Guide to the calibration of soil tests for fertilizer recommendations

FAO
SOILS
BULLETIN
18

FOOD
AND
AGRICULTURE
ORGANIZATION
OF THE
UNITED NATIONS

Foreword

The rationalization of fertilizer use in the developing world is quickly gaining importance. The general fertilizer recommendations which have been developed during the last two decades for large agricultural areas throughout the world were based on thousands of small experiments carried out under conditions of practical farming. This technique of small trials, which is described in an earlier FAO Soils Bulletin, led very quickly to fertilizer recommendations which were safe for the farmers as they resulted in high monetary returns. They did not, however, take into account the specific conditions of individual fields which would lead to even higher yield increases and benefits.

Individual fertilizer recommendations for each field can only be based on chemical soil analyses since they are quick and efficient enough to follow for the testing of many fields for many farmers per season. The difficulty in putting this well-known principle into a practical and efficient system is the interpretation of soil test data in terms of fertilizer requirements which varies from region to region.

This calibration of soil tests is done by the various soil testing laboratories in industrialized countries in very different ways, each working rather isolated from the others.

Most of the specialists in the laboratories of developing countries, be it FAO or national specialists, who want to calibrate their soil test values for improving fertilizer recommendations on a field to field basis, have no or little access to the calibration methods used elsewhere, mainly because these methods are not usually published. Nor do they have time and resources to visit many laboratories and to develop from the obtained information their own calibration methodology.

The purpose of this Bulletin is to serve as a guide for the mentioned specialists. It is the first attempt to compile and develop from the experience and information of various successful soil testing laboratories a suitable methodology for each step of the soil test calibration into a calibration system which can be applied under most varied soil and climatic conditions.

The hope is expressed that all those specialists who use this guide wholly or partly may communicate back to the Soil Resources Development and Conservation Service of FAO their experiences, opinions and obtained results. These will contribute most fruitfully to the build-up of a stock of experience on problems and difficulties met under the various conditions, which may eventually lead to an improved second edition of this guide.

Edouard Saouma
Director
Land and Water Development Division

Table of Contents

page

1. INTRODUCTION 1

Acknowledgements 2

2. THE BASIC PROBLEMS AS DISCUSSED IN THIS GUIDE 3

3. ERRORS IN SOIL TEST DATA AND THEIR PREVENTION 5

3.1 Error in the Soil Sample 5

3.1.1 Duplicate soil sample versus repeated analysis 6
3.1.2 Depth of soil sampling 6

3.2 Errors in the Laboratory 8

4. COMPARISON OF CHEMICAL SOIL TEST PROCEDURES FOR SELECTION OF THE MOST SUITABLE ANALYSIS 9

4.1 Introduction 9

4.2 Procedure 10

4.3 Repeated Cropping of the Potted Soils 12

4.4 Soil Test Methods Correlating Well with Yield Data 13

4.4.1 Nitrogen 14
4.4.2 Phosphorus 14
4.4.3 Potassium 15

5. GROWTH FACTORS AND MULTIVARIATE ANALYSIS 17

5.1 Multivariate Analysis 17

5.2 Growth Factors Influencing Yield 18

5.3 Check List of Growth Factors 18

5.3.1 Soil factors 18
5.3.2 Climatic factors 20
5.3.3 Farm management factors 20

6. FIELD EXPERIMENTS FOR SOIL TEST CALIBRATIONS 22

6.1 Lay-out, Design and Management of Field Experiments 22

6.1.1 Lay-out 22
6.1.2 Design 23
6.1.3 Management 24
6.1.4 Observations during crop growth 24
6.1.5 Harvest 24

page

6.2 Simultaneous Calibration for Two Nutrients 24

7. GRAPHICAL METHODS FOR IMPROVING SOIL TEST/YIELD RESPONSE CORRELATIONS 25

7.1 Corrections for Influencial Growth Factors 25

- 7.1.1 The principle 25
- 7.1.2 The graphical method 25
- 7.1.3 Disturbing interactions and correlations between growth factors 29
- 7.1.4 Successive corrections for various growth factors 31
- 7.1.5 Curvilinear arrangements of points 32
  - 7.1.5.1 The partition of graphs 32
  - 7.1.5.2 Intersection of regression lines and "critical level" 33
  - 7.1.5.3 The logarithmic regression 33
  - 7.1.5.4 Hand-drawn regression curves 36

7.2 Improving Soil Test/Crop Response Correlations, Using Nutrient Uptake Figures 36

7.3 Percent Yield Versus Absolute Response 37

7.4 Inconsistent Data 40

8. THE INTERPRETATION AND USE OF SOIL TEST/CROP RESPONSE CORRELATIONS FOR FERTILIZER RECOMMENDATIONS 41

8.1 The Interpretation Graph 41

8.2 Development of Interpretation Graphs from Experimental Data 41

8.3 Basic Fertilizer Recommendations 44

8.4 Site-specific Adjustments of Basic Recommendations 46

8.5 Follow-up Field Trials 46

8.6 The Philosophy of Soil Test Recommendations 47

9. INITIATION OF A SOIL TESTING SERVICE 49

9.1 General Requirements 49

- 9.1.1 Government attitude and placement of the soil testing service 49
- 9.1.2 Technical personnel 49
- 9.1.3 Technical approach to calibration problems 50
- 9.1.4 Facilities for field experimentation 50

9.2 Preparations in the Laboratory 50

9.3 Start of Field Experimentation 51

page

9.4 Operational Material and Other Requirements 51

9.4.1 Request forms, sample boxes and soil test reports 51
9.4.2 Crop information sheets 52
9.4.3 Soil testing information sheets 53
9.4.4 Assistance by extension service 53

REFERENCES 54

APPENDICES

1. Determination of Potassium Fixation by Soils 57

2. Calculation of a Regression Line 59
Calculation of the Correlation Coefficient r
Statistical Checks of b and r

3. Calculation of a Parabolic Return Curve 63
Calculation of the Optimum Fertilizer Rate.

4. Printed Forms and Soil Sample Boxes 64

1. INTRODUCTION

Since soil chemistry became a recognized discipline among the natural sciences in the middle of the 19th century, attempts have not ceased to predict crop yields from chemical soil analysis. At present soil testing has become such a general routine in the industrialized countries, that one is inclined to forget the decades of painstaking research which finally made it possible to predict yields from soil test values and to recommend appropriate fertilizer applications.

When talking about soil tests a clear distinction should be made between tests which can be interpreted easily in agricultural terms and those which cannot. In the first group belong, for instance, the pH measurement indicating directly the soil alkalinity, the tests for lime requirement, for salinity, etc. These soil tests are not the subject of this bulletin.

To the other group belong the tests for available plant nutrients in the soil, mainly N, P and K. The values from these tests do not show fertilizer requirements directly. The frequently used classification of soil test values of "high", "medium" and "low" does not indicate how much fertilizer must be applied to get the desired and economically justified yield increase. For making such recommendations the soil tests for available plant nutrients must be calibrated with field experiments and the methodologies and techniques used for the calibration are described in this bulletin.

It is unfortunate that a soil test interpretation worked out in one area is usually not valid for another different set of agricultural conditions. Therefore, the soil test calibrations which are applied in industrialized countries cannot be transferred to developing countries; in the latter case new calibrations must be made under local conditions if soil tests are to be used for fertilizer recommendations.

Although the calibration of soil tests can be used as the basis for the establishment of a soil testing service, it is not an easy or quick procedure; it can be foreseen that more and more of the new laboratories in the developing countries will undertake such calibrations themselves. Chemical soil testing is still the quickest and, in the long run, cheapest means to determine fertilizer needs and predict yields for individual fields.

For annual crops to which most of our staple food crops belong, soil testing cannot yet be replaced by any other equally efficient means. This is the reason why, even with all its shortcomings, soil testing is taking such an important place in the day to day guidance of commercial farming in the industrial countries.

In developing countries where soil fertility levels are rising with increased fertilizer use, the numerous simple fertilizer trials which gave initial and most important guidance for introduction and use of the fertilizer should logically be replaced gradually by calibrated soil testing.

For perennial crops plant tissue analysis is likely to give better short-term guidance than soil testing, the latter providing supplementary information if required. The calibration of plant tissue analysis is not described in this bulletin.

The calibration of soil tests is a rather complex procedure although its basic principle, the correlation between soil tests and crop responses, is extremely simple. The major complication is caused by the fact that the nutrient content of the soils is not the only factor which determines the yield, but one out of many. In all agronomic systems some of these other growth factors, or variables as they are called, exert strong influences on yields and fertilizer effects. This results usually in correlations between crop responses to fertilizer applications and soil tests not being as clear and significant as could be desired.

Methods to overcome these difficulties and to reach workable interpretations of soil test data are described in this bulletin. Since the different phases of work involved in soil test interpretation tend to be confusing, in the next chapter an attempt is made to state the involved problems clearly and to show how they are related.

Acknowledgements

The calibration of soil test data for practical farm advices has not developed yet to a separate discipline. The various laboratories work more or less independently from each other in accordance with the soils, climate and farm conditions of their particular areas and any one of them have developed certain outstanding and practical procedures and methodologies. It would not have been possible to write this guide without the very friendly and useful cooperation of many of these experienced laboratories. Special thanks are due to the soil testing laboratories of Minnesota, Indiana and North Carolina in the USA, to the concerned Institutes in Kiel and Weihenstephan (München) in Germany, and the Institutes in Oosterbeek, Wageningen and Haren in the Netherlands.

In the later phases of the work the detailed suggestion and comments of Prof. Dr. R.A. Barber (Purdue University, Indiana, USA) and of Dr. F. van der Paauw (Institute of Soil Fertility, Haren, Netherlands) were highly appreciated and are specially acknowledged.

2. THE BASIC PROBLEMS AS DISCUSSED IN THIS GUIDE

The principle of using soil tests as a basis for fertilizer recommendation is the dependance of the crop yield on the amount of plant available nutrients in the soil, the latter being determined by soil tests. Although this dependence undoubtedly exists, there are many influences which tend to obscure a clear relationship. Such influences may be simple errors in determining the required data, they may be unavoidable shortcomings in the technical possibilities and last, but not least, there are many growth factors other than the nutrient content of the soil which influences yields and responses to fertilizers.

For a systematic approach to tackle these problems it is necessary first of all that all precautions should be taken to reduce to a minimum the error inherent in soil test figures. This is discussed in Chapter 3.

The next problem concerns the soil extraction or analytical method used for the determination of "plant available" nutrients in the soil. The principle of these analyses is to simulate the activity of the plant root by a chemical extraction, using as an extractant weak acids, salt solutions or even pure water. There are two main reasons why this simulation cannot be perfect. First the ability to extract nutrients from the soil varies greatly with the type of plant. Secondly extraction in the laboratory is done in a matter of minutes or a few hours in order to make it a practical tool, while the crop plants have a full season to extract their nutrients. This time effect is of special importance if applied plant nutrients are released slowly during the season, as is the case with nitrogen from organic soil material, or if nutrients are fixed by the soil in less available forms. The fixation of potassium by certain clay minerals is an example. These nutrients can be extracted slowly by plants but are not extracted by the usual laboratory procedures. Therefore the simulation of the root action by a chemical extraction is at best an approximation. However, there are more and less suitable extractions and the method by which they can be compared in order to select the most efficient one for the given soil conditions is described in Chapter 4.

The climate-soil-plant system is a complicated interplay of variables, the influences of which determine in the end how the plant develops and what the crop yield will be. In Chapter 5 there is a description of an attempt to express the totality of these influences in one production equation, via multivariate analysis, in which some of the parameters quantify the influence of soil nutrients as determined by soil tests. Subsequently the various growth factors are discussed and a check list of factors is given.

Soil tests are calibrated by correlating them with the yield results of field experiments. Not all fertilizer experiments are suitable for that purpose. In Chapter 6 the lay-out and design for experiments specially suited for soil test calibrations are described.

However, even with the best soil test and field experimental data the spreading of points in the soil test/yield correlations may be wide. In Chapter 7 is described how these original correlations can be improved by correcting them for influences of known variables and by using nutrient uptake figures, which often correlate better with soil tests than the yield data. The methods employed are simple graphical procedures not involving advanced mathematics and especially suited for use by experts in field projects.

A section of Chapter 7 is devoted to an evaluation regarding the usefulness of relative crop responses such as "percent yield" for soil test calibrations since such data are frequently used in published research.

Having obtained good soil test/crop response correlations the last step is their correct interpretation and their use for making fertilizer recommendations. This final step is usually not reported in detail in the literature and is often a matter of considerable uncertainty for field experts when they try to make valid and correct recommendations. A suitable scheme and methodology is discussed and described in Chapter 8.

Chapter 9, the last, is devoted to certain aspects of organization and preparations which are important when a new Soil Testing Service is to be put into operation.

3. ERRORS IN SOIL TEST DATA AND THEIR PREVENTION

In the course of the work starting from the collection of a soil sample in the field to the point at which the analytical result is calculated that measures the soil's content of a plant-available nutrient, many errors can be made. The sources of error in that process have been studied extensively and invariably it has been found that the largest part of the total error involved is inherent in the soil sample itself (35). This part is usually 80–85 percent of the total error. The other 15–20 percent is the sum of errors made in the laboratory by sub-sampling for the analysis, and by the analysis itself including errors from the instruments involved etc. Also different laboratories deliver slightly different analytical values. These differences are rather small and are part of the mentioned 15–20 percent (13).

From the distribution of the total error in soil tests over the various phases of work, it can be seen that the laboratory work contributes a rather insignificant part of the error as long as it is run properly including the usual checks for all phases of the work as described in any good laboratory guide (11).

Thus the largest and most significant part of the total error of soil test values originates from the soil sample itself. This error alone can upset each correlation if proper care is not taken to keep it at the lowest possible level.

3.1 Error in the Soil Sample

Soils are heterogeneous and their properties vary from spot to spot. This variation is lower for some properties like pH values, and higher for others. The contents of available nutrients belong to the latter.

Schuffelen et al. (29) have determined the heterogeneity of a soil within one square metre by sampling each square decimetre and determining available potassium. Taking the average of the K-contents as 100 percent, the sub-samples varied between 43 percent and 200 percent all within this one square metre. The sampling error was 40 percent per sample.

Not all soils have such a high variability. The example shows the order of variability compared to other sources of error.

Typical of soil heterogeneity is the fact that there is little difference between small and large plots or fields. The variation in nutrient levels within one square metre of soil is nearly the same as that within a hectare. There are of course fertility differences between areas within this hectare, but these are rather small compared with the high spot to spot variation mentioned when these spots are in the order of one square decimetre, or a sample core.

This means that if the fertility differences between two fields are to be measured a large number of spot samples from each field must be taken in order to obtain a significant difference between the two averages of the fields.

In practical soil sampling many spots in the field are sampled, usually with a spade or a suitable auger and these subsamples are combined into composite samples.

The required number of subsamples recommended by many soil testing laboratories varies between 15 and 40, equally distributed over the field.

It can be calculated (36) that a practical maximum precision is reached with 40 subsamples per composite soil sample. This is shown in Figure 1. The error variance for one subsample is set 100 percent on the vertical axis. With an increasing number of subsamples (n on the horizontal axis) the percentage error variance decreases with the factor $1/\sqrt{n}$. With 4 subsamples the percent variance is $100/\sqrt{4} = 50\%$; with 15 subsamples it is 26 % and with 40 subsamples it is down to 15.8%. Any further increase in the number of subsamples will decrease the sample error only insignificantly.

If the error in the soil test for one subsample is 40% of its value as cited above, this error is reduced to 26% of 40 = 10.4% of the soil test value if 15 subsamples are collected in the field. By taking 40 subsamples the error in the soil test is reduced to 0.158 times 40 or 6.3% of the soil test value. For soil with less original heterogeneity the same calculation applies and all error values are smaller.

The error of 6% of the soil test values is not too high for the purpose of soil test calibration. In heterogeneous soils it is necessary to take 40 subsamples per composite soil sample. Since the soils' heterogeneity is not known in the test fields, it is safe to decide on 40 subsamples per composite soil sample for the calibration work. For later routine soil testing of farmers' fields, somewhat increased errors in test values are unlikely to change the soil test class of the field and the strict rule of 40 subsamples for the calibration can be relaxed to 15-25 subsamples for the advice of farmers.

3.1.1 Duplicate soil sample versus repeated analysis

From the error distribution between the soil sample and the laboratory work as described above, it follows that only a little precision is gained if the laboratory analysis is made on the same sample 3 or 4 times instead of the usual twice. Also there is little advantage in taking more than 40 subsamples for the composite sample analysed. If a still higher precision is required a practical way is to collect from the field in question two or three, instead of one, composite sample. By doing this the error variance of about 16% would be decreased to about 11% and 9% respectively, a considerable improvement.

For soil test/yield correlations it is recommended that one good soil sample of 40 subsamples be taken per replicate (block) of the field experiment at planting time, before fertilizer is applied.

3.1.2 Depth of soil sampling

The soil layer from which the roots of the crop plant take up the bulk of the nutrient should be sampled for soil testing. Sampling of a thicker or thinner layer of soil will reduce the precision of the interpretation.

For field soils the usual sampling depth is the plough layer, as roots develop freely there and fertilizers and soil amendments are mixed into that layer with every ploughing. Changes in nutrient contents and effects of soil treatments and of the cropping itself will therefore be most marked in the plough layer which is usually 15-25 cm thick.

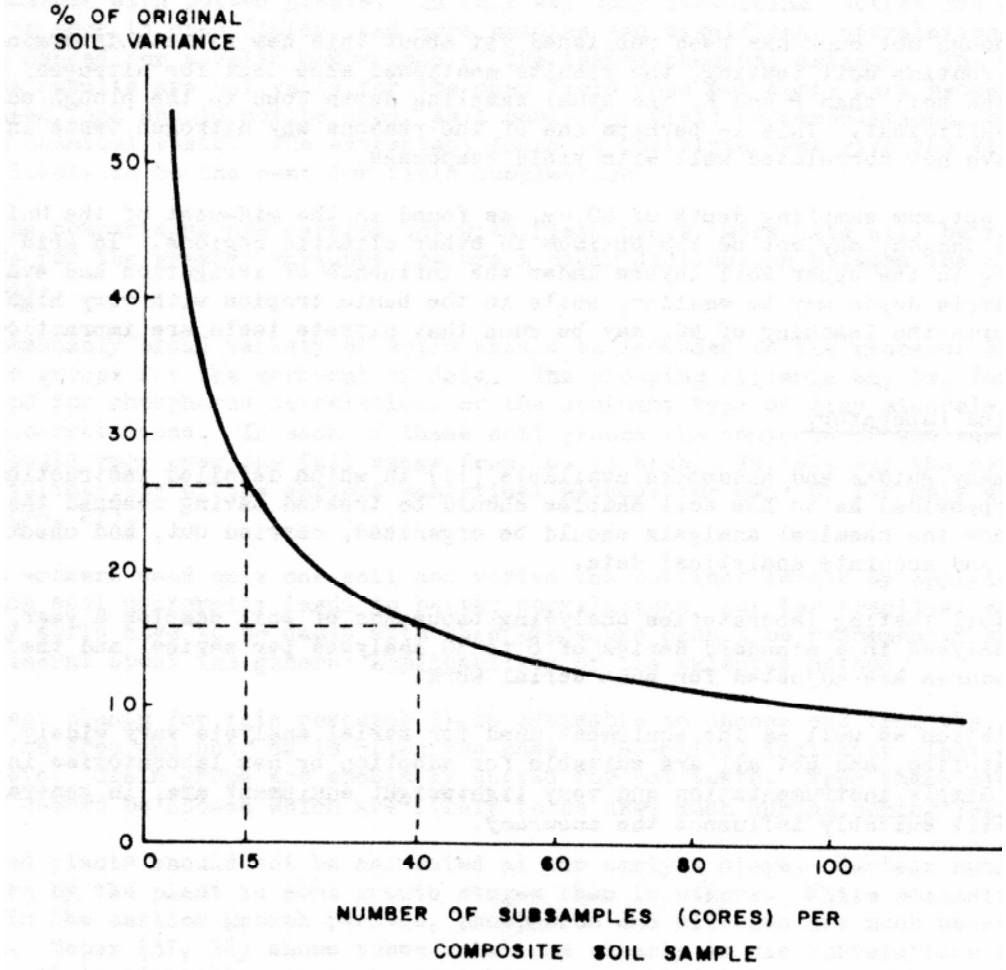

% OF ORIGINAL SOIL VARIANCE
50
40
30
20
10
0
0
15
40
60
80
100
NUMBER OF SUBSAMPLES (CORES) PER COMPOSITE SOIL SAMPLE

Figure 1

In grassland the soil layer of maximum root development and of most pronounced changes in nutrient contents is much thinner. Recommendations from soil testing laboratories for the sampling depth of grassland soil vary from 5 to 7 cm. Since small variations in this very shallow sampling affect the resulting soil test figures considerably, special sampling augers have been devised which are prevented from penetrating deeper into the soil than the prescribed depth by a simple horizontal steel plate. The sampling precision with such augers is very high since on every sampled spot exactly identical soil cores down to equal depth are taken.

