
PREDICTION OF THE QUANTITY OF FERTILIZER PHOSPHORUS TO BE APPLIED AND THE YIELD RESPONSE TO BE EXPECTED BY ANALYSING THE SOIL FOR AVAILABLE PHOSPHORUS

I. POT EXPERIMENT

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'AVAILABLE phosphorus' of a soil may be defined as that quantity of phosphorus of a soil available to the growing crop; and several analytical methods of assessing 'available phosphorus' have been tried out with varying degrees of success (Bray and Kurtz, 1945 and 1948; Das, 1926; Dyer, 1894; Fitts, 1956; Fried and Dean, 1952; Herman, 1943; Larsen and Cook, 1952 and 1961; Lechartier, 1884; Martin and Buchanan, 1950; Mc George, 1947; Merkle, 1940; Morgan, 1941; Nelson and Heidel, 1950; Nelson *et al.*, 1951 and 1953; Olsen, 1954; Spurway, 1938; Thornton, 1945; Truog, 1930; and Williams, 1950). The diversity of methods which have been used and are in vogue, though surprising, is due to the fact that practically all the analytical procedures seem satisfactory under different limited ranges of soil conditions, but none of the tests is sufficiently satisfactory to be universally applicable to all soils. Some studies have compared a number of methods (Fitts *et al.*, 1956; Hockensmith *et al.*, 1933; Lawton *et al.*, 1947; McConaghy and Stewart, 1963; and Thompson and Pratt 1954).

The NaHCO_3 method of Olsen (1954) is one which has gained wide acceptance. In most of the recent work done in the Ceylon Department of Agriculture, especially in the all-island paddy soil survey (1962, 1963), Olsen's method has been adopted for determining 'available phosphorus'. The suitability of a chemical method depends ultimately to a large extent upon the correlation of soil analytical data with responses of a given crop to application of fertilizers on different soils; this has not proved an easy task. Bray (1948) following Mitscherlich (1930) used the percentage yield concept— $(\text{No. P yield} / \text{P yield}) \times 100$ —and attempted to correlate soil test values with crop responses. Mitscherlich's equation $Y=A-be^{-ax}$ undoubtedly a classic, has its limitations because he assumed the

yield curve to be asymptotic ; it is now known that the yield-fertilizer curve takes a parabolic shape with a maximum value. Some investigators have adopted Mitscherlich's equation, or modifications of it, with only partial success. Attoe and Troug (1949) evolved an equation by which the yields of alfalfa and clover hay could be predicted. Their equation is

$$\text{Tons hay per acre} = a \log \text{lb. available P} + b \log \text{lb. available K} + C.$$

But they found that a , b and c vary with different soil types. An attempt is here made to estimate yield responses under greenhouse conditions with rice.

EXPERIMENTAL

Nine paddy soils collected from different parts of the Island and representing a wide variety of soils and climates were used in this investigation. Each soil received five levels of phosphate in the form of saphosphosphate, the treatments being 0, 20, 40, 80 and 120 lb. P_2O_5 per acre ; the quantities of saphosphosphate for the various treatments were calculated on an area basis. Saphosphosphate, the least expensive form of phosphate in Ceylon was used as it is established that the availability of phosphate is high in submerged paddy soils and there have been no significant differences in yield resulting from the use of different forms of phosphate fertilizers in experiments conducted throughout the Island (Ponnamperuma, 1958, 1960). 10 lb. of air-dry soil, after being passed through a 2 mm. sieve were placed in glazed pots. Each soil was given an adequate dressing of nitrogen and potash ; potash being supplied as muriate and nitrogen as sulphate of ammonia or urea in accordance with the recommendations of the Department of Agriculture for the particular soil. After the different phosphatic treatments were applied the soils were puddled and 2 germinated rice seeds of the variety H4 were dibbled in each pot, and the level of water was maintained at about one inch above the surface of the soil by the daily addition of distilled water. At harvest the grain yields were recorded for each treatment of the different soils.

The $NaHCO_3$ method of Olsen (1954) was used for the extraction of available phosphorus and the colour development of the extract was done by the method of Dickman and Bray (1940). Standard methods were used for the other chemical analysis of the soils.

