
Economics of Fertilizer Use *

V. ABEYWARDENA
(Coconut Research Institute)

FOR nearly half a century, agronomists and soil scientists have felt the need for more precise criteria to guide them in the economic utilization of fertilizers for agricultural production. Though agronomic research has amassed a wealth of information regarding the responses of crops to fertilizers, the development of a sound methodology for the economic evaluation of this information lagged far behind. It was only within the last decade that *Agricultural Economics* developed as an applied science through the co-operative effort of agronomists, soil scientists, economists and statisticians. It is now realised that fertilization problems must necessarily be approached through a knowledge of and principles drawn from both agronomy and economics. Agronomic research provides precise information regarding the responses expected from fertilizers, and economic principles as expressed and understood with the aid of mathematics forms the basis of decisions regarding the optimum utilisation of fertilizers. This integration of widely different disciplines such as agronomy, soil science, economics and mathematics, permits us to use fertilizers with maximum profit.

BACKGROUND OF FERTILIZER ECONOMICS STUDIES

An agronomist who wishes to know how best a particular crop is to be fertilised under given conditions has, at some time or other in the scheme of field experimentation, to lay down a factorial experiment with a minimum of three levels of each nutrient, thereby providing for some form of economic analysis of the data. But even with such provisions, in most fertilizer experiments any form of economic analysis is avoided. It was considered sufficient to understand the crop responses shown at the experimental levels of fertilizer application, which are merely certain discrete points on the fertilizer axes. For instance, if the experiment happens to be a $3 \times 3 \times 3$ NPK factorial, the analysis seldom extends beyond ascertaining: (1) whether there is a significant response to a particular nutrient, (2) whether the response to a particular nutrient is indicative of a falling off at higher levels i.e., diminishing returns, and (3) whether there are any nutrient interactions i.e., whether the presence of one nutrient is favourable or unfavourable to the

* Paper read at the 1963 sessions of the Ceylon Association for the Advancement of Science.

response to another nutrient. Apart from these, the analysis is seldom extended to the determination of the response function which is necessary to predict yields at fertilizer levels other than those tried out in the experiment and thereby get a better assessment of the economics of fertilizer use.

The first attempt to express crop response as a function of added fertilizers was made by Mitscherlich (1909). Spillman (1933) independently confirmed the relationship suggested by Mitscherlich. Though these contributions aroused considerable interest among agronomists and fertilizer experts, hardly any progress was made in the field of fertilizer economics until about 1953. During this interim period, agronomists and statisticians continued to think in terms of response equations, law of diminishing returns, optimum fertilizer applications, etc. This interest was more or less of an academic nature because, until recently, response functions and economic concepts were seldom the bases for making fertilizer recommendations. Since 1953, however, with the universal acceptance of chemical fertilizers as a very important aspect of agricultural production, interest in the field of fertilizer economics grew rapidly, and as a result there are various new concepts and techniques to evaluate economic fertilizer dosages.

This paper gives an introduction to some of these new concepts and techniques which have reorientated the outlook on the fertilization of crops. The results of the application of these techniques on the data from a fertilizer experiment on coconut are also given by way of illustration.

ECONOMIC ANALYSIS OF FERTILIZER RESPONSE DATA

1. *The physical production function-response curve*—The first step in the economic analysis of fertilizer response data is the determination of the physical production function or the *response equation* as it is commonly known. This equation is determined by applying regression techniques on the observed data, taking the yield as y (the dependent variable) and the fertilizer levels as x (the independent variable). The decision as to what type of mathematical model is to be fitted is one of considerable agronomic importance and therefore should not be left to the statistician alone as is usually done. The agronomist must satisfy himself that the type of model to be used caters adequately to established biological trends in the problem. This point needs to be emphasised because when a curve is to be fitted on some biological data, the tendency is to fit polynomials. This is considered by some as the standard approach, sometimes the only one, for curve fitting on any data. Probably it may not be realised that 'fitting of polynomials' is merely one out of several methods of numerical interpolation given in any text book on numerical

analysis and has no special claim to be used in all types of data. For most biological problems which call for curve fitting, some background knowledge of the expected trends is usually available. Such prior knowledge could be made use of to ensure that the mathematical model to be fitted is adaptable to the circumstances under study.

Suppose the problem is to fit a curve to express the height of coconut palms at varying ages. The agronomist should warn the statistician that the height of the palm will not reduce after reaching maximum growth and the statistician should take the clue and avoid using the common quadratic model because an asymptotic model would be more realistic in these circumstances. Again, suppose the problem is to find an expression for yield and fertilizers. If the response shown is very marked up to the point of maximum yield, and the depression observed or expected after the point of maximum yield is relatively at a lower rate, then again the quadratic model will be unrealistic. A square root model of the following form is preferable—

$$y = a - bx + c\sqrt{x}$$

A recent study (Abeywardena, 1961) suggests that, as a standard universally applicable mathematical model for fertilizer responses is not available, the polynomial models (quadratic and square root) may be reasonably used. Further, evidence was adduced to show that the square root model is relatively more generally applicable. A comparison of four popular mathematical models was made on results obtained in 19 greenhouse experiments. Table 1 gives the number of experiments which were fitted best and second best by each of the models.

TABLE 1

Number of experiments fitted best and second best by four mathematical models

<i>Model</i>	<i>No. of experiments showing—</i>	
	<i>best fit</i>	<i>2nd best fit</i>
(1) Mitscherlich's $Y = A - be^{-ax}$..	1	3
(2) Cobb-Douglas' $Y = a + \beta x^\alpha$..	1	4
(3) Quadratic $Y = a + bx - cx^2$..	4	8
(4) Square root $Y = a - bx + c\sqrt{x}$..	13	4

It is observed that out of 19 experiments, the square root model fitted best on 13 experiments, the quadratic model on 4 experiments and the other models on one each, showing that the square root model is the most adaptable. The above refers to one independent variable.

2. *The physical production function-response surface*—The problem becomes a little more complicated when there are two or more independent variables as those met with in multi-factor fertilizer responses.

In the conventional factorial type of fertilizer experiments several nutrients are applied singly and in combination, and mathematical models have to be adapted to accommodate such multi-factor responses and their interactions. Such production functions give rise to a 'response surface' (Fig. 1), contrary to the common response curve in the case of univariate fertilizer responses. The results of a fertilizer experiment carried out at Bandirippu wa Estate have been used to demonstrate such a response surface. This experiment consisted of 3 levels each of N, P and K arranged factorially in order to assess the responses to these nutrients singly and in combination.

A statistical analysis of the data of this experiment revealed that there is a significant response to K and also an N \times K interaction with no response to P, indicating that the response to K differs at different levels of N. The observed yields are given in Table 2—

TABLE 2
Yield of copra (lb./acre) at different levels of N and K

	K ₀	K ₁	K ₂
N ₀	1390	1734	1785
N ₁	1277	1868	1900
N ₂	1268	1660	1996

$$N_0 = \text{zero}$$

$$K_0 = \text{zero}$$

$$N_1 = \cdot 25 \text{ lb. N/palm/year}$$

$$K_1 = \cdot 375 \text{ lb. K}_2\text{O/palm/year}$$

$$N_2 = \cdot 50 \text{ lb. N/palm/year}$$

$$K_2 = \cdot 75 \text{ lb. K}_2\text{O/palm/year}$$

When there is a two-nutrient interaction, a correct assessment of the yield response for varying combinations of N and K is possible only through a response surface (Fig. 1).

If as suggested earlier the square root and the quadratic models hold good for fertilizer response curves, the following adaptations of the same models may be recommended for 2-factor interactions such as observed for coconut.

