THE RELATIONSHIP BETWEEN P SOIL TEST AND MAIZE YIELD ON AN AVALON MEDIUM SANDY LOAM

(Met opsomming in Afrikaans)

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Abstract

Fertilizer use no longer represents a major innovation. The majority of farmers today are aware of the necessity to use fertilizer and wish to know what quantities of fertilizer are required to optimise profits. Optimum economic usage can best be determined from response functions relating yield to indices of soil fertility. Soil tests can provide valuable and reliable estimates of fertility, but few attempts have been made in Natal to conduct the necessary correlative work. In this investigation an attempt was made to develop a single nutrient response function relating maize yields to P soil test on the sandy hydromorphic soils of northern Natal.

In the initial stages of the investigation the predictive values of three soil test methods using 0,05 N H_2SO_4, a solution of 0,03 N NH_4F and 0,025 N HCl, and a solution of 0,05 N HCl and 0,025 N H_2SO_4 were compared. The method considered superior was subsequently used to establish the relationship between soil test and percentage yield over five growing seasons. By determining the mean increase in soil test per unit of P carrier applied and by considering 100 per cent yield as the mean of the top plots in each season, it was possible to express both yield and soil test in monetary terms. Gross and net profit functions were constructed and the soil test values subtending maximum economic returns per unit area and maximum returns per unit of variable input were established.

Introduction

Notwithstanding the fact that over 80 000 soil samples are analysed annually by commercial and State laboratories specifically for the purpose of predicting fertilizer requirements, decision-making with regard to fertilizer usage remains a very arbitrary undertaking in South Africa. Few relationships between soil test values and crop yields have been established and soil testing presently constitutes little more than an extension tool; a means of establishing contact with the farmer and of making him more fertilizer conscious. Until fairly recently this was perhaps partially justified in that fertilizer use represented a major innovation to the majority of farmers. The task of education was to get farmers to use some fertilizer and the predictive value of soil tests was of secondary importance. Today, however, farmers in most major cropping areas of the Republic are aware of the need to use fertilizer. The economic and educational task is now more nearly that of getting optimum quantities of fertilizer into use. Quantities which will maximise profits under various resource situations and not necessarily quantities which will maximise yields — a distinction not always appreciated by soil and crop specialists. A farmer with adequate capital or limited land, for example, may wish to maximise profit per hectare. On the other hand a farmer with limited capital or with numerous high-return investment alternatives may more nearly prefer a rate of fertilization which maximises return on investment in fertilizer. Thus, farmers require information which will permit more sophisticated decision-making. A level of decision-making which South Africa's annual investment in fertilizer certainly warrants.*

Although less restrictive approaches to the problem have been used (Bray, 1948, Richardson, 1952, Van der Paauw, 1952, Möhr, 1972) optimum fertilizer usage for annual crops can probably best be determined from the results of fertilizer response research based on effective soil tests and encompassing single, clearly defined soil-plant-bioclimatic systems.

The central methodological problem in establishing optimum fertilizer usage is statistical and involves the determination of the mathematical form of an experimentally established relationship between soil test and crop yield (Heady, 1956). However, there are other methodological problems which are auxilliary to this central problem. Generally, it is these problems with which the agronomist and soil scientist must be concerned if satisfactory experimental data are to be obtained. They will not be considered in detail here, but include problems of experimental design (Heady, 1961, Colwell, 1971; Boyd, 1972), accommodating the effects of uncontrolled variables within a particular soil-plant-bioclimatic system (Hanway, 1971), selecting priorities (Johnson, 1956), sampling, sample pretreatment, and laboratory analysis (Van der Paauw, 1952; Hanway, 1971), engendering suitable interdisciplinary co-operation (Johnson, 1956), and problems relating to the adoption of suitable agronomic practices (Pesek, 1956).

The data to be discussed here were obtained from an experiment which was not originally designed for calibration purposes. Consequently, certain of the limitations inherent in the problem areas mentioned above were operative. There were, for example, too few nutrient levels incorporated into the experimental design, there were no zero levels of N and P, and the experiment was not replicated on other sites within the same soil-plant-bioclimatic system.

The objectives of this study were:

1 To evaluate three commonly used phosphorus soil test methods in terms of correlation between P soil test results and maize yields, and to select the best method.