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RESULTS AND DISCUSSION

Analysis of the soils is given in Table I. Their available phosphorus varied from 20 to 117 lb. P_2O_5 per acre (1 acre $\equiv 2 \times 10^4$ lb.), pH from 4.3 to 6.3, nitrogen from 0.04 to 0.24 percent, organic matter from 1.10 to 6.86 percent, t.e.b. from 1.4 to 8.9 m.e. per 100 grams, and their texture varied from sandy loams to silty clays.

The grain yields for each soil increased, reached a maximum and then decreased with the increasing levels of phosphate added. Graphs drawn with grain yields per pot (y) and the amounts of fertilizer P_2O_5 per acre (x) as co-ordinates fitted the second degree polynomial $y = a + bx + cx^2$ with c small and negative; different soils gave different values for a, b and c. These are given in Table II and graphically shown in fig. I. Regressions of the equations were subjected to analysis of variance and were found to be significant; standard statistical procedures were used for all calculations.

Initial yield is taken as the yield in grams per pot with no P_2O_5 applied.

Maximum yield is the yield in grams per pot where $dy/dx = 0$.

Maximum P_2O_5 to be applied is at the point where the maximum yield is.

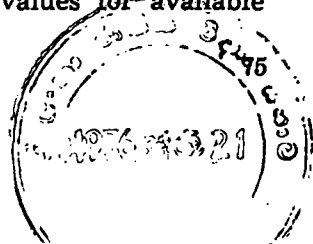
Based on the above definitions the values calculated from the equations are given in Table II.

Scatter diagrams were drawn and correlations calculated yielded the following results:—

1. There was no significant correlation between the initial yields and the soil test values for available phosphorus.
2. There was no significant correlation between the maximum yields and the soil test values for available phosphorus.
3. There was no significant correlation between the maximum yields and the maximum P_2O_5 values.
4. There was no significant correlation between the maximum P_2O_5 values and the soil test values for available phosphorus.

There was a significant correlation between the initial yields and maximum yields. This was to be expected and no important inferences could be drawn from it.

On further examination it was noticed that there is a negative correlation between the initial increases in yield per pound of P_2O_5 added (b of the equations) and the soil test values for available



phosphorus. The regression equation is $y = -0.002164x + 0.2833$; the correlation coefficient which is significant at one per cent. is -0.8484 . This is graphically shown in Figure II.

The guaranteed price of a bushel of paddy is Rs. 12, the cost of one ton of saphosphosphate containing 27.5 percent P_2O_5 is Rs. 210, the area of the pot is 64 sq. inches.

The *optimum yield* is defined as the yield where the gradient (dy/dx) is equivalent to one bushel per acre divided by the amount of fertilizer P_2O_5 cost of which is Rs. 12, or stating it in other words where the gradient indicates an increase in yield of 1 bushel per acre brought about by the addition of that quantity of P_2O_5 cost of which is Rs. 12, i.e. the point beyond which further applications of fertilizer give increases in yield the value of which is less than the cost of fertilizer required to produce the increase. It therefore follows that beyond this point the application of fertilizer is unremunerative. Converting bushels per acre to grams per pot and finding the amount of fertilizer P_2O_5 the cost of which is Rs. 12 the gradient was calculated and found to be 0.00587.

Optimum quantity of P_2O_5 to be applied per acre is at the point of optimum yield i.e. at the point where the gradient (dy/dx) is equal to 0.00587.

Optimum yield response is the optimum yield minus the initial yield.

The optimum yields, the values for optimum fertilizer P_2O_5 per acre to be applied and the optimum yield responses calculated from the equations are given in Table III. Regression equations and correlations were calculated and the following inferences were drawn.

