THE ECONOMIC OPTIMUM IN THE RATE OF FERTILIZER APPLICATION*

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Adjustment of rates of fertilizer application to suit the variety of crop or the agronomic environment in which it is grown, is a feature of agriculture which any planter is accustomed to. But given a particular crop grown in a particular environment, any suggestion to adjust its normal rate of application to suit extraneous socio-economic phenomena, may not find ready acceptance. For instance a proposal to change the fertilizer mixture (i.e. N : P : K ratio) with the fluctuations of crop prices may sound meaningless to most of us; or a suggestion that when the level of fertilizer application is reduced (say due to limited capital) the composition of the mixture should also change, may also be baffling. It will be the purpose of this article to show that such adjustments are quite valid and in fact essential, if the emphasis is on the economic aspects of fertilizer application. There are innumerable such socio-economic complexes that call for a valid revision of fertilizer dosages, quite independent of the agronomic requirements. With changing price situations, limitations of capital, restrictions on fertilizer availability, subsidies on fertilizers, control of production levels, competitive demands for capital by other crops or other investments etc. etc., the question becomes insistent as to what is the economic optimum in the rate of application and combination of nutrients for a particular situation; and the modern investor needs precise answers to such a question.

Recent developments in agricultural economics enable one to make use of the results of agronomic experiments to find satisfactory answers to such a question. The use of these economic principles and concepts will be illustrated by an analysis of the data of a fertilizer experiment on coconut carried out by the Soil Chemist's Division of this Institute at Bandirippuwa Estate. The main purpose of this discussion is to introduce the practical planter to some aspects of the economic outlook on fertilizer use. Whatever fertilizer dosages for coconut are suggested herein as optimal to various situations, should not however be construed as general

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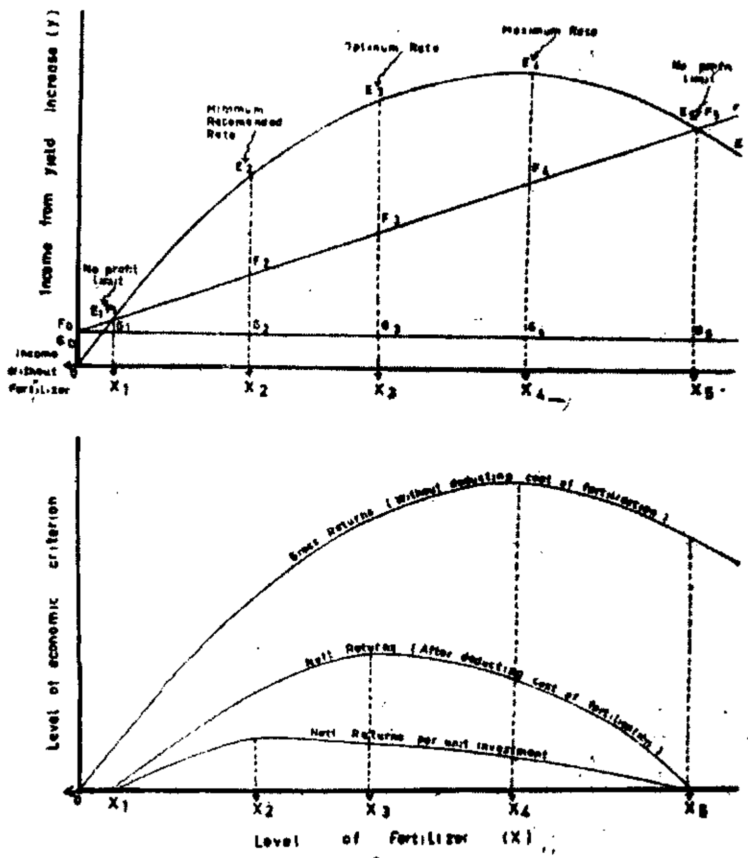
fertilizer recommendations for coconut. A particular experiment is an unique experience and the extrapolation of the results of any such an unique experience to other environmental conditions has to be done with care and at any rate by an agronomist or a soil scientist.

Critical Rates of Fertilizer Application

The simplest expression of yield responses to applied fertilizers over the region of economic interest is given by a curve of diminishing returns. This characterizes a simple shape showing a continuous fall in effect of the nutrient. The first dose produces the largest effect and subsequent doses less and less effect till finally no additional gain and sometimes even disadvantage ensues.

