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soil and plant testing and analysis

FOOD AND AGRICULTURE ORGANIZATION
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CONTENTS

I. INTRODUCTION

Among its other activites, FAO has focused on developing natural resources and approaches for their better utilization in order to increase food production in developing countries.

Knowledge gained from scientific research over the years and its successful application have made a tremendous impact on agricultural production in recent times. The introduction of high yielding varieties has resulted in greater demands on plant nutrients which cannot be met from the inherent soil fertility. Expensive inputs, such as fertilizers, must be introduced if the required yield levels are to be achieved. Rational use of these inputs is imperative, particularly under the conditions in developing countries where the financial limitations of the farmers are a major constraint. Even in the developed countries, one cannot overlook the rational and economic use of such inputs as fertilizers because of financial considerations as well as the ever-growing concern for environmental pollution.

Methods for evaluating nutrient status in order to obtain better plant growth and increased yields are constantly being developed and improved. New analytical techniques and procedures for soil and plant analysis have been invented and tested in many countries and laboratories. There have been innovations in data processing leading to the preparation of more refined and specific fertilizer recommendations.

The purpose of the Consultation was:

i. to review advances in a) methodologies for soil and plant chemical analysis, and b) interpretation of the results obtained and the preparation of fertilizer recommendations based on these results; 1/

ii. to identify progress made and areas requiring further attention with regard to the organization of soil testing services in general and, in particular, in developing countries.

ACKNOWLEDGEMENT

The Consultation, although organized by FAO at its Headquarters, was held with the financial assistance of the Government of Finland. The participants and FAO expressed their appreciation for this support and the interest displayed by the Government in the technical programme of the Organization.

1/ A publication on Soil and Plant Testing as a basis for Fertilizer Recommendations, prepared by Dr. A. Cottenie, as a result of this Expert Consultation, is printed as FAO Soils Bulletin 38/2.

NOTE ON FERTILIZER TERMINOLOGY - EXPRESSION OF PLANT NUTRIENTS

In the working papers, plant nutrients have been expressed either in the elemental or oxide form and in some instances the conversion has been given in brackets following whichever has been used. For ease of reference, the following conversion factors are given:

P_2O_5	x	0.4364	=	P	P	x	2.2919	=	P_2O_5
K_2O	x	0.8302	=	K	K	x	1.2046	=	K_2O
CaO	x	0.7147	=	Ca	Ca	x	1.3992	=	CaO
MgO	x	0.6030	=	Mg	Mg	x	1.6582	=	MgO

II. CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

The need for increased food production and for higher returns from agriculture makes the rational use of mineral and organic fertilizers imperative, particularly because these inputs are dependent on price fluctuations on the world market which affect the economics of their use.

Soil testing and plant analysis in conjunction with fertilizer trials in the field are indispensable tools in respective research, and for the formulation of fertilizer recommendations. The need for improvement and coordination of these services is of great importance, particularly in developing countries where resources must be put to maximum use.

With these basic considerations in mind, the participants in the Expert Consultation arrived at the following conclusions:

i. soil testing and plant analysis are important means of increasing crop production by the rational use of fertilizers in combination with the application of other up-to-date management practices;

ii. supplemented with field experiments, they serve as a tool to gradually refine fertilizer recommendations and to provide for a balanced use of fertilizers at the country or regional level as well as on individual farms;

iii. they are helpful in elucidating crop problems originating from soil conditions;

iv. as a method for diagnosing the nutrient status of both the plant and the soil, plant analysis has to be considered as a valuable complement to soil analysis;

v. plant analysis is an aid in fertilizer experiments in order to observe effects not directly shown by yield measurements (and to determine the nutrient uptake from the soil and from fertilizers);

vi. it is important for determining the fertilizer needs of many perennial crops, and to an increasing extent of other crops;

vii. plant analysis is required for evaluating the nutritional value of food stuffs and possible toxicities to man and beast.

1.1 Soil Testing

The execution of soil testing differs according to the degree of development in the particular country. There are three levels of intensity of testing.

i. Low intensity: this level refers to areas currently under production and/or designed for crop production but where no previous fertilizer trials have been conducted, also to areas where deficiency symptoms in plants occur and the anticipated or potential yields are not obtained. Under such conditions it is recommended that:

   a. the first steps for establishment of a soil testing service should preferably include the organization of an analytical laboratory, fertilizer trials in the field and pot tests in greenhouses or out of doors;

b. in the case of difficulty in establishing such a laboratory, the samples collected by specially qualified people could be sent to a laboratory outside the country.

ii. Medium intensity: in countries where fertilizer trials have already been conducted and limited soil testing services are available it is recommended that:

a. efforts should be concentrated on calibration of chemical analysis with yields in field or pot tests, as well as on selection of the most suitable extractants based on this calibration;

b. particular attention should be given to reliable sampling techniques, suitable depths and frequencies of borings for obtaining representative samples. Sampling of soil to a depth of 60 to 120 cm is recommended for some particular cases, for example, in determining nitrates and salts for salinity control;

c. the minimum number of analytical determinations required depends on local conditions but those for pH, phosphorus, potassium and soil organic matter should certainly be undertaken. In areas where deficiencies of other nutrients or toxicities are suspected, or lime requirements are evident, the analysis should include buffer pH, exchangeable acidity, magnesium, calcium, ammonium and nitrate nitrogen and salinity. Laboratory equipment could include time saving devices such as automatic shakers, pipettes, burettes, etc;

d. where a soil survey is planned or being conducted, soil analysis facilities should be combined for both soil survey and soil testing.