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* Expenditure on fertilizer in 1971 was approximately R110 000 000.

2 To calibrate the soil test values obtained by this method in terms of soil test required for specified maize yields on the sandy hydromorphic soils in Phillip's (1969) mild subarid grassland to wooded savanna.

Materials and Methods

Field methods

Yield data and soil samples were obtained from a maize fertilizer trial conducted on an Avalon medium sandy loam near Dundee, northern Natal. Selected physical and chemical properties of a representative soil profile are presented in Table 1.

The experiment was initiated in 1966. Three levels of N, P, K, and Ca were applied in all combinations to eighty-one 0,0078 hectare plots arranged in an unreplicated 3^4 design. N, P and K were applied annually, but applications of Ca were discontinued after the 1967/68 season. The following fertilizers were used: urea (53,5, 107,0, 214,0 kg N/ha), single superphosphate (24,2, 48,4, 96,8 kg P/ha), muriate of potash (0, 87,3, 174,6 kg K/ha), and gypsum (0, 102, 204 kg Ca/ha). All fertilizers except two thirds of the urea, which was applied as a side-dressing when plants in the best plots were approximately 45 cm high, was broadcast and disced into the soil just prior to planting. Uniform dressings of $ZnSO_4.7H_2O$ (26,5 kg/ha), $CuSO_4.5H_2O$ (26,5 kg/ha), $Na_2B_4O_7.10H_2O$ (16 kg/ha), $(NH_4)_6Mo_7O_{24}.24H_2O$ (0,5 kg/ha) and $MgSO_4.7H_2O$ (233 kg/ha) were applied annually. The yellow maize cultivar SA60 was planted at a spacing of 30 cm x 90 cm. Maize grain yields were determined at maturity and all stover was removed from the experimental site.

Laboratory Methods

Soil samples were air-dried and ground to <1mm. In the 1966/67 season three widely used extractants (0,05 N H_2SO_4, a solution 0,03 N in NH_4F and 0,025 N in HCl, and a solution 0,05 N in HCl and 0,025 N in H_2SO_4) were used to extract 'plant available' P. All extractions were made using a five minute shaking period. Acid washed carbon (Darco G–60) was added prior to shaking to decolorise the solutions. Soil to solution ratios of 1:10, 1:7, and 1:8 were used respectively with the H_2SO_4, NH_4F–HCl, and HCl–H_2SO_4 solutions. Phosphorus in the extracts was determined colorimetrically using the phosphomolybdovanadate procedure.

Results and Discussion

Evaluation of extractants

A prerequisite of a successful soil test is that the results show a high degree of correlation with rate of nutrient application and measured crop response in the field. To compare the three extractants under consideration post-fertilization soil samples from all 81 plots in the experiment were initially correlated with level of P applied. The H_2SO_4 and NH_4F–HCl extractants proved to be equally effective ($r=0,88$) and were superior to the HCl–H_2SO_4 mix ($r=0,77$) (Table 2). Several commonly used growth response functions were then fitted by least squares to the grain yield/soil test data pairs. Only plots receiving the optimum N dressing were considered as marked N deficiency at the lowest level of N and severe yield depressions at the highest level of N indicated that both these levels could be considered irrational. The N levels were too widely spaced to permit satisfactory interpolation. Absence of responses to both K and Ca made it possible to consider all the optimum N plots. Thus, 27 pairs of data were used to obtain the correlation coefficients shown in Table 2.

It is evident (Table 2) that 0,05 N H_2SO_4 extraction provided the most satisfactory index of plant available P and this extractant was adopted for use in subsequent seasons. It was also noted that $y = a + bx + cx^2$ provided the best fit for all three soil test methods.

Calibration of soil test with relative yield over five seasons

To be of practical value a soil test should be so calibrated that average seasons are accommodated. This can only be done satisfactorily by using data obtained over several seasons. In this study five years was considered a sufficiently long period to validate the calibration for high probability seasons as the mean annual rainfall over this period closely approximated the long term mean for the area.