Fig. 1.

Critical Levels of fertilizer Application



A production curve invariably shows some yield even without the application of fertilizers unless the soil is completely void of nutrients. Suppose the response curve (in terms of income) is OE (Fig. 1). This gives for various levels of fertilizer application, the income from yield in excess of what is obtainable without the addition of fertilizers. Let G_0G be the line indicating fixed costs i.e. cost of application; F_0F the line representing the cost of fertilisation i.e. cost of fertilizer plus cost of application; and OX the fertilizer axis.

With a response curve of this type, it is possible to define five critical rates of fertilizer application.

Fig. 1 shows that there are two points at which the cost curve F_0F cuts the income curve OE. These points E_1F_1 and E_5F_5 are termed break-even points. Below the point E_1F_1 and above the point E_5F_5, the cost of fertilization is higher than the income accruing from fertilization. The rates of fertilizer application corresponding to these break-even points are X_1 and X_5. These two critical levels constitute the lower and the upper limit respectively of the profitable range of fertilizer application; and the other three levels to be described below fall within this range.

The third critical level is the maximum level. It shows the rate of application at which the total production is a maximum. This level is X_4 corresponding to E_4 which is the highest point on the production curve.

The fourth critical level is the familiar and all-important optimum dosage. At this level viz. X_3, the nett returns (or the absolute profit after deducting cost of fertilizer) is a maximum. This is the recommended level of fertilizer application, provided capital is not limiting and there are not strictures on production. It ensures the maximum profit per acre of land.

The fifth critical level is termed the minimum recommended rate. When capital is available ad lib and if the main aim is to make the maximum profit per acre of land, one applies the optimum level X_3. When capital is limited, one is compelled to apply lower rates. But a curious economic feature is that as the rate of application is reduced from the optimum level (X_3), the relative profit (i.e. the ratio $\frac{EF}{FX}$ which gives the nett return per unit investment in fertilizer) really increases, until a point X_2 is reached when this criterion is a maximum. Thus while the lowering of the rate of application below X_3 reduces the absolute nett profit per acre, the average return per unit investment really increases down to X_2, thereby ensuring in fact a more efficient use of fertilizer resources per rupee invested. This critical point (X_2) at which the nett return per unit investment in fertilizer is a maximum, is termed the minimum recommended rate.

Thus when capital is limited, one could profitably manure the whole estate at the highest rate permitted by the capital provided the rate is not below the minimum recommended rate (X_2). This is because within the range X_2 to X_3, the higher the level of application the higher will be the absolute nett profit per acre. But if capital is insufficient to apply at least the X_2 rate over the whole estate, then it will be more profitable to apply the X_2 rate over the limited acreage permitted by the capital available.

Economic Analysis of Fertilizer Responses

(*a*) *Response Equation:—*

The response equation for Bandirippuwa soil obtained from an analysis of the yield data of the $3 \times 3 \times 3$ NPK experiment at Bandirippuwa Estate is given by :—

$$Y = 1377.9300 + 0.0655\,N - 0.0667\,N^2 \quad 10.3182\,K \\ - 0.0618\,K^2 + 0.0210\,NK$$

where Y is the expected yield of copra (lbs/acre) when Sulphate of Ammonia (20.6% N) is applied at the rate of N lbs. per acre and Muriate of Potash (50.0% K_2O) at the rate K lbs. per acre. (An acre is reckoned to contain 66 palms). The yield expected for any application of N and K can be estimated from this equation.

(*b*) *Optimum Fertilizer Dosage :—*

For a given nutrient-crop price ratio the optimum fertilizer dosage is that combination of nutrients which gives the maximum absolute profit per acre of land.

Based on the above response equation the optimum dosages of N and K for coconut under Bandirippuwa Estate conditions have been worked out (Table 1). The cost of Sulphate of Ammonia (20.6% N) was taken at Rs. 320/- per ton and Muriate of Potash (50% K_2O) at Rs. 385/- per ton. Three broad levels of market prices viz. Rs. 100 per candy, Rs. 180 per candy and Rs. 260 per candy, representing low, medium and high market conditions, were considered. Although the experiment did not show any responses to Phosphate, certain considerations justify our inclusion of a basal dosage of P equivalent to 33.00 lbs. of P_2O_5 per acre. i.e. 120.12 lbs. per acre of Saphos Phosphate (27.5% P_2O_5) at Rs. 260 per ton.

