EVALUATING THE P-STATUS OF SOILS

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Introduction

Agricultural extension in its broadcast sence covers a wide field and its successful application depends on an unimpeded flow of information from the extension services through to the farmer. Any information therefore which promotes facility of communication along this channel will undoubtedly have the advantage of being more readily acceptable. Soil testing is probably one of the oldest extension tools available on matters concerning crop production and its value as a communication catalyst has been proved time and time again in the early stages of development. Under these conditions results are often dramatic even although the actual scientific value of a soil test is more apparent than real. Eventually a position is slowly reached where information on how to improve further becomes more difficult and the effects less dramatic. This position corresponds to the so-called second-stage extension where the prognostic value of soil testing has to assume a higher degree of acceptability if it is to remain a usefull tool.

By accepting that soil testing will always remain as an aid to recommendation services continued experimentation is necessary to ensure that its diagnostic proficiency remains a step ahead of increasing production levels.

Often there is a very real time lag between development and acceptance and this undoubtedly may be accounted for by the seemingly insuperable problem of testing the economic feasibility of a development. The object of this paper, therefore, is to briefly outline the methods adopted in evaluating the nutrient status of soils (in this instance phosphorus) by placing emphasis on the main points of calibration procedure and attempting to instill a greater awareness of the irrefutable importance and relevance of economic considerations involved.

Soil testing methods

Soil testing methods for phosphorus have developed together with new knowledge of the mechanism of phosphorus uptake by plants and improved knowledge regarding the chemistry of phosphorus in soils. Each proposed method has attempted to extract from soil that fraction presumed to represent the 'available' quantity. Bray (1937) was the first to realize that the best method would be that which measured the predominant forms or form of a nutrient source from which plant roots satisfy their seasonal requirements.

Organic forms of phosphorus probably represent the main reserve for plant growth in soils of cool, wet climes but since mineralization of phosphorus is difficult to measure and predict, soil tests are designed to extract mainly inorganic forms.

Being one of the most reactive substances in soil, inorganic phosphorus reacts with clay, iron, aluminium, calcium as well as with organic material and other substances to form a host of different compounds. Some of these reaction products are not available while others present themselves at varying rates depending on soil factors such as pH value and clay type. As a result of the widely differing pedological and chemical properties of soils, even within a given bioclimatic region, no soil testing system is capable of universal application and interpretation. Systems in current use have developed along emperical lines to suit local conditions of crop, climate and soil. Even the most avid protagonist of soil testing appreciates that the success of any given system depends on calibration between a given method of extraction and local investigational research on response to applied fertilizer.

In 1894 Dyer proposed the use of a one per cent citric acid solution to extract phosphorus from soils and since then numerous other procedures and extraxtants have been advanced. In many instances proposals were accepted simply because they extracted a convenient quantity of phosphorus under a given set of conditions. Many of these methods have fallen into disuse and the most widely accepted are Bray's extractant No 1 for acid soils (0,025N HCl and 0,03N HN_4F) and Brays extractant No 2 for slightly acid to alkaline soils (0, 1N HCl and 0,03N NH_4F). Other procedures to have gained fairly wide acceptance are Olsen's sodium bicarbonate extractant (for calcereous soils of drier regions) which has been approved by the FAO and a resin extractable procedure recently proposed by Larsen and which appears to be gaining considerably in popularity.

Although the hot-water P soluble procedure proposed by van der Paauw at Groningen in the Netherlands is proving to be a reliable index of availability it is unlikely to gain acceptance in this country in view of the low inherent phosphorus contents of our soils.

In South Africa each soil testing authority has elected to adopt its own procedure and wide and varied methods are currently in use. In most instances each method is no worse or better than the next since the lack of adequately calibrated data has prevented any given method from soliciting sufficient support for national acceptance. Member companies of the Fertilizer Society of South Africa have standardised on Bray's No 2 solution (originally developed for more alkaline soils) but there is reason to believe that this may not necessarily be the most satisfactory in view of the relatively acid nature of most of our soils. Acceptance of this procedure was not based on any supporting experimental evidence but simply because it also extracted a convenient and easily measureable quantity of phosphorus. Under acid soil conditions the relative acidity of the extractant (Bray's No 2) is greater than originally intended (for alkaline soils) with the consequences that relatively insoluble forms of phosphorus which may not significantly or directly contribute to the total phosphorus supply may be dissolved.