(1) *Quadratic* :

$$Y = a \pm b_1 N \pm b_2 N^2 \pm b_3 K \pm b_4 K^2 \pm b_5 NK$$

(2) *Square root* :

$$Y = a \pm b_1 N \pm b_2 N^{\frac{1}{2}} \pm b_3 K \pm b_4 K^{\frac{1}{2}} \pm b_5 NK$$

(3) *Combined* :

$$Y = a \pm b_1 N \pm b_2 N^2 \pm b_3 K \pm b_4 K^{\frac{1}{2}} \pm b_5 NK$$

or

$$Y = a \pm b_1 N \pm b_2 N^{\frac{1}{2}} \pm b_3 K \pm b_4 K^2 \pm b_5 NK$$

The quadratic model is used in the analysis of the data given in Table 2 and the equation of the response surface is :—

$$Y = 1377.9300 + 0.0655 N - 0.0067 N^2 + 10.3182 K \\ - 0.0618 K^2 + 0.0210 NK$$

Where Y is the expected yield of copra (lb./acre) when sulphate of ammonia (20.6% N) is applied at the rate of N lb./acre and muriate of potash (50% K₂O) at the rate of K lb./acre (an acre reckoned to contain 66 palms).

Fig. 1

N - K PRODUCTION SURFACE FOR COCONUT
(AT BANDIRIPPUWA)

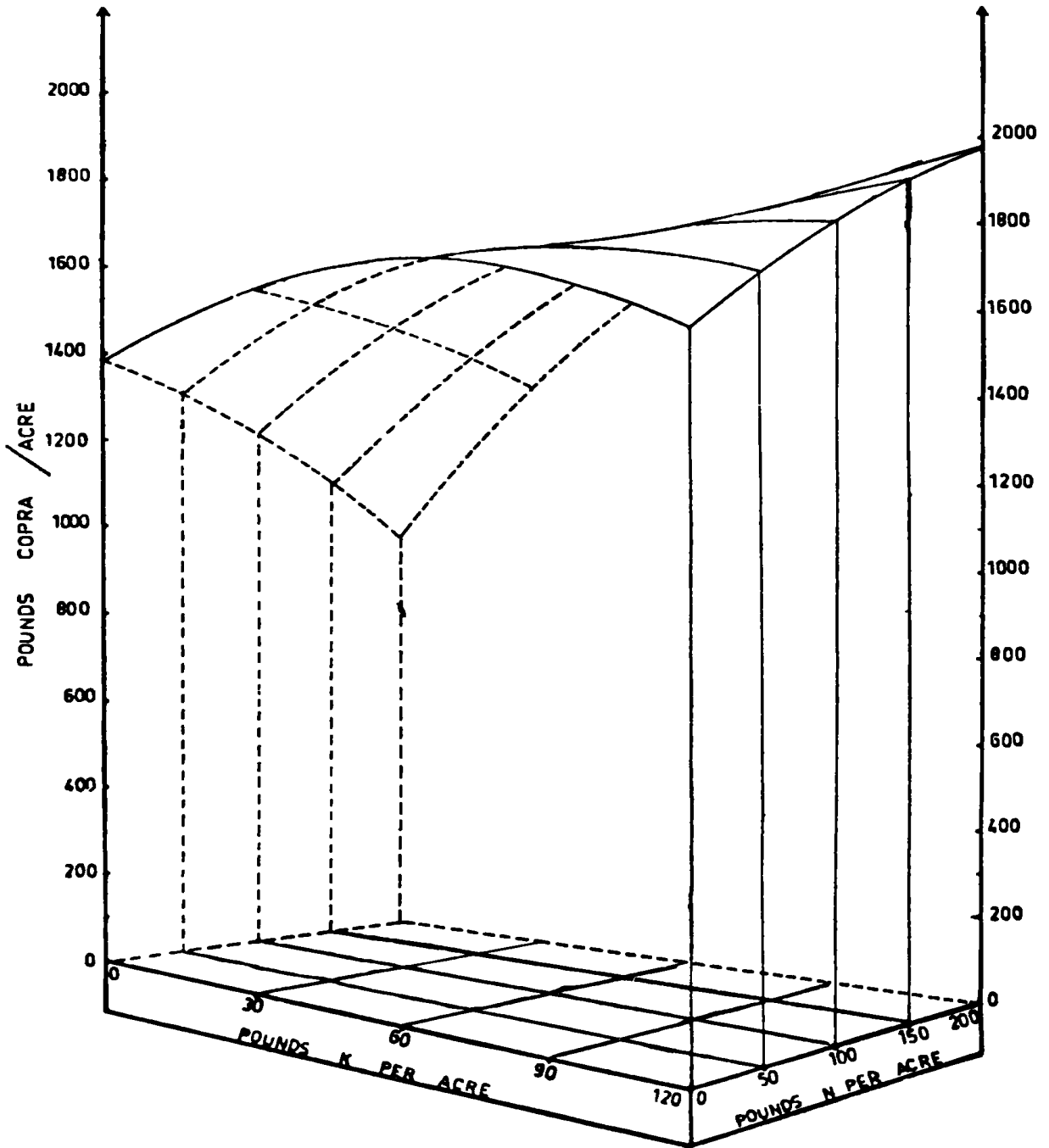


Fig. 1 gives the N-K response surface for coconut at Bandirippuwa Estate based on the above equation.

3. *Economic Analysis*—Having derived the response function, the first problem is the determination of the optimum fertilizer dosage taking into consideration the economics of fertilization.

(a) *Optimum fertilizer dosage*—The optimum fertilizer dosage is commonly understood to be that combination of nutrient levels which gives the maximum absolute or nett profit per unit area.

Alternatively (taking N and K to be the nutrients involved) the optimum fertilizer dosage will be that combination of N and K at which the income obtained from the additional yield (ΔY) due to small increments of both nutrients (ΔN and ΔK) will be equal to the cost of the small increments of ΔN and ΔK .

$$\text{i.e.} \quad \Delta Y C_P = \Delta N C_N + \Delta K C_K$$

where C_P , C_N , and C_K are the costs per unit of the yield, nitrogen and potash respectively.

These optimum values could be obtained mathematically by equating the partial derivatives of the production function (with respect to N and K) to their corresponding nutrient to crop price ratios. For instance, if the production function is given by

$$Y = a + b_1N - b_2N^2 + b_3K - b_4K^2 + b_5NK,$$

then the optimum dosages of N and K will be given by a solution of the following equations :

$$b_1 - 2 b_2 N + b_5 K = \frac{C_N}{C_P} \dots\dots\dots (1)$$

$$b_3 - 2 b_4 K + b_5 N = \frac{C_K}{C_P} \dots\dots\dots (2)$$

The left hand side of the above equations are merely the partial derivatives of the production function with respect to N and K respectively, and the right hand side gives the corresponding nutrient to crop price ratios.

On this basis the optimum dosages of N and K for coconut, under Bandiripuwa Estate conditions, have been worked out (Table 3). 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/Candy, Rs. 180/Candy and Rs. 260/Candy, representing low, medium and high market conditions, were considered. Although the experiment did not show any response to phosphate, certain considerations justify the inclusion of a basal dosage of P equivalent to 33.00 lb. of P_2O_5 per acre i. e. 120.12 lb. per acre of saphos phosphate (27.5% P_2O_5) at Rs. 260/ton.

TABLE 3—Economics of Manuring Coconut at 50 per cent. Subsidy—(Small Holdings)

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

(1) Market price of Copra Rs. per Candy	(2) OPTIMUM DOSAGE/ACRE (66 palms)			(3) Cost of fertilization per acre (Rs.)	(4) Cost 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 fertilization Rs./acre	(8) Profit from fertilizer alone Rs./acre	(9) Profit from investment on fertiliza- tion Per cent.
	Sulphate of Ammonia 20.6 % N	Saphos Phosphate 27.5 % P ₂ O ₅	Muriate of Potash 50 % K ₂ O							
LOW										
Rs. 100	(1) 0.424	0.501	0.775	35.40	1963.95	315.31	313.04	246.06	69.25	196%
per	(2) 2.06	1.82	1.55							
candy	(3) 135.80	120.12	102.60							
	(4) 7.8 %	9.2 %	14.3 %							
MEDIUM										
Rs. 180	(1) 0.492	0.501	0.820	37.42	1972.81	596.70	595.44	442.91	153.79	411 %
per	(2) 2.39	1.82	1.64							
candy	(3) 157.60	120.12	108.00							
	(4) 8.4 %	8.6 %	14.0 %							
HIGH										
Rs. 260	(1) 0.517	0.501	0.835	38.30	1974.86	878.70	877.84	639.76	238.94	625 %
per	(2) 0.51	1.82	1.67							
candy	(3) 165.90	120.12	110.10							
	(4) 8.6 %	8.5 %	13.9 %							

Note.—(1) lb. of element per palm

(2) lb. fertilizer per palm

(3) lb. fertilizer per acre

(4) proportion of nutrient element in mixture

The economics of manuring coconut at these optimum rates as applicable to small-holders utilising 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 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 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 arising from this analysis. These are (a) the optimum fertilizer dosage increases as the market improves and (b) the ratio of the nutrients applied also changes with the market. In this particular case, as the market of copra improves, relatively more of 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.