These sampling methods have been in use for a long time mainly for the determination of plant available P and K. Nitrogen tests are done by only a few laboratories because these tests have not correlated well with the N-uptake by plants. However, recent research in the U.S.A. with a specific nitrate sensitive electrode gave promising results (4, 9). Calibration tests with maize showed good correlation of nitrate tests with yield. The most suitable depth of soil sampling for that purpose was found to be 60 cm (two feet). It was recommended that the composite soil sample for the nitrate test be taken with a suitable auger and dried quickly in the open air to interrupt bacterial action. 1/

Although not much has been published yet about this new nitrate determination and its use for routine soil testing, the results mentioned show that for nitrogen, which is more mobile in the soil than P and K, the usual sampling depth down to the plough sole is likely to be insufficient. This is perhaps one of the reasons why nitrogen tests in plough layer samples have not correlated well with yield responses.

The optimum sampling depth of 60 cm, as found in the mid-west of the United States and south Canada, may not be the optimum in other climatic regions. In arid climates with water moving in the upper soil layers under the influence of irrigation and evaporation the necessary sample depth may be smaller, while in the humic tropics with very high rainfall and permeable soils the leaching of NO_3 may be such that nitrate tests are impractical.

3.2 Errors in the Laboratory

There are many guides and handbooks available (11) in which detailed instructions and suggestions are provided as to how soil samples should be treated having reached the laboratory and how the chemical analysis should be organized, carried out, and checked to obtain reliable and accurate analytical data.

Efficient soil testing laboratories analysing thousands of soil samples a year, always carry out the analyses in a standard series of 8 to 30 analyses per series, and the analytical procedures are adjusted for such serial work.

The organization as well as the equipment used for serial analysis vary widely in different laboratories, and not all are suitable for adoption by new laboratories in developing countries. Simple instrumentation and very lightweight equipment are, in general, preferable and will suitably influence the accuracy.

1/ Independent from this work Soper (31, 32) obtained very similar results, also recommending a sampling depth of two feet (60 cm) for NO_3 tests to obtain the best correlation with yield data.

4. COMPARISON OF CHEMICAL SOIL TEST PROCEDURES FOR SELECTION OF THE MOST SUITABLE ANALYSIS

4.1 Introduction

The best soil test procedures are those which reflect closely the nutrient uptake of a large variety of crop plants and which, in addition, are insensitive to the type of soil.

The comparison of extractants, or soil test methods in general, can best be carried out in a greenhouse with potted plants. In this way many disturbing factors are excluded, compared to work in open fields, and more precise and significant correlations can be obtained which are needed for a valid comparison of the tested chemical methods. The objection that greenhouse results are not valid for the open field does not apply here because the results are not used, and should not be used, as a basis for field recommendations, but only for comparing chemical tests. The extractant found to correlate best with the yields in a greenhouse is likely to be the best for field samples too.

If the comparisons are carried out with field plots, more data will be required to compensate for the greater variance, before a clear distinction between the chemical methods can be made.

A reasonably broad variety of soils should be included in the research and they may be split into groups for the work-out of data. The grouping criteria may be, for instance, the soil pH for phosphorus correlation, or the dominant type of clay minerals in soils for potassium correlations. In each of these soil groups the contents of the tested nutrient element should vary over the full range from low to high. In this way the results will show the suitability of the various analytical methods for many or for only special types of soil, (26, 27).

Some workers used only one soil and varied the nutrient levels by applying fertilizers (19). Such soil uniformity leads to better correlations, but for practical advisory work, where many soils have to be dealt with this procedure cannot be recommended since nothing would be learnt about the general applicability of the selected method.

As test plants for this research it is advisable to choose one from the important field crops of the area and not, as is often the case, a so-called indicator plant such as salad, spinach, etc. Grain crops are specially suited for pot tests. From these plants improved varieties should be chosen which are likely to be used much during coming years.

Potted plants should not be harvested at too early a stage. Certain nutrients are needed more by the plant in some growth stages than in others. While potassium is largely taken up in the earlier growth periods, phosphorus and nitrogen are much needed for seed formation. Soper (31, 32) shows these relations clearly in his correlations with soil tests. Therefore, it is advisable not to harvest before a full development of heads in the case of grain. Similar precautions should be applied to other test crops. In all cases the amount of soil (pot size) must be adequate to take the plants to maturity.

In addition to the determination of plant yields per pot, the contents of the investigated element in the harvested plant material should also be determined in order to know the total uptake of the element per pot. The uptake is a direct indication of the availability of the element in the soil. The plant will take up easily available nutrients even if other outside influences prevent it from using the nutrient to the fullest possible extent for yield production. Therefore the uptake figure is often a more reliable measure of "availability" of the nutrient in the soil than the yield.

Some researchers are in favour of using the nutrient content expressed in percent of dry plant material rather than the total nutrient uptake. They reason that total nutrient uptake, which is obtained by multiplying the percent content in the plant material with the yield, is partly dependent on the yield and therefore more dependent on general growth conditions than is the pure percent content. This, however, is not so. Poor plant growth which is not caused by a deficiency of the tested nutrient element usually results in a relatively high content of this element in the plant material, which would wrongly indicate a "high uptake". The real uptake is low, however, due to the poor plant development. Hence, the figure of "total uptake" is the best value that can be used, beside the crop response itself.

4.2 Procedure

Bulk samples should be taken from 20, 30 or more fields including the main soils of the area. The soils' contents of the tested element should cover uniformly a broad range from low to high. Preliminary soil tests will help to make the right selection.

Each bulk sample should be well mixed and samples of it submitted to the usual routine soil analysis, which may be carried out in triplicate.

The available content of the nutrient under consideration should also be tested using each of the methodologies to be compared.

Six 10 litre plant pots should then be filled with each soil and test plants seeded. Three of the six pots receive all nutrient elements, except the one to be tested; these are the "checks". The other three pots are given the same nutrition plus the investigated element; these are the "fertilized" pots. The nutrient salts should be mixed well with the soil. They should not be added as a solution as this may result in an unequal nutrient distribution in the soil.

After harvest the total dry weight of produced plant material per pot is determined and analyses are carried out for the determination of the total uptake of the tested element.

Data resulting from such research are shown in Table 1. The comparison of four extractants for testing plant available phosphorus was carried out in Thailand using 16 main types of paddy soils of this country. The test crop was a favoured high yielding rice variety. The two treatments referred to in this example were for the "check" 120-0-80 in kilogram nutrients per hectare and for full fertilizer 120-80-80.

The four columns of soil test data show the figures obtained with each extraction method. The next four columns show the absolute crop data and the last column the relative values of percent yield. 1/

The soil test figures of each of the extractants were correlated with each of the five types of crop data and the resulting correlation coefficients are shown in Table 2.

1/ Check yield times 100 divided by fully fertilized yield.

Table 1 Comparison of the Correlation of phosphorus extractions with yield and nutrient uptake.

	Soil Test Data				Crop Data (grain + straw)				
	Extractants				gr/pot		mg/pot 1/		
Soil No.	Bray 1	Bray 2	Truog	Olsen	Check yield	Yield response	Uptake of P_o	Addit. uptake	% yield
Bn 1	6.6	9.0	2.7	7.3	57.9	17.7	59	48	77
Bn 2	1.2	6.0	0.9	8.0	39.8	37.2	40	73	52
Db	3.0	6.9	5.4	4.6	60.6	13.6	65	76	81
Sb 1	6.1	12.8	6.9	9.9	74.9	1.4	176	− 27	98
Cn	2.3	8.8	3.6	13.1	59.9	2.0	143	− 15	97
Ok 1	2.8	7.8	2.2	3.3	8.5	39.0	4	40	18
Sm	0.6	9.0	3.3	5.8	74.0	8.1	88	43	90
Np 1	3.8	16.0	5.4	12.2	62.0	− 1.8	119	− 4	103
Hd	2.3	7.2	5.1	5.5	52.9	14.6	56	59	78
Re 1	4.2	8.5	2.2	6.2	44.2	28.1	33	84	61
Rs	7.1	26.0	5.8	2.9	57.9	21.5	52	51	73
Ok 2	10.7	29.5	9.1	6.6	58.4	9.6	68	35	86
Sb 2	3.3	8.4	2.9	3.2	43.2	36.8	49	61	54
Ub	8.2	8.8	1.0	1.6	48.4	15.8	47	57	75
Lp	5.3	7.3	2.9	2.3	56.4	21.3	63	75	73
Pb	15.7	53.2	11.3	9.6	58.0	9.0	93	25	87
Sum	83.2	225.2	70.7	102.1	857.0	273.9	1,155	681	1,203
Average	5.20	14.08	4.42	6.38	53.56	17.12	72.2	42.6	75.2

1/ Uptake of P_o = P-uptake by "check" plants

Addit. uptake = P-uptake by "fertilized" plants minus P-uptake by "check" plants.

Source: These results, obtained by Dr. Puh Yen-Sun, FAO expert in Thailand, are used here as an example with the kind agreement of the Ministry of Agriculture, Bangkok, Thailand.

Table 2 Correlation coefficients for comparing soil extractants

Extractants	Check yield	Yield response	Uptake P_o	Addit. uptake	% Yield
Bray 1($HCl + NH_4F$)	+ 0.162	- 0.252	+ 0.099	- 0.156	+ 0.238
Bray 2($HCl + NH_4F$)	+ 0.207	- 0.301	+ 0.182	- 0.265	+ 0.284
Truog (H_2SO_4)	+ 0.437	- 0.545*	+ 0.438	- 0.422	+ 0.503*
Olsen ($NaHCO_3$)	+ 0.388	- 0.606*	+ 0.733**	- 0.736**	+ 0.512*

* = Significance level of 5%

** = same of 1%

These results show that the acid extractants of Bray and Truog did not result in data correlating well with yield data. This was partly due to the rather divergent nature of the rice soils as found in Thailand. The slightly alkaline extractant of Na-bicarbonate of pH 8.5 was superior indicating its insensitivity for the type of soil and its suitability for paddy soils.

The data obtained with the Olsen extractant show a weak correlation (15% significance level) with check yields, significant (5%) correlations with yield response and percent yield and highly significant correlations with P-uptake of checks and additional P-uptake due to P application.

This example illustrates the process of comparing extractants or soil test methods, regarding their suitability for predicting yield responses.

Finally it should be mentioned here that a study of all the correlation graphs should never be neglected. It will show details important for a correct interpretation, for instance which soils are deviating from the main trend for a specific extractant, or which irregularities are repeated for all or only some extractants and which are arbitrary, suggesting analytical errors, etc. These details will allow the researcher to make the right judgements. Without them the finally calculated correlation coefficients are of limited interpretative value. See Figure 8 for above example.

4.3 Repeated Cropping of the Potted Soils

After the harvest of the first crop as described above, a second, and even a third crop may be grown in the same soils. This will give additional information with regard to the nutrient supplying power of the various soils and will also increase data material and knowledge regarding the mechanism of the soil test/yield correlations.

Before planting the second crop the soil of each set of three pots being used as replicates of one treatment should be thoroughly mixed and the old roots sieved out. Analyses of the tested nutrient can be made again with each of the testing methods to be compared and the same pots (in order to save cleaning) can be refilled so that the three replicates start with a uniform soil. During mixing and sieving the soil should not be completely air-dried but left in a "field-moist" condition. The second crop can now be planted and it may be the same plant as used for the first cropping or another main crop.

In contrast to the first crop, the nutrients applied for this second one should not contain the tested element neither for "checks" nor for previously "fertilized" pots. The plants growing in the soil of the previous check pots will have to draw further on the natural supply of the soil. And the plants growing in the formerly fertilized soils will largely profit from the residual effect of the previously applied nutrient.

The yield determinations and plant analyses are carried out also for the second crop as already described, allowing the calculation of total uptake of the investigated nutrient.

The correlation calculations are carried out again for this second set of data as has been described. The following important information is obtained from the second cropping.

a) In the check soils: how much the soil test figures have dropped due to the nutrient uptake by the first crop. This figure is to be related with the actual amount of the tested nutrient removed by the plant. (The nutrient content of the roots may be determined.) The ability to supply available nutrients may vary from soil to soil.

b) In the previously fertilized soils: the soil test after the first crop will show an increase in available nutrient which should be related with the residual effect. The originally available nutrient of the soil, the application for and the uptake by the first crop and the new soil test figure will give an insight into the nutrient balance which may differ for different soils.

This additional information from a second, and similarly from a third, cropping is of special value for research on potassium because of the potassium equilibria mentioned in section 4.4.3 below.

In spite of these advantages from repeated cropping, the researcher may find it more desirable to spend time and effort on a new set of tests in order to increase his basic data material, rather than going into more detail by repeated cropping.

4.4 Soil Test Methods Correlating Well with Yield Data

During recent years a very large amount of research has been done and published, comparing extractants and analytical procedures regarding their usefulness for testing available soil nutrients. It is not the intention to sum up in this section all these methods nor to review the concerned literature. However, work during the last years has shown that certain extractants have been found by many scientists to be superior to others. These soil test procedures are now more and more adopted by laboratories and would be in use on an even wider scale were it not for the well-known problems which soil testing laboratories have to face in changing from an old procedure to a new one.

The following discussion is restricted to these analyses for determining the available main nutrients N, P, K in soils and will show essential difficulties involved.

4.4.1 Nitrogen

Soil tests for available nitrogen have never attained the popularity of phosphorus and potassium tests although for many crop plants and especially for the newly developed high yielding varieties nitrogen is the first requirement among the main nutrients. Nitrogen requirements were and are usually recommended by the soil testing laboratories based on field trials and on nutrient relations, but seldom by direct determinations.

The reason for this rather surprising situation is the well known fact that the microbial processes in the soil can mineralize unavailable organic nitrogen compounds to available NO_3 and by this and similar processes the nitrate level in the soil can change rather quickly, even in the time between taking the soil sample and the analysis.

Some laboratories determine available nitrogen and the more common analyses are:

(i) the determination of inorganic N after incubation;

(ii) the same determination after weak oxidation;

(iii) the estimation of nitrogen release based on organic matter content and texture;

(iv) the direct determination of free NO_3.

In addition to these possibilities all soil test laboratories make use of information on previous crops especially regarding nitrogen since leguminous crops leave considerable amounts of available nitrogen in the soil.

It should be mentioned that in more recent research the last method has gained importance by the development of an electrode with which the NO_3 concentration can be measured directly, similarly to a pH measurement (9, 12, 39). The two important findings of this research were:

(a) that for tests of available NO_3 the soil must be sampled deeper than the plough layer. For the Middle West of the U.S.A. and for Canada (31, 32) the most suitable depth was found to be two feet or 60 cm as mentioned before;

(b) that with this increased sample depth and the normal air-drying of soil samples the NO_3 content of the soil correlated well with crop yields and responses.

It is obvious that NO_3 as the most mobile form of the major nutrients does not stay within the plough layer but moves with the water. It is also taken up with the water by the plant roots. This indicates that the optimum sampling depth may not be the same for all climates as has been explained in section 3.1.2 above.

It is hoped that research with this method will be carried out soon in many countries and under various conditions since nitrogen is at present the most required nutrient and is the only one which cannot be stored in the soil, but leaches out of the root zone if surpluses are applied. Very correct application rates are therefore most important.

4.4.2 Phosphorus

Many extractants have been developed for determining plant available phosphorus in soils. In more recent years numerous comparisons of extractants have shown rather consistantly that the best correlations with yield responses and phosphorus uptake by plants were found under most varied soil and cropping conditions with three extractants.

The first place is taken by the sodium-bicarbonate extraction by Olsen et al.(24), and the two other extractants were developed by Bray and Kurz (3) and are weak solutions of ammonium fluoride (0.03 N for complexing Fe and Al ions) and two weak concentrations of hydrochloric acid (0.025 N and 0.10 N HCl). The weaker solution usually goes under the name of "Bray I" and the extractant with 0.10 N HCl under the name "Bray II". These methods are described in FAO Soils Bulletin No. 10 (11).

When these extractants were newly developed it was thought that the sodium-bicarbonate extraction of Olsen was mainly suited for alkaline soils and the Bray extractions for acid soils. While the latter was confirmed by recent research, it was proved that the bicarbonate extraction gave not only outstanding results for alkaline soils but also usually for acid soils, and this was found in both tropical and temperate climates. This method performed very satisfactorily on paddy soils too, an example of which was shown above.

This extraction developed by Olsen et al. (24) may be the best choice available at present, although it should be mentioned that several other extractants have been and still are in constant use by many modern laboratories and the results obtained are sufficiently satisfactory to base fertilizer recommendations on them.

One other extraction method should be mentioned here, which was recently developed by Dutch workers (27, 30). It is a simple water extraction but with the wide soils to water ratio of 1:60 on a volume basis. It is reported that the method was tested with a large variety of temperate and tropical soils and that it was largely insensitive to soil types, which is an important advantage. It has given good results in the Netherlands where the P-levels in the soil have become rather high. If results are also reliable for soils low in available phosphorus, this extraction may find extended use in developing countries.

4.4.3 Potassium

The fraction of soil potassium which is directly available to plants is dissolved in the soil solution and adsorbed on the soil colloids. The part of potassium not available to plants is locked in the lattices of soil minerals.

The available K is therefore determined by leaching the soil with a neutral salt solution or weak acid. The extractant used most frequently is N ammonium acetate of pH 7 (11), but other salt extractants can be used equally well.

The resulting data of available K correlate well enough with crop data to be used by the majority of soil test laboratories which actually base fertilizer advice on these tests.

The most severe limitation of the K soil test concerns less weathered soils which may release originally unavailable K in an available form on air-drying of the soil samples. This leads to too high K-test values. Since this behaviour is related to the type of soil, it is easy for the soil test laboratory to define the areas in which such deviating soil behaviour can be expected, by means of a soil map, and to treat these soils separately.

Another point to be mentioned is the fixation of applied potassium by certain clay minerals, mainly those of the illitic type. When the lattices of these clay minerals are undersaturated with potassium, the applied K-ions, adsorbed on the clay surface, pass into the lattice and are no longer freely available to plant roots. The process is only slowly reversible.

Considerable amounts of potassium can be fixed in this way until the clay minerals are saturated to the extent that K-fixation is reduced to an insignificant level. In areas where potassium has been applied regularly for several years, the originally K-fixing soils have been saturated sufficiently and the problem has vanished. In developing countries where no regular potassium treatments have been applied, these soils will still fix potassium which may disturb soil test/crop response correlations. However, this problem is also directly linked to the soil type and therefore can be localized by means of a soil map.

A simple determination of the soil's capacity to fix potassium is described in Appendix 1.

The disturbances of correlations between K-tests and response as described above are exceptions rather than the rule and hence the determination of dissolved plus adsorbed potassium is generally adopted as the most suitable K-test.

5. GROWTH FACTORS AND MULTIVARIATE ANALYSIS

5.1 Multivariate Analysis

A crop plant grows under the influence of many environmental factors which together determine the development and the final yield of the crop. Three of these factors are the amounts of plant nutrients N, P and K available in the soil which are determined by soil tests. Others are water supply, sunshine, temperature, density of the plant population, competition by weeds, salinity of the soil, plough depth, planting time, etc.

All these factors have a certain influence on the yield and with suitable experiments each of these influences can be measured and expressed in a yield gradient or regression line, the slope of which shows how much the yield changes with a certain change of the factor. For some factors a regression curve might be found instead of a straight line.

Ideally, therefore, it should be possible to express the whole plant production system in a mathematical equation of the type $y = b_1x_1 + b_2x_2 + b_3x_3...$ in which y is the yield, the x_1, x_2, x_3... are the measured growth factors and the b_1, b_2, b_3... are the slopes of the regressions for each factor.

This is actually the principle and basis of multivariate analysis which is being applied more and more to biologic problems such as crop production, (15).

The execution of such research is basically also simple. It consists of a large set of field experiments in which all the known growth factors are measured. These would include various soil characteristics including available nutrients, data for water supply, climate and management factors such as planting time, plant population, etc.

All these data together, the yields on one side as the dependent variable and the growth factors on the other side, can now be processed mathematically to obtain an equation of the type shown above. If more than two or three factors are involved the calculations are elaborate and a computer is needed.

This very brief description of the principle of the multivariate analysis, in which the actual execution is more complicated and usually beyond the possibilities of the FAO field expert, shows the dependence of the soil test/yield correlation on the other factors, but it shows also that if the influence of these other factors on the yield are known (as expressed in the above yield function by the regression coefficients b_1, b_2, b_3, etc.) the prediction of yields by soil tests will be possible.

The complicated part of the computerized process of the multifactor analysis is the simultaneous treatment of all factors in all experiments in order to obtain results (regression coefficients) which fit the data best.

As will be seen in Chapter 7 there are very simple graphical methods by which the influences of each growth factor on the soil test/yield correlation can be measured one by one, and for each factor the correlation can be corrected, also step by step, even for those factors which have clearly curvilinear influences on the yield.