According to Bray (1963) "It is now recognised that the Illinois P_2 test (Bray's No 2), which extracts both the sorbed and apatite forms of phosphorus, has no place in a soil-testing programme because the native apatite and rock phosphate forms are not available for crop growth". In contrast Bray believes that the P_1 test (Bray No 1) more accurately reflects the available phosphorus fraction of native apatites and rock phosphates.

This problems is not uncommon in South Africa and research should allow consideration to be given to establishing the merits of this method of extraction in an attempt to achieve a higher degree of perfection and efficiency.

The value of soil classification

After selection of a particular extractant, taking into consideration various soil factors such as degree of acidity and general organic matter content, interpretation of results can at most only attain a moderate standard of reliability. A single soil testing system operating over a heterogeneous soil population will seldom provide a completely acceptable service. The wider the range of soils and bioclimatic regions the lower will be the ultimate progrostic value of a given test since a given extractant is dissolving phosphorus from an almost complete spectrum of chemically and physiochemically active sources of supply. A solution to this problem could come from two avenues. The first would be to define climatic regions more clearly and to determine the most reliable extractant for each sub-region; secondly and probably the most logical approach would be to classify soils into a number of groups with reasonably uniform pedological and chemical characteristics. Correlative data between soil test levels and response to applied fertilizer could then be conducted on a soil grouped basis and should result in a greater predictive efficiency since a given extractant would now be dissolving phosphorus from relatively similar chemical forms within a group of pedologically related soils. The ultimate prognostic value of a soil test through application of some soil classification system will obviously also be influenced by the reliability of the criteria used in the classification itself.

In South Africa, Farina (1971) and Möhr (1973) have clearly demonstrated the benefits in the form of an improved prognosis from soil tests by grouping soils according to some or other acceptable classification system.

Calibration procedures

Before field and laboratory experimentation can begin, detailed documentation of the methods and techniques to be employed must be available in order to ensure that experimental data obtained is scientifically sound to permit the establishment of acceptable relationships. According to Hanway (1971) two basic principles must be adhered to. Firstly controlled and uncontrolled variables must be quantitized by standard methods if the results of different experiments are to be interrelated and secondly, soil samples must be representative of a known part in the field. A few of the more important aspects will be dealt with in detail.

Soil sampling

The focal point of correlative work is the analysis of a representative soil sample. All pitfalls and shortcomings associated with sampling procedure should be carefully studied if the final analysis is to provide a reasonably accurate index of nutrient availability. Since a soil sample represents an extremely small percentage of a given test plot sufficient cores must be collected to provide composite samples which will accurately reflect the fertility status of each plot. Plots on which fertilizer has been band-placed should preferably be ploughed prior to sampling in order to dilute local concentrations and consideration should also be given to horizontal sampling if this is considered expedient.

Time of sampling

During calibration studies irrespective of the type of experimental design employed the time of soil sampling is crucial for the correct interpretation of analytical data. Basically a soil test should provide an index of nutrient availability before growth and uptake of that nutrient commences. Soils sampled prior to the application of fertilizer do not provide an indication of nutrient availability for the ensuring growth period since contributions from this source are not included in the soil test. During growth the plant is confronted with two sources of phosphorus supply, viz native or residual phosphorus (from previous fertilizer) and currently applied fertilizer yet the soil test on which correlation work is to be conducted is only representative of one of these sources, ie the former. Ultimate yield obtained on the other hand reflects nutrient availability from both sources. Under these circumstances correlation between soil test and plant response cannot be made since it is impossible to isolate the individual contributions from the two sources to total yield.

As a result of this problem and in order to arrive at an acceptable critical soil level for phosphorus on a Hutton type soil Skeen, Dudding and Clayton (1972) had to rely on the residual soil level built up over the years, as a source of supply by witholding annual fertilizer applications. Möhr (1972), on the other hand, had to rely on indirect methods to establish critical levels of phosphorus on different soil types since his data also did not provide nutrient applications subsequent to sampling, to be reflected in the soil analysis.