From the above, it is doubtful how far it is justifiable to fix the ratio of nutrients in marketed mixed fertilizers. If a particular market product contains 7.5%N, 8% P₂O₅ and 18% K₂O, the planter has only the option to change the total quantity of the mixture to be applied depending on whether the market is favourable or not. Based on the above economic analysis the nature of the mixture of fertilizers should be varied at least for 3 broad categories of market conditions such as shown in Table 3 *i.e.* for low prices, for average prices and for high prices.

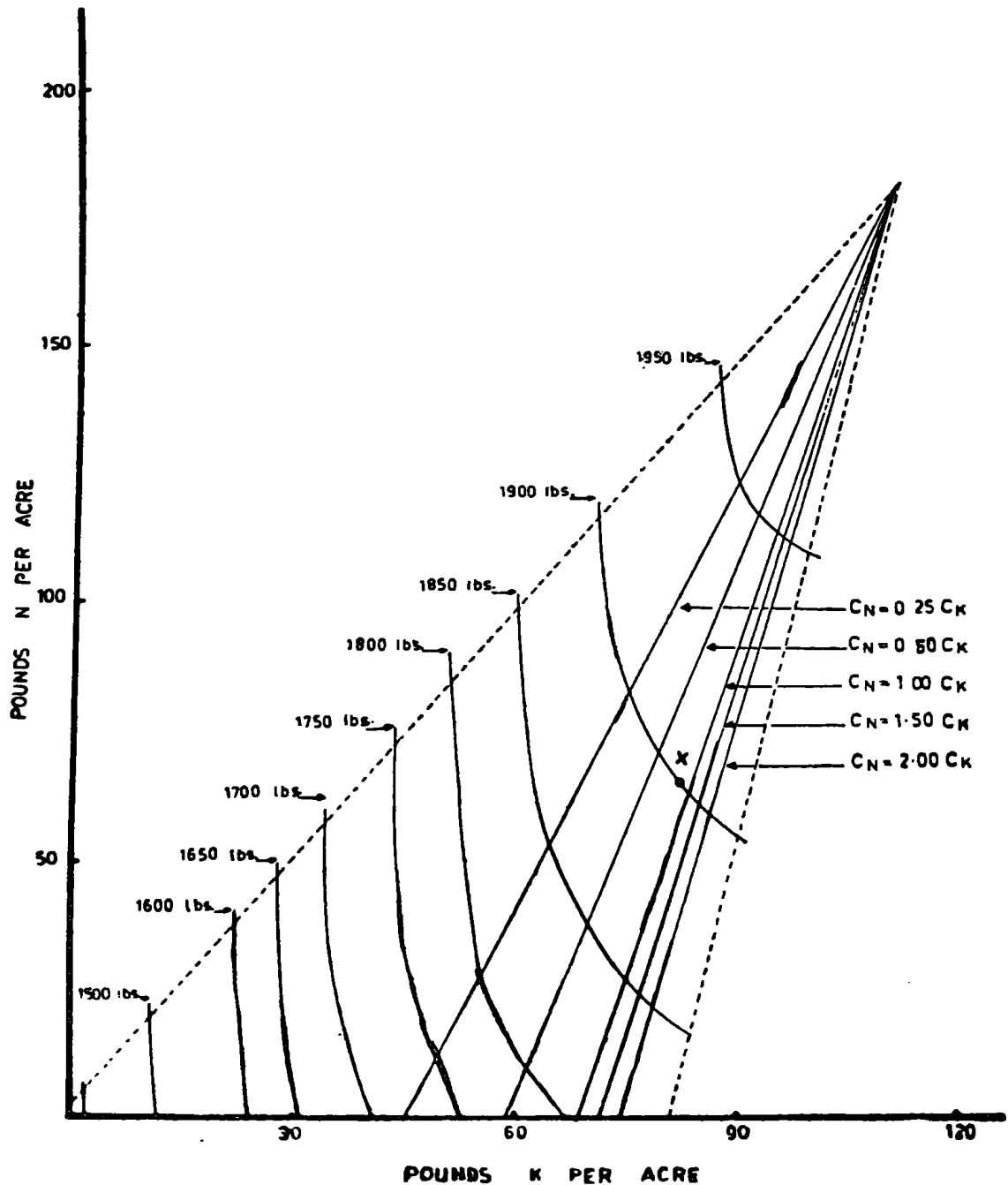
(b) *Economic dosages for fixed targets of production*—The concept of an optimum fertilizer dosage dealt with earlier did not place any restriction on production, the main aim being to derive the maximum absolute profit. However under certain market conditions or depending on the availability of processing 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, perhaps, due to the fact that the available processing machinery is limited, it may be necessary to set a target of production lower than the level of maximum absolute profit. In the converse situation, it may be that the demand is higher than the production at maximum absolute profit and a rigorous restriction to this maximum profit level of production compels importations to meet the deficit. A situation may also arise that unless production is more than the level of maximum absolute profit, machinery and permanent labour may have to idle. In such situations production should be more than the optimum. Such problems call for a precise determination of the combination of nutrients that will secure a given target of production, and at the same time be least costly.

This leads to the concepts of *isoquants* and *isoclines*. If the response surface (Fig. 1) is cut by a plane parallel to the horizontal nutrient plane at a height

proportional to the given target of production, it follows that all points on the cut surface will have the same height and therefore the same level of production (i.e. the target). If each point on this cut surface is projected on to the nutrient plane by means of perpendicular lines, the corresponding points on the latter give rise to an *isoquant*, which may therefore be defined as the curve on the nutrient plane which corresponds to identical yields on the response surface (Fig. 2).

Fig. 2

Isoquants and Isoclines for Coconut
(AT BANDIRIPPUWA)



The co-ordinates of every point on a particular yield isoquant correspond to different nutrient combinations. For instance, considering the yield isoquant corresponding to the target of 1,800 lb. copra per acre, either 30 lb. of N and 57.75 lb. of K or 60 lb. of N and 52.48 lb. of K can give the identical yield of 1,800 lb. copra per acre. Thus there can be a large number of alternative combinations of the two nutrients which may give rise to the same level of production. The optimum combination of fertilizers corresponding to a given target of production will therefore be the one that is least costly, out of the many possible combinations of nutrients shown at each point on the particular isoquant.

If Y_t is the target of production and C_N and C_K the costs per unit of N and K respectively and C_F the total cost of fertilizer, then we get :—

$$Y_t = a + b_1N - b_2N^2 + b_3K - b_4K^2 + b_5NK \dots\dots\dots (3)$$

$$\text{and } C_F = C_N \cdot N + C_K \cdot K \dots\dots\dots (4)$$

The optimum nutrient combination of N and K to achieve the given target of production, Y_t , will be such as to minimise C_F subject to equation (3) above.

This leads to the equation of the *isocline*, i.e., the curve giving the locus of points of the minimum cost combinations of N and K for a given price ratio of nutrients. This is obtained mathematically by equating the ratio of the partial derivatives of the production function to the price ratio of nutrients, i.e.—

$$\frac{\delta Y}{\delta N} \bigg/ \frac{\delta Y}{\delta K} = \frac{C_N}{C_K}$$

$$\text{i.e., } \frac{b_1 - 2 b_2 N + b_5 K}{b_3 - 2 b_4 K + b_5 N} = \frac{C_N}{C_K} \dots\dots\dots (5)$$

This is the equation of the isocline, and it is seen from its derivation that at all points along an isocline the ratio of the rate of increase in yield per unit increase of N to the rate of increase in yield per unit increase in K is constant and is equal to the price ratio of nutrients.