iii. High intensity: in the countries sufficiently advanced in soil surveying, field fertilizer experiments and research on soil fertility, soil test programmes should include:

a. more sophisticated equipment (atomic absorption apparatus, etc.) for quick determinations of macro and micronutrients including iron, manganese, copper and zinc;

b. some measures for protection of equipment from heat and damp, especially in the humid tropics, should be used such as air conditioned rooms and use of dehumidifiers;

c. more precise field and pot studies should be undertaken with lime macro and micronutrients for calibration against the results of soil and plant tests;

d. whenever necessary and possible, modern computer techniques for data processing and preparation of fertilizer recommendations should be applied;

e. storage and retrieval systems for soil/plant analytical and related data should be established.

1.2 Plant Analysis

i. Methodology

From the methodological point of view the following successive steps should be considered:

a. identification of nutrient anomalies;

b. confirmation by analysis of representative samples and positive crop responses;

c. survey of nutrient status by observation and plant analysis in order to provide possibilities for more efficient use of available fertilizers and formulations.

ii. Sampling

For each crop the procedure for the sampling of plants should be clearly specified and should be carried out under close supervision.

iii. Interpretation

a. Plant analyses must not be considered as an alternative system for other existing methods of nutrient diagnosis, but should be used in connection with soil properties and soil analytical data, as well as with other factors (climatic, management, etc.);

b. Fertilizer experiments must constantly be conducted as a means of improving the interpretation system for both soil and plant analysis.

2. RECOMMENDATIONS

Based on the discussions, the following recommendations were proposed.

2.1 Analytical methods

i. Methods that are simple and accurate should be used, taking into account the availability and dependability of utilities and maintenance services. Whenever possible the most efficient instruments should be used.

ii. Plant and soil analytical tasks should be confined to a single laboratory under one unified supervision.

iii. The analytical programme for routine analysis should be confined to the elements known to be of prime importance for economic crops of the particular country.

iv. It is advised to check methods for plant analysis used in a particular laboratory by means of reference (official) methods or by participation in sample exchange programmes.

v. When plant analysis is to be used for formulating fertilizer recommendations standard methods should be studied with a view to improving the system of diagnosis.

vi. The correlation between plant and soil analytical results should be studied systematically.

2.2 Procedures

i. Feedback: in developing countries research on soil and plant analysis and routine testing cannot be clearly distinguished and should not be arbitrarily separated. One must complement the other. Research should solve the analytical and interpretation problems. Testing laboratories should supply the research results as quickly as possible.

After having received advice for fertilization on the basis of soil or plant analyses, the extension officer should determine the effectiveness of the recommendations and give this information to the testing laboratory.

ii. As already realized with regard to some experience, it is recommended that good and lasting contact be established between research workers in the field of specific crops in order to exchange information through coordinators.

iii. Where facilities do not permit, laboratories be advised to start their activities in the field of soil testing or plant nutrient diagnosis on a limited number of crops.

iv. Calibration of the analytical methods for soils and plants by field fertilizer experiments is indispensable, and a series of fertilizer experiments should therefore be established in all developing countries. Exceptionally, some methods could be used without local calibration if such a calibration has been done under similar ecological and management conditions elsewhere.

v. To ensure future maximum use of data produced, it is advisable from the start to standardize a record-keeping system. Efforts should be made to ensure uniformity of terminology on an international basis, as proposed by FAO in "Guidelines for coding of soil data[1]".

vi. It is strongly recommended that soil samples from these field experiments be stored for a long period of time, following completion of analysis. These samples could then be used later in the evaluation of new soil test methods. If the size of the sample is large enough to carry out further pot studies, the samples are of even greater value. Soil containers should be labelled to identify them with previous treatment.

vii. Particular attention should be paid by FAO to the promotion, establishment and development of plant and soil analytical laboratories in developing countries. In order to reach this goal it is suggested that training of personnel and exchange of information be organized and arrangements be made for giving advice on laboratory equipment, analytical methods and interpretation systems. Financial support should be provided when possible.

2.3 Organizational aspects

i. Institutional position of the testing service

a. Analytical services should be closely linked to the extension/advisory services and should maintain a functional relationship with universities, research stations, etc.

