11} and $a_{22} < 0$ all the maximization operations using first derivatives of the production function will produce maximums and we shall not refer to the second order conditions again.

4. Farmer discounts response by 20 per cent and wants a 15 per cent return to the last rupee spent, but is also afraid of a crop failure which he feels occurs one year in five (an additional 20 per cent risk). Optimum combination N = 74 lbs., P_2O_5 = 56 lbs.

5. Farmer discounts his yield by 50 per cent (not a high discount as about 20 per cent of the farmers whose crops were sampled in a recent crop cutting investigation had yields 50 per cent below the average), asks 15 per cent return as before and sees a risk of crop failure as one year in five. Optimum combination N = 32 lbs., P_2O_5 = 37 lbs.

In each case the maximum profit formula was used, but prices were adjusted to reflect the various assumed conditions. For example if the farmer wants 15 per cent on the last rupee spent for fertilizer, it means that the effective price of fertilizer increases by 15 per cent, or $P'_p = P_p\,(1.0 + .15)$ and $P'_n = P_n\,(1.0 + .15)$ where P'_n and P'_p are the adjusted prices. Likewise, if he discounts yield by 20 per cent, or wishes to add a 20 per cent discount for crop failure, the price of his product (P_y) would decrease by 20 per cent.

A word must be said about "return on money" used above. This is the return to the *last* rupee spent on fertilizer, not the *average* return on all the money spent for fertilizer. The distinction is important. Profit will be maximized where the last pound of fertilizer used adds to total revenue neither more nor less than its cost. If it adds more to revenue than it costs, the producer will gain by using another unit of fertilizer. If the last pound used adds less to revenue than it costs, its use reduces the total profit of the grower by the difference between the cost of the unit of fertilizer and the revenue its use earned. The largest profit from the use of fertilizer occurs at the point where the last increment of fertilizer just pays for itself. At this point the profit on the money spent on the last unit is zero. The average profit per rupee spent on fertilizer, *i.e.*, total profit divided by total fertilizer cost, will be larger than zero but this fact tells us nothing about when to stop adding fertilizer to the land.

In Table II the optimum combinations of N and P_2O_5 are listed for different levels of total fertilizer expenditure per acre. The prices assumed were P_n =Rs.0.75, P_p = Rs. 0.50 and P_y = Rs. .1585.

TABLE II

Total Expenditure per acre on N and P_2O_5 (Rs.)	Optimum Combination of N and P_2O_5		Net Return to the last rupee spent on additional fertilizer (Rs.)
	N	P_2O_5	
10.00	0 lbs.	20 lbs.	—
20.00	8	27	2.68
30.00	19	32	2.22
40.00	29	36	1.94
50.00	39	41	1.68
60.00	50	45	1.40
70.00	60	50	1.16
80.00	70	55	.87
90.00	80	59	.61
100.00	91	64	.32
110.00	101	68	.07

In calculating the "net return to the last rupee spent on additional fertilizer" (Column 4, Table II) the price of wheat to the farmer was assumed to be Rs. 13.00 per maund. This column gives the *incremental* rate of return. The net *average* rates are quite different. For example, an expenditure of Rs. 30.00 per acre brings a *net* profit (*i.e.*, net to fertilizer) of Rs. 104.97 or an average net return to each rupee spent on fertilizer of Rs. 3.40. However, the 30th rupee only brought Rs. 2.22. The net profit at Rs. 50.00 expenditure is Rs. 144.37, an average net return of Rs. 2.89 to each rupee spent. Nevertheless the 50th rupee only returned to itself Rs. 1.68—still a handsome profit, but a long way from Rs. 2.89. At Rs. 110.00 per acre the net profit is Rs. 198.00, or Rs. 1.80 per rupee spent, but here the 110th rupee only made 7 nP. for its expenditure.