Thus the co-ordinates of the point of intersection of the isocline for a given price ratio of fertilizers and the isoquant representing a given target of production give the optimum nutrient combination corresponding to the given target of production (Fig. 2).

If the price ratio (C_N/C_K) is equal to 0.83 and the target of production is 1,900 lb. per acre, the point of intersection of the isocline and isoquant corresponding to these values is the point X in Fig. 2: and the values of N and K given by the co-ordinates of X are 64.61 lb. N per acre and 84.98 lb. K per acre. These are the economic dosages of N and K to achieve a target of 1,900 lb. per acre under the given fertilizer costs.

These values could be worked out accurately by solving equations (3) and (5), and substituting the given target of production for Y_t .

TABLE 4
Optimum dosages of N and K for different targets of production

Level of Production lb. copra/acre	Optimum Dosage (lb./acre)		
	N	*P	K
1,500	—	—	40.07
1,600	—	—	48.69
1,700	—	—	58.4
1,800	2.26	—	69.52
1,900	64.61	—	84.98
Maximum P 1976	184.92	—	114.80

* Basal dosage

Table 4 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 a nutrient price ratio of 0.8312.

(c) *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, i.e., when capital is limited. Normally the cost of fertilization per acre of coconut based on the optimum dosage at maximum profit is Rs. 37.42, but the situation may arise that the owner cannot afford more than Rs. 20 per acre on fertilization. Does it mean that under these circumstances that a lower quantity of fertilizer, based on the ratio of money available to money required, should be applied. For example, if the money available is Rs. 20 per acre, deduct Rs. 9.90 as the cost of application, leaving a balance of Rs. 10.10 for purchase

of fertilizer ; whereas if money is available *ad lib*, the owner could 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 $\frac{10\cdot10}{27\cdot52}$ of the optimum dosage. An

important point to remember is that the ratio of nutrients does not change but only the quantity applied is reduced proportionately.

In instances when capital is limited, landowners adopt another procedure. Where only Rs. 20 against a required Rs. 37·42 is available they fertilize a proportionate part of the estate at the usual dosage. The number of palms manured in an acre will be given by $\frac{20}{37\cdot42}$ of 66, i.e., 35 ; the balance 31 palms

will be left unmanured (66 palms to an acre).

Both these systems seem to be popular. But the new light thrown on this question of fertilizer mixtures by means of the economic analysis clearly shows that both these systems may, after all, not be economic. It is certain that the notion of a constant ratio of nutrients at all levels of production and at all levels of fertilization is economically unsound.

The next step is to apply econometric techniques to determine the most economic dosages of N and K when capital is limited, and ascertain to what extent the latter is superior to the two popular systems mentioned above.

Suppose N and K to be the required optimum combination and C_M the amount of cash available per acre. Then,

$$C_M = C_N \cdot N + C_K \cdot K \dots\dots\dots(6)$$

The minimum cost line (i.e., the isocline) is given by—

$$\frac{b_1 - 2 b_2 N + b_5 K}{b_3 - 2 b_4 K + b_5 N} = \frac{C_N}{C_K} \dots\dots\dots(7)$$

For a given nutrient price ratio (i.e. $\frac{C_N}{C_K}$) and a given outlay C_M , equations (6) and (7) could be solved to obtain the optimum nutrient combination for the outlay, C_M . Or, graphically the required dosage is given by the co-ordinates of the point of intersection of the isocline for a given price ratio and the cost line for the given value of C_M .

For the prevailing N : K price ratio of 0·8312 and cost at 50 per cent. subsidy per pound of N = Rs. 0·0715 and K = Rs. 0·0859, the optimum dosages for coconut for different levels of available capital have been worked out (Table 5).

Table 5.—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 Economic Dosage Level					
	lb./acre			Yield of Copra lb./acre	Profit from fertilizer alone	N	lb./acre			Yield of Copra lb./acre	Profit from fertilizer alone	N	lb./acre			Yield of Copra lb./acre	Profit from fertilizer alone	
	N	P	K				N	P	K				N	P	K			
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 per 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 per 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 per 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 per acre ..	143.75	109.56	98.60	1962.7	152.96	157.60	120.12	108.00	1936.7	144.60	138.14	109.56	103.20	1964.7	153.60			

This Table gives the comparative profits from fertilizer applied on the basis of the two systems mentioned earlier as against the economic dosage given by econometric analysis when capital is limited. The economic dosage is preferable to the other systems. Moreover it is interesting to note how the N : K ratio changes when the level of fertilization is lowered. When capital is available *ad lib*, N : K ratio is 15 : 10 ; and when capital available gets low, the quantity of N relative to K is reduced. In fact at Rs. 20 per acre only 17·39 lb. per acre of N and 73·27 lb. per acre of K are given having a N : K ratio of 10 : 42. This shows a complete reversal of the importance of N relative to K as the levels of application decrease.

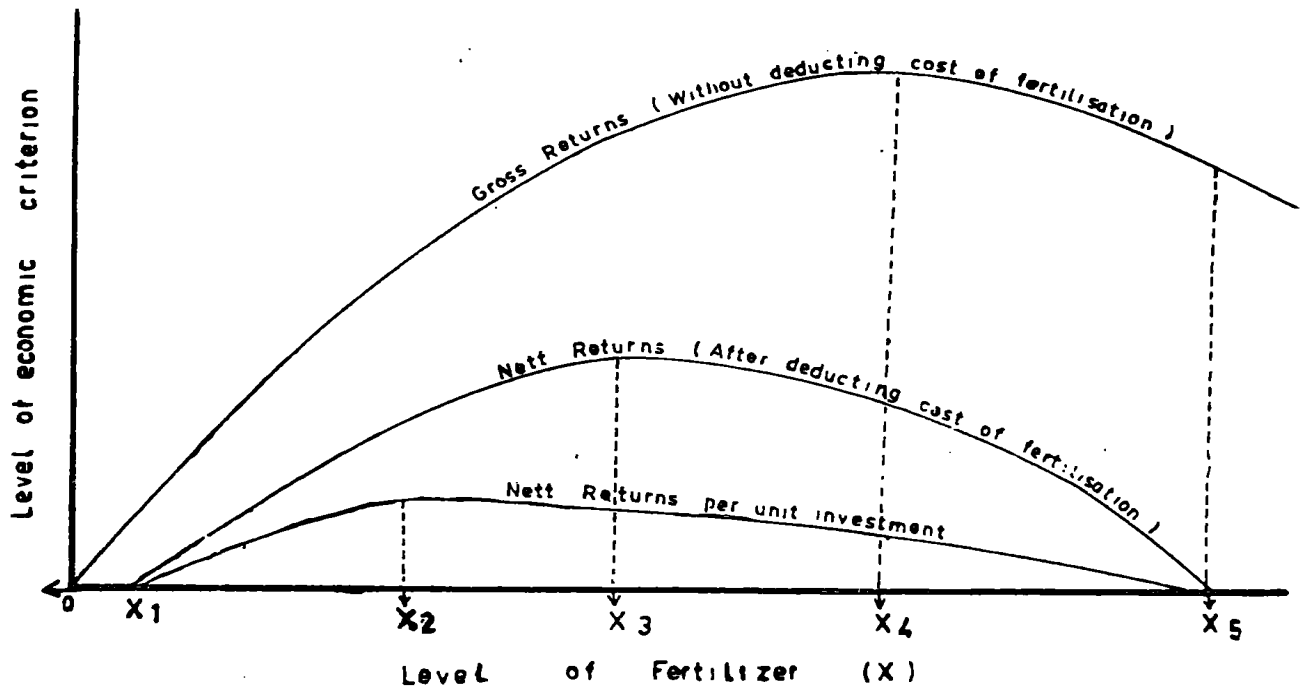
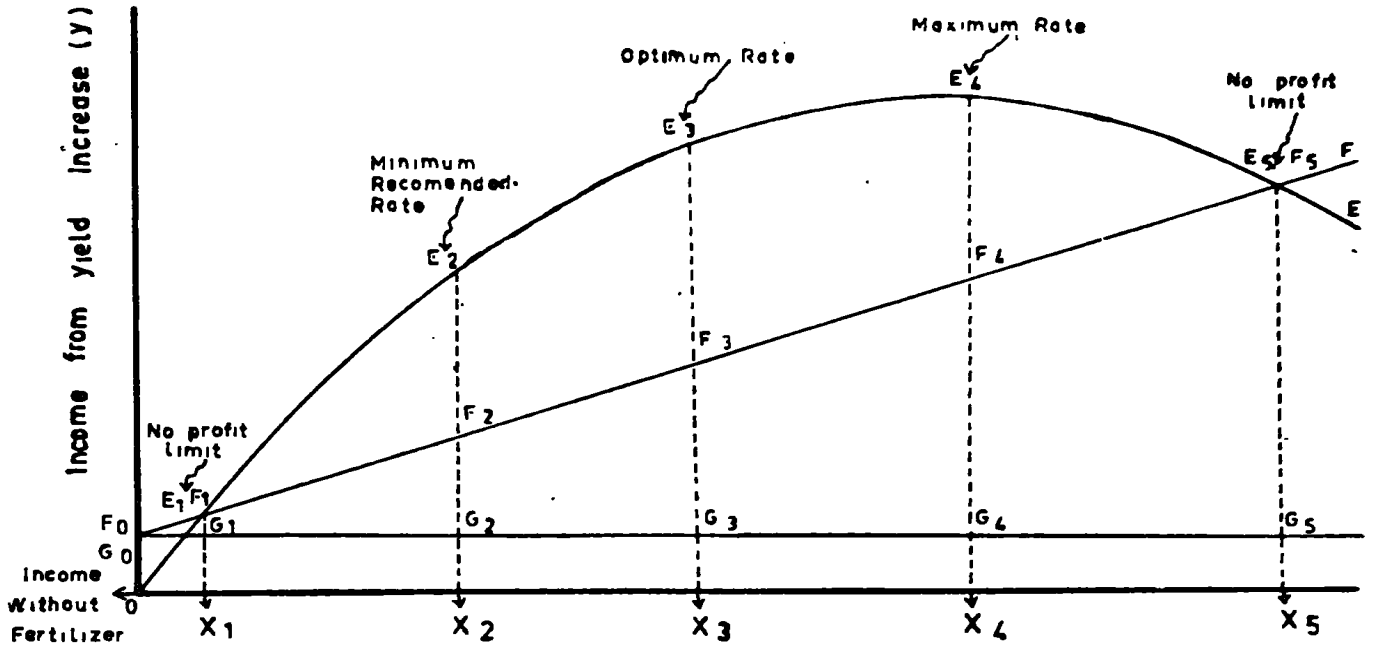
(d) *A minimum recommended dosage*—These economic nutrient dosages applicable under conditions of limited capital are subject to a certain lower limit which may be called the minimum recommended rate. This concept is illustrated with the aid of the response curve.