The principle of these simple graphical correction methods is basically the same as that of the comprehensive multivariate analysis. The obtained results are not the best regression coefficients of the other growth factors but estimates of them, effectively improving the soil test/yield correlations. Their great advantage is that with a sheet of graph paper and a desk calculator the influence of any growth factor on the soil test/yield correlation can be checked in a matter of minutes or hours depending on the number of data and the practice of the man.

5.2 Growth Factors Influencing Yield

For multivariate analysis or its simpler graphical variant the factors included must be quantified numerically. Only then is it possible to determine a gradient or regression slope which indicates how much the yield or response changes with each unit of the concerned factor. If, for instance, the crop response is lowered by decreasing soil pH, the analysis will show how much the response decreases for each pH unit.

There are other factors which influence yields and responses but which cannot be quantified numerically, for instance crop variety, soil type, or rainfall pattern. In sets of calibration field experiments these factors must be kept constant for all experiments or alternatively the experiments must be separated into groups. In each group the soil test/yield correlations must be established separately, which may be impossible if the groups are too small.

In order to avoid such grouping of data attempts must be made to express the non-numerical factors by related factors which can be expressed numerically. For instance if crop responses are found to vary with soil types in the districts under consideration then the soil properties which are likely to cause these differences should be used for the factor analysis. Such properties may be texture, organic matter content, pH, soil depth, salinity, and several others which can all be expressed numerically. Instead of the rainfall pattern the precipitation in certain critical growth periods can be used for correcting the correlation graphs and similar numerical replacements may be found for other non-numerical variables.

In the case of crop variety this possibility does not normally exist and therefore calibration field trials should all be done with the same crop variety favoured in the area and likely to be used in the future.

The following list of growth factors cannot possibly be complete. Under each one of the innumerable growth conditions certain factors are dominant, others unimportant. But the list may help the researcher to remember variables which are not obvious but possibly influential in his particular conditions.

5.3 Check List of Growth Factors

These factors can be grouped into three categories which are:

(a) Soil factors;

(b) Climatic factors;

(c) Management factors.

5.3.1 Soil factors

Apart from the soil's contents of available major plant nutrients N, P and K which are to be correlated with crop responses, the following soil properties may influence crop responses.

pH

Very high pH values in soils are related to salinity and sodicity expressed usually as ESP = Exchangeable Sodium Percentage and SAR = Sodium Adsorption Ratio, (11).

In the medium pH ranges plants have certain preferences which for crop plants such as small grain are little pronounced, while others like clover or tea are strongly affected by unsuitable soil pH.

Low pH values are associated with active aluminium and iron in the soil, both of them fixing phosphates, and with low available Si which affects growth of lowland rice negatively.

Liming

Lime applications for correcting soil acidity have great influence on crops and fertilizer effects. For fertilizer recommendations based on soil tests, previous limings are an important factor to be taken into consideration.

Salinity

Saline conditions, usually expressed as electrical conductivity, depress crop growth and have a negative effect especially on the uptake of nitrogen, and less on the uptake of P and K. This may be due to the fact that N-utilization depends much on available water and that salinity causes a physiological water stress in the plant. Here it should be mentioned that electrical conductivity is a better measure of the effect of salt on plants than the percent values of salt determined gravimetrically. This is because the types of salt harmful to plants have a higher conductivity than the harmless salts.

Cation exchange capacity (CEC)

This value is an important characteristic for soil classification and as such varies with the soil type. CEC usually has no great influence on soil test/crop response correlations. However, if this value shows marked variations between test fields, its influence on the correlations should be checked as described in Chapter 7.

Free carbonates

The percentage of free carbonate in soils is usually of limited direct influence on plant development. However, in the higher carbonate ranges, as found in arid zone soils, a pronounced indirect effect is their influence on the availability of micro nutrients. Lime induced iron deficiency and to a lesser degree manganese deficiency are major limitations to plant growth.

Texture, structure, content of organic matter

These physical soil characteristics may influence plant development as much as the chemical properties discussed above. Plants have decided preferences for specific texture classes related to their root systems. As a quick estimate of texture the "water saturation percentage" may be determined. (11) In addition to such preferences the soil structure and aeration of the root zone influence healthy plant development. A higher content of organic matter in soils usually improves soil structure and since soil structure cannot readily be quantified, the figures of texture or saturation percentage and of organic matter content are frequently used for the characterization of the physical soil conditions. There are of course other physical soil properties which can be measured such as water permeability, pore volume, etc. but they are rarely determined in routine soil testing.

The factors texture, structure and organic matter are closely related to the water holding capacity of the soil. Such water storage lowers or prevents water losses and helps the plant to overcome dry spells.

Clay minerals

Especially for the calibration of potassium soil tests the type of clay minerals in the soils may have to be taken into account (see 4.4.3). Clay minerals cannot be investigated as a soil testing routine in each soil sample, but if a soil survey is available it will provide the required estimates on clay minerals.

Subsoil

The physical and chemical characteristics of the subsoil can and usually have considerable influence on yields and crop responses. These characteristics are sometimes shown on soil survey maps. In other cases they may have to be measured by the farmer in the field. An example of the latter is found in North Carolina where lighter soils are underlain by clay and the depth down to the clay layer is a criterion for the soil test interpretation. In Minnesota the nutrient content of subsoils is laid down in specific subsoil maps made for that purpose and the subsoil is taken into account for the interpretation of soil tests. Subsoil data available from soil surveys as related to soil types may be checked in new areas for their influence on soil test/yield correlations.

For nitrogen tests it is likely that soil samples will always include part of the subsoil, see section 4.4.1.

5.3.2 Climatic factors

Water

The water supply for the plant takes a predominant place in most conditions. In dry zones the amount of rainfall and the number of irrigations can be a useful measure of this influence. The distribution of water supply throughout the season may be of great importance and for practical purposes this influence can be quantified by recording the amount of rain or the number of irrigations until a certain key day or for a certain critical growth period in addition to the total water supply for the crop.

In humid areas and lowland conditions the drainage may be more influential than the water supply. This is a factor closely linked with the soil and for practical soil test interpretation the distinction between "drained" and "not drained" must be made in areas where this factor is of influence. Under certain conditions more than two drainage groups may be required.

Temperature and light

These two factors often mentioned in connection with lowland rice in Asia are not likely to play a role in soil test calibration, except if the area included in one such calibration stretches over more than one climatic zone. Such a condition may occur in South Korea for instance where distinct climatic zones come close together, mainly with regard to temperature. In that and similar cases a temperature gradient may be found and may have to be used for the proper calibration of soil tests.

5.3.3 Farm management factors

The great extent to which the skill and practical knowledge of a farmer can augment yields is well known. A main factor is the exact timing of his field work - including ploughing and seedbed preparation at the right soil moisture condition, fertilizer applications, seeding, weeding, irrigation and spraying for plant protection. His correct judgement is mainly based on his observation of nature, including weather forecasts. These factors are partly difficult to quantify. Recording the dates of each or some of these actions would be the obvious way but that would leave some influences still hidden. For instance, if one farmer applies his fertilizer just before a heavy shower of rain and the other farmer after this shower which is then followed by a longer dry spell, the first farmer will get more benefit from his fertilizer application than the second.

In field experiments used for soil test calibration the management should be optimal and uniform; optimal in order to prevent yield or response depressions due to poor management, and uniform because of the difficulty to quantify these factors.

To this rule there are, however, certain exceptions permissible and even desirable. If for instance in a certain area the planting time has a consistant influence on the crop yield and response, it is an advantage to include this variable in the calibration and to quantify this influence by determining the regression and subsequently correcting the correlation accordingly, (see Chapter 7). This will allow the factor of planting time to be taken into account for farm recommendations.

In general it is, nevertheless, not advisable to include too many variables in the basic set of calibration experiments, but rather to keep these variables to a minimum which can be done most easily by keeping management variables constant. Their influences may then be worked out with special field experiments later.

The management factors which may have to be taken into consideration for the final farm advice are:

(a) field history: previous crops and their yields, previous applications of fertilizer, manure and amendments;

(b) crop or crops intended to be grown;

(c) intended plant population;

(d) available water supply (if irrigated);

(e) expected or aimed-at yield;

(f) difficulties experienced in establishment and maintenance of crop.

Any one of these, and possibly other management factors, requires at least some study to adjust the recommendations based on soil tests.

6. FIELD EXPERIMENTS FOR SOIL TEST CALIBRATIONS

The subjects discussed in the previous chapter already will have indicated in some detail the role that the many variables play or should play in the working out of the basic soil test/yield correlations. In this chapter an outline is given showing how the field experimental work can be planned and carried out in order to obtain the required accurate data.

It may be mentioned here that unreplicated trials laid out as dispersed experiments on farmers' fields, as described in FAO Soil Bulletin No. 11, are excellently suited for determining fertilizer recommendations quickly and for large areas, but they are not so well suited for soil test calibration. Unreplicated trials do not give an exact yield information for each site as is required for correlating these yields with the exact soil tests of each site. For that purpose replicated experiments are much better suited. When calibrating soil tests with yield data of unreplicated trials the scatter due to chance deviations in yields is much wider than with replicated trials. A larger number of trial data can partly make up for that shortcoming, increasing the reliability of the broad average. The replicated trials described below are specially designed for soil test calibration.

The reader will appreciate that the outline now given is one of several possible suggestions. The experimental plan described aims at a suitable combination of simplicity and accuracy, the latter because of the many error possiblities involved.

The suggested experimental plan can be varied either to suit local conditions better or to enlarge the scope of experimentation. The basis on which decisions should be made for any such changes is explained fully in the previous sections. It should be kept in mind, however, that the working out of clear soil test/crop response correlations is not in itself easily accomplished. Any additional complication should therefore be avoided. Such complications may arise from unsuitable treatment combinations chosen for the experiments, or from too many sites with relatively low accuracy per site, etc. Any such mistakes degrade the value of the whole work and usually require its repetition in a simpler and more precise way.

6.1 Lay-out, Design and Management of Field Experiments

6.1.1 Lay-out

A number of fields on uniform soil types are tested for the available nutrient under research and from them 30 to 40 fields are selected so that the soil tests range from very low to high with a rather uniform distribution over the whole range. In this selection the uniformity, the crop history and the fertilizer history must be taken into account. If the uniformity of an otherwise suitable field is in doubt, it is advisable to take 15 to 20 soil samples evenly distributed over the field on a grid and analyse them. This will show unwanted heterogeneities if present. Regarding crop and fertilizer history it may not be advisable to select fields on which the last crop was a legume, or which was fertilized above the general level of the area. Both will increase the fertility status of the field to a level atypical for the area.

At planting time the fields must already be selected. Then three good composite soil samples, one of each replicate, should be taken again from each field before fertilizer treatments are applied, each composed of 40 subsamples. The analysis of available nutrients is made thrice for each sample. With these nine analytical data per field irregularities in the field and in analysis can be detected. If agreement is satisfactory according to the explanations in Chapter 3, the best estimate of available nutrient contents is the average of the nine figures. Beside available nutrients other soil properties should also be determined such as pH, organic matter, texture, salinity, etc. as explained in Section 5.3.

6.1.2 Design

On each field a simple fertilizer trial is laid out consisting of 15 plots arranged in three rows. The plot size need not be more than about $30\ m^2$ for small grain and 4 x 6 to 4 x 8 m per plot would be convenient. With three rows of five plots each the whole trial would cover an area of 20 x 18 to 20 x 24 m.

Each row should contain one replicate of five treatments. The treatments are simply five rates of the tested element equally spaced. In the case of phosphorus the rates would be denoted P_0, P_1, P_2, P_3, P_4. It is important that the lowest rate should always be zero and the highest rate be high enough to obtain a maximum yield or even slightly higher. A complete return curve is very important for the purpose. In addition to these increasing rates of the tested nutrient all plots should be given a basal dressing of the two other main nutrients which must be high enough to be in approximate balance with the penultimate treatment of the tested element.

If trace element deficiencies have been observed in the area these nutrients should be applied too in suitable quantities.

As stated, each row of the experiment contains one complete replicate of the five treatments. The treatments are applied in the order shown below.

0	1	2	3	4
3	1	4	2	0
4	2	0	3	1

In this way the three replicates of each treatment are distributed over the experiment so that gradual changes in fertility within the field do not influence or only minimally the treatment means. This is true not only for fertility changes in the two main directions of the rectangle, but also for fertility gradients in the direction of the two diagonals. This arrangement of treatments is therefore highly preferable to randomization which only by accident results in an arrangement insensitive to fertility shifts in the field. These 15 plots should be surrounded by the same crop in order to prevent border effects or border damage. This is an important precaution and must be observed in addition to the prescription for the harvest described later.

Another suitable arrangement is the laying out of long narrow plots, all fifteen beside each other. The first five plots would be the first replicate and the treatments are assigned to these five plots at random. The same treatment sequence is then used also for the two other replicates consisting of plots 6 to 10 and plots 11 to 15. Also these test fields must be surrounded by a stand of the same crop to guard against border effects.

It is advisable to choose a main crop of the area, if possible a small grain as harvest data are more regular, and a variety which is likely to be used much in the future. The seeding should be very regular and a small experimental drill is recommended in order to obtain the greatest possible uniformity of plant stand.

6.1.3 Management

All fields throughout the area should be planted with the same variety and the complete management from seeding to harvesting should be the same for all experiments, see section 5.3. Deviations from the general management lines should be carefully recorded for each field as this might later explain deviations in data.

The plants should be fully protected against damage by diseases and pests. If possible the same spraying plan should be applied for all fields. In this regard special attention should be paid to the composition of the chemicals used. Phosphates and other plant nutrients contained in these chemical sprays are usually taken up more quickly and effectively than fertilizer nutrients. If nutrient-free chemicals are not available, all fields should be sprayed simultaneously each time and with equal quantities.

6.1.4 Observations during crop growth

It is highly advisable to visit field experiments regularly and to record any changes, crop damage or other observations. In addition to that a visual rating of the crop development (stand) of each plot should be carried out one to three times during the growing season. This is a valuable safeguard against complete loss of results in case of serious damage to experiments in later stages. If such damage should occur the plot ratings would allow the classification of the damaged plots into groups of undamaged ones with similar ratings.

Full comparability of rating of all fields and plots is an obvious necessity and in order to achieve this it should be arranged that always the same two or three people rate all the plots at the same time but independently of each other. The rating criteria must be agreed upon first. These may be number of leaves or tillers, plant colour, plant height, ear development etc. Each person gives a rating figure for each of these criteria for each field plot. These ratings should then be averaged for the records.

6.1.5 Harvest

The plots should be harvested in such a way that first a border of half to one metre of each plot is cut and this is not included in the yield measurement. The clear rectangular centre part of the plot is thus left for the measurement of the yield. The plants should be cut just over the soil surface and the weight of straw and grain determined separately per plot. It is necessary, especially in humid climates, to determine the moisture content from samples of the harvested material and to calculate "dry yields" for the records and further use. Representative samples of straw and grain must be taken for plant analysis in order to determine how much of the tested element was taken up by the crop.

6.2 Simultaneous Calibration for Two Nutrients

It might be intended to save time by calibrating soil tests for the two nutrient elements P and K simultaneously. In this case it should be remembered that the selected sites must cover a wide range of soil test values of the investigated element. It is likely to be difficult to find a set of fields which uniformly covers wide ranges of both P and K values. If the fields for the P-test calibration are found, it may be necessary to look for additional fields which fill in gaps in the K-range.

On sites used for both the P and K series, it is necessary to lay out three blocks each for P and K. It is not advisable to save on the number of plots by a combined design, although three plots of the two sets of 15 receive the same treatment. It is more important to maintain the clarity of the lay-out and sampling than to save three plots out of thirty.

The rest of the work is carried out as described by sampling the soil of every replicate separately, etc.

7. GRAPHICAL METHODS FOR IMPROVING SOIL TEST/YIELD RESPONSE CORRELATIONS

7.1 Corrections for Influential Growth Factors

7.1.1 The principle

In the previous sections it has been shown that from soil tests and field experiments the following four types of basic data are obtained.

(1) Soil test data from all experimental sites (3 replicates, one of each block).

(2) Yield data of five treatments per site (3 replicates).

(3) Nutrient uptake data of all treatments per site (3 replicates).

(4) Data on other growth factors for each site.

The aim of the soil test calibration is to obtain correlations between the soil test values (available nutrients in the soil) and the crop responses to nutrient applications as found in the area where the field experiments are carried out. The treatments of the experiments include one control and four application rates of the investigated nutrient, see 6.1.2. Hence there are four sets of response figures, one for each application rate, to be correlated with soil test values of the experimental sites. This leads to the four basic correlation graphs often referred to in the following text.

In Chapter 8 it will be seen that the raw response data as calculated from the original yields should not be used for the four basic correlation graphs but responses derived from these raw data. This, however, has no bearing on the correction methods as described in the following sections of this Chapter.

7.1.2 The graphical method

If yield responses to a certain nutrient application are plotted against soil test values for a series of field experiments, a diagram may result similar to that shown in Figure 2. In that figure selected data from cotton responses to 45 kg/ha P_2O_5 in a large irrigated area are plotted against soil test data of available P extracted with Na-bicarbonate according to Olsen (24).

The diagram shows a certain tendency to declining response with increasing P-test. This is verified by the calculated regression line, the equation of which is shown in the figure. Due to the wide scatter of points the correlation coefficient r has the low value of -0.61. The calculation of this line, the correlation coefficient and the statistical checks is shown in Appendix 2.

The most influential growth factor was the water supply expressed in the number of irrigation which varied from 4 to 11 in the growing season.

In order to check if the factor irrigation is partly responsible for the wide scatter of points in Figure 2 and if so, to measure the magnitude of this influence, the vertical deviations of each point in the diagram from the regression line (d's) are plotted against the number of irrigations each test field received. This process results in Figure 3, which may be called a "correction graph".

Making the correction graph is confusing if the data are not arranged in an orderly way. How to do this is shown in Table 3. The first column shows the P-tests of each of the 20 sites, the second shows the observed crop responses in kg/ha. From these two columns the regression line of Figure 2 is calculated.

The third column shows the vertical distances (deviations d) expressed also in kg/ha of each point from the regression line in Figure 2, and the fouth column shows the number of irrigations per site, w (which stands for water).

The correction graph, is plotted from the columns 3 and 4 and the regression line for this graph is calculated and shown in Figure 3.

The measurements of the deviations d and their transfer from the original Fig. 2 to the correction graph Fig. 3 can conveniently be made with the aid of a pair of compasses. However, for those who prefer to calculate the d-values, which can be done easily with the aid of any table calculator, the formula to be used is $d = y_i - (a + bx)$ in which y_i is the measured crop response of each site and between parentheses is the right side of the regression equation as shown for the example in Fig. 2. Hence for that example the d-values are: $d = y - (156.46 - 6.16x)$ in which the y is the response and the x the soil test value of each of the sites. The values are rounded off to whole numbers.

This correction graph shows that there exists a relation between the deviations in Figure 2 and the number of irrigations with a correlation coefficient of $r = + 0.83$. The slope of the regression line indicates that on the average over all points (sites) one additional irrigation increases the response to 45 kg/ha P_2O_5 by 13.7 kg cotton per hectare.

With this most important information two things can be done. Firstly, the original correlation graph, Figure 2, can be corrected and secondly advice given to farms can be varied according to available irrigation water. Both processes are briefly explained below.

(1) Correction of the original graph

By calculating for each point (site) what the response would have been if say 8 irrigations had been applied, and by plotting these new, corrected response values against the soil test, a graph is obtained with all responses reduced to 8 irrigations. This number of 8 irrigations is chosen because it is close to the area average which is 7.55, see Table 3.

The values which must be added to, or subtracted from the original responses in order to reduce them to the level of 8 irrigations are:

$$\text{correction value} = (8 - w).13.7 \text{ kg/ha}$$

This value has to be added to the original response. These correction values are shown in column 5 of Table 3, rounded off to whole numbers and the corrected responses are given in column 6.

If these corrected responses are plotted against the soil test values Fig. 4 is obtained. Obviously this corrected graph shows a much improved correlation expressed in the high correlation coefficient of $r = -0.82$ against $r = -0.61$ of the original graph Fig. 2.