1/ First Draft - Proposals for an International Soil Data Bank, FAO, May 1977.

b. Where soil survey organizations already exist they should be very closely coordinated with the soil fertility/testing department.

c. The institutional position of the soil fertility/testing organization and its operation should be backed by the appropriate government authority.

ii. Laboratories

a. Soil and plant analysis, and water analysis when appropriate, should be located in the same building and be under one unified administration.

b. Laboratories should be constructed of a size and shape specifically designed to suit the particular equipment and space requirements for modern analytical work.

c. In countries where transport of soil samples from the field to a main laboratory is difficult and time consuming, sub-laboratories should be established under the guidance of the central laboratory.

iii. Training

a. Analytical assistants should:

- receive in-service training as part of their daily routine work;
- receive after two years of experience a short period of formal training, as far as possible within the country, with the object to motivate and encourage personal interest in the work.

b. Instrument technicians

- Where there are other laboratories at the same site, an instrument technician could be jointly employed economically. Such positions usually fall into the lower grades within governments' wage structure. If well trained, weighting in the "equivalent of local currency" should be considered to avoid them being tempted away from government service.
- It is strongly recommended that instrument manufacturers be encouraged to provide regional training courses in the function and maintenance of their products and also more detailed training for the very sophisticated instruments.

c. Analyst/supervisor

The analyst/supervisor should obtain some training in instrument maintenance and keep abreast with modern developments.

d. Soil scientist

- The soil scientist in charge should belong to professional and learned societies in order to keep abreast of innovations and extend the knowledge of his special field.

- He should also periodically receive training in managerial skills.

iv. Standardization

a. Equipment, methods and techniques used both in laboratories and in the field should be standardized.

b. Governments should provide appropriate orientation and coordination of aid projects to implement the above recommendations.

c. Suitable literature on soil/plant testing should be made available.

2.4 Financial aspects

i. Adequate funds should be supplied for the establishment and subsequent maintenance and continued operation of all the services connected with the soil advisory section.

ii. Countries experiencing temporary financial/foreign currency difficulties should be assisted in the establishment and continued operation of soil fertility/testing services. The use of proceeds from fertilizer grants and/or the supply of instruments, training and chemicals would be among the appropriate means.

III. TECHNICAL PAPERS

Paper 1

PRESENT STATUS OF SOIL AND PLANT ANALYSIS FOR FERTILIZER RECOMMENDATIONS AND IMPROVEMENT OF SOIL FERTILITY

by

F.G. Viets Jr.
102 Yale Way, Fort Collins, Colorado 80521, USA

1. URGENCY OF THE PROBLEM

There is unanimous agreement that maintaining and actually improving soil fertility through good soil management and use of organic wastes and mineral fertilizers is essential if the world is to provide the food needed in the next 25 years to meet the needs of a world population that will almost double before the year 2000. Doubling food production will continue to sap the nutrients from soil now cultivated. Expansion of agriculture to land not now cultivated may require even more fertilizer because of the low nutrient status of much of this land, e.g. the tropics.

Doubling food production will at least double the need for fertilizers. The amount needed could even triple. Although the supply of raw materials for fertilizer manufacture appear to be adequate, the costs of manufacture and transportation may rise even faster than the prices of commodities due to the increasing shortage of energy and the rapid rise in its cost.

The increasing need for food and the escalating cost of energy and fertilizers compound the need for improved soil management and the most efficient use of fertilizers. Soil testing and plant analysis for the guidance of management and fertilizer use can and will play a major role in this increase in the food supply and efficiency in its production. Soil testing and plant analysis can thus be looked upon as the ultimate in applied soil and plant science because they are concerned with prediction. Prediction is always more difficult than writing the history of what has happened.

There is a common opinion in developed countries that the future problems of food supply and fertilizers needed to produce it will fall most heavily on the developing countries. It is difficult to generalize about developing countries because they differ in resources, population trends and awareness of their problems. Nevertheless, the reasons given for more acute problems in the developing countries are several. Some have high birth rates that show little sign of declining. The consensus of opinion is that most food must be produced near where it is consumed. Imports can supply only a fraction of the needs. Some countries lack the raw materials and the energy supplies for fertilizer manufacture. Under these conditions, fertilizers must be purchased with foreign exchange accumulated by exports of raw materials and commodities that others need, or by grants or borrowing: the last two methods are not dependable and cannot last indefinitely. Soils in some tropical developing countries occupying Central Africa and Latin America that are not cultivated now pose special problems of low nutrient status and high adsorption capacities that are difficult to satisfy. Finally, we lack a large background of scientific knowledge and research experience with many of these soils, such as we have accumulated in North America and Western Europe from several centuries of study and experience.

For the reasons cited, a focus on the soil testing problems of the developing countries is especially warranted. These countries can use a part of the technology developed in the temperate zone, but certainly not all of it, and should use none of it without further laboratory and field testing to see if it applies.

In the short time and space available I cannot hope to give a complete review of the history of soil testing and plant analysis. Such a review would take several volumes and has never been done. Rather I hope to concentrate on what I think have been the more significant developments and give some opinions on where I think these sciences may be heading. I have never operated a soil testing or plant analysis laboratory concerned with routine handling of samples. I make no apologies for this lack of experience for I have worked on the development of soil tests for micronutrient cations, particularly Zn, and have done some work on the leaf analysis of maize. Needless to say, I have used many analytical methods used in such laboratories in my research on soil-plant relations.