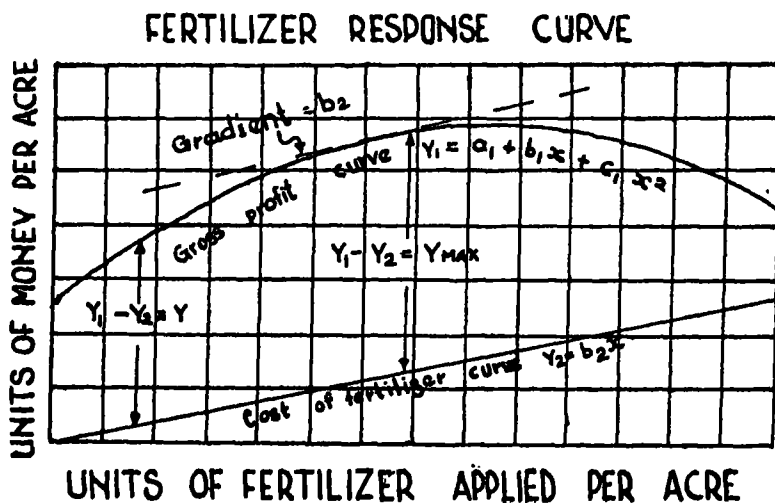
1. There is a negative correlation between the optimum yield responses (optimum yield minus the initial yield) and the soil test values for available phosphorus. The regression equation is $y = -0.0954x + 11.803$; the correlation coefficient which is significant at one per cent. is -0.8618 . This is graphically shown in Figure III.

2. There is a negative correlation between the optimum quantities of P_2O_5 to be applied per acre and the soil test values for available phosphorus. The regression equation is $y = -0.187x + 85.641$; the correlation coefficient which is significant at 5 per cent. is -0.7867 . This is graphically shown in Figure IV.

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3. There is a positive correlation between the optimum yield responses and the optimum quantities of fertilizer P_2O_5 to be applied per acre. The regression equation is $y = 0.333x - 18.498$; the correlation coefficient which is significant at five per cent. is 0.7131. This is graphically shown in Figure V.

From Figure III it is possible to predict the optimum yield response that could be expected for a particular soil test value for available phosphorus. Similarly from Figure IV the optimum quantity of fertilizer P_2O_5 to be added per acre for a particular soil test value of available phosphorus could be predicted, and likewise from Figure V the optimum yield response that could be expected from the application of the optimum quantity of fertilizer P_2O_5 per acre could be predicted.



The grain yields per pot in grams and the amounts of fertilizer P_2O_5 per acre were shown to be connected by the equation $y = a + bx + cx^2$. Converting grams per pot to bushels per acre and considering the price of a bushel of paddy to be Rs. 12 a new equation $y_1 = a_1 + b_1x + c_1x^2$ could be derived; y_1 is the gross profit per acre and a_1, b_1 and c_1 are constants. This is shown in the diagram above. The cost of fertilizer curve $y_2 = b_2x$ is also shown in the same diagram.

By definition the optimum yield is at the point where the gradient (dy/dx) is equivalent to one bushel per acre divided by the amount of fertilizer cost of which is Rs. 12, i.e. at the point where the gradient of the gross profit curve $y_1 = a_1 + b_1x + c_1x^2$ is equal to the gradient of the cost of fertilizer curve $y_2 = b_2x$.

$$\text{thus } b_1 + 2c_1x = b_2$$

$$\text{or } b_1 - b_2 + 2c_1x = 0 \dots\dots\dots (1)$$

Considering the gross profit curve $y_1 = a_1 + b_1x + c_1x^2$ and the cost of fertilizer curve as $y_2 = b_2x$, $y_1 - y_2$ is seen to be the net profit. $y_1 - y_2 = y = a_1 + (b_1 - b_2)x + c_1x^2$. This equation has a maximum at the point where $dy/dx = 0$.

$$dy/dx = b_1 - b_2 + 2c_1x = 0 \dots\dots\dots (2)$$

Equations (1) and (2) are identical ; thus showing that the optimum yield is at the point of maximum profit.

SUMMARY

Under greenhouse pot conditions nine different paddy soils were given varying dressings of phosphorus ranging from 0 to 120 lb. P_2O_5 per acre with adequate dressings of nitrogen and potash. 'Available phosphorus' was determined by the $NaHCO_3$ method of Olsen (1954). Graphs drawn with grain yields (y) and the amounts of fertilizer P_2O_5 (x) as coordinates fitted the second degree polynomial $y = a + bx + cx^2$ with c small and negative ; different soils gave different values for a , b and c .

The optimum yield is defined as the yield where the gradient (dy/dx) is equivalent to one bushel per acre divided by the amount of fertilizer P_2O_5 cost of which is rupees twelve (the guaranteed price of a bushel of paddy is rupees twelve).