TABLE 1

ECONOMICS OF MANURING COCONUT AT 50% SUBSIDY—(Small Holdings)

(Based on an economic analysis of the data of the N.P.K. Experiment at Bandirippuwa)

(1) Market price of Copra Rs/Candy	(2) OPTIMUM DOSAGE/ACRE (66 palms)			(3) Cost of fertilization per acre (Rs)	(4) Yield of Copra at optimum dosage lb/acre	(5) Nett Income at opt. dosage (i.e. minus cost of ferti. Rs/acre	(6) Income at maximum response Rs/acre	(7) Income without fertilisation Rs/acre	(8) Profit from fertilisation Rs/acre	(9) Profit from investment on fertilisation percentage
	Sulphate of Ammonia 20·6% N	Saphos Phosphate 27·5% P	Muriate of Potash 50% K							
LOW ..	(1) 0.424	0.501	0.775							
Rs. 100 ..	(2) 2.06	1.82	1.55	35·40	1963·95	315·31	313·04	246.06	69.25	196%
per ..	(3) 135.80	120.12	102.60							
candy ..	(4) 7.8%	9.2%	14.3%							
MEDIUM ..	(1) 0.492	0.501	0.820							
Rs. 180 ..	(2) 2.39	1.82	1.64	37·42	1972.81	596.70	595·44	442.91	153·79	411%
per ..	(3) 157.60	120.12	108.00							
candy ..	(4) 8.4%	8.6%	14.0%							
HIGH ..	(1) 0.517	0.501	0.855							
Rs. 260 ..	(2) 2.51	1.82	1.67	38.30	1974.86	878.70	877.84	639.76	238.94	625%
per ..	(3) 165.90	120.12	110.10							
candy ..	(4) 8.6%	8.5%	13.9%							

Note:— (1) lbs. of element per palm. (2) lbs. fertilizer per palm.
(3) lbs. fertilizer per acre. (4) proportion of nutrient element in mixture.

The economics of manuring coconut at these optimum rates as applicable to small-holders utilizing the 50% subsidy are also shown in the same table. It gives for three levels of the copra market (1) the optimum dosage (2) the cost of fertilization including the cost of application at 15 cts. per palm (3) the expected yield of copra (4) the nett income from yield at optimum fertilizer dosage (i.e. after deducting the cost of fertilization) (5) the income if fertilizers had not been applied (6) profit due to fertilizer alone and (7) the percentage profit from investment on fertilizer.

Apart from the economics of fertilizer application, there are some points of interest emanating from this analysis. These are (1) the optimum fertilizer dosage increases as the market improves and (2) the ratio of the nutrient applied also changes with the market. In this particular case, we observe that as the market improves, relatively more Nitrogen, (the expensive element) can and should be used for optimum production. This is in contrast to the general belief that the ratio of nutrients once determined does not change with market conditions etc.

Arising from the above, we are left wondering how far one is justified in fixing at a constant level, the ratio of nutrients in marketed fertilizers. A particular market product will contain (say) 7.5% N, 8% P_2O_5 and 18% K_2O and the planter has only the option to change the total quantum of the mixture to be applied depending on whether the market is favourable or not. Strictly speaking, we should adjust our mixture too at least for 3 broad categories of market conditions such as shown in Table 1 i.e. low prices, average prices and high prices.

(c) Economic dosages for fixed targets of production :—

The concept of an optimum fertilizer dosage dealt with above did not place any ceiling value on production. The main aim was to derive the maximum absolute nett profit. However under certain market conditions or depending on the availability of processing machinery etc., it may be necessary to place a limit on production. This is especially so with seasonal crops. In certain cases either to avoid a glut in the market or (may be) due to the fact that the available processing machinery is limited, one may have to set a target of production lower than the optimum. In the converse situation it may be that the demand is higher than the optimum production and if we rigorously restrict ourselves to the optimum dosage, we may have to import to meet the deficit, or it may be that unless we produce more than the optimum, we may have to lose by having to allow machinery and permanent labour to idle. In such a situation we shall have to produce more than the optimum. Such problems, wherein we are restricted to a certain target of production for whatever reason it may be, call for a precise determination of the least cost combination of nutrients that will just secure the target of production.