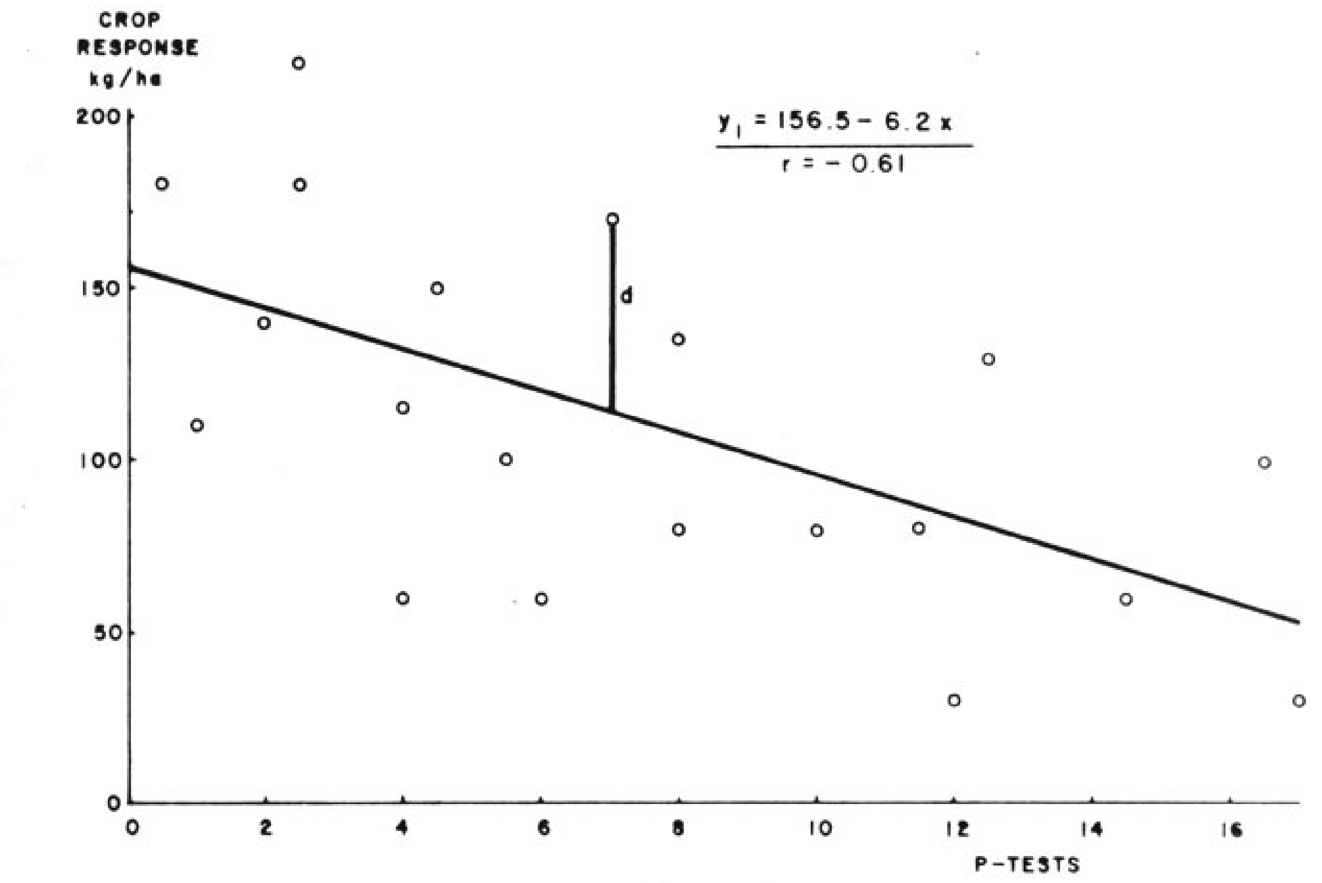


Figure 2

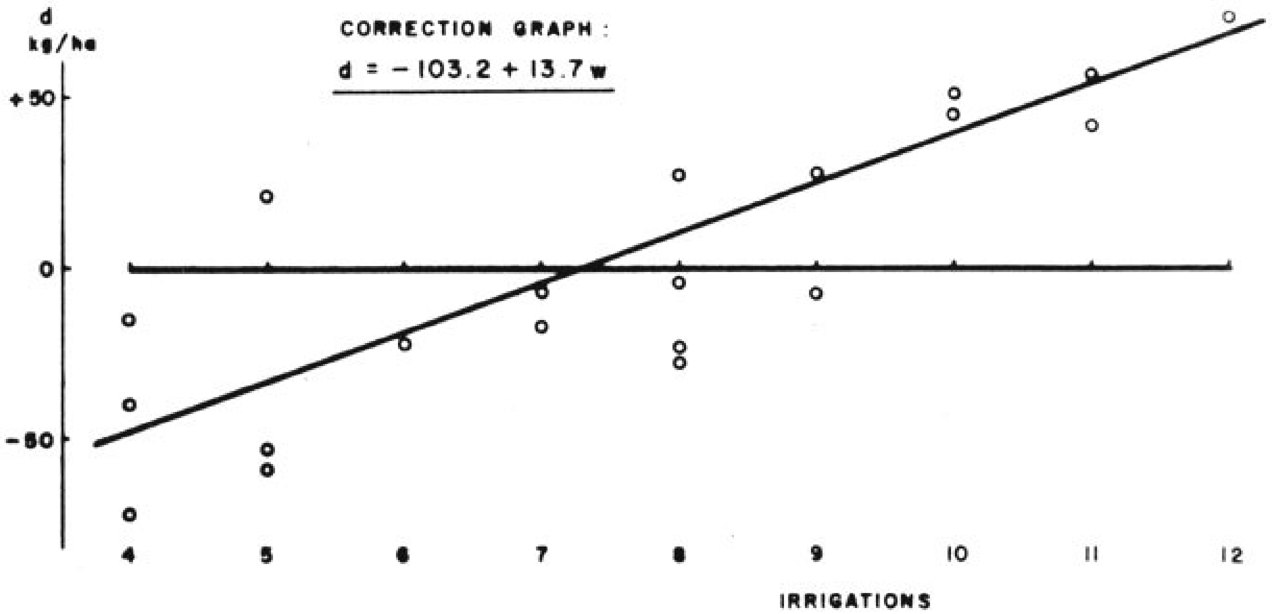


Figure 3

Table 3. Graphical Correction of a Soil Test/Crop Response Correlation

1 P–test x	2 Crop resp. kg/ha y_1	3 Deviations from regression kg/ha d	4 No. of irrig. w	5 Correction for w $(8-w).13.7$	6 Corrected response kg/ha y_2
4.0	115	−17	7	+14	129
2.0	140	− 4	8	0	140
16.5	100	+45	10	−27	73
8.0	80	−27	8	0	80
1.0	110	−40	4	+55	165
3.0	180	+42	11	−41	139
12.5	130	+51	10	−27	103
10.0	80	−15	4	+55	135
4.5	150	+21	5	+41	191
0.5	180	+27	8	0	180
17.0	30	−22	6	+27	57
7.0	170	+57	11	−41	129
5.5	100	−23	8	0	100
2.5	215	+74	12	−55	160
14.5	60	− 7	9	−14	46
6.0	60	−59	5	+41	101
12.0	30	−53	5	+41	71
8.0	135	+28	9	−14	121
4.0	60	−72	4	+55	115
11.5	80	− 6	7	+14	94
Sum 150.0	2,205	0	151		2,329
Aver. 7.5	110.25		7.55		116.45

This example may illustrate how an original correlation can be corrected for the influence of any important growth factor. From the described field experiments there result four correlation graphs, one for each nutrient application rate. It goes without saying that each of these correlation graphs is corrected for the same growth factor in the way described above.

(2) Correction graph and fertilizer recommendation

In the corrected graph, Figure 4, a broken horizontal line is drawn which shows the crop response needed for just repaying the fertilizer costs. Any response lower than this level will cause the farmer a financial loss. The regression line showing the decline in response with increasing soil test values at 8 irrigations cut the broken line of marginal economy between soil test 14 and 15. With soil tests lower than that value the applied rate of 45 kg/ha P_2O_5 pays, provided 8 irrigations are applied.

If the farmer knows that he will only have water for say 7 or 6 irrigations the responses will diminish by 13.7 kg/ha cotton per irrigation (see regression coefficient in equation of Figure 3) and the regression line of Figure 4 will have to be lowered at the same rate. This is shown in Figure 5, where for each number of irrigations a separate regression line is drawn. According to that graph a field with a soil test value 10 and irrigated 6 times will just return the fertilizer costs but will not give extra benefit, while the same field with 10 irrigations will return nearly twice the invested fertilizer costs.

This type of evaluation may be done for the four corrected correlation graphs, one for each fertilizer application rate. This will give a rather detailed picture of the influence of the investigated yield factor, in this example water, at various fertilizer application levels.

7.1.3 Disturbing interactions and correlations between growth factors

Before discussing further the possibilities and variants of the graphical correction, the effects of interactions and correlations between growth factors on the interpretation of soil test/crop response correlations must be explained.

Interaction

If one factor increases the effect of another, the two interact positively. An often observed example is the increase in the effect of nitrogen by a phosphorus application. The yield increases caused by N alone and by P alone are together smaller than the increase of a combined NP application.

If there should be a positive interaction in the example, Table 3, between water supply w and soil phosphorus x, the lines in Figure 5 would not be parallel, but the upper ones would have less slope and the lower (lower w values) would have a steeper slope forming together a design of a fan with the handle on the left side. A negative interaction would influence the slope in a reversed way forming a fan with the handle on the right side.

Mathematically the interaction is expressed by one member of the function. In the example of Table 3 the yield response function would read $y = a + bx + cw + \underline{dxw}$, the last member being the interaction member.

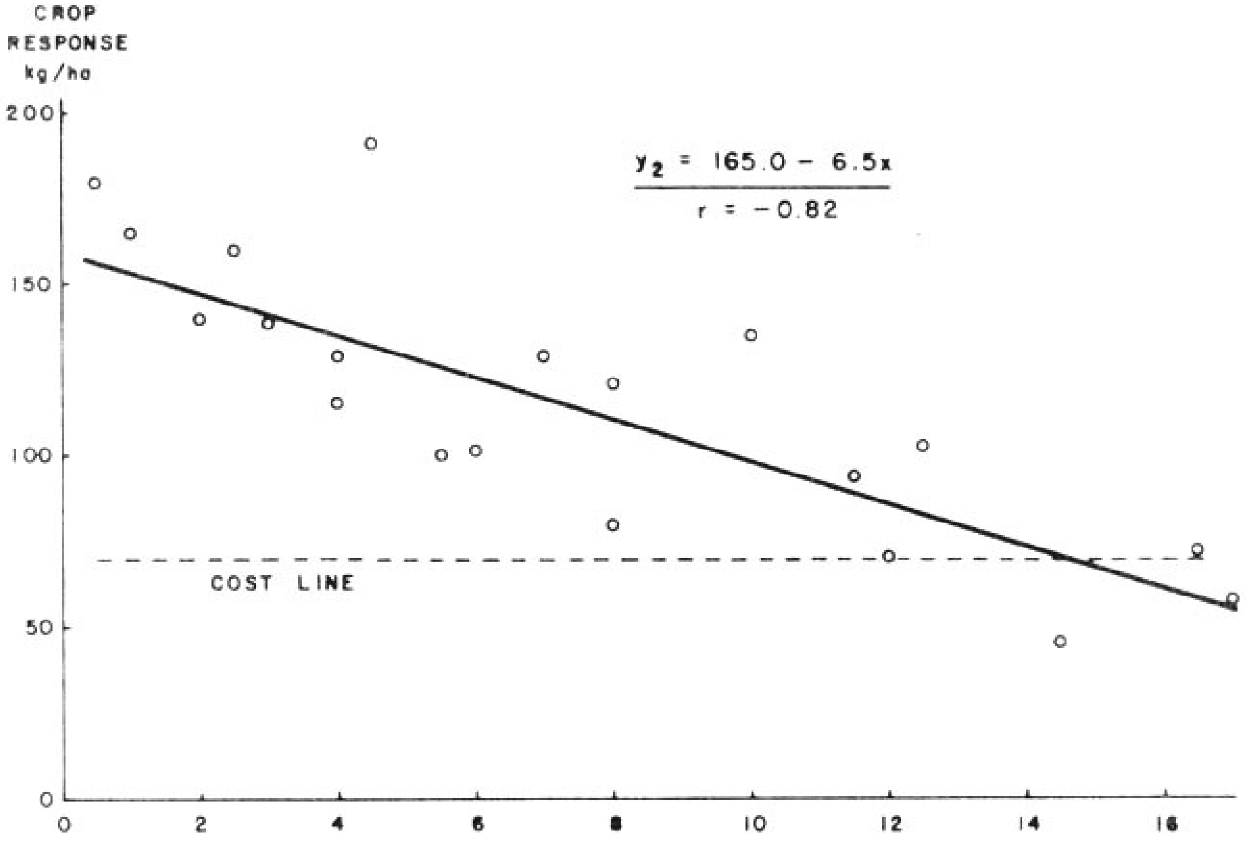


Figure 4

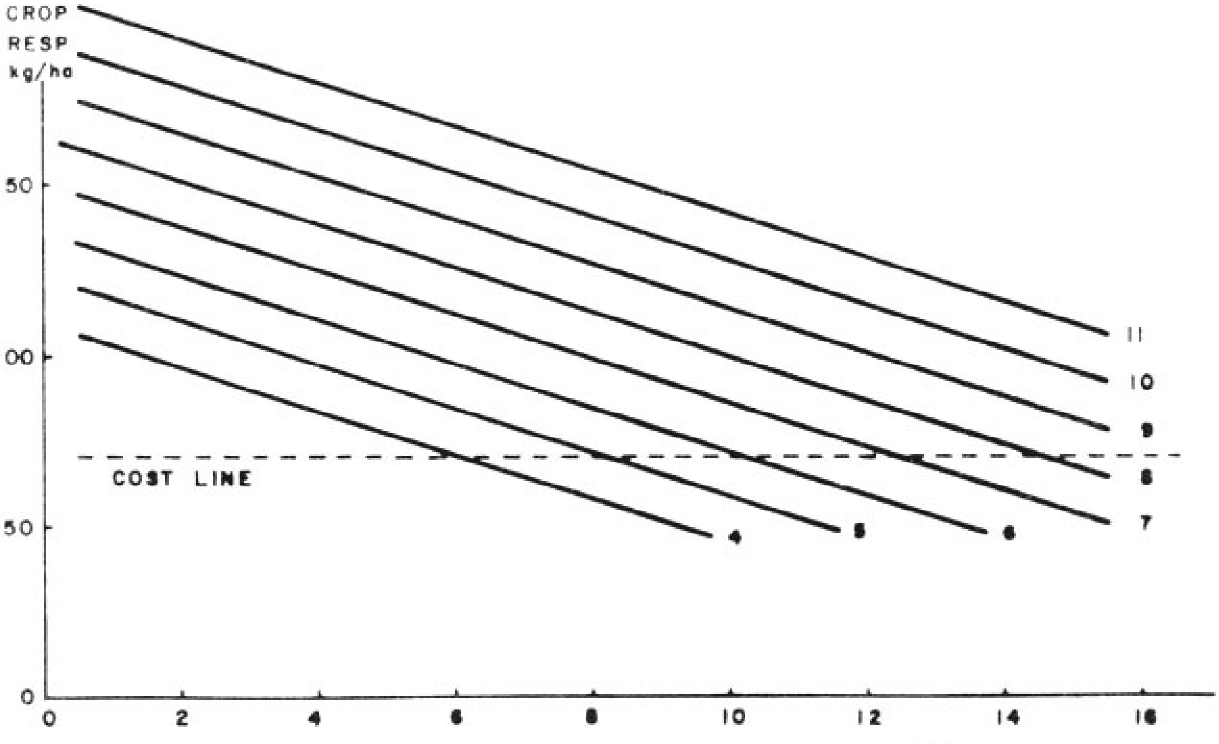


Figure 5

For practical purposes the interaction between any growth factor like w in the example for the soil tests can be checked by calculating one soil test/crop response correlation for the low range, say 4 to 6 irrigations, and another for the high range 9-12 irrigation. If that is done for the cotton example, Table 3, the slope of the regression line for few irrigations is $b = -5.5$ and for many irrigations it is -6.4. The difference between these two is not significant for so few points and hence it can be concluded that there is no interaction of consequence. If a larger difference between the slopes is found the range of the interacting factor has to be divided into two or three classes, low, medium and high and the proper regression lines for each class calculated and used.

Correlation between factors

If another growth factor is correlated with the factor soil nutrient (soil test), the graphical correction as well as the multifactorial analysis will result in regression lines which are not correct. Using again the cotton example of Table 3, a correlation between soil tests (x) and number of irrigations (w) would render the position and slope of the regression line of Figure 4 incorrect.

The check on the existence of such a correlation can easily be done by calculating the correlation in the usual way. In the above example the w/x correlation has the coefficient $r = 0.04$. This low value indicates that there is no correlation and hence the interpretation shown in Figure 5 is correct.

However, if there was a correlation then the only practical way of dealing with this situation would be to divide again the w-range into say three classes and calculate the soil test/crop response correlation for each class separately using the original crop response data. One would find three quite different regression lines for the three sections.

With regard to the practical importance of such interfering interactions and correlations their effects should not be overestimated. Especially in the beginning of calibration work, when the search is for general and little refined correlations between soil tests and response, weak interactions and correlations with coefficients of 0.3, 0.4 or even 0.5 may still have very limited influence on the first results. In areas as yet unknown in that regard these first results will mainly give a general picture of the position and slope of the soil test/yield regressions as related to fertilizer economy (see cost lines in Figures 4 and 5) and as such will give directives for further work. The latter will then be able to pay due consideration to interaction effects and further refinements.

7.1.4 Successive corrections for various growth factors

The process as described above for determining the influence of a growth factor and the correction of a correlation graph can be repeated for the next growth factor. In this case one starts with the graph already corrected for the first factor and proceeds with the second correction exactly as for the first, extending Table 3 by more columns. This can be repeated for a third and more factors.

In the actual practice of the work not more than two or three factors may be found which clearly influence the correlation and for which a correction is worthwhile. This can be checked easily be plotting the deviations d of Table 3 against the various factors or even more simply by calculating the regressions b. If the regression shows a distinct slope a correction is worthwhile. If, however, the factor has no clear influence, the slope of the regression i.e. the b-value will be near zero. The more influential factors are always corrected first.

The improvement of the soil test/crop response correlation by every successive orrection will result in an increase in the correlation coefficient r, since a part of the nfluences, which are responsible for the scatter of the points in the graph, has been emoved.

For each growth factor the slope of the regression line of the concerned orrection graph shows its influence on the crop response and can be taken into account for ertilizer advice as explained before.

7.1.5 Curvilinear arrangements of points

It may happen that in plotting yield responses against soil test values the oints in the scattered diagram show an arrangement which indicates not a straight regression ine but a regression curve with a shape as shown in Figure 6. In this case obviously the raphical correction with straight regression lines, as shown in the previous sections, will ead to poor results.

In principle the described graphical correction can always be applied as long s a regression curve or line is drawn which fits the points in the graph as closely as ossible. Whether this line is arrived at via a mathematical function or by estimate is of o consequence for the application of the graphical correction.

In the following sections three methods of obtaining curved regression lines re described. The first two methods are mathematically based and as such are rigid and ather complicated compared with the third.

The first is the partition of the original scattered diagram into two sections s shown in Figure 6 and Table 4. The assumption is made that within each section, i.e. ange of soil test data, the regression is a straight line.

The second method is a simple replacement of the original soil test figures by heir logarithms, resulting in a logarithmic scale along the x-axis. This usually changes he curved into a nearly straight line regression which allows the graphical correction to e applied as described before without any change or partition of the graph. The logarithmic ethod is therefore usually more efficient. For a worker who is acquainted with the raphical correction the time involved in both methods is about the same.

The third method does not make use of mathematical functions, but the position f the regression curve is estimated and drawn by hand. If there are many points with imited scatter the curve or line can be drawn with reasonably good precision. In case of ide scatter, use can be made of section means, or gravity points, as explained later.

The usefulness of this simple graphical method may be underestimated because t lacks sophisticated mathematical basis. Nothing is more wrong than this opinion. If here are enough points the position of the regression line is closely determined and very ittle freedom is left for a personal estimate. Even more important is the fact that athematical models are often a poor solution and do not correctly describe the desired egression as will be seen later.

The methods are briefly described below.

7.1.5.1 The partition of graphs

In correlation diagrams covering a wide range of soil test values the left side of the diagram will indicate a steeper regression, while on the right side in the range of high and very high soil tests the crop responses are equally low. Calculating separate regression lines for the two parts leads, of course, to a better fit of the data than one common regression line.

The most practical way to determine at which soil test value the graph should be divided into the two sections, is to estimate the position of the two regression lines, the steeper line for the left section and the flat line for the right section. At or near the intersection of the two estimated regression lines the vertical division line is drawn. For Figure 6 this was the point of soil test value 10. (The later calculated regression lines intersected at soil test 12. The difference is of no consequence).

A data table may now be made arranging the figures according to increasing soil tests as shown in Table 4. The regression equations are calculated for the two parts of the graph. For this example these equations are shown in the lower part of Table 4 under "Regressions with straight x values".

When this parted graph has been obtained the correction of each part for influential variables can be carried out according to the method described in section 7.1.2. For that purpose one common correction graph for both sections of the correlation can be used.

7.1.5.2 Intersection of regression lines and "critical level"

The two regression lines intersect near the soil test value 12. Some researchers (5) call this point or the equivalent point in graphs showing percent yield, the "critical soil test level", because at lower soil tests the crop responses are high, whereas on soils testing higher than the critical level the crop responses can be expected to be low or nil. This intersection point will always be found at or near the soil test level which divides the soil test ranges 'high' and 'medium'. For actual fertilizer recommendations the knowledge of this point is not sufficient. Information on the lower soil test ranges is required especially for developing countries where the economic limits of fertilizer rates are often rather low. Actually the decision to apply fertilizer and in what quantity is not related to the intersection of the two regression lines but to the intersection of the cost line and the soil test/response regression as shown in Figures 4 and 5.