Graphs were drawn, regression equations calculated and correlations were established between the following :—

1. The optimum yield responses and the soil test values for available phosphorus.
2. The optimum quantities of fertilizer P_2O_5 to be applied per acre and the soil test values for available phosphorus.
3. The optimum yield responses and the optimum quantities of fertilizer P_2O_5 to be applied per acre.

It is deduced that there is a possibility of predicting the quantity of fertilizer phosphorus to be applied and the yield response to be expected by analysing the soil for available phosphorus ; the optimum yield is also shown to be at the point of maximum profit.

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TABLE I—Soil Analysis

Soil	Available Phosphorus P_2O_5 lbs/acre	pH	Organic matter %	Nitro- gen %	c.e.c.	t.e.b.	Conduc-	Exchange-	Coarse	Fine	Silt %	Clay %
					m.e./100 grms	m.e. 100 grms	tivity in 1 : 5 Solution milli mhos/cm	able potassium m.e. 100 grm	Sand %	Sand %		
1. Bibile ..	.. 20.3..	6.3..	1.21..	0.06..	5.6..	3.4..	0.037..	0.10..	40.9..	34.6..	5.4..	15.6
2. Pussellawa ..	.. 22.8..	4.4..	6.03..	0.16..	16.6..	1.8..	0.064..	0.28..	13.7..	22.2..	13.4..	46.4
3. Medawachchiya ..	.. 29.5..	5.0..	1.75..	0.11..	11.0..	7.2..	0.057..	0.28..	26.9..	44.6..	7.8..	16.1
4. Mirigama ..	.. 42.0..	4.3..	1.92..	0.10..	6.0..	2.3..	0.059..	0.19..	7.6..	58.7..	9.1..	24.1
5. Kilinochchi ..	.. 52.0..	4.7..	1.10..	0.04..	5.3..	2.1..	0.153..	0.18..	38.5..	39.1..	7.0..	16.0
6. Walawe ..	.. 60.0..	5.9..	1.75..	0.09..	13.7..	8.9..	0.122..	0.33..	33.5..	29.3..	3.2..	32.2
7. Kandy ..	.. 67.9..	4.8..	3.57..	0.20..	13.9..	3.3..	0.078..	0.28..	17.6..	24.0..	12.0..	41.0
8. Bombuwela Peaty ..	.. 73.0..	4.6..	6.86..	0.21..	10.6..	1.4..	0.083..	0.18..	34.6..	34.9..	4.6..	19.1
9. Karapincha ..	.. 116.7..	4.5..	6.03..	0.24..	8.8..	1.8..	0.127..	0.15..	29.3..	46.4..	4.0..	14.6

TABLE II—Yields in grams per pot, Maximum Values, Equations, etc.