The response curve (in terms of income) is OE (Fig. 3). This is the income from yield in excess of what is obtainable without the addition of fertilizers as indicated by the fact that the curve starts from the origin O. Let G_0G be the line indicating fixed costs, i.e., cost of application ; F_0F the line representing cost of fertilization, i.e., cost of fertilizer plus cost of application ; and OX and OY are the fertilizer and income axes respectively.

With a response curve of this type it is possible to define as much as five critical economic criteria with regard to the level of fertilizer application. There are two points at which the cost curve F_0F cuts the income curve OE. These are E_1F_1 and E_5F_5 and may be termed 'break-even' points. The corresponding rates of fertilizer application are X_1 and X_5 and therefore the range X_1 to X_5 constitutes the profitable range of fertilizer application. The third critical level is X_4 corresponding to the maximum production. The fourth critical level is the optimum level X_3 at which point the absolute net profit (EF) is a maximum and therefore is the recommended level of fertilizer application provided capital is not limiting.

However, when capital is limited we are compelled to apply lower rates. These, as suggested earlier, should not be lower than the "minimum recommended rate" (Pesek and Heady, 1958). What is the "minimum recommended rate" ?

Fig. 3
Critical Levels of fertilizer Application



As the rate of application is reduced from the optimum level X_3 , the relative profit (i.e., $\frac{EF}{FX}$, giving the average return per unit of investment in fertilizer)

increases until we reach a point X_2 at which this criterion is a maximum. Therefore although the lowering of the rate of application below X_3 brings about a lower absolute nett profit, the average return per unit of investment increases down to X_2 , thereby ensuring in fact a more efficient use of fertilizer resources per rupee invested. This critical point X_2 is what is termed the "minimum recommended rate".

The curve of yield response is given by :—

$$Y_1 = bx + cx^2$$

The cost curve for fertilizer is given by :—

$$Y_2 = a + rx,$$

where a is the fixed cost of application expressed as a ratio of cost of unit yield and r is the price ratio of a unit of fertilizer to a unit of yield.

The return per unit investment is given by :—

$$y = \frac{Y_1 - Y_2}{Y_2}$$

The "minimum recommended dosage" is the value of X when Y is a maximum, i. e., when $\frac{dy}{dx}$ is zero. The corresponding value of X is given by :—

$$X_{\min} = \frac{-2ac \pm \sqrt{(2ac)^2 - 4abc r}}{2rc}$$

It may be relevant to point out that, as shown by the formula, the minimum recommended dosage is dependent on the cost of application in addition to the price of crop and cost of fertilizer. The optimum dosage on the contrary is independent of the cost of application. The lower the cost of application, the lower is the minimum dosage.

Thus where capital is limited, the whole estate could be manured at the highest rate permitted by the capital as long as 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. But when capital available is insufficient to apply at least the X_2 rate over the whole estate, then it will be more economical to apply the X_2 rate over a limited acreage depending on the capital available. By using this approach of the response surface for coconut, the maximum percentage profit per unit investment is given when capital invested on fertilizer is Rs. 17 per acre and the corresponding rate of fertilizer application is 65.25 lb. of K. per acre with no N. This gives a percentage profit of 632 per cent. and also an absolute profit of 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 lb. of K. per acre and this gives a profit of Rs. 93.99 on the investment.

However, if the minimum rate X_2 (i.e., 65.25 lb. K. per acre) is applied over a fraction of the estate (i.e., $\frac{59.91}{65.25}$ or 92 per cent. of the estate) a profit of 632 per cent. of the investment *viz.* Rs. 94.81 is realised. This profit is higher than the profit obtained if the whole estate is manured at the usual economic dosage permissible with Rs. 15 per acre.

(e) *A comparison of popular fertilizer mixtures*—A further interesting feature of the response surface is that for the first time a comparison could be made of the economics of fertilizer mixtures sold in the market (Table 6).

For obvious reasons the names of institutions or firms that recommend or market the manure are avoided. Although some mixtures are recommended to be applied even at higher rates, for the sake of comparison a rate of 6 lb. of these mixtures per palm per year is considered—the optimum dosage according to the present estimate being 5.85 lb. per palm per year. In fact if the higher dosages recommended by the firms are used, the income will be reduced still further.

Table 6.—Economies of Manuring Coconut with Popular Fertilizer Mixtures at 50% Subsidy

(Market price of Copra Rs. 180/Candy)

(Based on an economic analysis of the data of the N. P. K. Expt. at Bandirippuwa Estate, Lunuwila) 0

Fertilizer Mixture	Amount of Nutrients			Cost of Fertilization per acre (Rs.)	Yield of Copra lb./acre	Nett income per acre (Rs.)	Profit due to fertilization per acre (Rs.)	Offset from profit at optimum dosage (Rs.)
	N	P ₂ O ₅	K ₂ O					
Optimum Dosage (5.85 lb.)	(1) 0.492 (2) 2.390 (3) 157.600	0.501 1.820 120.120	0.820 1.640 108.00	37.42	1972.8	596.70	153.79	—
Mixture 1 (6.00 lb.) ..				38.63	1920.9	578.82	135.91	—17.88
Mixture 2 (6 lb.) ..				39.60	1894.7	569.40	126.49	—27.30
Mixture 3 (6 lb.) ..				39.34	1811.4	542.91	100.00	—53.79
Mixture 4 (6 lb.) ..				36.42	1937.7	586.42	143.51	—10.29

Note :—(1) lbs. of element per palm,

(2) lbs. fertilizer per palm,

(3) lbs. fertilizer per acre.