Since absolute yields are markedly affected by uncontrolled seasonal effects (mean yields at the top level of P varied from 7192 kg/ha in 1966/67 to 4597 kg/ha in 1968/69), soil test was related to relative yield. Yields obtained from each plot under consideration were expressed as a percentage of the mean yield at the top level of P. The 135 comparisons so obtained over five seasons are shown in Fig 1. Seasonal effects on the shape of the response relationship made it unlikely that the response equation providing the best fit in the 1966/67 season (Table 2) would provide the best fit over all seasons. The growth equations tested previously were therefore again tested for goodness of fit. Over five seasons the response function which provided the best fit was $y = a + bx + cx^{1/2}$ (Table 3).

The residual sum of squares (the sum of squares of the vertical deviations about the fitted line) was smallest and the correlation coefficient between observed and fitted values was highest for this function. However, as was the case in the 1966/67 season there was in fact very little difference between the better functions.

Estimation of P requirement

The production function (Fig 1) makes it possible to determine whether a favourable response to applied P is probable, but in itself gives no information regarding the profitability of further P dressings. Such information can only

TABLE 1 Selected physical and chemical characteristics of six soil horizons of an Avalon medium sandy loam

	Horizon					
	Particle size distribution % (Hydrometer)					
	0–15cm	15–30cm	30–45cm	45–60cm	60–75cm	75–90cm
c. sand	12	12	12	9	7	6
m. sand	27	24	27	18	12	11
f. sand	43	45	31	33	30	28
silt	4	4	6	6	8	8
clay	14	15	24	34	42	46
	Extractable cations in me% (N NH_4OAc pH7)					
Na	0,02	0,02	0,03	0,12	0,28	0,34
K	0,16	0,15	0,14	0,12	0,36	0,58
Ca	0,56	0,63	0,69	0,69	0,94	1.40
Mg	0,22	0,26	0,81	1.87	4.19	4.56
* S value (me%)	0,96	1,06	1,67	2,80	5,77	6,88
+ C E C (me%)	1,61	1,70	3,24	4,58	8,43	9,00
% base saturation	59,5	62,5	51,5	61,0	68,5	76,5
pH NKCl (1:2)	3,9	3,9	3,9	4,0	4,5	4,9
pH H_2O (1:2)	4,9	4,7	4,6	5,0	6,1	6,4

* Sum of metal cations

\+ Cation exchange capacity

TABLE 2 Statistical measurements of degree of correlation between transformed P soil test and maize grain yield using three soil test methods

Response Function	Coefficients of correlation between soil test and yield (n=25)		
	0,05 N H_2SO_4	0,03 N NH_4F + 0,025 N HCl	0,05 N HCl + 0,025 N H_2SO_4
$y = a + bx + cx^2$	0,857	0,746	0,736
$y = a + bx + cx^{1/2}$	0,839	0,720	0,729
$y = x/(a + bx)$	0,830	0,730	0,720
$y = a + b \log x$	0,828	0,713	0,727
$y = a + bx^{1/2}$	0,814	0,714	0,724
$\log y = a + b \log x$	0,792	0,685	0,714
$\log (100-y) = a + bx$	–0,781	–0,700	–0,736
$y = a + bx$	0,788	0,701	0,712
Value required for significance at 1% level = 0,4869			

TABLE 3 Statistical measurements of degree of correlation between transformed P soil test and maize grain yields for five seasons

Response function	Coefficient of correlation (n = 133)	F– Test*
$y = a + bx + cx^{1/2}$	0,495	42,86
$y = x/(a + bx)$	0,492	42,61
$y = a + bx + cx^2$	0,480	39,53
$y = a + b \log x$	0,471	37,93
$\log y = a + b \log x$	0,449	33,54
$y = a + bx^{1/2}$	0,444	32,56
$\log (100-y) = a + bx$	–0,407	26,40
Value required for significance at 1 % level = 0,2540		

* F-test of ratio of sum of squares due to fitting the response function to the sum of squares of the residuals

be obtained if relative yield and input are expressable in monetary terms. Relative yields must be transformed to absolute values and reasonably accurate estimates of product price and input costs must be available.

Relative yields were expressed in absolute terms by considering 100 per cent yield over the five years as the mean yield of the high P plots over this period. This mean yield was 6228 kg/ha. Each percent relative yield thus represented an absolute yield of 62,28 kg. At the current price of maize this represents approximately R2,16.