Soil		Yields in grams per pot at various levels of P_2O_5 added					Available P_2O_5 lbs/acre	Maxi- mum P_2O_5 lbs. Acre to be added	Maxi- mum Yield grams per pot	Equation
		0	20 lbs P_2O_5 per Acre	40 lbs P_2O_5 per Acre	80 lbs P_2O_5 per Acre	120 lbs P_2O_5 per Acre	Soil test Values			
1. Bibile	O	.. 27.7..	32.5..	35.9..	37.8..	37.1..	20.3..	86.4..	38.4..	$y = 27.99 + 0.242x - 0.00140x^2$
	C	.. 28.0..	32.3..	35.4..	38.4..	36.9				
2. Pussellawa	O	.. 22.2..	27.1..	32.8..	34.0..	33.5..	22.8..	86.1..	35.1..	$y = 22.35 + 0.296x - 0.00172x^2$
	C	.. 22.4..	27.6..	31.4..	35.0..	33.1				
3. Medawachchiya	O	.. 32.3..	35.4..	37.0..	38.0..	37.5..	29.5..	87.9..	38.3..	$y = 32.79 + 0.125x - 0.00071x^2$
	C	.. 32.8..	35.0..	36.7..	38.2..	37.6				
4. Mirigama	O	.. 27.8..	32.4..	34.7..	35.0..	33.0..	42.0..	73.1..	35.8..	$y = 28.28 + 0.206x - 0.00141x^2$
	C	.. 28.3..	31.8..	34.3..	35.7..	32.7				
5. Kilinochchi	O	.. 43.9..	47.5..	48.8..	49.8..	47.7..	52.0..	72.6..	50.1..	$y = 44.17 + 0.164x - 0.00113x^2$
	C	.. 44.2..	47.0..	48.9..	50.1..	47.6..				
6. Walawe	O	.. 32.6..	37.6..	38.8..	38.9..	38.8..	60.0..	80.1..	40.1..	$y = 33.49 + 0.165x - 0.00103x^2$
	C	.. 33.5..	36.4..	38.4..	40.1..	38.5				
7. Kandy	O	.. 33.6..	36.7..	38.5..	38.8..	36.8..	67.9..	70.6..	39.3..	$y = 33.83 + 0.154x - 0.00109x^2$
	C	.. 33.8..	36.5..	38.2..	39.2..	36.6..				
8. Bombuwela Peaty	O	.. 24.7..	28.7..	29.2..	29.7..	29.3..	73.0..	78.6..	30.4..	$y = 25.39 + 0.127x - 0.00080x^2$
	C	.. 25.4..	27.6..	29.2..	30.4..	29.0				
9. Karapincha	O	.. 32.8..	33.3..	33.4..	33.9..	33.6..	116.7..	90.0..	33.8..	$y = 32.80 + 0.0225x - 0.000125x^2$
	C	.. 32.8..	33.2..	33.5..	33.8..	33.7				

O—Observed values.

C—Values calculated from the equations.

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TABLE III—Initial Increases in Yield (b of the Equations),
Optimum Values, etc.

Soil	Available P_2O_5 lbs per acre soil test Values	Initial Increases in Yield (b)	Initial Yield grms per pot	Optimum Yield grms per pot	Optimum Yield response be grms per pot	Optimum P_2O_5 to be applied lbs per acre
1. Bibile ..	20.3 ..	0.242 ..	28.0 ..	38.4 ..	10.4 ..	84.3
2. Pussellawa ..	22.8 ..	0.296 ..	22.4 ..	35.1 ..	12.7 ..	84.3
3. Medawachchiya ..	29.5 ..	0.125 ..	32.8 ..	38.3 ..	5.5 ..	83.8
4. Mirigama ..	42.0 ..	0.206 ..	28.3 ..	35.8 ..	7.5 ..	71.0
5. Kilinochohi ..	52.0 ..	0.164 ..	44.2 ..	50.1 ..	5.9 ..	70.0
6. Walawe ..	60.0 ..	0.165 ..	33.5 ..	40.1 ..	6.6 ..	77.3
7. Kandy ..	67.9 ..	0.154 ..	33.8 ..	39.3 ..	5.5 ..	68.0
8. Bombuwelapeaty ..	73.0 ..	0.127 ..	25.4 ..	30.4 ..	5.0 ..	75.0
9. Karapincha ..	116.7 ..	0.023 ..	32.8 ..	33.7 ..	0.9 ..	66.5

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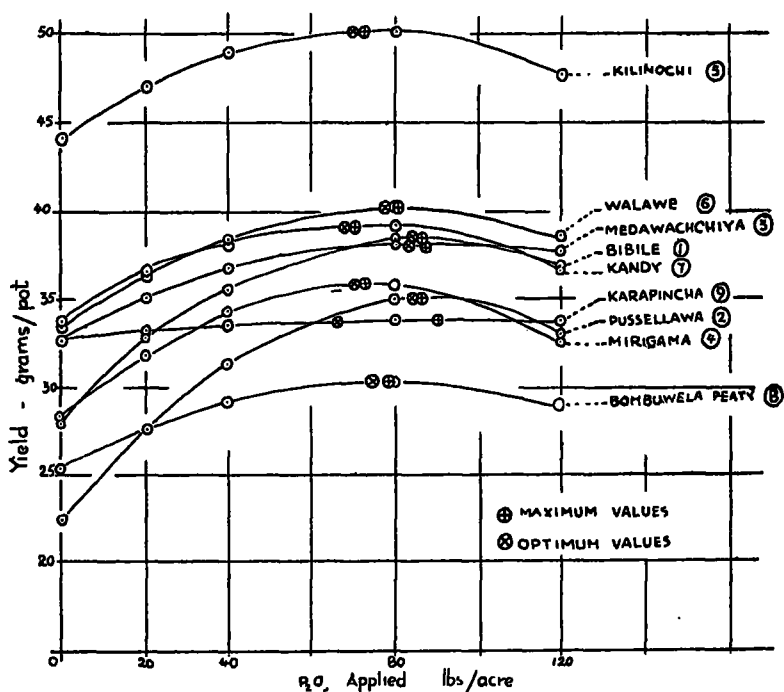