7.1.5.3 The logarithmic regression

The second method of dealing with correlation diagrams indicating a curvilinear regression is somewhat simpler and may be more effective than the partition of graphs. According to this method the numerical values of soil tests are replaced by their logarithms, resulting in a logarithmic scale along the horizontal axis. The expected curved regression is straightened out by this process.

If semi-logarithmic graph paper is available, the plotting of points is easier but not the calculation of the regression line. It is therefore recommended to add to the data table next to the x-column (soil tests) another column for log x as shown in Table 4. Then log x is used instead of x throughout the whole process of calculating regressions, applying the correction method etc. as described in section 7.2 and onward.

After the last step is done and one has arrived at the corrected graphs of the type of Figure 4 and 5, the final regression lines are re-converted to the numerical x-scale, using again the x and log x columns of Table 4 and the straight lines will now appear as logarithmic curves.

An example of the process of converting is shown in Figure 7. There the points of Figure 6 are plotted against log x, the logarithms of the soil test values. The curved arrangement of the points as seen in Figure 6 has changed to a straight line characteristic. The regression line was calculated in the usual way, using the log x instead of the x values, and was drawn. The equation of the regression line is shown in Figure 7. This graph may now be corrected as described in section 7.2.

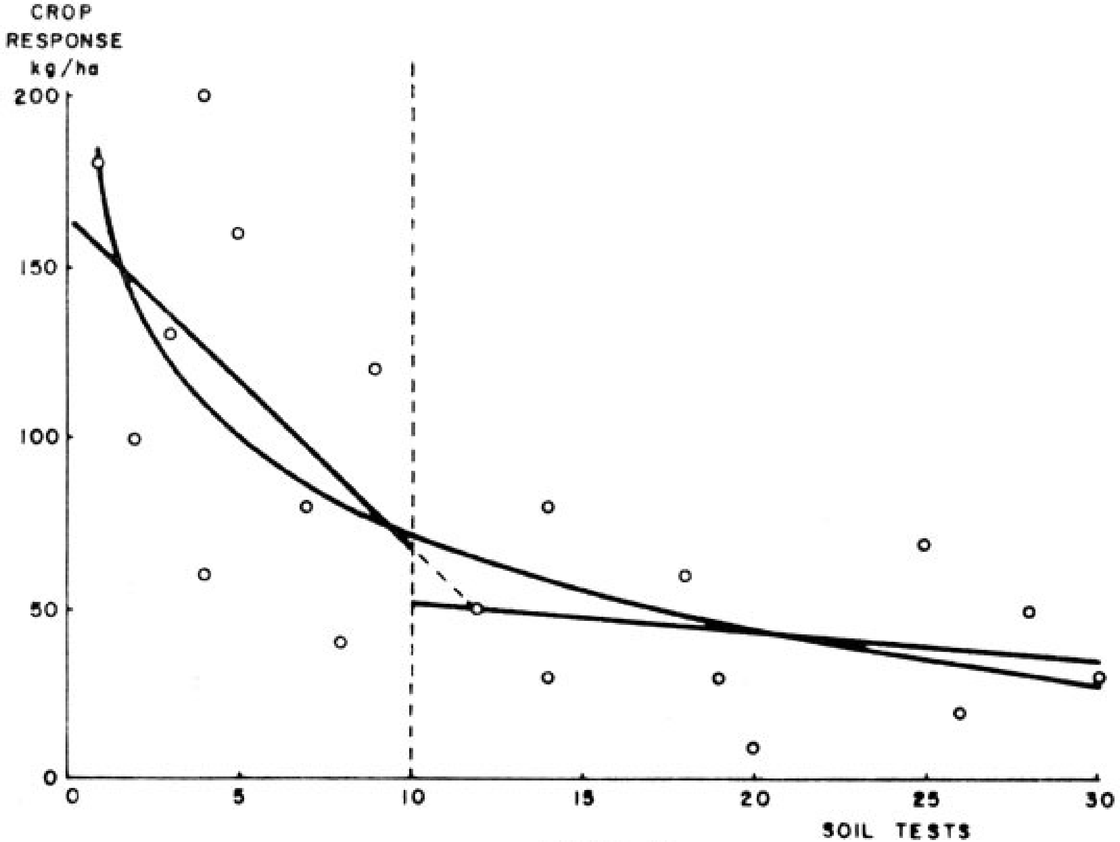


Figure 6

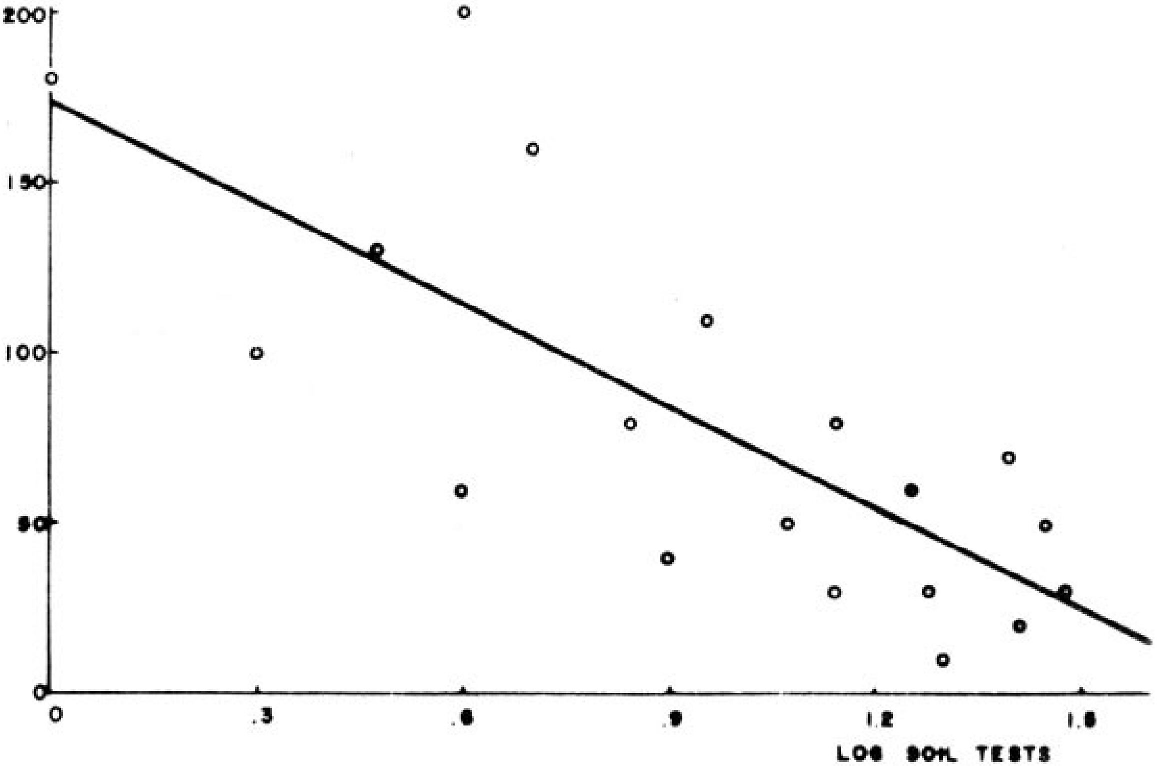


Figure 7

Table 4

	Part I			Part II		
	Soil test	Crop response	Log soil test	Soil test	Crop response	Log soil test
	x	y	log x	x	y	log x
	1	180	0.000	12	50	1.079
	2	100	.301	14	30	1.146
	3	130	.477	14	80	1.146
	4	60	.602	18	60	1.255
	4	200	.602	19	30	1.279
	5	160	.699	20	10	1.301
	7	80	.845	25	70	1.398
	8	40	.903	26	20	1.415
	9	110	.954	28	50	1.447
				30	30	1.477
Sum	43	1 060	5.383	206	430	12.943
Average	4.78	117.8	0.598	20.6	43	1.294

Regressions with straight x values:

$$y = 165 - 9.8x \qquad\qquad y = 60 - 0.8x$$

Regression of <u>all</u> data with the log x values:

$$y = 174 - 98.9 \log x$$

The regression line of Figure 7 was converted to the numerical x-scale and the resulting logarithmic regression curve is shown in Figure 6.

With experimental sets including many fields and soils the soil test/response correlations show regressions which make a decision between the curved and the straight line concept difficult. As shown in Figure 6 the two types of regressions are so near together and compared with that nearness the scatter of points is so wide, that the difference between them is not significant.

7.1.5.4 Hand-drawn regression curves

As has been mentioned before the drawing of regression curves by hand without using mathematical functions, has a definite place in soil test calibration. If there are many points with not too wide a scatter, it is hardly a matter of personal estimate to draw a smooth line through the points. The possible variations are very small.

A similar opportunity to draw a curve or line without any aid may occur with a small number of points, when small sections of graphs are interpreted. In such cases, relatively few points may describe the position and shape of the regression very clearly. In this situation the line can be drawn easily and correctly by hand, but it would be most difficult to find a mathematical function fitting the points as satisfactorily.

If the scatter of the points is wide, it is more difficult to estimate the right position of the regression line. In that case and especially if there are sufficient points, a practical method is to divide the correlation graph into several rather small sections by vertical lines. Then the average x and y values from the points in each section are determined and these "gravity points" are plotted. It will now be much easier to draw a smooth regression curve through these gravity points.

Hand-drawn regression lines can be used for graphical correction similar to mathematically based regressions. The disadvantage of mathematical functions is their lack of flexibility. Usually such functions fit the points in one section of the graph better than those in other sections. This can be seen clearly in Figure 6 where both the logarithmic and the straight line fit the points well on the right side, but on the left side both are not quite satisfactory. The fact that a regression is mathematically calculated is not a guarantee for a good fit under all conditions. Different sets of data may require different methods to obtain well-fitting regressions and visual judgement should play an important part in this work.

7.2 Improving Soil Test/Crop Response Correlations, Using Nutrient Uptake Figures.

In section 4.1 above it was mentioned that the amounts of nutrients taken up by the plant often correlate better with soil test data than the yield. The reason is that plants will take up nutrients when they are readily available even if outside influences prevent the plant from using the nutrients fully for yield production.

If the correlation between soil tests and crop response is found to be considerably weaker than the correlation between soil tests and nutrient uptake by the plant, then the latter data can be used to improve the former. This is the case with the Thailand experiments shown in Section 4.2, Tables 1 and 2. There the nutrient uptake by the control plants and the additional nutrient uptake due to fertilizer application both correlated better with soil tests (Olsen extraction) than the two corresponding yield values: check yield and yield response.

The following method improves the soil test/crop response correlation in so far as it transfers on an average basis the higher precision (lower scatter) of nutrient uptake data to the crop response data, the latter being the values on which fertilizer recommendations can be based.

In Figure 8 three graphs are shown derived from the Thailand data, Table 1. The upper graph marked A shows the uncorrected correlation between yield responses and the soil test values. The equation of the regression line is shown. The correlation coefficient $r = -0.606$ is significant.

The second graph B in Figure 8 shows the correlation between crop responses (y-axis) and the additional nutrient uptake (x-axis) with the equation of the regression line. The regression coefficient (slope) of +0.268 in this equation indicates that on the average of all the concerned data the yield increases with 0.268 grammes dry plant material per pot for each milligramme phosphorus taken up by the plants. The equation of that graph allows the average response y to be calculated for each value of additional uptake x. For instance Table 1 shows for the first soil Bnl an additional uptake of 48 mg P per pot. This corresponds according to the equation in Figure 8B with a corrected response $y = 5.70 + 0.268.48 = 18.6$ gr/pot instead of the original response of 17.7 gr/pot. For the second point of Table 1 the corrected response is $y = 5.70 + 0.218.73 = 25.3$ gr/pot instead of the original 37.2 gr/pot, etc. This calculation is done for each point resulting in a new set of response data, based on the response/uptake relation.

The correlation of these 'adjusted' response values with the soil tests is shown in the lower Graph C of Figure 8, which is directly comparable with the unimproved correlation Graph A. The adjusted responses correlate much better with the soil test values, the correlation coefficient r having increased to the value -0.737 which was found to be highly significant.

It will be understood that this process also aims at smoothing out the wide scatter of points while maintaining the correct relations inherent in the given data population.

7.3 Percent Yield versus Absolute Response

In many publications and scientific essays on soil test calibrations, soil tests are correlated with relative values such as 'percent yield'. If phosphorus is the nutrient under research the percent yield is the yield of the NK plots expressed in percent of the NPK yield, or NK.100/NPK.

The main reason for using percent yield (2) or similar relative crop values instead of the absolute crop responses is their better correlation with soil tests. This is because some of the site influences are eliminated by using yield relations from plots on the same site.

For soil test calibrations intended for practical fertilizer advice relative yield data cannot be used effectively even if they correlate better with soil tests than the absolute crop responses. The reason is obvious. Fertilizer advice is based on economic considerations. A certain percent yield increase may be a high or a low absolute amount and it is therefore no basis for the required benefit calculation. This shortcoming cannot be compensated for by a somewhat better correlation.

In this connection it should be stressed again that a wide scatter of points in a correlation graph does not mean that there is no or only a weak correlation between available nutrients and yield. This correlation is not in doubt. The scatter is caused by other growth factors as explained. The primary aim must be to identify and measure these influences and use the knowledge for improving the fertilizer recommendation.

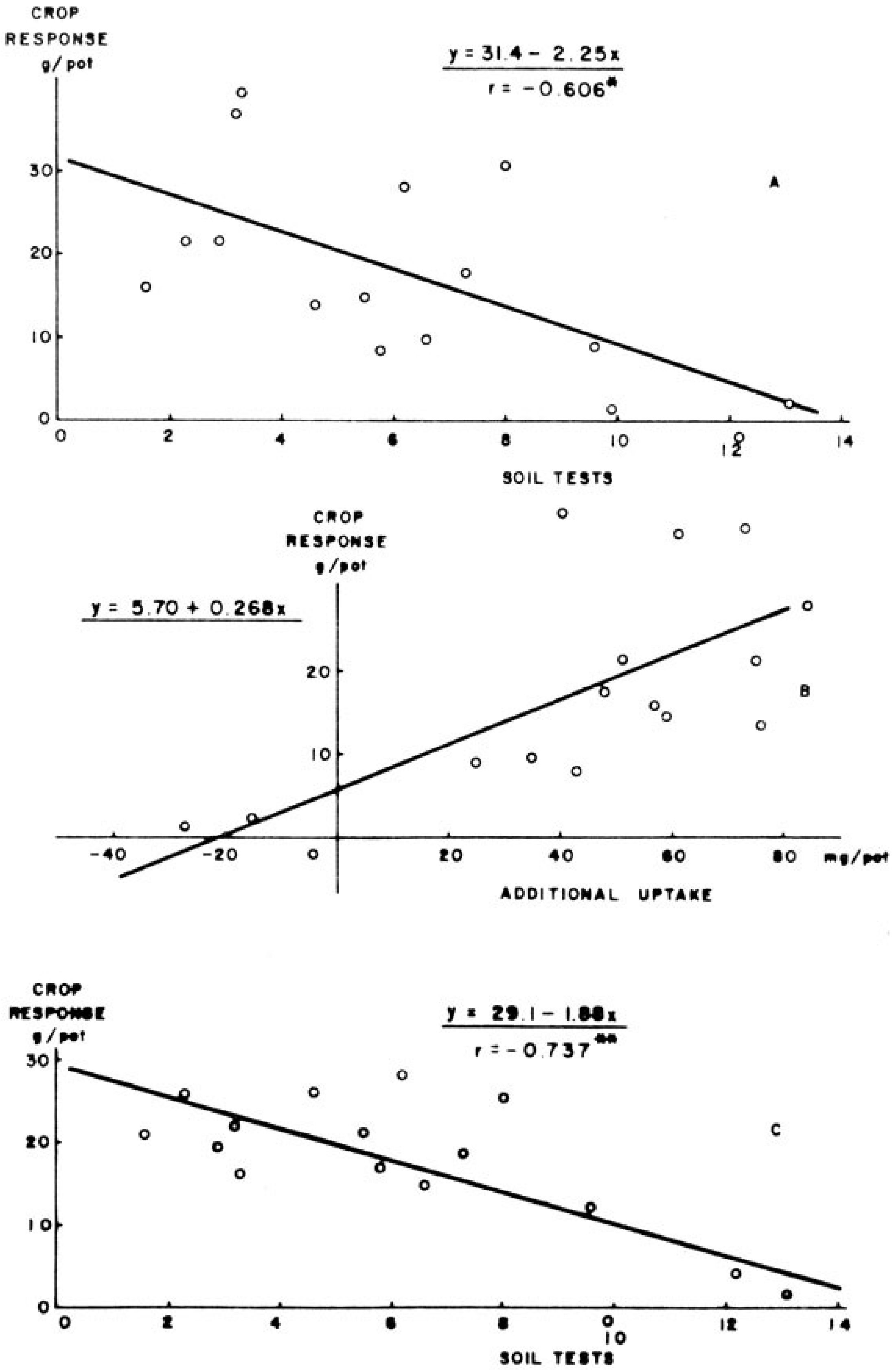
CROP RESPONSE g/pot
y = 31.4 − 2.25x
r = −0.606*
A
0
10
20
30
0
2
4
6
8
10
12
14
SOIL TESTS
CROP RESPONSE g/pot
y = 5.70 + 0.268x
B
10
20
-40
-20
20
40
60
80
mg/pot
ADDITIONAL UPTAKE
CROP RESPONSE g/pot
y = 29.1 − 1.88x
r = −0.737**
C
0
10
20
30
0
2
4
6
8
10
12
14
SOIL TESTS

Figure 8

The relative values of percent yield may be useful for comparing responses to certain treatments of different crops. Or they may be used for comparing extractants as described in Chapter 4, because there the comparison of the correlations obtained with various extractants is the end of this research, and no economic evaluations in terms of absolute crop responses are required.

Finally, since in the literature the opinion is expressed here and there that soil tests may be calibrated with relative yields "using also" absolute data for developing fertilizer recommendations, an example shown below may illustrate how complicated the relations between yield levels and responses are.

Three hundred fertilizer trials with irrigated wheat in the arid zone of Iran were grouped according to check yields as shown in Table 5. The fertilizer application referred to was 30 kg of N and P_2O_5 each per hectare. K was not required in these soils.

Table 5. Responses of wheat to fertilizers in Iran

Check yield groups kg grain/ha	Mean check yields kg/ha	Mean fertilized yield kg/ha	Mean yield Increase due to fert.applic.		Percent yield
			kg/ha	%	
700 or less	506	988	482	95	51
700 - 1,200	968	1,620	652	67	60
1,200 - 1,700	1,453	2,165	712	49	67
1,700 - 2,200	1,973	2,618	645	33	75
2,200 - 2,700	2,437	3,006	569	23	81
2,700 and more	3,234	3,649	415	13	89

If one looks first at the absolute yield increases, column 4, it is seen that the response is low at low check yields, it increases up to the third check yield group and declines again.

The reason for this rise and decline of responses is that the growing conditions causing a very low check yield also prevented fertilizers from being fully effective. As growth conditions improve lack of nutrients becomes more prominent relative to other growth factors with a resulting peak of the response in the third group. There the high response lifts the yield up over the 2000 kg mark which is a fairly high yield for the local wheat of the area. From there on the increasing nutrient levels in the soil and the effect of diminishing return when nearing the yield ceiling, decrease fertilizer effects.

The economic benefits from fertilizer applications follow the same course as the absolute responses.

The relative values of percent increase or percent yield, shown in the two last columns, do not reflect the changes in the absolute responses. They decrease or increase over the whole range and actually bear no relation to the absolute yield increases at the various check yield levels, the latter reflecting to a certain degree the sum of growth factors including nutrient levels. The differences are marked mainly at lower levels of productivity as they occur for instance in traditional farm systems of developing countries.

This may show that percent yield is not easily related with absolute response, a step involving much uncertainty, and the reader will appreciate the saving in time and effort and the gain in precision by correlating soil tests directly with absolute crop responses.

7.4 Inconsistant Data

In sets of data and graphs as discussed above usually some figures deviate considerably from the general line. If there is no reason to assume that the deviation is due to an error in laboratory or field work, the first thing is to locate the field from which the exceptional figure originates. If other data from this field also deviate from the rest, the experiment should not be included in the general correlation work. If, however, the other data from that field do fit the general line well, the erratic figure should be taken out and should not be carried through all the graphs. Such chance deviations may occur and these figures may be replaced statistically in the same way as a missing figure.

If a certain number of fields deviate consistantly from the rest with regard to response and uptake figures and their correlations, these fields form a separate group which should not be combined with the rest. Strong soil influences are usually responsible for such a circumstance.