HOW PLANTS FEED

Ever since the publication of Liebig's famous book 'Die Chemie in ihrer Anwendung Auf Agriculture and Physiologie' in 1840, the theory that plants derive their nutrients from mineral elements has been generally accepted. This theory put to rest older ideals that plants get their substance from ingestion of soil particles and humus. Subsequent research has shown that there are at least 16 elements essential for the growth of higher plants. The C, H and O come from air and water. The rest come mainly from the soil, but some of them like ammonia (N) can be absorbed through the leaves and many of them can be taken up from foliar sprays applied to the foliage. In addition Si appears to benefit some plants such as rice. Chlorine, although essential, is not known to be deficient in nature. Cobalt is essential for Rhizobia. Although organic compounds can be absorbed by roots and may exert beneficial effects under special circumstances, most plants can be grown in sand or solution cultures just as well as in soil given proper attention to details. As a result of the acceptance of the mineral theory of plant nutrition and the extension of the list of essential elements, soil and plant testing has been confined to determining the adequacy of the mineral elements. Attention went first to testing for N, P and K but has been broadened particularly in recent years to include the so-called secondary elements Ca, Mg and S, and now the microelements Fe, Mn, Cu, Zn, B and Mo.

Except for Si, which may enter the plant as some form of SiO_2, the view now held is that all elements enter the plant in ionic form from the soil solution. There is the possibility that some of them are absorbed by a direct exchange of an ion, usually H, between the root surface and ions adsorbed on soil colloids. Such a process of ion exchange is by no means essential for the adequate nutrition of the plant. Most ions are probably sorbed by the root against a concentration gradient and so the process presumably involves the use of metabolic energy by the root.

A number of processes are responsible for solution of ions from the mineral and organic phases of the soil including simple solution from a mineral, cation and anion exchange between solution and adsorbed ions on colloidal surfaces, and microbial mineralization of organic matter. In addition, small concentrations of ions are added in rain and irrigation water and much higher concentrations are deliberately induced by use of fertilizers and organic wastes.

Many of the solution reactions in soil are carried out by the activity of bacteria, fungi and other microorganisms. The plant, too, also excretes or secretes H ions, organic acids and chelating agents into the rhizosphere that aid in the solubilization of nutrients. Much more information is needed on the capacity of different plant species and even of cultivars within species to dissolve nutrients. I shall develope the possible use of such knowledge later.

Perhaps the greatest contribution of recent theory on ion transport to the root has been the delineation of the roles of root extension, ion diffusion, and bulk transport (mass flow) to the sorbing root surface. Root extension allows the plant to explore new zones from which ions have not been extracted. Mass flow or bulk transport is simply the sweeping along of ions as water moves to the root. Mass transport is particularly important for ions that are not adsorbed on soil colloids such as nitrate and sulphate in most temperate zone soils and only sparingly in some subtropical and tropical soils. Because of mass flow, a plant sufficiently deficient in N can extract all of the nitrate from a soil. Potassium, phosphate and the micronutrient cations are adsorbed to soil colloids with various degrees of affinity and are greatly retarded in movement with the soil water. Diffusion is the main mode of transport from the solid phase to the root surface for these "non-mobile" ions. In many soils having soil solution concentrations that are high relative to plant needs, mass transport may account for more than enough of an element to meet the plant needs. Diffusion may be away from the root and not towards it. This counter diffusion may occur with Ca, Mg and SO_4 in some soils, but is probably rare for P, K and the micronutrient cations.

The distance involved in diffusion is quite short, from a fraction of a millimetre to 1 to 2 mm depending on the ion and the affinity of the soil. The significance of this short range and the low density of root exploration per unit volume of field soil means that in a season the plant can effectively explore only a small fraction of the soil volume. This lack of exploration often explains the low recovery in a single season of some of the "non-mobile" elements such as K and P.

The significance of these developments of theory to soil testing for non-mobile elements is that it explains why a chemical solvent will not extract the same amount of nutrient as does the root, and any attempt to match the values is rather futile. The root can contact only a part of the soil; a chemical colvent can contact all but some internal surfaces.

Fertilizer fixation has been a much abused term. Often the low recovery of elements such as P, K and the micronutrient cations in one crop season can be explained simply by their inaccessibility to the root system because of slow diffusion mentioned above. In other cases the native soil may have such a low nutrient content and such high adsorption capacity that the root cannot effectively compete for the added nutrient. This appears to be true for P for many humid tropical soils. In other cases there is true precipitation of P in very refractory forms.

Since the development of the glass electrode much attention has been given to soil pH. Measurement of pH has become routine in soil testing laboratories. In the usual range of pH 4 to 8 it is not the significance of the pH itself, but rather what it may mean to the availability of essential nutrients and to the toxicities of non-essential elements. Under controlled conditions in solution culture free of toxic elements and with adequate maintenance of solution concentrations, many species can be grown over the pH range of 4 to 8 or 9. The significance of pH in soils is as an indicator of other conditions that may prevail. Low pH in soils with illitic and montmorillonitic clays indicates low base status and the possible need for lime for many kinds of crops. On kaolinitic soils and ones with amorphous clays it indicates the possibility of toxic concentrations of Al and sometimes Ni. One must have a considerable knowledge of the soil to interpret the pH.