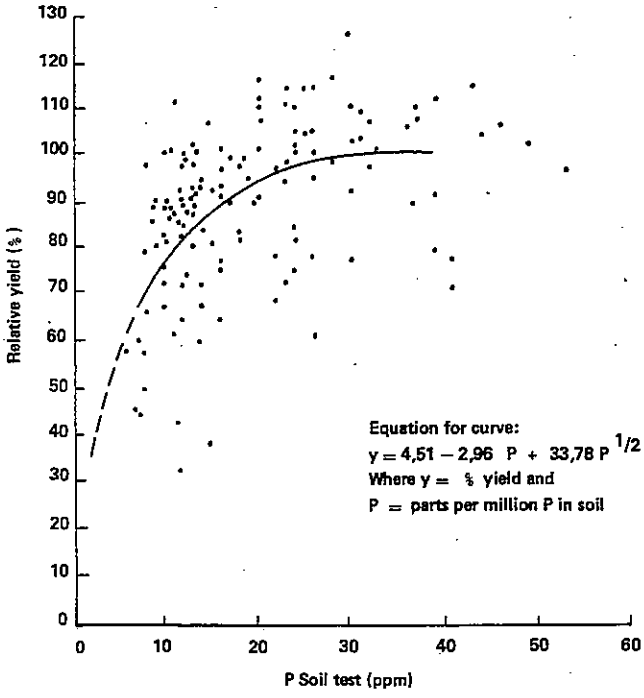

Fig 1 The relationship between P soil test and percentage yield of maize

Input costs are made up of fixed costs, in this instance all costs other than P viz seed, labour, machinery, fuel, pesticides, herbicides, hail insurance, bags, interest on money borrowed, and other fertilizer costs, and the variable cost per hectare of P. For the situation under consideration fixed costs amounted to R98,00 per hectare. The cost of P per hectare was obtained from the experimentally established relationship between increase in soil test and P application over the five seasons 1966/67 to 1970/71 (Fig 2). On average an application of 6,5 kg P/ha resulted in 1 ppm increase in soil test. In northern Natal this presently represents an investment per hectare of R2,50 per ppm using single superphosphate (8,3 % P).*

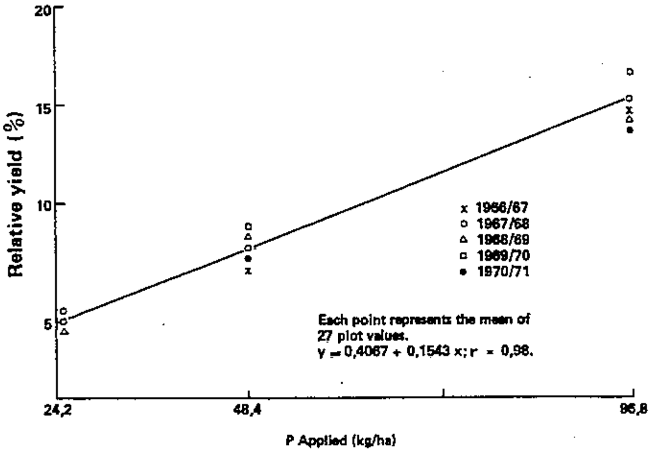

Fig 2 The relationship between P application and increase in P soil test (1966/67–1970/71)

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* Maize and fertilizer prices and rail tariffs as on 31/7/73.

Optimal fertilizer usage depends upon the economic circumstances with which the farmer is faced. To illustrate how the economic optimum may vary the calibration data discussed above will be applied to two extreme situations using an approach proposed by Heady (1971):

1 The farmer has adequate capital and wishes to maximise profits per hectare.

2 The farmer has limited capital and wishes to maximise return on capital invested in fertilizer.

1 To determine the P soil test which maximises profit per hectare, the profit function, A, is computed. This is equal to the difference between the total gross return, calculated by multiplying the price per cent relative yield (R2,83) by the production function, and the fertilizer cost function where fixed costs are R98,00 per hectare and the cost per ppm of extractable soil P is R2,50.

$$\text{Thus } A = \left[(2{,}83)\,(4{,}51 - 2{,}96\,P + 33{,}78\,P^{1/2}) - (98 + 2{,}50\,P)\right]$$

Maximum profit is obtained where the marginal revenue equals the marginal cost. The profit maximising P soil test is thus obtained by setting the derivative of profit, A, with respect to P, equal to zero.

$$0 = 47{,}80\,P^{-1/2} - 10{,}88$$

Solving for the value of P, the soil test which maximises profit per hectare is 19 ppm.* The amount of P the farmer will require per hectare to reach this optimum soil test can then be obtained by multiplying the difference between the optimum soil test and the soil test of his land by 6,5 (the quantity of P required per hectare to bring about a 1 ppm increase in soil test).