It can be suggested as a general rule that in no case should one or two strongly deviating points be allowed to disturb a set of graphs or correlations. The soil test interpretation must necessarily be based on a broad average relation of data and should not be concerned with occasional chance deviations.

8. THE INTERPRETATION AND USE OF SOIL TEST/CROP RESPONSE CORRELATIONS FOR FERTILIZER RECOMMENDATIONS

8.1 The Interpretation Graph

A calibration of soil tests to be used for fertilizer advice and based on the four previously mentioned basic correlation graphs, is illustrated in the model shown in Figure 11.

The three curves show the crop responses on soils with low, medium and high soil test. On soils rich in the tested nutrient low responses can be expected while soils with low levels of available nutrients will produce high responses to fertilizer applications.

The straight line in this model shows for each fertilizer application rate the response needed to just repay fertilizer costs. The section of the graph above this cost line is the area of profit, and below the line the area of monetary loss.

The arrows show the points of the two upper curves where the vertical distance from curve to cost line is greatest indicating the fertilizer rate of highest economic benefit often called optimum rate. This optimum rate is of course higher for soils testing low than for soils testing medium. In this example the soils testing high will show an increase of yield by nutrient application but these increases would not be economical.

If the fertilizer price decreases relative to the price of the crop, or if the crop price increases, the cost line will be flatter as indicated by the broken line in the model. In this case all the optimum rates increase and even on soils testing high it is economical to use limited fertilizer rates.

8.2 Development of Interpretation Graph from Experimental Data

The procedure described below aims mainly at smoothing out sufficiently the scatter of the measured data to reach a clear interpretation and furthermore to determine, if possible, the influence of other growth factors, which knowledge can then be used to refine fertilizer advice.

For the type of basic data which would be obtained following the outlines as given in previous sections of this guide, the described procedure is among the best that can be recommended. Other types of basic data may require some changes or adjustments to parts of the procedure.

The first step is to obtain a return curve for each experimental site or, to be more exact, the best estimate of such a curve. For that purpose the 15 yield figures of each site (3 replicates of 5 treatments each) are plotted against the 5 treatments as shown in Figure 9. Small graphs are more convenient than large scale ones for that purpose.

The average yield for each treatment is also plotted as marked by x's in the graph. Now the yield curve is drawn through these points, smoothing out deviations, using the average points as the main lead, but giving little or no weight to obviously exceptional deviations, such as point P in Figure 9.

It is hardly worth calculating these curves mathematically; first of all because possible deviations from the unattainable ideal curve hardly influence the final results, secondly because the parabolic shape, the only function which can be calculated fairly easily, may not fit the points suitably and may introduce an error, and thirdly because of the undue input of time and effort. Drawing the curve by hand and smoothing it with French Curves will serve the purpose perfectly.

Having arrived at this curve the line Ch (Checkyield) is drawn horizontally from the point at which the curve starts. The vertical distances from that line to the curve R_1, R_2, R_3, R_4 are the average crop responses to the four nutrient rates applied. The reader will appreciate that by this process a considerable amount of variation in the original data has been cancelled out which greatly facilitates the following phases of work.

Having obtained in this way a return curve for each experimental site there are two possibilities to continue depending on how small or large is the variability among the curves.

For estimating this variability the soil test range covered by the experiments is tentatively divided into three classes similar to the division shown in Figure 10, and the curves are grouped accordingly. The soil test range can also be divided into more than three classes, but for clarity three classes are always adhered to in this and the following text.

If by this grouping of the curves it is found that in the group of low soil tests the curves are consistently and markedly steeper at their origin and reach higher than the curves in the medium soil test group, and if those in the high soil test group are distinctly flatter than the rest, the variation among curves is small. In this case it may be possible to combine the curves within each group to average curves for low, medium and high soil tests respectively and to draw directly the interpretation graph as shown in Figure 11.

The chances are that the variations among the curves within groups would be fairly high so that almost certainly it would be necessary to improve on this quick, direct approach by following the second more elaborate but more exact method in addition.

This second approach would have to be followed in all those cases where the curves within soil test classes vary widely between steep and flat slopes. Such a variation indicates that other growth factors have influenced yields and therefore an effort should be made to eliminate these influences.

For this approach the next step is the plotting of the basic soil test/crop response correlations, an example of which is shown in Figure 2, Section 7.1.2.

For that purpose the average soil test of each experimental site is set out on the x-axis, while in the vertical direction the average crop responses of each site, denoted by R_1, R_2, R_3, R_4 in Figure 9, are plotted. Hence there are four correlation graphs, one for each nutrient application rate. The first graph correlates the R_1 values (responses to the P_1 application) of all sites with the soil test values, the second graph all R_2 values etc. All sites are included in this process disregarding soil test ranges.

The following step is the correction of these four graphs for the influence of growth factors (listed in Section 5.3) as far as they are known and recorded for each experimental field. This process was illustrated with the factor of irrigation in Chapter 7. Needless to say that all four basic graphs should be treated and corrected in the same way.

In the four corrected soil test/crop response correlations are obtained, the average crop responses must be determined for various soil test classes. For this purpose the whole range of soil test values is divided into three classes as shown in Figure 10. This graph is the corrected soil test/crop response correlation of the cotton example in Chapter 7, Figure 4.

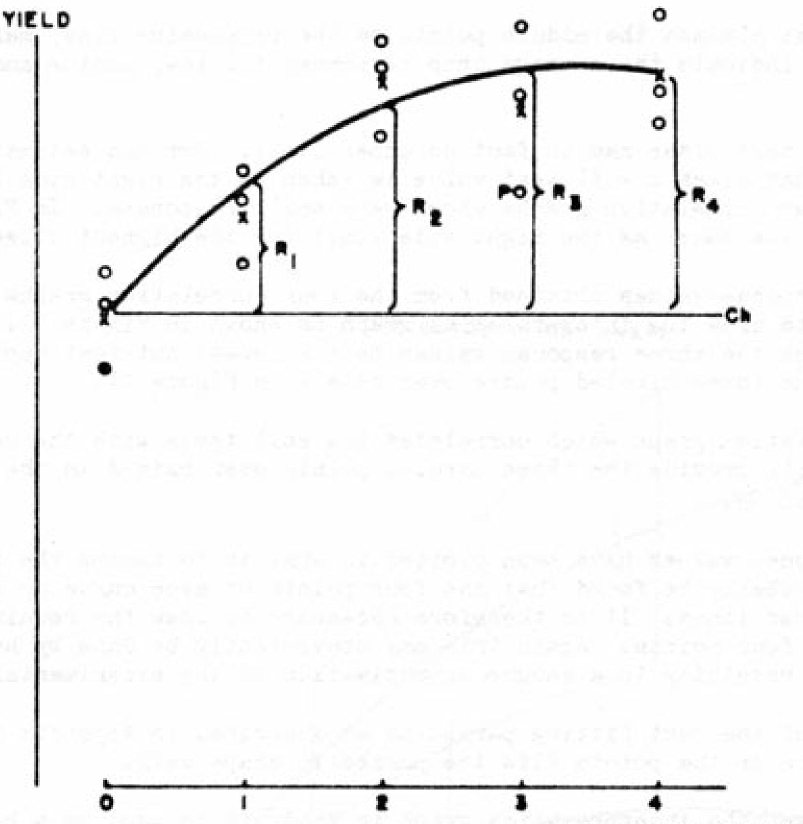


Figure 9

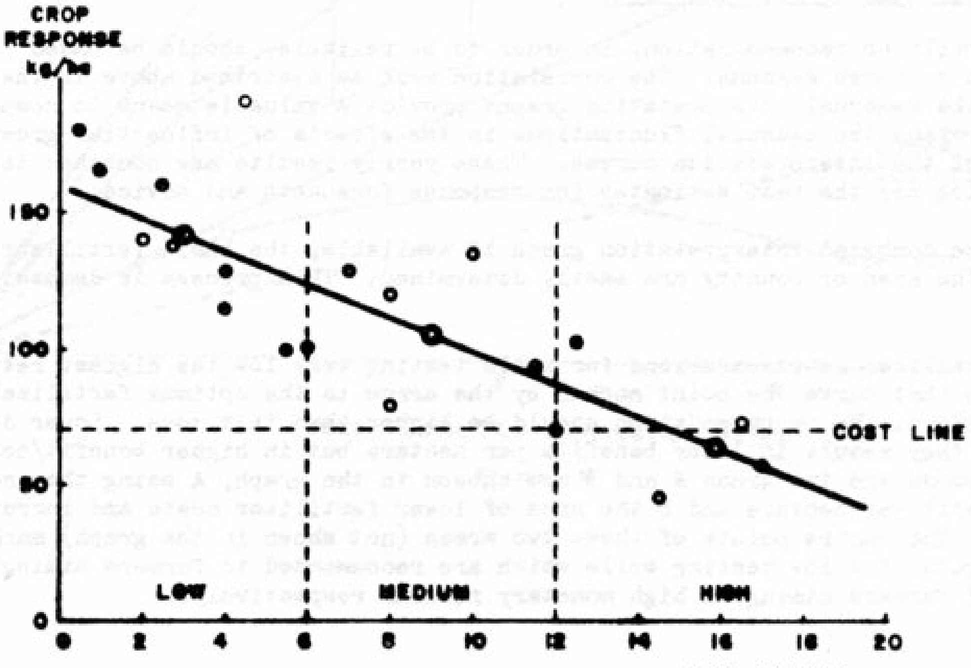


Figure 10

The soil test values at which the vertical division lines of classes are drawn may be chosen freely, although the position and shape of the regressions of the four correlation graphs should facilitate this decision.

In these soil test classes the middle points on the regression line, marked by small circles in Figure 10, indicate the average crop responses for low, medium and high soil test values.

The highest soil test class has in fact no upper limit. For the estimate of the average response of that class a soil test value is taken as the right side limit of the class which in all four correlation graphs shows very small responses. In Figure 10 the soil test value of 20 was taken as the right side limit for the highest class.

These average response values obtained from the four correlation graphs mentioned earlier are now used to draw the interpretation graph as shown in Figure 11. From the first correlation graph the three response values to the lowest nutrient application rate are derived and are the three circled points over rate 1 in Figure 11.

The second correlation graph which correlates the soil tests with the responses to the application rate P_2 will provide the three circled points over rate 2 in the interpretation graph Figure 11, and so on.

If these 12 response values have been plotted in what is to become the interpretation graph, it will most probably be found that the four points of each curve do not really describe smoothly curved lines. It is therefore necessary to draw the required smooth curves nearest to the four points. Again this may conveniently be done by hand with the aid of French Curves, resulting in a secure approximation of the experimental facts.

The calculation of the best fitting parabolas as described in Appendix 3 is recommended only if the position of the points fits the parabolic shape well.

With this last step the interpretation graph is ready to be used as a basis for advice.

8.3 Basic Fertilizer Recommendations

Any fertilizer recommendation, in order to be reliable, should be based on results of at least two or three seasons. The correlation work as described above is the same in each season and the seasonal interpretation graphs provide a valuable means to compare years and to understand the seasonal fluctuations in the effects of influential growth factors as well as of the interpretation curves. These yearly results are combined to give averages which are the best estimates for response forecasts and advice.

Once the combined interpretation graph is available, the basic fertilizer recommendations for the area or country are easily determined. This process is demonstrated in Figure 11.

For fertilizer recommendations for soils testing very low the highest return curve applies. On that curve the point marked by the arrow is the optimum fertilizer dose as explained before. No recommendation should be higher than this dose. Lower doses are allowed and they result in lower benefits per hectare but in higher benefit/cost ratios. On these grounds the two areas A and B are chosen in the graph, A being the area of highest benefit per hectare and B the area of lower fertilizer costs and increased benefit/cost ratio. The centre points of these two areas (not shown in the graph) mark those basic fertilizer rates for low testing soils which are recommended to farmers aiming at highest profits, and farmers aiming at high monetary returns respectively.

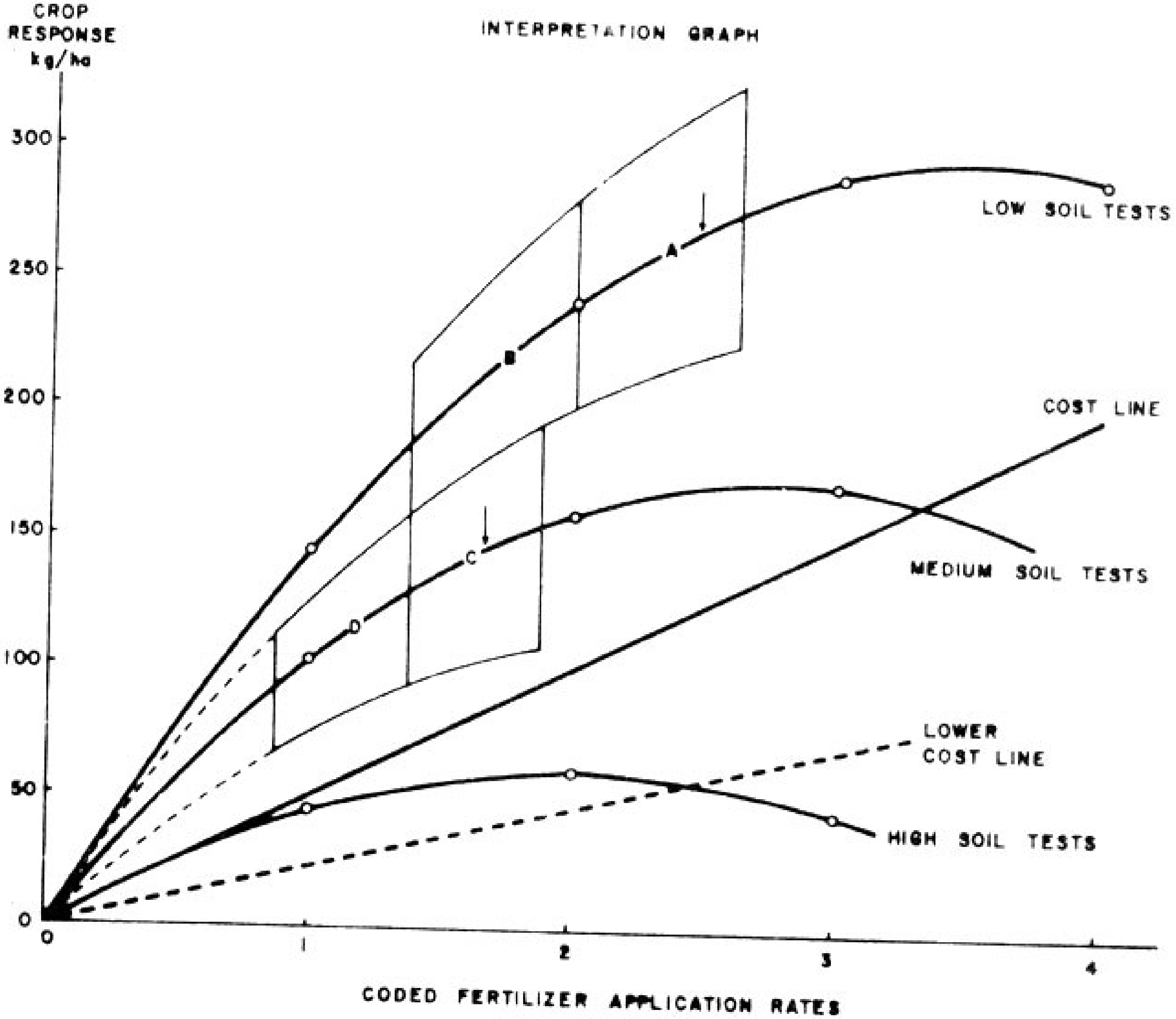

CROP RESPONSE kg/ha
INTERPRETATION GRAPH
300
250
200
150
100
50
0
0
1
2
3
4
LOW SOIL TESTS
A
B
COST LINE
C
D
MEDIUM SOIL TESTS
LOWER COST LINE
HIGH SOIL TESTS
CODED FERTILIZER APPLICATION RATES

Figure 11

This concept of two distinctly different fertilizer recommendations is not usually applied in the industrialized countries with price relations favouring high application rates, but it is important for developing countries where fertilizer prices may be higher.

The corresponding recommendations for medium soil tests are those marked by the centres of the areas C and D in the graph. The reader will understand that there is some flexibility in the choice of these areas.

For soils testing high no application can be recommended according to this graph. If the cost line was lower then small fertilizer applications might be economical and recommendations would be determined as shown for the other return curves.

8.4 Site-specific Adjustments of Basic Recommendations

It will be understood that the interpretation graph is attained by repeated averaging and fitting regressions, which smoothed out the original wide fluctuations in figures, and gives response curves which reflect average growing conditions of the area. However, each growth factor varies in the area as for instance the number of irrigations cited in the first example with cotton. Eight irrigations was the average and each irrigation less than eight lowered the crop response by 13.7 kg/ha. This influence was quantified by the graphical method described in 7.1.2. It is obvious that the basic fertilizer recommendation, as indicated by the interpretation graph which is valid for an average of 8 irrigations, cannot be applied for a field receiving only 4 or 5 irrigations.

But since it is known how much lower the response will be, the fertilizer rate to which the recommendation must be reduced for optimum return, can be determined.

This process of adjusting basic recommendations for certain growth factors may seem complicated. In fact, however, it is rather easy because for each growth factor four correction graphs are made, one for each nutrient application rate. For each of these rates it will be known therefore how much the crop response decreases for say two irrigations less than the average 8. These decreases can be plotted in the interpretation graph and the lower response curve will be obtained.

A similar adjustment can be made for any other growth factor of influence in the area. In practice there will only be a few major factors in each area to be taken into account for fertilizer recommendations and since it is not practical to make graphs for each farm, recommendation tables can be prepared covering the main factor combinations in the area. Examples of such tables will be shown later.

8.5 Follow-up Field Trials

If the soil test calibration has reached the stage where basic fertilizer recommendations can be made, the most difficult step has been achieved. In the previous section was described the way in which these basic recommendations can be adjusted to the individual needs of specific areas or fields by taking into account the influences of special growth factors.

After these first steps it is always necessary to continue research for the refinement of the system. In each area or on special soils there are certain important variables which may require specially designed experiments to evaluate their influences. No fixed method of approach can be given for this follow-up research as requirements differ greatly from region to region.

Besides these refinements of recommendations, which serve the individual farmer in particular and make it absolutely necessary that the scientist in charge is intimately acquainted with the methods and implications of commercial farming in his region, there are some more general research subjects which require continuous attention. These subjects concern innovations made available to farming by science and industry such as new plant varieties, new fertilizer materials, new machinery, new farm management methods, etc. Once such innovations are being adopted by farmers, the soil testing service must find out the influence of these innovations on the recommendations based on soil tests.

If a soil testing service should cease to keep up-to-date in the described way, the farmers will lose interest quickly. This is equally true for developed and developing countries. The linkage between the follow-up work and the agricultural extension service will be discussed in the next chapter.

8.6 The Philosophy of Fertilizer Recommendations

The term "philosophy of fertilizer recommendation" and similar expressions are frequently heard, particularly in high industrialized countries where farming itself has assumed the character of an industry. A few words may be said here regarding the meaning and background of such expressions.

The soil test values are only a measure of the plant available nutrients in the soil. They do not indicate directly how much fertilizer should be applied. This depends on the kind of crop to be planted, the desired yield level and on the economic benefits of the various possible application rates.

Especially when the fertilizer is cheap compared with the crop price and when the fertilizer costs are only a small part of the total production costs, there are several different fertilizer recommendations that can be made, all based on the same soil test result. These possibilities are:

(a) to apply a relatively low amount of fertilizer in order to get the highest possible monetary return from the money spent on fertilizer. This would be suitable for poorer farmers; (areas B and D in Figure 11)

(b) to apply those higher rates which are expected to result in the highest possible benefits per hectare. This is the "optimum" rate; (areas A and C in Figure 11)

(c) to apply still higher rates in order to increase the general nutrient level of the soil for the benefit of future crops;

(d) to apply fertilizer to specific crops in a rotation rather than to the others.

The farmer has a free choice among these and other possibilities and indeed his choice depends on his preferred philosophy just as a banker chooses among various money investments.

The soil testing service should try to meet the interests of the farmer as much as possible by including certain questions in the request form, for instance: what yield level does the farmer wish to obtain, or what is the second crop in his rotation etc. These and similar questions will narrow down the possible choice, but it still remains wide enough for the soil testing service to decide on a certain "philosophy". The latter is of course a decision in the sense explained above, which by experience leads to average best results in the area.

When sets of the same soil samples are sent simultaneously to several soil testing services, asking them for the analytical results and their recommendations, it is usually found that the soil test values differ little among laboratories. The recommendations differ much more and this is due to the various philosophies which are based mainly on local experience.

This shows that it would be basically wrong to expect similar fertilizer recommendations from laboratories in different areas if they find the same soil test values for the same soil type.

In developing countries fertilizer use is intended to gain either the highest return per invested money or the highest benefit per unit area. Recommendations for both these purposes can be derived directly from the interpretation graphs as described in Section 8.3.