EFFECT OF ENVIRONMENTAL FACTORS

The interaction of solution, transport and activity of the root surface along with mediation of microorganisms makes the whole system of nutrient availability and uptake by the plant very responsive to environmental factors in the soil and to some extent to the environment above. Lists of these factors may be found in almost any book on plant nutrition and soil fertility. Most of the processes are accelerated by increases in temperature up to their optima, then decline. The overall effect of the soil temperature regime for optimum nutrient uptake and plant growth represents a compromise of the various optima. The agronomist generally finds the optimum soil and aerial temperature by plant adaptation studies and grows varieties and species that do best. His only real control over temperatures is the selection of planting dates where he has a sufficiently long and favourable moist season to provide alternatives. He grows cool season crops in the cool season and warm season ones when the weather is warm or hot.

Oxygen is essential for the oxidative processes in soil, for the activity of many of the important microorganisms including the nitrifiers to produce nitrate, the activity of all root systems and the plant oxidative metabolism essential for ion uptake. Even rice, taro and some other aquatics require oxygen that is transported downward through the stems and becomes available to at least a part of the root system. The oxygen content of the soil is largely controlled by the amount of water in the pore space, falling rapidly as saturation is approached or high biological oxygen demand is created by incorporation of large amounts of readily decomposable organic wastes. Oxygen content is also partly controlled by temperature that affects microbial activity and the solubility of O_2 in water and by soil structure and surface crust that may impede oxygen diffusion. Downward diffusion may be substantially reduced by puddling or a thick crust. Seed germination, which is largely anaerobic, is not inhibited by oxygen deficiency but subsequent seedling development, mineral uptake and even water absorption are inhibited by anoxic conditions. The plant dies.

The water content of the soil and how near it can be maintained to the optimum throughout the season is highly important to nutrient availability and to the interpretation of soil tests. All of the processes that solubilize nutrients, favour their transport to the root surface, and maximize plant growth are most favourable at soil water contents near "field capacity" but are not seriously impeded until higher water content reduces oxygen diffusion, reduces top and root development, or leads to leaching of soluble nutrients. Drought reduces nutrient availability as well as the need for nutrients. With irrigation or in humid areas with dependable rain, water deficits are not a problem for nutrient availability, but in semi-arid regions and in the wet-dry tropics water availability must be given very high priority in interpreting soil tests and the amount of fertilizer that can be risked.

So far, emphasis has been laid on the complexity of the system by which plants get their nutrients and the impact of some of the factors of the climatic environment on it. This emphasis was intentional and had the purpose of making it clear that those who make recommendations must know a lot more about the soils, the crops and the climate than is revealed in any simple soil test. A chemist can produce good analytical data, but without the experience of an agronomist or a horticulturist, and sometimes an economist, he cannot make sound recommendations. For this reason recommendations are usually made by extension specialists or other advisory personnel who know the setting in which the advice is to apply. Items that must be considered in addition to those mentioned are how the fertilizer is to be applied, i.e. broadcast or banded. Is the objective to get the most out of the fertilizer this season or is it one of longer range to improve gradually the fertility of the soil? Economics and price projections are also involved as there must be markets at an adequate price. Credit availability and finance costs must be considered. All of these are limitations to which the answers are often not clear even in developed countries. The risks become greater for soil testing and fertilizer application decisions as the uncertainty increases.

4. DIFFERENCES AMONG PLANT SPECIES

Most of what is known about the details of the mineral nutrition of plants has come from intensive study of a few species, e.g. ion absorption by barley roots. This kind of information is extrapolated to other species. Much of what is known about soil chemistry and solubility of nutrients has been accumulated without regard to plants or only a few species of plants. Yet we know that species differ widely in their rooting habits, in the demand of the shoots for nutrients, the concentration of the soil solution needed for optimum growth and the extracting power of the root system. Although a soil test usually gives a single value as an index of availability (availability is defined as the amount the plants actually absorb), this value must be interpreted in relation to the kind of crop, its stand density and the water regime of the soil. That is why soil testing is so complex with the complexity extending far beyond the simple laboratory operations.

Much uniformity and much diversity exist in the nutrient needs of plants and their ability to get them. There is not much reason to believe that the cultivated varieties of the major food crops, wheat, rice, maize, sorghum, millets, sweet and white potatoes differ very much within the species. A possible exception to this statement was the breeding of the short strawed varieties of rice resistant to lodging that could effectively use more N. I mentioned cultivated species because not much attention has been given to the selection and breeding of varieties that may have special capabilities. However, some varieties of wheat have remarkable tolerance to Al while other varieties are very susceptible. Breeders in producing varieties unknowingly selected for this characteristic because presence or absence of exchangeable Al was a property of the site and region where they worked. Selection for yield produced varieties with the tolerance. Who knows how far we might be able to go in developing varieties with an unusual capability of extracting P from the soil or of growing well on a much lower concentration of P in the soil solution than the standard varieties? Furthermore, there are opportunities for selecting varieties that may have need for a lower internal concentration of the element than the standard varieties. However, in selecting for a lower internal need we must not forget the nutritional needs of animals or man. If the mineral deficiency cannot be made up with mineral supplementation in the diet in some other way, selection for low mineral content but high yield could be self defeating.