Table 6 gives for each mixture at the copra price of Rs. 180 per Candy, (1) the cost of fertilization (including cost of application at 15 ct. per palm), (2) expected yields, (3) nett income, (4) the profit due to fertilizer, and (5) how the profit compares with that from the application of the optimum dosage.

It is observed that all other mixtures give a lower income than the optimum dosage. This was expected. A striking point is that most mixtures have too much potash and too little nitrogen.

(f) *Other economic dosages*—These econometric techniques may also be applied to a variety of other problems, such as for instance, the optimum allocation of a limited quantity of fertilizer when one has to manure two different crops such as coconut and rubber.

CONCLUSION

It is hoped that this preliminary introduction to some modern concepts of fertilizer economics will help stimulate a more practical interest in the economic aspects of the use of fertilizers in agricultural production. These techniques would help agronomists and soil scientists to understand the results of their research in the light of the socio-economic background and thus enable them to offer to the growers advice of the highest value, viz., how to derive the maximum benefit from limited resources.

ACKNOWLEDGMENTS

I am grateful to Dr. D. A. Nethsinghe, Soil Chemist, Coconut Research Institute of Ceylon, whose encouragement has been largely responsible for my interest in this field. The co-operation received from Messrs. Gamini Karunasena and Ranjit Fernando of the Division of Biometrics, Coconut Research Institute, is also gratefully acknowledged.

REFERENCES

1. ABEYWARDENA, V.—(1961) A comparison of some popular mathematical models used for the determination of the physical production function in respect of univariate fertilizer responses. *Tropical Agriculturist* CXVII. 227–243.
2. NETHSINGHE, D. A. & ABEYWARDENA, V.—(1961) Optimum fertilizer dosage for coconuts. Paper read at the 17th Annual Sessions of The Ceylon Association for the Advancement of Science.
3. PESEK, JOHN and HEADY, EARL. O.—(1958) Derivation and application of a method for determining minimum recommended rates of fertilization. *Soil Sci Soc, Amer Proc.* 22 : 419–423.
4. (1957) Economic and Technical Analysis of Fertiliser Innovations and Resource Use—Iowa State College Press—Ames, Iowa, U.S.A.
5. SPILLMAN, W. J. (1933) Use of the exponential yield curve in fertilizer experiments. USDA Bull. No. 348.

DEPARTMENTAL NOTES

NEW ACQUISITIONS TO THE CENTRAL LIBRARY

1. Poultry Management and Production—by A. A. McArdle (Angus & Robertson Ltd., Sydney).
2. A Laboratory Manual of Milk Inspection—by Aggarwala & Sharma, 4th ed. (Asia Publishing House, New York).
3. Veterinary Toxicology—by R. J. Garner, 2nd ed.
4. Surgical Diseases of the Dog and Cat—by F. Hobaday, 6th ed.
5. Veterinary Bacteriology and Virology—by Merchant and Packer, 6th ed.
6. Textbook of Meat Inspection—by H. Thornton, 4th ed. (Items 3 to 6 published by Bailliere, Tindall and Cox, London).
7. Anatomy and Dissection of the Honey Bee—by H. A. Dade (Bee Research Association, London).
8. Chamber's Dictionary of Scientists—by A. V. Howard (W. & R. Chambers Ltd., London).
9. Elementary Algebra for Schools—by Hall & Knight, 9th ed.
10. Higher Algebra—by Hall & Knight, 4th ed.
11. A School Geometry—Parts I-VI, by Hall & Stevens (Items 9 to 11 published by Macmillans, London).
12. Modern Inorganic Chemistry —by J. W. Mellor, 5th ed. (Longmans Green & Co., London).
13. Universal Decimal Classification, Abridged English ed. (British Standards Institution).
14. Nutrition of Pigs and Poultry—edited by Morgan & Lewis (Butterworths, London).
15. The Semen of Animals and Artificial Insemination—edited by J. P. Maule (Commonwealth Agricultural Bureaux).
16. Carbohydrate Resources within the Perennial Plant—by C. A. Priestley.
17. A Review of Nitrogen in the Tropics, with Particular Reference to Pastures. (Items 16 & 17 published by Commonwealth Agricultural Bureaux).
18. Manual of Elementary Practical Chemistry—by Brown and O'Donnell (Melbourne University Press).
19. Trace Elements in Plants—by W. Stiles, 3rd ed. (Cambridge University).

20. **The Wonderful World of Nature**—by M. Phillips (Constable and Co., London).
21. **Pigs**—by V. C. Fishwick, 8th ed.
22. **Modern Poultry Husbandry**—by L. Robinson, 5th ed. (Items 21 & 22 published by Crosby Lockwood, London).
23. **The Story of Ceylon** —by E. F. C. Ludowyk (Faber & Faber, London).
24. **Soil Biology**—by W. Kuhnelt (Faber & Faber, London).
25. **Agricultural and Horticultural Seeds** (F. A. O. Agricultural Study 55).
26. **World List of Plant Breeders.**
27. **Soil Erosion by Wind and Measures for its Control.**
28. **Trade Yearbook, Vol. 14, 1960.** (Items 26 to 28 Published by F. A. O. Rome)
29. **Compost Vegetable Growing**—by B. G. Furner (W. Foulsham & Co. Ltd., London).
30. **Tea Share Manual, 1961**—by Stephens & Dwight (Gastreel & Co., London)
31. **Living Insects of the World**—by Klots and Klots (Hamish Hamilton, London).
32. **Cereal Diseases**—by Moore & Moore, 3rd ed.
33. **Potatoes, 3rd ed.**
34. **Rotations**—by H. G. Sanders, 5th ed.
35. **Seed Potatoes—Maintenance of Pure and Healthy Stocks.**
36. **Toxic Chemicals in Agriculture and Food Storage.** (Items 32 to 36 published by the Ministry of Agriculture, Fisheries & Food, London).
37. **It's a Vet's Life**—by A. Duncan (Michael Joseph Ltd., London).
38. **Applied Clay Mineralogy**—by R. E. Grim.
39. **Techniques for Efficient Remembering**—by Laird & Laird (Items 38 and 39 published by McGraw Hill Book Co., New York).
40. **Seed Preservation and Longevity**—by L. V. Barton.
41. **Modern Coffee Production**—by A. E. Haarer, 2nd ed.
42. **Rubber : Botany, Production and Utilization**—by L. G. Polhamus.
43. **Coffee : Botany, Cultivation and Utilization**—by F. L. Wellman. (Items 40 to 43 published by Leonard Hill Ltd., London).
44. **A Handbook of Succulents**—by H. Jacobsen, Vol. I-III (Blandford Press, London).
45. **Systema Helminthum, Vol. II : The Cestodes of Vertebrates**—by S. Yamaguti (Interscience Publishers, New York).

46. *Banana Diseases*—by C. W. Wardlaw (Longmans Green, London).
47. *Introduction to Plant Ecology*—by M. Ashby.
48. *Engineering Science*, 2nd ed., Vols. I-III—by Brown & Bryant. (Items 47 & 48 published by Macmillans, London).
49. *Diagnostic Methods in Veterinary Medicine*—by G. F. Boddie, 5th ed. (Oliver and Boyd Ltd., Edinburgh).
50. *Advances in Horticultural Science and their Applications*—by J. C. Garnaud (Pergamon Press, Oxford).
51. *Work Study on the Farm*—by A. A. Pakenham-Walsh (Isaac Pitman & Sons, London).
52. *Economics and Management in Agriculture*—edited by W. H. Vincent (Prentice-Hall, Englewood Cliffs, New Jersey).
53. *Orthopaedic Surgery of the Dog and Cat*—by E. P. Leonard (W. B. Saunders Co., Philadelphia).
54. *The Cat Owner's Guide*—by J. P. Volrath (The Universities Federation for Animal Welfare, London).
55. *Ticks and Disease*—by D. R. Arthur (Pergamon Press, Oxford).
56. *The Grasses : the Earth's Green Wealth*—by A. C. Moore (Macmillans, New York).
57. *Cucurbits : Botany, Cultivation and Utilization*—by Whitaker & Davis (Leonard Hill, London).
58. *Soil Management for Conservation and Production*—by R. L. Cook (John Wiley & Sons, New York).
59. *The Veterinary Annual, Third Year 1961*—edited by W. A. Pool (John Wright & Sons, Bristol).
60. *Sigiri Grafitti*—by S. Paranavitana Vols. I & II (Oxford University Press).
61. *History of Ceylon, Vol. I Part I-II*—edited by H. C. Ray (Ceylon University Press, Colombo).
62. *A True and Exact Description of Ceylon*—by P. Baldeus (Ceylon Historical Journal, Vol. 8, Colombo).
63. *Diaries in Ceylon, 1908-1911*—by L. Woolf (Ceylon Historical Journal Vol. 9, Colombo).
64. *Classical Sinhalese Sculpture, 300 B.C. to 1000 A.D.*—by D. T. Devendra (Alec Tirant, London).
65. *In the Days of Sri Wickrama Raja Singha*—by P. B. Dolapihilla.
66. *Tales of Old Ceylon*—by Fijjik (Items 65 & 66 published by the Saman Press, Maharagama).