In calibration studies involving phosphorus on a sandy Avalon Farina (1972) drew samples for analysis about four weeks after phosphorus fertilizer had been applied. This period he believed was sufficient to allow equilibrium between the applied fertilizer phosphorus and soil to be achieved and short enough to discount any effect that that young growing plant would exert on the soil analysis over that period. The subsequent soil test was regarded as an index of the phosphorus available to be crop for the ensuring growing season and hence a more correct parameter for correlation. It is hoped that the Fertilizer Society of South Africa is now adopting this sampling time on all its conventional 3^3 NPK factorial maize experiment.

A further alternative proposed by the writer, is to apply phosphorus fertilizer at different levels in relatively large quantities and allowing the crop to draw from these reserves for three to five seasons without further annual additions during this period (apart from a small 'starter' application which is common to all plots). Nitrogen and potassium may be applied annually in optimum quantities or at different levels in combination with phosphorus in a factorial arrangement. This technique eliminates any confounding from annual fertilizer phosphorus applications and permits sampling at any convenient time before planting. The Research Unit of the Fertilizer Society of South Africa is currently, applying, this so called 'P-depletion' technique to assist in confirming and refining its indirectly determined critical levels for phosphorus.

Expressing yield

Annual seasonal fluctuations and level of management are two important factors which may influence the relationship between yield and soil test value. Further, if these relationships from a number of different sites are to be integrated into some production function then the influence of factors such as season, soil type and managerial competence on absolute yield should be eliminated. This may be done by relating soil test level to relative yield, viz percentage of the maximum. According to this mode of expression the response as a proportion of the maximum yield will always be of the same percentage irrespective of yield limiting factors such as season and management practices.

The growth response function

In order to provide an idea of the nature of response to successive nutrient increments some growth function must be fitted to the data. This growth function must be developed from the combined results of a series of experiments on similar soils and conducted over a number of seasons in which yields (for functions thereof) are related to applied fertilizer (expressed as a soil test level). Figure 2 illustrates an idealized experimentally established relationship between quantity of fertilizer phosphorus applied and the concomitant increase in soil test level. To be successful, the results should show an acceptable degree of correlation between soil test and measured crop response in the field, but should also be easy to interpret. By this is meant that the empirical equation reflecting the average relationship should be fairly simple while at the same time providing an acceptable 'goodness of fit' to the scatter. Figure 1 gives an example of a relationship between soil test levels and percentage yield together with the production function providing the best fit (ideally for similar soils over a number of seasons). This function does not provide information as to the optimum level of fertilizer but serves only to illustrate the relative responses to applied fertilizer at different levels, ie whether favourable responses to additional increments are probable. Examples of empirical equations expressing a production relationship are numerous of which the pure quadratic ($Y=b_0+b_1X+b_2X^2$) and square root ($Y=b_0+b_1\sqrt{X}+b_2X$) of the polynomial type of functional form are the most popular. No general law with regard to the most suitable form has so far been deduced or seems forthcoming. Further discussion on the mathematical forms of other type functions fall outside the writers competence and scope of this paper.

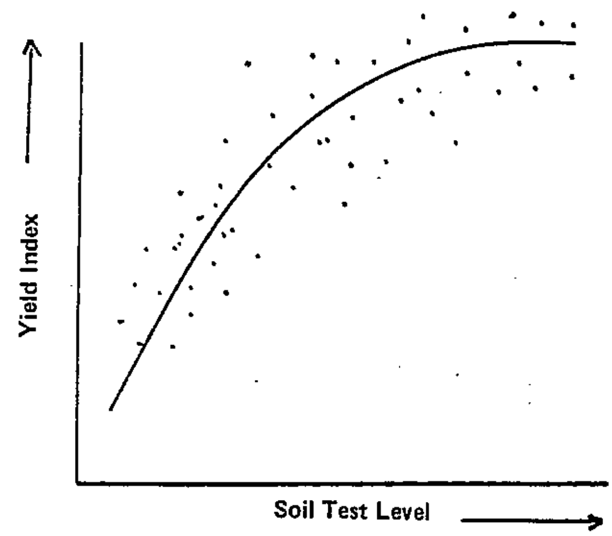

Fig 1 The average relationship between yield and soil test value for a group of similar soils (Idealized).