Recent developments in production economics involving such concepts as response surfaces, isoquants (i.e. yield contours) and isoclines (i.e. paths of minimum cost nutrient combinations) enable us to evaluate the economic dosages for given targets of production.

For explanations of these concepts, the reader is referred to the original paper (by the author) of which this article is only a simplified adaptation.

It would however be necessary to appreciate that the presence of yield contours (or isoquants) necessarily implies that there are several nutrient combinations giving rise to any given yield. For instance, it would be observed that substituting either 30 lbs. of N and 57.75 lbs. of K or 60 lbs. of N and 52.48 lbs. of K, in the response equation, give the identical yield of 1800 lbs. per acre. The optimum dosage corresponding to a given target of production will therefore be the least costly out of the alternative combinations of nutrients yielding this target of production.

Table 2. Optimum dosages of N and K for different targets of production

(Market price of Copra : Rs. 180/Candy)

Level of Production lb. copra/acre	*Optimum dosage*	*lbs/acre*	
	N	*P**	*K*
1500	—	—	40.07
1600	—	—	48.69
1700	—	—	58.40
1800	2.26	—	69.52
1900	64.61	—	84.98
1950	114.04	—	97.23
Maximum Production 1976.8	184.92	—	114.80

* Basal dosage.

Table 2 gives the optimum dosages in respect of various targets of production for coconut at Bandirippuwa Estate, the cost of Sulphate of Ammonia (20.6% N) being Rs. 320/- per ton and Muriate of Potash (50% K_2O) being Rs. 385/- per ton giving us a nutrient crop price ratio of 0.8312.

It is observed from Table 2 that the N : K nutrient ratio changes as much as the quantity applied, when the level of production is changed.

In fact below a production target of 1800 lbs. copra per acre, it is not economic to use any Nitrogen while at higher levels of production the amount of Nitrogen applied even exceeds the amount of Potash.

(d) Economic dosages when capital is limited :—

The optimum dosages calculated at the very outset did not presuppose any shortage of capital nor did it set a limit on production. The main aim was to get the maximum profit. The second set of optimum dosages just explained set a limit on production, but assumed unlimited capital. There is yet another situation (and a very common one) which calls for the calculation of economic dosages. This is when capital is limited. While normally the cost of fertilization per acre of coconut based on the optimum dosage is Rs. 37.42, the situation may be that one cannot afford more than (say) Rs. 20.00 per acre, on fertilization. Does it mean that under these circumstances we are to apply a lower quantity of fertilizer based on the ratio of money available to money required? For example, if the money available is Rs. 20/- per acre, we deduct Rs. 9.90 the cost of application, leaving a value of Rs. 10.10 for purchase of fertilizer; whereas if money is available ad lib, we spend Rs. 37.42 minus Rs. 9.90 (i.e. Rs. 27.52) on the purchase of fertilizer. Thus the amount of fertilizer applied will be $\frac{10.10\text{th}}{27.52}$ of the optimum dosage. An important point to remember being that the ratio of nutrients does not change but only the quantity applied is reduced proportionately.

It appears that when capital is limited, land owners adopt another procedure. If they have (say) only Rs. 20/- against a required Rs. 37.42, they fertilize a proportionate part of the estate at the usual dosage. That is, the number of palms manured in an acre will be given by $\frac{20}{37.42}$ of 66 i.e. 35; the balance 31 palms will be left unmanured.

Both these systems seems to be popular. But the new light thrown on this question of fertilizer mixtures by means of the economic analysis gone through up to now, makes it abundantly clear that after all any of these systems may not be the most economic. The notion of a constant

ratio of nutrients at all levels of production and at all levels of manuring is economically unacceptable. Economic dosages have to be calculated fresh for a given capital.

For the prevailing N-K price ratio of 0.8311 and cost at 50% subsidy per pound of N—Rs. 0.0715 and K—Rs. 0.0859, the optimum dosage for coconut for different levels of available capital have been worked out. (Table 3).