67. Vanished Trails—by R. L. Spittel (Associated Newspapers of Ceylon Ltd., Colombo).
68. Isle of Lanka : Ceylon—by J. Vijayatunga (Orient Longmans, Calcutta)
69. Among those Present—by D. B. Dhanapala (M. D. Gunasena & Co., Ltd., Colombo).
70. Subject Matter Index of "Poultry Science", Vols. 1-20 inclusive—edited by D. R. Marble.
71. Author & Subject Matter Index of "Poultry Science", Vols. 21 to 30 inclusive, and Author Index, Vols. 1-20 (Items 70 to 71 published by the Poultry Science Association, Kansas).
72. Audel's Masons's and Builder's Guide, Vol. I—by F. D. Graham.
73. Audel's Plumber's and Steam Fitter's Guide, Vol. 3—by F. D. Graham,
74. Audel's Power Plant Engineer's Guide—by F. D. Graham.
75. Audel's Pumps, Hydraulics, Air Compressors—by F. D. Graham.
76. Audel's Sheet Metal Worker's Handy Book—by Graham and Anderson (Items 72 to 76 published by T. Audel & Co., New York).
77. Dairy Industry Plant Training Manual (American Dairy Science Association, White Plains, New York).
78. Orchids for Home and Garden—by T. A. Fennel, jr., 2nd ed. (Holt Rinehart & Winston, New York).
79. Pesticide Handbook 14th ed. 1962 compiled by D. E. H. Frear (Pennsylvania State College Press).
80. Simple Library Cataloguing 4th ed.—by S. G. Akers.
81. Introduction to Reference Work—by M. Hutchins. (Items 80 & 81 published by the American Library Association, Chicago).
82. The University Library—by Wilson & Tauber 2nd ed. (Columbia University Press, New York).
83. Crop Adaptation and Distribution—by C. P. Wilsie (W. H. Freeman & Co., San Francisco).
84. Practical Mycology : Manual for Identification of Fungi—by S. Funder, 2nd ed. (Broggers Boktrykkeri A/S, Oslo).
85. Bacterial Plant Diseases in India—by G. Rangaswamy (Asia Publishing House, London).
86. Poultry Housing, 5th ed.
87. Farm Sprayers and their Use.
88. Records and Accounts for Farm Management. (Items 86 to 88 published by the Ministry of Agriculture, Fisheries & Food, London).

89. Animal Breeding—by A. L. Hagedoorn, 6th ed. (Corsby Lockwood, London).
90. Manual of Library Economy—by J. D. Brown, 7th ed. (Grafton & Co., London).
91. First Steps in Librarianship—by K. C. Harrison, 2nd ed. (Andre Deutsch Ltd., London).
92. A Librarian Looks at Readers—by E. A. Savage, 2nd ed. (Library Association, London).
93. The Making of Books—by S. Jennett, 2nd ed.
94. Five Hundred Years of Printing—by S. H. Steinberg. (Items 93 & 94. published by Faber & Faber, London).
95. Animal Nutrition—by Maynard & Loosli, 5th ed.
96. Destructive and Useful Insects, 4th ed.,—by Metcalf & Flint. (Items 95 & 96 published by McGraw Hill Book Co., New York).
97. Genetic Aspects of Dairy Cattle Breeding—by I. Johansson (Oliver & Boyd Ltd., Edinburgh).
98. The Agricultural Notebook, 14th ed.—by P. McConnell (Iliffe, London).
99. Annual Review of Plant Physiology, Vol. 13 (Annual Reviews Inc., Palo Alto, California).
100. Pot Plant Production—by G. H. Copley (Lockwood Press, London)
101. Elements of Library Classification—by S. R. Ranganathan, 2nd ed. (Association of Assistant Librarians, London).
102. A Student's Manual of Bibliography—by A. Esdaile, 3rd ed. (Allen & Unwin and Library Association, London).
103. Pesticide Index—compiled by D. E. H. Frear (Pennsylvania State College Science Publishers).
104. The Nature and Uses of Modern Fungicides—by E. G. Sharvelle (Burgess Publishing Co., Minneapolis).
105. The Administration of the College Library—by G. R. Lyle, 3rd ed. (H. W. Wilson Co., New York).
106. Symposium on Helminthiasis of Animals (exclusive of Poultry) (Commission for Technical Co-operation in Africa South of the Sahara).
107. Animal Sanitation and Disease Control—by R. R. Dykstra, 6th ed.

108. Self-Teacher in Farm Mechanics—by Brakensiek & Phipps (Items 107 & 108 published by Interstate Publishers, Danville, Illinois).
109. Outlines of Veterinary Clinical Pathology—by M. M. Benjamin, 2nd ed. (Iowa State University Press, Ames).
110. Flowering Trees of the World—by E. A. Menninger (Hearthside Press, New York).
111. Farm Crop Irrigation : the Economic Aspects—by Nix & Prickett (Cambridge University School of Agriculture).
112. Farming Programs for Students in Vocational Agriculture—by Hammonds & Binkley (Interstate Printers & Publishers, Danville, Illinois).
113. Systema Helminthum, Vol. III, Parts 1 & 2—by S. Yamaguti (Interscience Publishers, New York).
114. Food in India—by R. P. Sinha (Oxford University Press, Calcutta).
115. Pathology of Trees and Shrubs—by T. R. Peace (Clarendon Press, Oxford).
116. The Water Buffalo of India and Pakistan—by D. C. Rife (International Co-operation Administration, Washington).
117. Bromeliads, A Cultural Handbook—by M. B. Foster (The Bromeliad Society, Los Angeles).
118. Audel's Plumber's and Steam Fitter's Guide, Nos. 1, 2, & 4—by F. D. Graham (T. Audel & Co., New York).
119. Gibberellins (American Chemical Society, Washington).
120. Tumours in Domestic Animals—by J. E. Moulton (California University Press, Berkeley).
121. Fifteenth International Horticultural Congress Proceedings, Vols. 2 & 3—edited by J. C. Garnaud (Pergamon Press, New York).
122. Diseases of Sorghum, Sudan Grass and Broom Corn—by S. A. J. Tarr (Commonwealth Mycological Institute, Kew).
123. Economics of Pig Production—by R. F. Ridgeon (Cambridge University School of Agriculture).
124. Succulents in Cultivation—by V. Higgins (Blandford Press, London).
125. Physics for the Modern World—by E. N. da C. Andrade (Harrap, London).
126. European Architecture—by R. F. Jordan (Thames & Hudson, London).
127. Tropical Inland Fisheries—by C. F. Hickling (Longmans Green, London).