9. INITIATION OF A SOIL TESTING SERVICE

9.1 General Requirement

The establishment of a soil testing service, including the preparatory field work and research involved in it, is not a matter of one or two years but longer and should be considered as the first period of a continuous and gradually improving service for the similarly improving farm operations in an area or country. After two or three seasons when the basic correlations allow the issue of the first soil test based fertilizer recommendations for one or two main crops, a great advance has been achieved but unless work is continued these first successes will not have much consequence.

The major requirements therefore are continuity in all main aspects of the work and the right placement of the Service among the government institutes.

9.1.1 Government attitude and placement of the soil testing service

From the very beginning of the project all concerned government institutes should be fully aware of the permanent nature of the soil testing service, and of the importance and need for permanency of personnel, budget and technical approach as described below.

As regards the place of a Soil Testing Service in the government infrastructure, there are two possibilities which have been found suitable. One is to attach this Service as an independent unit to a government agricultural research institute, or soils institute if one exists, the other is to attach it - alsc as an independent unit - to a university institute, most conveniently the soils department.

The reason for this placement is the essentiality of close liaison between the Soil Testing Service and an active research unit.

Another necessary liaison is with the agricultural extension service as this link provides the important feed-back of knowledge from the field to the Service. This liaison is of great importance to the Soil Testing Service solely if the Extension Service is not only active but also effective, in the sense that it is giving real guidance and useful advice to farmers and is fully accepted by them. In most countries the liaison with research may be more important especially in the first phases, and the Soil Testing Service is housed in a university or attached to experimental units.

9.1.2 Technical personnel

The leading staff from the chief of the Service, who should be a capable technical expert, to laboratory and field supervisors should be permanent employees selected for their dedication to the work and their interest. Those who are concerned with field work should have a good knowledge of local farming and should become valuable team members dealing with the scientific staff, farmers and extension agents equally. Such relations do not develop in a short time and are interrupted by changes of personnel.

9.1.3 Technical approach to calibration problems

Actual plans for the work and experimentation ought to be made for several seasons in advance, and many details such as designs, measurements, field techniques, recordings etc. should be standardized in order to reduce the chances of errors to a minimum, and to increase the compatability of results obtained during longer periods. Changes in plans and practices should not be made unless absolutely necessary. Discontinuity, often caused by changes in the leading personnel, should be avoided. Many of the routines established in the first period should be maintained and will greatly add to the smooth efficient operation of the Soil Testing Service later on.

9.1.4 Facilities for field experimentation

Calibration field trials should be conducted on fields which have the average properties of those of the commercial farmers, so that the resulting soil test calibration will be valid under these conditions. For special research, mainly for working out the influence of certain variables, more closely controlled fields belonging to experimental stations or farms are required. Finally checks on new soil extraction methods require greenhouse facilities. For these various types of experiments facilities must be available on a permanent basis. With regard to experiments on farmers' land the extension service should play an important role as will be seen later.

9.2 Preparation in the Laboratory

In countries or areas where a new soil testing service is to be developed, the only needed unit is a normal soils laboratory where all the usual types of soil analyses can be carried out, and where a number of trained analysts and laborants are available.

When the field and laboratory work for soil test calibration starts the first analyses may still be made by certain semi routine procedures, as used for a limited number of tests. As long as effective precautions are taken to avoid analytical errors by (a) running regular and frequently (usually with each series) known standard samples and (b) checking regularly the test solutions, apparatus and instruments, the semi routine procedures may be adequate for a long time, even after the first seasons of calibration field trials. However, it is advisable for the laboratory to prepare rather early for an increased capacity.

The right arrangements of rooms for a continuous smooth flow of samples is important. A small room for crushing and sieving soil samples should be adjacent to a larger space for drying samples on trays fitting into shelves and laboratory space, office room, sample store, etc. should all be in a compact unit.

The change from old to new equipment is always a source of error. These errors are usually systematic ones in which the general level of resulting figures is shifted up or down but the relation among figures stays unchanged. For the soil test calibration such changes in levels are greatly disturbing. It needs a prolonged check by parallel series with both equipments in order to be sure of the required continuity. The laboratory leader may design various cross tests using experimental field samples in order to increase reliability and skill regarding new procedures.

Special attention must also be given to the recording and evaluation of data. The right equipment using colour marked serial frames avoids marking glasses altogether and cuts down marking of frames to a minimum.

Preferably the instruments should be equipped with scales for reading the answers directly in terms of the required units. Each analytical series should have one record sheet throughout the whole channel. Hand copying should be avoided completely.

For all these routine procedures several systems are suitable and in use. Experience has shown that any recording system will undergo certain changes until it is suitable and practical. There is no 'best' system but every system has both advantages and disadvantages. In highly developed services the recent changes to computerized print-outs have altered systems considerably, but for most new soil testing laboratories any practical, arranged, error-proof registration system will meet the requirements.

9.3 Start of Field Experimentation

From the very beginning of field operations the cooperation of the extension agents of the involved areas should be secured, naturally with the full blessing of the Head of the Extension Service. This can best be done by a training course or seminar in which the purpose of the Soil Testing Service is explained and detailed information is given to the agents about the field work required for the basic calibration, the duration of this preparatory phase, the nature of the first fertilizer recommendations to be expected and their further refinement. The agents should be very clear about the contributions they can make in any of these phases and the information they can give to the farmers in order to secure their cooperation.

It is of advantage to hold this training course before the first field operations for soil test calibration start in order to give the agents time to inform the farmers about what will happen and to make the start of field activities more generally known.

The first work consists in the collection of a large number of composite soil samples for the selection of experimental sites. At planting time experiments will then be laid out on the selected sites as described in Chapter 6.

From that time on intensive cooperation with the concerned extension agents should never slacken. They must be given periodical information material about the progress of work and other interesting aspects of soil testing in order to keep their and the farmers' interest awake. In seasons of low agricultural activity visits by farmers to the laboratory may be organized and during harvest time the harvesting of the calibration field experiments can be used for organizing an instructive "field day" for the farmers.

It is very important that in all these and following field activities the extension agents are involved and take part as far as possible. They must be fully aware of each step done in the field and its purpose, because it will normally be the extension service which keeps the Soil Testing Service in business later on to the advantage of the farmer.

9.4 Operational Material and Other Requirements

9.4.1 Request forms, sample boxes and soil test reports

It will be clear to the reader by now that for valid fertilizer advice the soil test figures of a sample alone are not sufficient. The farmer who sends the soil sample for analysis must answer a number of questions before the Soil Testing Serivce can give suitable advice. This advice will depend on the previous crop, the previous fertilizer applications, the crop to be planted, the water available, the drainage of the field and on several other items concerning important environmental factors which determine the crop yields, and finally the yield which the farmer wishes to attain.

The soil testing service needs all that information in a standard form and in addition it must ascertain that the farmer takes the soil sample in such a way that it really represents the soil of the field. Therefore, the soil testing service issues to the farmers, directly or via the extension agents, printed soil test request forms which contain all the important questions to be answered by the farmer.

With this form goes a very clearly printed description of how to take a soil sample, and finally one or more cardboard boxes (folded) for sending soil samples of the right size. Usually a brief version of the instruction of how to take the samples is printed also on these boxes.

The request forms and the questions contained in them are not the same for all countries or regions. In one area drainage may be all important, in another area subsoil conditions or typical soils differences may have an essential influence on the final fertilizer recommendation. It is therefore not possible to give a standard form of request sheet which is suitable for all conditions. Just to give examples, two such request forms and one unfolded sample box are reproduced in Appendix 4.

By the time a new soil testing service has worked out the basic correlations and is able to issue fertilizer recommendations, the influences of important variables and the respective questions to be asked of the farmer are well known and hence the designing of a suitable request form is no problem.

When a certain soil sample is analysed the service sends the results, the interpretation of them and the final fertilizer recommendation to the farmer on a printed standardized soil test report. A specimen of such a report is reproduced also in Appendix 4.

9.4.2 Crop information sheets

Another type of printed paper usually issued by an active soil testing service are information sheets on how to fertilize specific crops. They serve as a very valuable guide for both the farmers and the extension agents. In order to prevent dullness and to give these pamphlets more individuality they are not printed in a standardized shape and colour but vary in mape-up, colour, and slightly in size in addition to the front picture which shows the crop itself.

The crop information sheets provide an excellent opportunity to teach extension agent and farmer more about soil test-based advice. In these pamphlets the peculiar needs of the crop are explained and how they relate to other crops. The most suitable time for fertilizer application and the best kind of fertilizers are given, also how the crop is to be planted and treated, what difficulties may be met and how to overcome them. This greatly helps the farmer to create for each crop he grows the optimum conditions which in turn will optimize the fertilizer effects and hence the economic benefits.

Such pamphlets are always issued if some new findings or new varieties are available making a revision of the old pamphlet desirable. A pamphlet may also be issued if the farmers in an area persistently make a mistake regarding certain crops.

Since such pamphlets have no value for the farmer if they do not take fully into account the peculiarities and implications of commercial farming in the area, experienced extension agents, if available, should take part in their designing.

9.4.3 Soil testing information sheets

Sometimes it is necessary to inform by printed sheets the extension agents and farmers about certain matters or changes in the laboratory. This is always necessary if an analytical procedure is changed and the resulting figures are different from those to which the agents and farmers have become accustomed. Furthermore regarding new findings, new ways of evaluation, etc. resulting in different designs of the soil test reports or similar changes, special information sheets for agents and farmers will probably also be highly appreciated by all.

9.4.4 Assistance by extension service

Farmers, especially those who have not been able to have higher schooling, usually find it difficult to work according to instruction sheets, to fill out forms and to understand some of the technical terms which cannot be avoided. For instance one can hardly expect them to understand why a soil sample must be taken in such a complicated way as prescribed instead of just going to the field and taking a spade of soil, putting it into a bag and sending it to the laboratory.

This difficulty is experienced equally by farmers in highly developed and developing countries and therefore it has happened that in actual practice most of the soil samples are taken for the farmer by extension agents who also help the farmers with the correct completion of forms and, finally, with a correct understanding of the soil test reports. In the U.S.A. and possibly elsewhere, the soil sampling and fertilizer application are sometimes done by small firms working, under contract, with the farmers, and keeping close and efficient contact with the soil testing service, using it to the utmost benefit of all concerned with great technical efficiency.

In developing countries it will be necessary in most cases that selected extension agents specialize in this type of assistance to farmers and keeping in very close contact with the soil testing service. An important job for these agents will be to obtain reliable information on the actual effects of the issued fertilizer recommendations with regard to yield increases and economic returns, and to re-channel it to the soil testing service.

References

1. Boyd, D.A. and Frater,A. 1967 Analytical methods for potassium and their correlation with crop response. Ministry Agric., Fishery and Food, Tech. Bull. 14, 55-62.

2. Bray, R.H. 1948 Correlation of soil tests with crop response to added fertilizer and with fertilizer requirements. The American Potash Institute, pp. 53-85.

3. Bray, R.H. and Kurtz, L.T. 1945 b Determination of total, organic and available forms of phosphorus in soils. Soil Sci. 59, 39-45.

4. Bremner, J.M., Bundy, L.G. and Agarwal, A.S. 1968 Use of a selective ion electrode for determination of nitrate in soil. St. Univ., Ames, Iowa, USA; Analyt. Abstr. 18.

5. Cate, R.B. and Nelson, L.A. 1965 A rapid method for correlation of soil test analyses with plant response data. Techn. Bull. 1, Intern. Soil Testing Series, North Carolina State University.

6. Cate, R.B. and Nelson, L.A. 1971 A simple statistical procedure for partitioning soil test correlation data into two or more classes. S.Sci.Soc.Am. Proc. 35, 658-660.

7. Chandler, R.F., Peach, M. and Bradfield, R. 1945 A study of techniques for predicting the potassium and boron requirements of alfalfa I. S.Sci.Soc.Am.Proc. 10, 141-146.

8. Colwell, J.D. 1968 Assessment of factors limiting the significance of soil tests for fertilizer requirements. 9th Int. Congr. S.Sci.Transac. Adelaide IV 709-718.

9. Dahnke, W.C. 1971 Use of the nitrate specific ion electrode in soil testing. Soil Science and Plant Analysis 2(2) 73-84.

10. Eagle, D.J. and Mathews, B.C. 1958 Measurement of nitrate-supplying power of soils by an incubation method and correlation with crop yield response. Can.J. Soil Sci. 38, 161.

11. FAO 1970 Physical and chemical methods of soil and water analysis. FAO Soils Bulletin No. 10.

12. Fenster, W.E. and Overdahl, C.Y. 1971 Monitoring nitrogen use on corn. Agr.Ext. Service, Univ. of Minnesota.

13. Ferrari, Th.J. and Vermeulen, F.H.B. 1955 The reliability of soil analysis. (Dutch) Landbouwvoorlichting 12, 9, 389-399.

14. Grimme, H. Nemeth, K. and Von Braunschweig, L.C., 1971 Some factors controlling potassium availability in soils. Transact. Int. Symp. Soil Fert. Evaluation, New Delhi, February 1971.

15. Hanway, J.J. 1967 Field experiments for soil test correlation. Soil Sci. Soc. Am. Special Publ. No. 2, Soil Testing Part I, 1967, 103-114.

16. Hauser, G.H. 1941 The non-exchangeable fixation of potassium in soil. (German) Dissert. Wageningen, Netherlands, Sept. 1941.

17. Hemingway, R.G. 1955 Soil sampling errors and advisory analysis. The Journ. o. Agri. Sci., Vol. 46, June 1955.

18. Hooper, L.S. 1970 The basis of current fertilizer recommendations in England and Wales. The Fertilizer Soc., Min. Agr. Fish. & Food, Reading, U.K., Proceed. Fert. Soc. 118.

19. Lakanen, E. and Ervio, R. 1971 A comparison of eight extractants for the determination of plant available micronutrients in soils. Suomen Maatal. Seuran Julkaisuja 123, Acta Agralia Fennica.

20. Lathwell, D.J. and Peech, M. 1964 Interpretation of chemical soil tests. Cornell Univ. Agr. Exp. Sta., Bull. 995, Oct. 1964.

21. Nemeth, K. 1970 Characterization of the K-status of soils by means of K-desorption curves. (German), Geoderma 5. 1971.

22. Nemeth, K. 1971 Possibilities for the determination of factors governing soil fertility by means of elector-ultrafiltration (EUF). (German), Landw. Forschung, Sonderheft 26/1, 1971.

23. Nemeth, K., Mengel, K. and Grimme, H. 1970 The concentration of K, Ca and Mg in the saturation extract in relation to exchangeable K, Ca and Mg. Soil Sci. 109, 3, 179-185.

24. Olsen, S.R., Cole, C.V., Watanabe, F.S. and Dean, L.A. 1954 Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S. Dep. Agr., Circ. No. 939.

25. Paauw, F., Van Der, and Ris, J. 1955 The importance of the K-status for potatoes on clay soils in North Holland. (Dutch) Versl. Landbk. Onderz. (1955).

26. Paauw, F. Van Der, and Sissingh, H.A. 1968 The P-water figure as a new measure for the availability of phosphate in the soil. (Dutch with extended English summary) summary), Landbouwvoorlichting 25, 348-359.

27. Paauw, F. Van Der. 1969 Development and use of a new water extraction method for the determination of plant available phosphate. (German) Landw. Forschung 23/II, Sonderheft 1969.

28. Rouse, R.D. 1967 Organizing data for soil testing calibration. Soil Sci. Soc. Am. Special Publ. No. 2, Soil Testing part I. 115-123.

29. Schuffelen, A.C., Hudig, J. and Wittewaall, B.W.G. 1945 Chemical differences in the plough layer at short horizontal distances. (Dutch) Landbk. Tijdschr. 56-57, 457-465.

30. Sissingh, H.A. Dissolving soil phosphorus by water extraction as related to the
1969 development of a new "P-water" method. (German), Landw. Forschung 23/11.

31. Soper, R.J., Racz, G.Y. and Fehr, P.I. Nitrate nitrogen in soil as a means of
1971 predicting the fertilizer nitrogen requirements of barley. Can. J. Soil Sci. 51, 45-49.

32. Soper, R.J. Soil tests as a means of predicting response of Rape to added N, P and
1971 b K. Agron. J. 63, N. 4, 564-566.

33. Tamhane, R.V. and Subbiah, B.V. Correlation between soil analysis and responses to
1960 fertilizers with special reference to the rice crop in India. News Letter IRC (Int. Rice Comm.), Vol. IX, No. 4, Dec. 1960.

34. Truog, E. Test for available soil nitrogen. Comml. Fertil. Atlanta 88, 72-73.
1954

35. Vermeulen, F.H.B. The precision of the determination of available potassium in
1956 soil samples. (Dutch), T.N.O. Nieuws, 128, 524-527.

36. Vermeulen, F.H.B. Sampling of soil. (Dutch), T.N.O. Niews 167, 20-22.
1960

37. Williams, C.H. Chemical soil tests as an aid in increased productivity. Trans.
1962 Int. Soil Conf. N.Z. 1962, 820-834.

38. Williams, R.J.B. and Cook, G.W. Measuring soluble phosphorus in soils, comparing
1965 of methods, and interpretation of results. Min. Agr. Fish. Food, Tech. Bull. 13, 84-93.

Fertilizer Recommendation Systems

39. Fertilizer Recommendations for Crops in North Dakota Soils Department,
1971 N.D. State Univ., Fargo N.D.

40. Guide to Computer Programmed Soil Test Recommendations in Minnesota.
1971 Agr. Ext. Serv., Univ. of Minn., Special Report 1.

Determination of Potassium Fixation by Soils

As explained in the text some clay minerals have the ability to take up in their crystal lattices potassium from the soil solution and from the exchange complex. This fixed potassium is no longer exchangeable by salt solutions in the laboratory but the plant roots can take it up by lowering the potassiun comcentration in the soil solution and the exchanged complex causing a slow reversing of the fixation process.

The extent to which a soil fixes applied potassium depends on the potassium deficit in the lattices of its clay minerals and this can be determined by the method quoted and it also depends on the amount of potassium added or, more precisely, on the potassium concentration around the fixing soil particles, which can be varied in the analysis.

Earlier workers determined potassium fixation by adding a potassium solution to the soil and drying it at 70°C, then rewetting it with water, drying it again and repeating that several times. The high K-concentrations during the drying process force much more potassium into the clay mineral lattices than could ever be fixed in the field. Therefore such repeated dryings are not recommended but the method described below gives two alternatives, one without drying and one with a single drying only.

The method

- weight 10 gr. of air-dry soil into a small beaker or dish
- add 7.5 ml KCl solution containing exactly 10 mg K^+
- shake slightly to mix the soil well with the solution, and cover with a watch glass.

Alternative (a) - leave the suspension at room temperature for 16 hours (overnight);

Alternative (b) - leave the suspension for 6 hours at room temperature, then dry at 70° C.;

- leach the soil with N ammonium acetate of pH 7 as done for the determination of exchangeable potassium;
- measure by flame photometer the amount of potassium in the leachate.

This method, which resulted from a study of a number of typical soils covering the range of very high to zero fixation (38) shows the following fixation values:

Alternative (a) - 16 hours wet : <u>0 - 4.5 mg K fixed</u> out of the 10 mg K added

Alternative (b) - with drying : <u>0 - 7.5 mg K fixed</u> out of the 10 mg K added.

It should be noted that this method gives relative fixation values by which the K-fixing capacity of soils is characterized and which can be used for correcting soil test/crop response correlations as described in Chapter 7 if K-fixation influences this correlation.

The K-fixation values as found with this method do not show how much potassium the soils would fix in the field. 10 mg K^+ per 10 gr soil corresponds to more than 2 tons of K^+ or 4 tons of KCl per hectare. The much lower potassium applications to crops result in much lower K-concentrations and therefore in relatively lower fixation percentages as compared with the laboratory procedure. In spite of that, the amounts of potassium fixed in fields with strongly fixing soils can be very high.

Calculation of a Regression Line

Definitions: The regression line for a number of points is that line for which the sum of the squares of the vertical distance from each point to the line is in the minimum.

Its general equation is: $\underline{y = a + bx}$ in which

a = the y-value in the graph for $x = 0$

b = the slope = the tangent of the angle the line makes with the x-axis.

The factors a and b are to be calculated for a set of points of which the x and y values are known (soil tests and crop responses respectively).

Calculations: n = the number of points of x-y-pairs

Sx = sum of all x values

Sy = sum of all y values

$\bar{x}$ = average x value = Sx/n

$\bar{y}$ = average y value = Sy/n

$S(x^2)$ = sum of all squared x-values

$S(xy)$ = sum of the product $x.y$ of all figure pairs.