The table gives the comparative profits from fertilizer applied on the basis of the two systems mentioned earlier as against the economic dosage given by our analysis. Further it is interesting to see how the N : K ratio changes when the level of fertilization is lowered. When capital is available ad lib, we use N and K in the ratio 15 : 10; and when capital available gets low, we reduce the quantity of N relative to K. In fact, at Rs. 20/- per acre we give only 17.39 lbs. per acre of N as against 73.27 lbs. per acre of K, giving us a N and K ratio of 10 : 42. This shows a complete reversal of the importance of N relative to K as the level of application decreases.

(e) A minimum recommended dosage:—

These economic nutrient dosages applicable for the whole estate under conditions of limited capital are subject to a certain lower limit. This is the 'minimum recommended rate' explained earlier. Where capital is limited, one could manure the whole estate at the highest rate permitted by the capital as long as the rate is not below the minimum recommended rate. But when capital available is insufficient to apply at least the minimum rate over the whole estate, then it will be more economic to apply the minimum rate over a limited acreage depending on the capital available.

For coconut it is found that the maximum percentage profit per unit investment is given when capital invested in fertilizer is Rs. 17/- per acre; and the corresponding rate of fertilizer application is 65.23 lbs. of K per acre, without the addition of any N. This is the 'minimum recommended rate'. It gives a profit of 632% on the investment viz. Rs. 107.45.

Suppose the capital available is only Rs. 15/- per acre. The dosage that could be applied over the whole estate with this capital is only 59.91 lbs. of K per acre and if we do so we get a profit of Rs. 93.99 on the investment.

However if we apply the minimum recommended rate (65.25 lbs. K per acre) over a fraction of the estate (i.e. $\frac{59.91}{65.25}$ or 92% of the estate),

Table 3. ECONOMICS OF MANURING COCONUT AT 50% SUBSIDY WHEN CAPITAL IS LIMITED

(Market price of Copra Rs. 180/Candy)

(Based on an economic analysis of the data of the N.P.K. Expt. at Bandirippuwa)

Capital available per acre	Quantity of fertilizer applied on ratio basis					Fraction of Estate manured on ratio basis					Manured at the Economics Dosage level				
	lbs/acre					Rate/acre					lbs/acre				
	N	P	K	Yield of Copra lbs/acre	Profit from fertili. alone (Rs)	N	P	K	Yield of Copra lbs/acre	Profit from fertili. alone (Rs)	N	P	K	Yield Copra per acre lbs/acre	Profit from fertili. alone (Rs)
Ad lib Rs. 37·42 per acre	157·60	120·12	108·00	1972·8	153·79	157·60	120·12	108·00	1972·8	153·79	157·60	120·12	108·00	1972·8	153·79
Rs. 20/- acre	57·84	44·08	39·67	1719·5	89·79	157·60	120·12	108·00	1693·4	81·40	17·39	44·08	73·27	1827·8	124·60
Rs. 25/- acre	86·48	65·91	59·31	1835·6	122·11	157·60	120·12	108·00	1774·5	102·46	57·60	65·91	83·24	1890·5	139·75
Rs. 30/- acre	115·11	87·74	78·96	1916·7	143·17	157·60	120·12	108·00	1855·6	123·54	97·92	87·74	93·24	1936·2	149·44
Rs. 35/- acre	143·75	109·56	98·60	1962·7	152·96	157·60	120·12	108·00	1936·7	144·60	138·14	109·20	103·20	1964·7	153·60

we could expect a profit of 632% of the investment viz. Rs. 94.81. This figure is higher than what we would get if we manure the whole estate based on the economic dosage for Rs. 15/-.

Conclusion

The above discussion should serve as a very simple and brief introduction to some recently developed concepts and techniques in the precise evaluation of the economic optimum in rates of fertilizer application.

The econometric methodology involved in this analysis is too mathematical for the average planter and therefore has been avoided in the article. However an appreciation of the new ideas on fertilizer use illustrated by this analysis would bring the planter to a closer understanding of the fertilizer recommendations given by soil scientists.

References

1. Abeywardena, V. (1963) 'Economics of Fertilizer Use'—a paper read at the Symposium on 'The Role of Fertilizers in Agricultural Production' held on 21st November, 1963 at the Annual Sessions of the Ceylon Association for Advancement of Science. (Published together with the other papers presented at the Symposium in Tropical Agriculturist, Vol. CXIX).