The greatest difference among feeding habits of plants exists among species. Cassava can grow well with only one-tenth the concentration of P in the soil solution needed by maize. Some species like buckwheat can utilize the P from rock phosphate much better than the cereals can. Large differences exist in the ability of different species to extract elements such as Cu and Mn from soil. Tolerance to iron chlorosis differs widely among species and even within species.

Undoubtedly these differences in species and even in cultivars affect the kinds of plant that grow naturally and in the adaptation of varieties. In the next quarter century of growing food needs and more expensive fertilizers we must give more attention to the plant side of the problem and depend less on the present philosophy of correcting every deficiency with fertilizers and toxicities with amendments.

5. DEFINITIONS

Soil testing, plant (foliar) analysis and the observation of deficiency symptoms are aids in the problem of diagnosis of some condition that causes plants to do more poorly than expected. Correction involves the determination of probable cause and the prescription for a cure if one exists.

Soil testing had its beginnings sometime after the acceptance of the mineral theory of plant nutrition. In its broadest sense soil testing includes a thorough inventory of the soil properties including primary and secondary minerals, particle size, exchange capacity and adsorbed cations, organic matter, etc. One cannot apply simple soil tests without at least a general knowledge of the range of the important parameters of the soils to which the soil test results are to apply. In the more restricted sense and the commonly understood one, soil testing consists of some biological or chemical test that can be used as an index of nutrient availability. This nutrient may be native or residual from past fertilizer or manure applications. This index of nutrient availability only indicates what is present or likely to become present during the growing season. How much and what kind of fertilizer to apply involves judgments as to probable yields, effectiveness of the fertilizer and other variables mentioned earlier. Biological soil tests have included various kinds of pot or container tests using rye, sunflower, lettuce and other plants and fungi such as *Aspergillus* spp. or bacteria such as *Azotobacter*. The most complex of the biological tests was the Mitscherlich one from which inferences could be drawn not only as to nutrient availability, but the response of the soil and the crop to fertilization. Those of you from Western Europe know how many hundreds of thousands of such tests have been done. Most biological tests are slow and time consuming. They have fallen from favour because of the lower cost and greater rapidity of chemical tests. A chemical test is the measurement of ions in a solution extracted from the soil either without prior incubation of the sample as for P, K, etc. or after incubation as for nitrate production.

Plant or foliar analysis depends on the predetermination of some relation between the mineral content of the whole plant, a selected leaf or petiole and the growth response to applications of fertilizer. After such curves or calibrations have been established analysis of single samples can be useful for noting what mistakes were made in the fertilizer programme and for future correction particularly on perennial crops. Paul Macy was perhaps the first to show that relationships between growth and mineral content could be used for diagnostic purposes.

A very comprehensive system of mineral, sugar and water content analyses of leaves, leaf sheaths and stalks for nutritional management of sugarcane called crop logging has been developed and widely used, particularly in Hawaii.

Finally, we should not forget that observation of deficiency symptoms in the field and their accurate interpretation from prior experience or corroboration by positive response to fertilizer or foliar sprays may eliminate much laboratory analytical work. Competence is needed to separate symptoms due to mineral shortages from those produced by pathogens, insects or viral infections.

Mineral deficiency symptoms shown by chlorosis or necrosis of leaves, death of cells of cambial layers, stunting and other characteristics peculiar to certain species are various plant signs that something is acutely wrong. However, less severe deficiencies of most elements may not show as symptoms even though the plant suffers substantially in its rate of growth and final yield. This suboptimal nutrient status is often called incipient deficiency or hidden hunger. In one field experiment I found that maize could suffer a yield reduction of 3 100 to 3 700 kg of grain per hectare due to N deficiency before there was any evidence of necrosis along the midrib of the lower leaves at silking. For each leaf per plant showing this symptom at silking there was a further yield reduction of about 940 kg of grain per hectare. These results were obtained with irrigated maize having 43 000 plants per hectare and a yield with adequate N of about 14 000 kg of grain per hectare. Soil analysis and particularly leaf analysis have their greatest usefulness in making evaluations of nutrient status between the region of deficiency symptoms and that sufficient for a maximum yield.