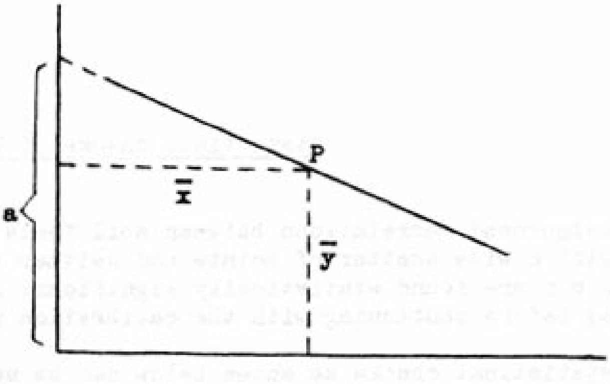
$SSx^2 = \underline{S(x^2) - (Sx)^2/n}$ which is the corrected sum of squares of x

$SP(xy) = \underline{S(x.y) - (Sx.Sy)/n}$ which is the corrected sum of products of xy

a and b of the regression equation are:

$\underline{b = SP(xy)/SSx^2}$

$\underline{a = \bar{y} - b.\bar{x}}$



The regression line always passes through point $P(\bar{x}, \bar{y})$

Notes: 1. If the regression line moves from the lower left to the upper right in the graph the SPxy is positive and the b-value (tangent) is therefore positive. If the line declines from the upper left to the lower right, b and SPxy are both negative, which is the case with soil test/crop response correlations.

2. The corrected sums of squares SSx^2 and SSy^2 are always positive.

Calculation of the Correlation Coefficient r

(For symbols refer to regression calculation above)

SSy^2 = corrected sum of squares of y. $SSy^2 = S(y^2) - (Sy)^2/n$

$$r = \frac{SPxy}{\sqrt{SSx^2 \cdot SSy^2}}$$

Notes: 1. With full correlation when none of the points deviates from the regression line the correlation coefficient r reaches its highest value r = 1.

2. The correlation coefficient is positive when the tangent of the regression line b, (and also SPxy) is positive and vice versa. See also Note 1 of the regression calculation above.

3. The square of the correlation coefficient times 100 shows how many percent of the total influences are due to the correlation between x and y. For instance in Figure 4 the value for r was -0.739, $r^2 = 0.546$, $100r^2 = 54.6$.

Hence 54.6% of the influences in that correlation are accounted for by the true correlation between soil tests and crop responses, the rest is due to other variables.

Statistical checks of b and r

The unimproved correlations between soil tests and crop responses usually show diagrams with a wide scatter of points and neither the regressions b nor the correlation coefficients r are found statistically significant on the 5% level. If such significance is demanded before continuing with the calibration work, it would probably never be started.

The statistical checks as shown below can be used for the final improved correlations as a measure of quality. If these correlations also do not reach 5% significance, the inference is that more correlation data must be determined and added to those already obtained. The inference is not that the obtained data are useless; one is perfectly right to go on with the interpretation of the obtained weak correlations, keeping in mind that verification by additional correlation data is desirable.

The usual statistical checks for b and r consist in calculating the t-values for b and r and comparing them with the table-values of t.

Calculation of the t-value for the regression coefficient b.

$$s_b = \sqrt{\frac{SSx^2 \cdot SSy^2 - SPxy}{(SSx^2)^2 \cdot (n-2)}}$$

t value for b: $t_b = r \cdot \frac{b}{s_b} = \sqrt{\frac{(SPxy)^2 \cdot (n-2)}{SSx^2 \cdot SSy^2 - SPxy}}$

t value for r: $t_r = r \cdot \sqrt{\frac{n-2}{1-r^2}}$

Calculation of a Parabolic Return Curve

Fertilizer response curves start from the axis origin and therefore the calculation shown below is only for these curves, which have the general equation

$$y = bx + cx^2$$

Similar to Appendix 2, the symbols used are:

Sx^2 = the sum of all squared x-values

Sx^3 = the sum of all cubed x-values

Sx^4 = the sum of the fourth powers of all x values

Sxy = the sum of the products $x.y$ of all figure pairs

Sx^2y = the sum of the products $x^2.y$ of all figure pairs

By means of a table of seven columns, the first two for the measured values of x and y (soil tests and crop responses respectively) and the other five columns for the above values, the calculation can be done in an easy and orderly manner.

The values of b and c of the equation are

$$b = \frac{Sxy.Sx^4 - Sx^2y.Sx^3}{Sx^2 . Sx^4 - (Sx^3)^2} \qquad c = \frac{Sx^2 . Sx^2y - Sx^3.Sxy}{Sx^2 . Sx^4 - (Sx^3)^2}$$

The highest point of the curve denoting maximum crop response has the coordinates:

$$x_{max} = -\frac{b}{2c} , \; y_{max} = \frac{1}{2} \cdot bx_{max}$$

Calculation of the Optimum Fertilizer Rate

These rates resulting in the highest benefits per hectare are indicated in Figure 11 by arrows. At these points the tangent on the curve is parallel to the cost line. It is obvious that the position of these points on the curves depends on the slope of the cost line.

In the example of Figure 11 it needs a crop response of 150 kg to just repay the fertilizer rate 3. Therefore the slope (tangent) of the cost line is 150/3 = 50.

The equation which was calculated for the upper curve in Figure 11 in the way described above was found to be

$$y = 169x - 24x^2$$

The optimum fertilizer rate is calculated by

$$x_{opt} = -\frac{b - f}{2c} \quad f = \text{slope of cost line}$$

which is for the Graph Figure 11:

$$x_{opt} = -\frac{169 - 50}{-48} = \underline{2.48}$$

Soil Testing Request Forms

The first two forms reproduced below are in use by the soil testing laboratories in Texas and Indiana respectively. These forms have to be filled out by the farmers and contain questions which must be answered for a correct interpretation of the soil test values. It will be noted that in Texas a question early in the form concerns the soil phase (upland, bottom) and the irrigation, which under arid climate are most influential variables. That is followed by the question on the soil type. In Indiana with a colder and wetter climate the important questions in this category concern drainage, soil phases, slope and erosion together with soil type.

The cropping and fertilizer history make up a common set of questions which includes previous liming in Indiana but not in Texas where soils are usually high in lime and pH due to the arid climate.

Regarding the crops to be planted one question concerns the desired yield level. This question is seldom asked in that form in developing countries yet, where at present the main distinction is made between fertilizer rates for highest benefit per hectare and rates for highest return per invested money. However, with the development of correct working soil testing services and refined production economy the targetted yield levels will soon gain importance.

Cardboard Box for Sending Soil Samples to the Laboratory

The third reproduction shows the print on the unfolded cardboard box which is issued to the farmers of North Carolina for sending soil samples to the laboratory. The print prescribes briefly how soil samples are to be taken, and it says that 15 to 20 subsamples or cores are needed per composite sample.

The laboratory's mailing address is printed on the box.

Soil Test Reports

The fourth reproduction shows as an example the soil testing report with fertilizer recommendations used by the Indiana soil testing laboratory. Copies of each of these reports are usually sent also to the extension agent of the area who helps with the use of the recommendations as he has previously helped with collecting the soil samples. In the low right hand corner of this form the meaning of soil test results is shown.

This laboratory also issues other information sheets, one of which gives information on the interpretation of soil test values for specific crops.

Interpretation of soil test values for specific crops

This sheet is shown in the fifth reproduction. On this are indicated the soil test values under Indiana conditions which are called "very low", "low", etc. for specific groups of crops, and valid for the methods of analyses employed. Such information sheets help the extension agents greatly in understanding the interpretation of soil testing.

Finally the sixth reproduction shows the relations between fertilizer rates, yield targets and previous crops as worked out by the Indiana laboratory.

D-494 (Dist. 4, 5, 8, 9, 10 & 11)

TEXAS A&M UNIVERSITY
TEXAS AGRICULTURAL EXTENSION SERVICE
SOIL TESTING LABORATORY

ASCS Farm No...............

SOIL SAMPLE INFORMATION SHEET FOR FIELD CROPS

To aid in interpreting the soil test and making recommendations, fill in the following information sheet as completely as possible and submit with your soil samples. Each soil sample should be marked with your name and sample number which should correspond with the information furnished on this sheet. Cost of testing is $2 per sample. See mailing instructions on opposite side under Step 4.

NAME... COUNTY...

ADDRESS... LOCATION IN COUNTY...
(NE, S, SW, W, NW, etc.)

POST OFFICE... DATE...

EXTRA COPY TO: NAME...

ADDRESS...

ZIP CODE...

SAMPLES TAKEN BY:

Farmer...............
Co. Agt...............
Dealer...............
ASC...............
SCS...............
Vo-Ag...............
4-H...............

A. SOIL CONDITIONS: (Use ditto and check marks wherever possible)

Laboratory Number (Do not write in this space)	Your Sample Number	Acres in Sample	Location			Irrigated		Soil Type (if known)	Remarks
			Upland	Bottom	2nd Bottom	Yes	No		

B. CROPS TO BE GROWN

Sample Number	Next 2 Crops			
	Next Crop 196...		Year After 197...	
	Crop	Desired Yield	Crop	Desired Yield

C. CROPPING HISTORY

Last 2 Crops					
Present or Last Crop 196...				Previous Crop 19...	
Crop	Yield	Fertilizer			
		Grade	Lb./A	Crop	Yield

D. GENERAL: (Please answer following question if applicable to these samples).

1. Will Small Grain be grazed? No ....Yes .... Which fields?...............................
2. Has Lime been applied during past two years? Which fields?...............................
3. Will grass be used for hay? No........Yes .... Which fields?...............................
4. Will grass be used for grazing? No .... Yes .... Which fields?...............................
5. If grazed, how many animal units per acre? ....
6. Will a legume be grown in pasture? No .... Yes .... Which fields ....
   If so, what ....
7. What is the primary pasture grass?

Common Bermuda...........
Coastal Bermuda...........
Dallis Grass...........
Bahia Grass...........
Love Grass...........
Native Grass...........

PURDUE UNIVERSITY SOIL TESTING LABORATORY – AGRONOMY DEP'T – LAFAYETTE, INDIANA 47907 – AES FORM 286

FOR LABORATORY USE ONLY		
PAID	ASC	OTHER
DATE RECEIVED AT LABORATORY		

PLEASE PRINT

FIELD AND CROPPING INFORMATION SHEET
FILL IN AS COMPLETELY AS POSSIBLE!

NAME ______________________

STREET or ROUTE ______________________

TOWN ______________ STATE ______________

FARM LOCATION ______________ (COUNTY) ZIP CODE ______________

EXTRA COPY TO BE SENT TO ______________________

STREET or ROUTE ______________________

TOWN ______________ STATE ______________ ZIP CODE ______________

DATE ______________ 19 ______

☐ CHECK HERE IF COPIES ARE TO BE SENT TO COUNTY ASC

SAMPLE IDENTIFICATION				SOIL DESCRIPTION								PREVIOUS TREATMENTS								
				CHECK ONE			CHECK ONE		FILL IN IF KNOWN			FERTILIZER APPLIED				Manure Applied Last Year Tons/Acre	Plowing Depth if Applicable Inches	LIMING MATERIALS (LAST 5 YEARS)		
				SOIL DRAINAGE			POSITION					INCLUDE ALL FORMS – ROW, PLOWDOWN, AND SIDEDRESS								
												2 YEARS AGO		LAST YEAR						
SAMPLE NO. (ON BOX)	FROM FIELD NO.	LAB. NUMBER (Do Not Write Below)	ACRES REPRESENTED BY SAMPLE	POOR	GOOD	DROUGHTY	UPLAND	River Bottom	SOIL TYPE	Slope PER CENT	Erosion Class 1-3	N – P_2O_5 – K_2O	LBS/A	N – P_2O_5 – K_2O	LBS/A			MOST RECENT YEAR	LIME STONE T/A	MARL YDS PER A
1																		19___		
2																		19___		
3																		19___		
4																		19___		
5																		19___		
6																		19___		

CROP HISTORY FOR ABOVE SAMPLES

	LIST CROPS IN ORDER OF ROTATION (BE SURE TO INCLUDE INTERCROPS AND SEEDINGS IN SMALL GRAINS)							DESCRIBE MOST RECENT OR PRESENT HAY OR PASTURE CROP LISTED INCLUDE INTERCROPS SEEDINGS					REMARKS ON LAST CROP IF POOR, WAS IT WEEDS, INSECTS, POOR STAND, TOO WET, TOO DRY, STARVATION, OTHERS?
	TWO YEARS AGO		LAST YEAR					CONDITION NOW OR WHEN PLOWED					
NO ON BOX	19___ CROP	YIELD	19___ CROP	YIELD	CROP FOR WHICH YOU WANT RECOMMENDATIONS 19___	YIELD LEVEL DESIRED	ONE YEAR LATER 19___	YEAR	MOSTLY LEGUME	HALF & HALF	MOSTLY GRASS	GROWTH	
1								19___					
2								19___					
3								19___					
4								19___					
5								19___					
6								19___					

'R DRY SAMPLES BEFORE IBMITTING FOR TESTING

TO EXPEDITE PROCESSING, PLEASE INCLUDE FIELD REPORT AND REMITTANCE WITH SAMPLES. AN ADDITIONAL FIRST-CLASS LETTER POSTAGE RATE SHOULD BE PAID AND STATED ON THE PACKAGE AS: "FIRST CLASS LETTER ENCLOSED".

SKETCH AREAS SAMPLED ON BACK SIDE OF THIS COPY

PROCEDURE FOR TAKING SOIL SAMPLES

1. To obtain a soil sample that will be representative of the area you want tested, take a small uniform core (or slice) of soil from the surface to a depth you intend to plow (2 inches for established sods) in 15 or 20 spots. All of the cores should be collected in a clean pail and mixed thoroughly before placing a portion in the carton. Fill the box ½ to ⅔ full.
2. Soils that are distinctly different in appearance, crop growth, or past treatment (liming, manuring, fertilizing, or cropping) should be sampled separately. Small areas that differ from surrounding areas should be omitted or sampled separately.
3. Avoid fertilizer bands, terrace channels, dead furrows, roads and other unusual areas.
4. Mark the sample number, your name and mailing address on each container.
5. FILL OUT THE INFORMATION SHEET.
6. For more detailed information, see bulletin, "Soil Sampling—The Key to Reliable Soil Test Information" available from your county extension office.

PROCEDURE FOR MAILING SAMPLES

Wrap very securely, address, and prepay by parcel post, all samples to the

SOIL TESTING DIVISION
N. C. DEPARTMENT OF AGRICULTURE
RALEIGH, N. C. 27602

To avoid penalty, do not write on the sample box nor enclose writing in the package except your name, address and the sample number.

DO NOT FILL ABOVE THIS LINE

PLEASE PRINT PLAINLY

Name ____________________

____

Address ____________________

____

Sample or Field No. ______ ☐☐☐
(no more than 3 digits or letters)

PURDUE UNIVERSITY SOIL TESTING LABORATORY - - AGRONOMY DEPARTMENT - - LAFAYETTE, INDIANA - - AES FORM 400

SOIL TEST REPORT

for

A COPY OF THIS REPORT HAS BEEN SENT TO

________________ COUNTY EXTENSION OFFICE.

AN EXTRA COPY HAS BEEN SENT TO:

IDENTIFICATION		NUTRIENT RECOMMENDATIONS *				SOIL TEST RESULTS								
								LBS/ACRE						
LAB NUMBER	FIELD NUMBER	N LBS/A	P_2O_5 LBS/A	K_2O LBS/A	LIME T/A	SOIL-BUFFER pH	SOIL-WATER pH	PHOSPHORUS	POTASSIUM	CALCIUM	MAGNESIUM	% ORGANIC MATTER	COLOR	TEXTURE
			—	—										
			—	—										
			—	—										
			—	—										
			—	—										
			—	—										
			—	—										
			—	—										
			—	—										

REPORTED WHEN REQUESTED

*NUTRIENT RECOMMENDATIONS HAVE BEEN PREPARED FOR THE CROP YIELDS REQUESTED ON YOUR CROPPING HISTORY FORM. IF NO CROP YIELD LEVELS WERE LISTED, THEN STANDARD RECOMMENDATIONS WERE WRITTEN, THAT IS, FOR 125 BUSHEL CORN, 40 BUSHEL SOYBEAN, 50 BUSHEL WHEAT, 70 BUSHEL OATS, 6-TON ALFALFA, OR 4-TON RED CLOVER.

INFORMATION ON METHODS OF FERTILIZATION FOR EACH CROP ARE DISCUSSED IN YOUR SOIL TEST REPORT EXPLANATION SHEET.

NOTE: SOIL-BUFFER pH, THE BASIS FOR LIME RECOMMENDATIONS, IS ONLY USED WHEN THE SOIL-WATER pH IS BELOW 6.6. LIMING RATES INCREASE AS THE SOIL-BUFFER pH DROPS BELOW 6.8.

MEANING OF SOIL TEST RESULTS

SOIL TEST LEVEL	PHOSPHORUS TEST		POTASSIUM TEST
	FOR CORN, SOYBEANS LBS. P/A	FOR WHEAT, OATS, PASTURE LEGUMES ETC. LBS. P/A	ALL FIELD CROPS LBS. K/A
VERY LOW	0-10	0-10	0-80
LOW	11-20	11-20	81-150
MEDIUM	21-30	21-30	151-210
HIGH	31-45	31-70	211-300
VERY HIGH	ABOVE 45	ABOVE 70	ABOVE 300

Interpreting Soil Test Values for Specific Crops*

PHOSPHORUS TEST LEVELS (lbs. P/A)**

Soil Test Level	For corn, soybeans, sorghum	For small grains, pasture legumes, and grasses, etc.	For lawn, turf	For tomatoes, potatoes	For trees, gardens, flowers, shrubs
VERY LOW	0-10	0-10	0-20	0-15	--
LOW	11-20	11-20	21-45	16-30	--
MEDIUM	21-30	21-30	46-70	31-70	0-70
HIGH	31-45	31-70	71-100	71-100	71+
VERY HIGH	46+	71+	101+	101+	--

*These values are calculated on the basis of 7" plow layer, or 2,000,000 pounds of soil.

**Bray P_1 prscedure for measuring soil phosphorus was adopted on February 15, 1968.

- - - - - - - - - - - - -

POTASSIUM TEST LEVEL (lbs. K/A)

Soil Test Level	For corn, soybeans, small grains, pasture and hay crops, potatoes	For lawn, turf, tomatoes	For other vegetable crops	For trees, gardens, flowers, shrubs
VERY LOW	0-80	0-100	---	---
LOW	81-150	101-200	0-200	0-250
MEDIUM	151-210	201-300	201-330	251+
HIGH	211-300	301-400	331+	---
VERY HIGH	301+	401+	---	---

- - - - - - - - - - - - -

MAGNESIUM TEST LEVELS (lbs. Mg/A)**

Soil Test Level	Soil Color and Texture		
	Light-colored, coarse textured	Light-colored, medium to fine textured (S. Ind.)	All other Indiana Soils
Inadequate	0-75	0-100	0-200
Adequate	76+	101+	201+

The exchangeable magnesium in some Indiana soils has tested below the minimum level thought to be adequate by some agronomists. Magnesium plant deficiencies may be due to several factors including soil test level, weather conditions, crop demands, levels of exchangeable calcium and potassium, also ratio of soil potassium to magnesium. There is no conclusive research evidence in Indiana that either yield or crop quality is always reduced when soil levels are less than the appropriate "adequate" levels in the above table. For soils testing in the inadequate range, an application of dolomitic limestone based on limestone requirements, or 25-50 lbs. of Mg/A should be sufficient to bring future tests into the "adequate" range.

- - - - - - - - - - - - -

CALCIUM TEST LEVEL**

Calcium levels will usually be adequate for most Indiana soils. Periodic liming is effective in supplying adequate calcium. Use soil pH and lime requirement tests to determine lime needs on acidic soils.

**Exchangeable potassium, magnesium and calcium are extracted from soil by 1N Ammonium Acetate procedure.

Corn or Grain Sorghums[1]

Soil Test	Yield Levels (bu/A) target									
	100-110		111-125		126-150[2]		151-175		176-200	
	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O
Very Low	100	100	110	120	120	150	130	180	150	200
Low	70	70	80	90	90	120	100	140	120	160
Medium	40	40	50	60	50	70	60	90	70	120
High	30	30	30	30	40	40	50	60	50	80
Very High	10	0	10	0	20	0	20	0	20	0

Nitrogen Rates for Corn

Previous Crop	Yield Levels (bu/A)				
	100-110	111-125	126-150[2]	151-175	176-200
	Pounds Nitrogen Per Acre				
Good legume (Alfalfa, red clover, sweet clover)	40	70	100	120	150+
Average legume (Legume-grass mixture, or poor stand)	60	100	140	170	200+
Continuous corn (desired yield level has been obtained)	100	120	160	200	240+
Corn, Soybeans, small grain, grass sod	120	140	170	220	260+

---

1. Yield levels in excess of 150 bushels/acre are the results of combining numerous management practices, which favor high yields. Early planting, for example, could be more profitable than an additional increment of fertilizer. Nitrogen will be more efficiently used by corn, if the crop is planted on or near the recommended date.

   These recommendations are prepared to reach the desired yield level during the current growing season. Where the land has not been managed intensively in previous years, it is questionable as to whether the higher levels can be attained in one season.

2. This yield level (126-150 bu/A) is usually selected where a specific yield level is omitted, and the yield potential is apparent from the cropping information sheet.