128. Crop Spraying Simplified—by M. Breadford.
129. Biochemistry for Veterinary Students—by D. G. Harvey (Items 128 & 129 published by Blackwells, Oxford).
130. Dictionary of Agricultural Engineering—by H. J. Hine (W. Heffer & Sons, Cambridge).
131. The Diagnosis of Mineral Deficiencies in Plants—by T. Wallace, 3rd ed. (Chemical Publishing Co., New York).
132. Study of Tropical Vegetation : Proceedings of the Kandy Symposium (UNESCO, Paris).
133. The Wonderful Life of Flowers—by P. Jaeger (Harrap, London).
134. Intermediate Chemistry—by Lowry & Cavell, 8th ed. (Macmillans, London).
135. Plants, Viruses and Insects—by K. Easu (Harvard University Press).
136. General Index to Agronomy Journal, Vols. 1-20, 21-30 & 31-40 (American Society of Agronomy).
137. Introduction to Livestock Production—edited by H. H. Cole (W. H. Freeman & Co., San Francisco).
138. Index to "Philippine Agriculturist", Vols. I-XX (University of the Philippines, Los Banos).
139. Philippine Agriculture : Vol. I, Field Crops—edited by L. B. Uichanco, (Philippine University College of Agriculture).
140. Introduction to the Cataloguing and Classification of Books—by M. Mann, 2nd ed. (American Library Association, Chicago).
141. The Oxford Classical Dictionary—edited by M. Cary et al.
142. The Pig : Modern Husbandry and Marketing—by G. B. Clarke et al. (Geoffrey Bles Ltd., London).
143. Bacterial Plant Diseases—by C. Stapp (Oxford University Press).
144. Veterinary Drug Encyclopaedia and Therapeutic Index, 10th ed.,—edited by Stephenson & Mittelstaedt (Reuben H. Donnelly Corp., New York).
145. Methods of Analysis for Soils, Plants and Waters—by Chapman & Pratt (California University Division of Agriculture).
146. Breed Improvement in Cattle Breeding—by E. A. Novikov et al.

147. Parasitology and Parasitic Diseases of Livestock—edited by V. S. Ershov et al. (Items 146 & 147 published by the State Publishing House for Agricultural Literature, Moscow).
148. Cereal Laboratory Methods, 6th ed.—edited by E. C. Swanson (American Association of Cereal Chemists, St. Paul).
149. One-Table List of Orchid Hybrids, 1946—1960, Vol. II—by Sander & Mrs. Wreford (David Sanders Orchids Ltd.).
150. Plants that Feed Us—by E. Hvass.
151. Plants that Serve Us—by E. Hvass (Items 77 & 78 published by Blandford Press, London).
152. Grass, Clover and Lucerne Trials in O. E. E. C. Countries.
153. Livestock Diseases and the Organization of Veterinary Services in Europe (Items 79 & 80 published by the Organization for European Economic Co-operation, Paris).
154. Compost—by A. Seifert, 3rd ed. (Faber & Faber, London).
155. World Catalogue of Genetic Stocks, Rice, Supplement No. 8 (F.A.O., Rome).
156. The Emergence of Larvae from Cysts in the Genus Heterodera—by A. M. Shepherd (Commonwealth Agricultural Bureaux).
157. Bulb and Corm Production, 4th ed. (Ministry of Agriculture, Fisheries and Food, London).
158. Current Trends in Scientific Research—by P. Auger (United Nations and UNESCO).
159. Calf Rearing—by T. R. Preston, 4th ed. (H. M. Stationery Office, London)
160. Ducks and Geese, 4th ed. (Ministry of Agriculture, Fisheries & Food, London).
161. Handbook of Meteorological Instruments, Parts I & II (Air Ministry Meteorological Office, London).
162. The Mites of Stored Food—by A. M. Hughes.
163. Milk Powder.
164. Diseases of Vegetables—by L. Ogilvie, 5th ed. (Items 89—91 published by the Ministry of Agriculture, Fisheries & Food, London).
165. F. A. O. Commodity Review, 1961.
166. Farm Implements for Arid and Tropical Regions—by H. J. Hopfen.
167. Radio-Active Materials in Food and Agriculture.
168. The State of Food and Agriculture, 1960. (Items 92-95 published by The Food and Agriculture Organization of the United Nations, Rome).
169. Tropical Soils and Vegetation : Proceedings of the Abidjan Symposium.

170. Medicinal Plants of the Arid Regions.
171. Plant-Water Relationships in Arid and Semi-Arid Regions.
172. Salinity Problems in Arid Zones: Proceedings of the Teheran Symposium.
173. Arid Zone Hydrology : Recent Developments—by H. Scholler.
174. UNESCO Source Book of Science Teaching.
175. Utilization of Saline Water : Reviews of Research, 2nd ed. (Items 96 to 102 published by UNESCO, Paris).
176. Farm Power and Machinery Management—by D. Hunt, 3rd ed.
177. Nutritional and Economic Aspects of Feed Utilization by Dairy Cows, edited by C. R. Hoglund et al.
178. Principles of Veterinary Pathology—by R. A. Runnels et al.
179. Plant Growth Substances, 4th International Conference.
180. An Atlas of the Chromosome Numbers in Animals, 2nd ed.—by S. Makino.
181. Agricultural Production Functions—by Heady & Dillon.
182. Agricultural Supply Functions—edited by E. O. Heady *et al.*
183. Agricultural Finance—by Murray & Nelson, 4th ed. (Items 103–110 published by the Iowa State University Press, Ames).
184. The Useful and Ornamental Plants of Trinidad & Tobago—by Williams and Williams, 4th ed. (Guardian Commercial Printery, Port-of-Spain).
185. Encyclopaedia of Microscopic Stains—by E. Gurr (Leonard Hill, London).
186. United States Department of Agriculture Year-Book, 1961 : Seeds.
187. Plant Analysis and Fertilizer Problems, edited by W. Reuther (American Institute of Biological Sciences, Washington, D. C.)
188. Index to Botany as Recorded in the Botanical Review, Vols. 1-25, 1935—1959.
189. The Hive and the Honey Bee—edited by R. A. Grout, 2nd ed. (Dadant and Sons, Hamilton).
190. Handbook of Insecticide Dust Diluents and Carriers—by Watkins and Norton, 2nd ed. (Dorland Books, Caldwell, New Jersey).
191. Basic Agricultural Mathematics—by Whitson & Elston, 2nd ed. (National Press, Palo Alto, California).
192. Can Man Develop a Permanent Irrigation Agriculture ?—edited by R. M. Hagan (International Commission on Irrigation & Drainage, Denver).
193. The Modern Tropical Garden—by Kuck & Tongg (Tongg Publishing Co., Honolulu)
194. Handbook of Pest Control—by A. Mallis, 3rd ed. (McNair Dorland Co., New York).

195. Plant Buyer's Guide, 6th ed & Supplement—edited by H. G. Mattoon (Massachusetts Horticultural Society, Boston).
196. Nutrition and Diet in Small Animal Medicine—by M. L. Morris (Mark Morris Associates, Denver).
197. Results of the 1959 Fungicide Nematocide Tests (American Phytopathological Society).
198. Tobacco Science, Vol. III, 1959 (Lockwood Trade Journal Co. Inc., New York)
199. Laboratory Identification of Pathogenic Fungi Simplified—by Hagan and Reed, 2nd ed. (Charles C. Thomas, Springfield, Illinois).
200. Grass to Milk—by C. P. McMeekan, 2nd ed. (New Zealand Dairy Exporter, Wellington).
201. A Text-Book of Zoology—by Parker & Haswell, 7th ed. Vol. II (Macmillans, London).
202. The Artificial Insemination of Farm Animals—edited by E. J. Perry, 3rd ed. (Rutgers University Press, New Brunswick).
203. World Railways, 7th ed., 1961—62—edited by H. Sampson (Sampson Low Ltd., London).
204. A Bibliography of Eastern Asiatic Botany—by E. H. Walker, Supplement I (American Institute of Biological Sciences, Washington, D. C.).
205. Zoological Photography in Practice—by H. B. Cott.
206. Exacta Manual—by W. Wurst (Items 132 and 133 published by the Fountain Press, London).
207. Communication Among Social Bees—by M. Lindauer (Harvard University Press).
208. Biological Transmission of Disease Agents—edited by K. Maramorosch (Academic Press, New York).
209. Titles and Forms of Address, 11th ed. (Adam & Charles Black, London)
210. Secondary Science for Tropical Schools—by Pheasant & Clarke, Books I & II (Allen & Unwin, London).