6. PRINCIPLES OF SOIL TESTING

At the beginning of soil science agricultural chemists thought they could evaluate the fertility of a soil by making a total analysis for the essential elements. However, it was soon found that there was little relation between total content and availability to plants except for soils devoid or very low in total content of a nutrient. Many thousands of such analyses were made and some are still being made. They have value in studies of soil genesis but have little value in evaluating soil fertility. A similar approach was to extract the soil with very strong acids such as boiling HCl. This approach did not lead to progress. Then soil scientists turned their attention to solvents, other kinds of plants and microorganisms that they thought might imitate the way plant roots feed. It was presumed that the soil water in the immediate vicinity of the root was CO_2-saturated and so was acidic. This was before the pH scale was formulated and instruments had been made to measure it. This attempt to simulate the plant root led to use of moulds that produced high degrees of acidity on plaques of soil and the use of weak acids to extract the soil. Among the many that have been used are CO_2-saturated water and various dilute mineral and organic acids such as oxalic, lactic, and acetic and combinations of them with each other and with complexing agents such as F ions. Some of these worked reasonably well in many regions. Two such methods: (a) 0.25 N H_2SO_4-0.05 N HCl developed by Dr. Mehlich, and (b) 0.03 N NH_4F-0.025 N HCl developed by Drs. Bray and Kurtz are widely used on the neutral and acidic soils of the United States.

Concurrently attention was turning to extracting the soil solution by displacement with water, organic solvents or compressed air. It was found that the solution concentration was too dilute for ions like K and P to sustain plant growth for more than a few days. The soil test method must somehow measure the capacity of the soil minerals and organic matter to renew the solution phase. In the early days in the attempt to simulate the plant root the emphasis was on getting good agreement between what could be extracted and the amount taken up by the plant. The latter is the true measure of availability.

Although as mentioned earlier we now have a much better understanding of how nutrients are transported from the solid phase through the solution to and into the root absorbing cells, the knowledge is still very far from complete. The big unknowns are the interactions of the plant with the soil and differences among kinds of plants. To duplicate exactly the activities of the plant root with some single extraction appears to be futile in the present state of knowledge.

In fact, modern soil testing does not take this approach. Rather the emphasis is on the development of methods based on sound physical chemistry that may be used more universally and the results of which can be correlated and calibrated with good field experimentation on nutrient uptake and the response to applied fertilizers.

Let me illustrate what I mean by the sounder physical chemical approach. In a solution made from a soil with exchangeable Ca or containing free lime, the Ca and P concentrations are reciprocally related. If the Ca goes up the P goes down. If P goes up Ca may go down. So modern methods of P extraction employ some method of defining the Ca concentration. In parts of Europe with acidic soils the extractant used contains 0.1 or 0.01 M $CaCl_2$. In the $NaHCO_3$ extractant widely used for P in the Western United States and in many dry parts of the world, the Ca solubility is minimized by buffering the extractant at pH 8.5. Research has shown that the amount of P extracted is highly correlated with the labile P as measured with exchange reactions using ^{32}P. Furthermore, research has shown that the $NaHCO_3$ method gives values that correlate well with plant uptake on soils varying from mildly acidic to those containing high amounts of lime.

Another example of a soil testing procedure based on the physical chemistry of the system is the DTPA (diethylenetriaminopentaacetic acid) procedure developed by Dr. Willard Lindsay and students after making equilibrium studies of the chelate with a number of soils. The objective was to control the pH at 7.30 in the presence of 0.01 M $CaCl_2$ to avoid the dissolution of $CaCO_3$ and to provide sufficient buffer capacity to prevent drop in pH that would increase the solubility of Fe and Mn. The single extraction can be used for assessment of Zn, Cu, Mn and Fe. In studies with ^{65}Zn added to soils and subsequent uptake by maize the amounts of Zn extracted were highly correlated ($r^2 = 0.97$) with the labile Zn as measured by the maize. In fact in these container experiments the amounts of Zn as measured by plant uptake and by the extraction were almost identical, 4.6 and 4.3 ppm on a soil basis respectively. Note that I mentioned container experiments in which the degree of soil exploration by roots is much greater than in the field. This test is becoming widely used in areas having these deficiencies and offers the further advantage that four micronutrients can be measured on a single extract.

The last sentence emphasizes that there is a definite trend to adopt procedures that are not only soundly based on the physical chemistry of the soil but that permit many determinations on one extract, thus reducing laboratory costs.

Soil testers are recognizing that the method used should measure not only the intensity of the soil to supply the nutrient (concentration in the soil solution) but also the capacity of the soil to maintain this intensity throughout the season. These somewhat arbitrary separations are not easy to delineate in a soil test. A very sandy soil may have a relatively high concentration of P in solution, but be unable to maintain it when plants are growing. A clay soil may have both the intensity and the capacity to supply P throughout the season. However, once a clay soil becomes depleted in available P much more fertilizer is required to bring the solution concentration up to a desired intensity.

Testing of soils for N availability is the object of another paper at this meeting so it is sufficient to say that tests for N are among the most baffling of all soil tests. They have ranged from estimation of organic matter and calculation of total N through the C to N ratio, measurement of total N by Kjeldahl or Dumas methods and an estimation of the percentage of this N that might become available. Extraction of soluble N has included nitrate, exchangeable NH_4 or their sum. N solubilized by hydrolysis with acids or alkalis has also been used. More sophisticated tests include nitrate released after aerobic incubation or soluble N released after anaerobic incubation. When residual N from prior fertilization accumulates in the soil, many tests being used in the United States simply measure the nitrate accumulated in the soil before crop planting. Fertilizer rates can then be adjusted downward to offset this accumulated nitrate. This kind of testing is particularly important for crops like sugar beets whose sugar content may be reduced by over-fertilization. Nitrate measurement before planting is also being used in parts of the United States Midwest to avoid over-fertilization of maize in order to avoid possible water pollution. In estimation of accumulated nitrate prior to planting of sugar beets or maize, soils are often sampled to a depth of one metre.