What happens if the farmer decides to use only nitrogen, either because he is poorly advised, or because P_2O_5 is not available? In this case we are dealing only with the first column in Table I. Maximum physical production is attained at 62 lbs. of N per acre, and maximum profit (P_n = Rs. 0.75, P_y=Rs. .1585) at 40 lbs. per acre. A much lower level of application than when N and P_2O_5 are combined, yet more N without the plant vigour that comes from additional P_2O_5 will reduce yields. If the farmer discounts the experimental results by 20 per cent and wants 15 per cent on the last rupee spent, he would reduce his application of N to 29 lbs. Should he also be farming on 50 per cent shares and be responsible for the full cost of the fertilizer, he will find it unprofitable to apply nitrogen.

Let us now examine the effects of price changes for N and P_2O_5 on the quantity of these nutrients that would be used for production purposes. Here we make use of the concept of demand elasticity—that is, of the proportional changes in the quantity of N or P_2O_5 used that would result from a given proportional change in price.[4] Based upon the productive power of N and P_2O_5

---

4. The price elasticity of demand for N: $e = \dfrac{\frac{\Delta N}{N}}{\frac{\Delta P_n}{P_n}} = \dfrac{\Delta N}{\Delta P_n} \cdot \dfrac{P_n}{N}$

that is :

$$\underset{\lim \Delta P_n \to 0}{e} = \frac{\partial N}{\partial P_n} \cdot \frac{P_n}{N}$$

The demand for N at any price P_n is "derived" from the maximum profit formulation using the production function : $Y = f(N,P,A)$.

i.e.,

$$\frac{\partial Y}{\partial N} = \frac{P_n}{P_y} \quad \text{or: } P_y \frac{\partial Y}{\partial N} = P_n$$

differentiating with respect to N

$$\frac{\partial P_n}{\partial N} = P_y \frac{\partial^2 Y}{\partial N^2}$$

or :
$$\frac{\partial N}{\partial P_n} = \frac{1}{P_y \cdot \frac{\partial^2 Y}{\partial N^2}} \quad \text{therefore : } e = \frac{1}{P_y \frac{\partial^2 Y}{\partial N^2}} \cdot \frac{P_n}{N}.$$

Similar derivations may be made for N with respect to P_p, for P_2O_5 on its own price and the price of N, and for both N and P_2O_5 with respect to P_y.

we may conclude that if wheat sells for Rs. 13.00 per maund, N for Rs. 0.75 per lb., and P_2O_5 for Rs. 0.50 per lb., and if the farmer is presently using 30 lbs. of each nutrient per acre, then a 10 per cent *increase* in the price of N would result in a 7.6 per cent *decrease* in the quantity of N demanded, but an 8.1 per cent *increase* in the quantity of P_2O_5 used. A similar 10 per cent *increase* in the price of P_2O_5 would cause only a 1.6 per cent *drop* in the quantity of P_2O_5 demanded, but it would *increase* the optimum quantity of N used by 5.4 per cent. However, if the farmer is already using 60 lbs. of N and about 55 lbs. of P_2O_5 his optimum consumption would not be as responsive to price changes. A 10 per cent increase in the nitrogen price would bring about a 3.8 per cent reduction in consumption and a 4.4 per cent increase in the amount of P_2O_5 used. Likewise a 10 per cent increase in P_P would reduce the optimum level of P_2O_5 only .9 per cent and would raise the consumption of N by only 2.7 per cent. These consumption changes assume that as one price changes all the others remain constant. Obviously if they all change proportionately, *e.g.*, all go up 10 per cent, then the optimum levels remain the same since the *relative* prices have not changed.

In examining the experimental data on which this note is built it is evident that the data do not permit conclusions as to how much fertilizer Indian farmers should apply per acre if national production and not individual farm profit is to be maximized. Only three levels of fertilization with each input were used : 0, 30, and 60 lbs. It is, therefore, incorrect to fit a function of a higher degree than a quadratic through these levels. Had the experiment examined the production response to input levels between 0 and 30 pounds per acre as well as above 30 pounds it would have been possible to test for a cubic response that would cover the range of increasing and then decreasing returns. This is a shortcoming of the experiment.