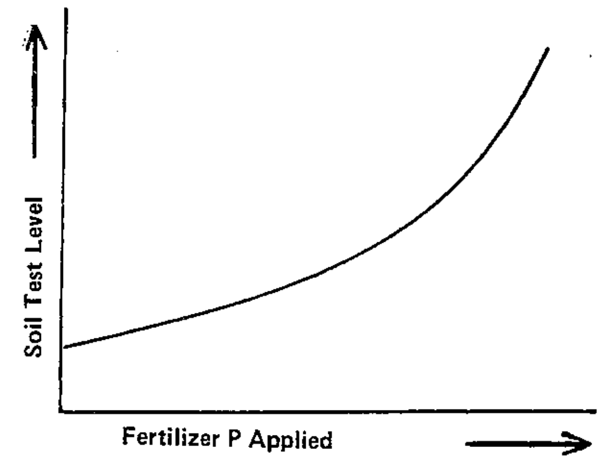

Fig 2 Hypothetical effect of the average influence of applied P fertilizer on the change in soil-P test level

Economic considerations

As pointed out by Pesek (1956) the economics of research designed to determine response to a given nutrient are simple, ie either the quantity of fertilizer used returns a profit or it does not. The most serious limitation of this approach is that there is no way of knowing whether more or less fertilizer would have returned a higher net profit. The response or production function provides the basis for overcoming this limitation by allowing the most profitable level of fertilizer applied to be determined. Various economic levels may be defined on the production function depending on the farmers economic environment and here Heady and Ray (1971) describe three distrinct situations viz

(i) Where the farmer has unlimited capital, that is enough to maximise profit per unit of land from fertilization;
(ii) Where the farmer has limited capital and wishes to maximise return on capital invested in fertilizer and;
(iii) Where he has alternatives for his capital with specified levels of return.

The principles outlined under (i) and (ii) are illustrated geometrically in figure 3.

The Y axis represents the yield response, ie the return expressed in monetary terms while the X-axis indicates the amount of nutrient added expressed as a soil test level from the relationship given in figure 2. OA represents the response function and BD the fixed cost. The slope of BC is the price per unit of fertilizer. The difference between the cost function BC and the production function OA represents the net profit per unit area of land.

The largest difference between the input and output functions occurs at soil test level T_3 and corresponds to the optimum fertilizer application, ie where land is limiting and capital is not. (Soil test level T_4 corresponds to maximum gross profit only).

On the other hand a farmer with very limited capital would prefer to fertilizer at a level which ensures maximum *rate* of return. To determine this point the total return from fertilization is divided by the total cost of fertilization to yield the rate of return curve donated by T_1R. In simple terms this represents the point on the output function where the gradient is greatest (assuming a linear input increase). In figure 3 the rate of return is greatest at soil test level T_2.

It should be clear from figure 3 that to define an optimum soil test level implies both a given product price and input cost since any change in the price structure will alter the optimum soil test level. Consider the example shown in figure 4 for a specific gross production function at two variable cost levels donated by AB and AC. At cost level AB the optimum soil test level is donated by T_1 while at cost level AC the optimum soil test level is denoted by T_2. Similarly the rate of return curve at the two cost levels will also obviously be different. Carollary wise, if the price of a bag of maize were to change from say R3-00 to R3-50 then the optimum soil test level at a given cost structure would alter accordingly. To the writers knowledge the only calibration work carried out in South Africa which has reached this level of sophistication in the final economic analysis was conducted by Farina and Mapham (1973).

Discussions so far have been limited to single-variable functions but the same principles apply in the economic analysis of functions involving two or more variables although they are obviously more complex in their interpretation. (Heady, 1956).

Conclusions

Experiments involving the economics of fertilization should show a high degree of co-operation among the services of

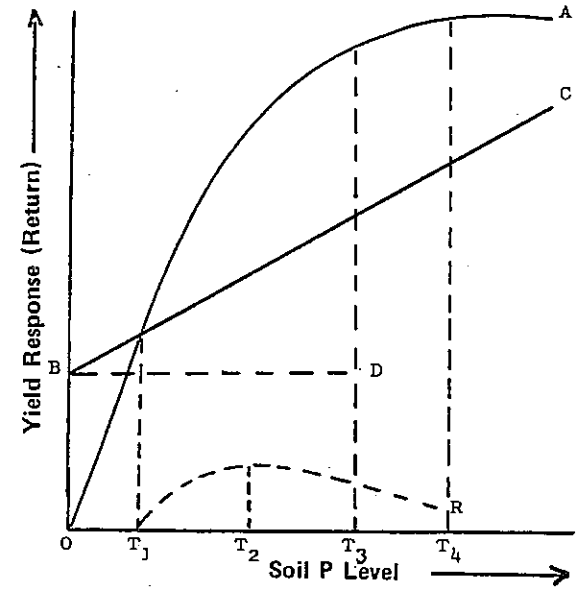

Fig 3 *Schematic illustration of response quantities and optimization. (After Heady and Ray, 1971).*