Fig. 1—Grain Yields in grams per pot—Fertilizer P_2O_5 lb. per acre

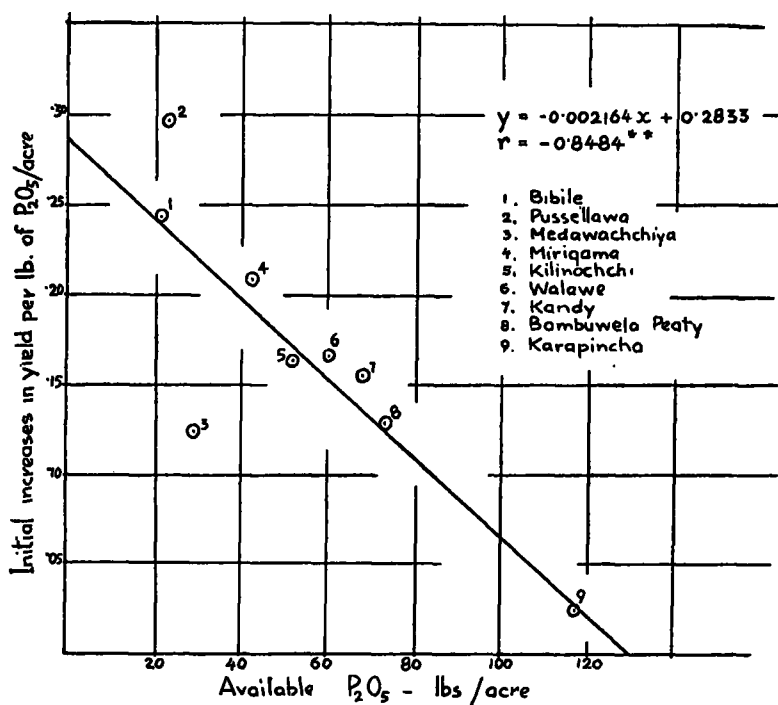


Fig. 2—Initial increases in ~~bucket~~ yield per lb. of P_2O_5 per acre (bs)
—Available P_2O_5 lb.