2 Where the farmer has limited capital – the more common situation among Bantu farmers in Southern Africa – he may more nearly wish to maximise return on his investment in fertilizer. He will wish to fertilize to that point where the rate of return, B (total return from fertilizer/cost of fertilization), is a maximum. In this instance

$$B = \frac{(2{,}83)\,(4{,}51 - 2{,}96\,P + 33{,}78\,P^{1/2})}{98 + 2{,}50\,P}$$

Rate of return is maximised where the derivative of B with respect to P is zero. Thus, the optimum rate of return is obtained at a P soil test of 13 ppm, a point where the cost of P per hectare is R15,00 lower than where maximum profits per hectare are desired. In fact, a farmer with severe capital limitations would be likely to have much lower fixed costs, especially if, as is the case with subsistance farmers, most operations are conducted manually by a family with few alternative employment opportunities. If, for example, the fixed costs were in the order of R35,00 per hectare, the P soil test resulting in a maximum rate of return would be 7 ppm.

The situations discussed above are but two examples of the manner in which experimentally established production functions can assist individuals involved with the formulation of fertilizer recommendations. Such information can also be used to advantage in other ways. It is possible to determine the optimum rate of investment in fertilizer if other high return investment opportunities exist and the most profitable allocation of available funds between different crops and soil types or between fixed and variable costs where operations can be expanded.

Although the single variable response function discussed in this paper has certain obvious limitations, preliminary results from a follow-up field scale (11 hectare) trial in northern Natal have been extremely promising. It was possible to fertilize to within 2 ppm of the desired soil test and relative yields were predictable to within five per cent.

The suggestion is made that South Africa might profitably devote greater attention to interdisciplinary agronomic-economic research designed to facilitate the development of nutrient response functions. Recent rapid advances in soil classification have provided a suitable research vehicle and decreasing farm profit margins require that the farmer be equipped to operate as efficiently as possible. The farmer is frequently told that farming today is a complex business operation, but few business undertakings can be successful without a sound economic framework within which to operate.

Opsomming

DIE VERBAND TUSSEN P GRONDONTLEDING EN MIELIE-OPBRENGS BY 'N AVALON MEDIUM SANDLEEM

Die gebruik van kunsmis is nie meer 'n nuwigheid nie. Die meeste boere besef deesdae die noodsaaklikheid van bemesting en wil graag weet watter hoeveelhede daarvan nodig is om optimum wins te maak. Optimum ekonomiese gebruik kan bepaal word met reaksiefunksies wat die verband tussen opbrengs en grondvrugbaarheidsindekse toon. Met grondontledings kan waardevolle en betroubare skattings van grondvrugbaarheid gemaak word, maar min pogings is nog in Natal aangewend om die nodige korrelasiewerk te doen. Hierdie ondersoek is 'n poging om die reaksiefunksie van enkelvoedingstowwe, wat die verband tussen mielie-opbrengs en P-gehalte van die grond toon, te ontwikkel vir die sanderige hidromorfiese gronde van Noord-Natal.

Aanvanklik is die voorspellingswaarde van drie grondontledingsmetodes vergelyk, nl 0,05N H_2SO_4, 'n oplossing van 0,03N NH_4F en 0,025N HCl, en 'n oplossing van

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* On this soil equivalent to ± 47 ppm using the FSSA soil test.

0,05N HCl en 0,025N H_2SO_4. Die metode wat as die beste beskou is, is daarna gebruik om die verband tussen grondontleding en persentasie opbrengs oor vyf groeiseisoene te bepaal. Deur die gemiddelde toename in grondontleding per eenheid toegediende P-draer te bepaal en deur 100 persent opbrengs as die gemiddelde van die toppersele in elke seisoen te beskou was dit moontlik om beide opbrengs en grondontleding in geldeenhede uit te druk. Bruto en netto winsfunksies is opgestel en die grondontledingswaardes wat maksimum ekonomiese rendement per oppervlakte-eenheid en maksimum rendement per eenheid veranderlike inset onderspan is bepaal.

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