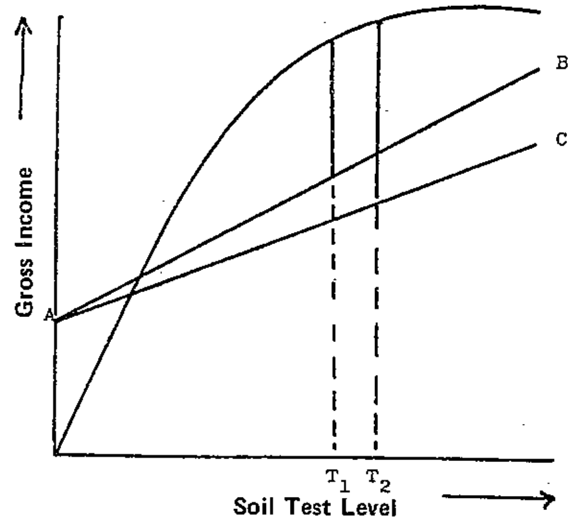

Fig 4 Schematic relationship showing influence of variable cost on the optimum soil test value

agronomists, statisticians and economists. Johnson (1956) emphasises that agronomic (soils and crops) and statistical training are complementary in most field experiments and the final analysis must include the contribution of an economist. The attainment of such a situation is referred to by him as 'Agricultural Research Statesmanship' in which the destructive competition for personal position and prestige among individuals with ill-advised loyalties to one discipline gives way to co-operative research.

Evaluation of the nutrient status of soils is clearly based on two sets of variables. The first is physical and biological which includes soil, plant, climate and fertilizer all of which must be quantilized and the second set is economic. Although the soil-plant-bioclimatic system represents a complex multi-variable situation the economic analysis of response to applied fertilizer should be simple if it is to be practical. The writer is of the opinion that the economic analysis of plant responses to applied nutrients should be restricted to single variable systems since intereaction be tween nutrients implies a deficiency of one or the other. Economic analysis of one variable is only possible when the others are in optimum.

The final situation involves decision making which as Heady (1956) points out depends on the individual farmer and his ability to bear risk as characterized by his capital, his equity position and his aversion for risk. Here he makes a clear distinction between the two types of farmers; the conservative individual with little capital and low equity applies the lower rate of fertilizer because "......... he feels assured that the probability is in favour of outcomes better than expected and that there is a slight change of outcomes worse than preducted"; on the other hand the farmer in a better capital position and with less risk aversion "......... wishes the greatest probability of success in expectations and plans".

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Discussions

Mr O van der Walt

Is it possible to tell what is the greatest risk a farmer runs of losing his investment?

Dr Skeen

You are probably familiar with the programme where you try and establish the most economical situation on a given farm. This programming is only possible once you have established the potential on the different soils, or the different crops. But one must under all circumstances make a recommendation on the optimum yield for maximum profit on a given soil. One should tailor one's recommendations based on the farmer's economic environment.

Dr H Ranwell

Na aanleiding waarvan verwerp u die warmwater-ekstraheermiddel vir P aangesien daar wel resultate verkry word wat op alle gronde van toepassing is?

Dr Skeen

Die rede waarom hierdie metode nie gebruik word nie, is moontlik omdat hier 'n ander tipe grond aangetref word; die gronde is meer verweer en moontlik is die fosfor in oplossing in Nederland hoër as dié in Suid-Afrikaanse gronde. Verder is daar twyfel of die resultate van hierdie ontleding op alle gronde van toepassing is, omdat slegs die intensiteit (en nie ook die kapasiteit) van die P-gehalte volgens die warmwatermetode ontleed word en dit dus nie volg dat die grond daardie hoeveelheid fosfor kan handhaaf deur die groeiseisoen nie.