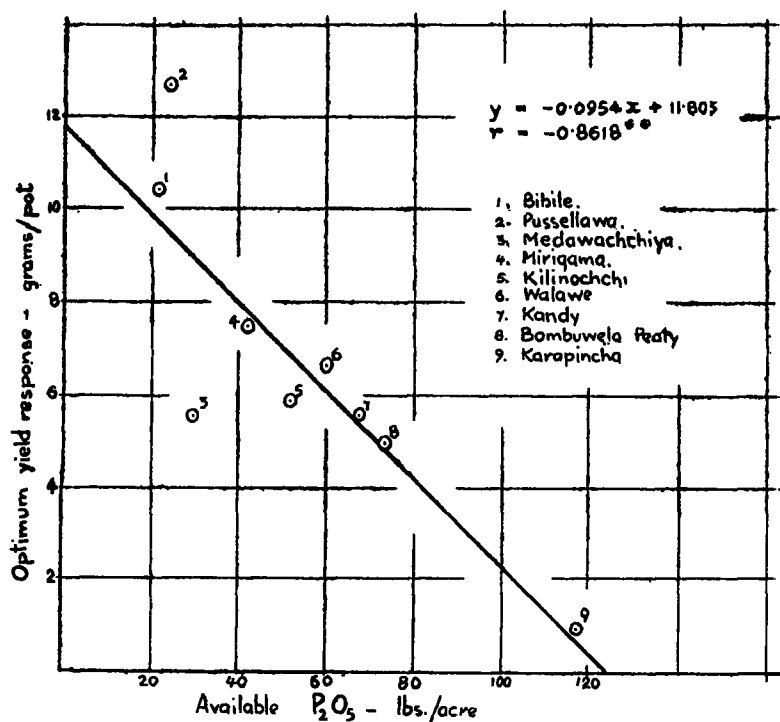


Fig. 3—Optimum Yield Response—Available P_2O_5

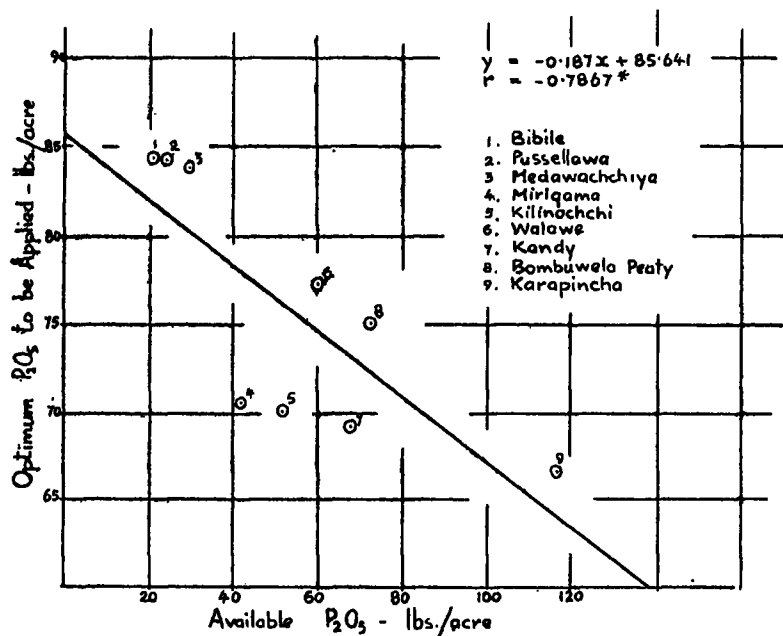


Fig. 4—Optimum P_2O_5 fertilizer to be applied—Available P_2O_5

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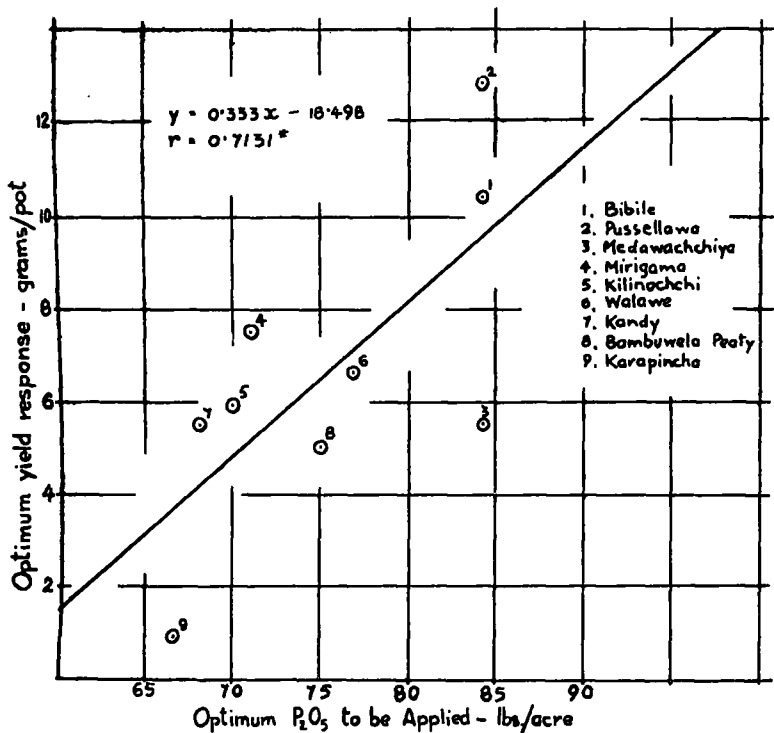


Fig. 5—Optimum Yield Response—Optimum fertilizer P_2O_5 to be applied.