Not only was the experiment short of low level observations, but it obviously did not go high enough in its rates of application to cover the levels most relevant to economic decisions, at least at presently prevailing prices. Except in very restricted cases, the optimum levels of fertilization found in this analysis were beyond the 60 pound limit covered in the research. This was especially true of nitrogen which demonstrated a very high productive potential when phosphate was also used. While the data presented must be carefully used, if used at all, they strongly suggest the need for agronomic investigations of plant response to high level applications of *complete* fertilizers.[5]

The optimums presented in this paper are economic optimums which will maximize the net return to the farmer. However, even allowing for the limitations of the experimental evidence that underpins the analysis, they are not quite correct. I have not considered the costs of applying the fertilizer, the risks of storage damage to the nutrients, the costs of transporting both the fertilizer and the extra product, the economic (and possibly social and psychological) cost of dealing with officials for fertilizer chits, etc. In some cases these factors may be appreciable and may alter the results substantially.

---

5. It has been pointed out to me by a botanist friend that higher rates of N probably would cause lodging and a consequent loss of yield. I have no reason to doubt this statement, but speculation is not a good substitute for experimental trial. In this we are both speculating by extrapolation—I from the data of experiment, he from his experience and knowledge of plant physiology. Both speculations concern a matter of fact which can and should be discovered by the courageous application of high to very high rates of fertilization. That these rates must involve more than one nutrient is clear from the importance of the interaction term in the present analysis.

Importantly the view taken here is that farm decision making aims first at increasing net income—profit—as the goal of production. If some other goal guides farmer decisions these optimums are unlikely to be realistic. But if policy makers were to wish to superimpose other goals on the farmer when his goal is the pursuit of profit, they would have to convince him of the value of these new aims through education and persuasion, or use subsidies or regulatory power.

Fertilizer is a powerful resource to the man who wrests his living from the soil. The farmer in the pursuit of profits who can produce as well as the Hoshangabad Station will apply fertilizer far beyond the presently recommended rates. Should he be restricted by rationing or other devices in his access to supplies, he will find it profitable to approach those who are less efficient or less aggressive producers with an offer to share his profit in return for the use of their rights to the scarce nutrients. His offer will be in the form of a price bid above the prevailing market rate. If this price is high enough many persons will find it more profitable to sell their rights for the offered price difference than to use them directly in farming.

Prices that can be offered by those seeking extra nitrogen, say, will depend upon how much they already have under control and the availability of phosphate supplies. In the example used here a farmer could pay *up to* Rs. 1.40 (*i.e.*, Rs. 617 per metric ton of ammonium sulphate) for an extra pound of N if he already had 20 pounds of N at his disposal and no access to phosphate. Even if he has 30 pounds of N he would find it profitable to buy an additional pound as long as it sold for less than Rs. 1.08. If he had access to phosphate he could, of course, afford to pay more for additional nitrogen as the presence of P_2O_5 assures a more efficient use of the applied N. In fact he can add 3 naye paise to his nitrogen bid for each pound of P_2O_5 he could combine with his final stock of N. We should expect, then, that any attempt to ration or "equitably" distribute a supply of fertilizer that is selling below its supply-demand price would result in a re-distribution among private persons at higher than market prices.

One last note : Economists have developed many useful and precise tools of analysis for a wide range of production problems. The present exercise is a most elementary example of the power and range of these techniques. But here, as in all applications, the results are only as good as the basic physical data which is the foundation of the entire work. The limitations of the economic statements made here cannot be overstressed. But neither can the implications this analysis has for experimental design. A larger number of treatment levels would have measurably improved precision. The inclusion of rainfall data along with water amounts would have extended the analysis to include the effects of this important productive input. Also, data on the timing of water applications and the use of time as a variable in the experiment, would have shed light on still other problems which confront the farmer who is seeking ways to improve his agriculture. I do not intend to imply that these items were not part of the original experiment, I only have a portion of what was actually done and have used it for illustrative purposes only. However, it does focus on the fact that when the agronomist and economist jointly address the production issues confronting the farmer they can be a powerful combination, involving the best their disciplines have to offer, and producing from both more than either can produce singly.