One of the biggest problems in soil testing is to give meanings or make recommendations from the numbers. Hopefully, the soil test gives an index of the amount of nutrient that may become available during the season. This index can be arrived at only by correlation or calibration with plant nutrient uptake as measured in the field, since the latter depends on the kind of crop and the temperature, water supply and other factors that operate during the season. The next step from the soil test is the recommendation of how much fertilizer should be applied to make up the deficit for the yield expected. This estimate involves an appraisal of weather conditions (usually assumed to be average) and some knowledge of the efficiency of uptake of the fertilizer. We are not at the point where we can make such projections on a theoretical basis, but must rely on field experimentation. Thus a good soil testing programme must accompany a good field experimental programme if the soil tests are to mean anything.

One of the problems in soil testing has been the reproducibility of results by different operators and in different laboratories using the same soil samples and supposedly identical methods. Studies in the southern and western states of the U S A have shown a threefold range in values on some soil samples. Reproducibility is essential for calibration against field tests especially when using calibrations of others, which frequently must be done. Much attention is now being given to reproducibility. Commercial soil testing laboratories in some states are cooperating with each other and with publicly owned laboratories by frequent analysis of standard or referee samples.

An additional problem in soil testing is adequate sampling of the field and making a composite on which the laboratory determinations can be made. Sampling is a subject within itself. The area represented by the composite sample should be as nearly uniform as possible. Judgements as to uniformity require observations of changes in topography, drainage patterns, soil surveys if available, prior cropping history, non-uniform distribution of animal manures or anything that may contribute to variation. Even with large apparently uniform fields the area sampled for making the composite sample should not exceed 15 ha. In developing countries, often with smaller fields and highly varied cropping and fertilizer history, the unit sampled must be much smaller.

There are many precautions needed in sample handling and storage prior to analysis. However, generalizations are difficult to make. Procedures are often a compromise between the ideal and the practical. Ideally, samples should be analysed quickly after collection and at the field moisture content at time of sampling. Such procedure is seldom possible and so the tester must know something about the effects of time and temperature of drying on what he is measuring. Some soils fix K in non-exchangeable form upon oven drying; other soils release K. Drying above 59°C may volatilize some NH_3. Slow drying at low temperatures may increase NO_3 on account of mineralization and nitrification by microbes. Soils that are to grow flooded crops such as rice should be analysed as collected from flooded soil or the samples flooded for a time before testing. Flooding generally increases nutrient availability for crops that withstand flooded conditions. Testing of dried samples may greatly underestimate nutrient solubility, particularly P, on soils that are to be submerged.

There are no uniformly accepted or official principles guiding soil testing. The development of principles is still in flux, hopefully improving. The principles are still characteristic of an empirical science and that is what soil testing is.

7. PRINCIPLES OF PLANT ANALYSIS

Plant analysis includes analysis for inorganic elements, for plant metabolites that may accumulate due to mineral deficiency or measurement of some specific enzyme whose activity is controlled by the concentration of the element in critically short supply. Assay for mineral elements has been the most used procedure. In mineral analysis the goal is to find a part of the plant that most clearly reflects by a wide range of content the nutritional status of the plant. The simple relations work best when only one element is critically deficient. When more than one element is deficient the relationshipsbetween content and yield become complex and often uninterpretable. Like soil tests, plant tests must be calibrated against field performance. Sometimes preliminary and often valid calibrations can be established in container experiments.

For some elements leaf blades are selected; for others, petioles are chosen as they represent the translocation path of minerals to the leaves. Regardless of the plant part chosen, it must be selected in a standard way with respect to age of plant part, its position on the plant and sometimes with respect to the time of day, e.g. nitrate. Plants offer the advantage that the requirements for sampling can be rather specific and defined in terms of physiological age. For many kinds of plant the most recently matured leaves or their petioles are chosen. Like in soil testing, adequacy of sampling the area is highly important and often easier than selecting the soil sampling pattern as plants themselves are often a better index of uniformity than a soil map. Since most analytical methods require grinding of a dry sample, careful attention must be given to avoiding contamination with the element being assayed. Particular care is required for the microelements.

8. OPPORTUNITIES FOR IMPROVING SOIL AND PLANT TISSUE TESTING

The data in Table 1 emphasize some of the problems still existing in soil testing and recommendations. Five different laboratories analysed the same soil samples and made fertilizer recommendations. These fertilizer materials were applied to plots replicated four times in the same field. Irrigated sugar beets were planted. Laboratories A to D were private laboratories serving the area, while E was operated by the Nebraska Soil Testing Service. All laboratories tested the same samples taken to a depth of 23 cm from the surface. In addition, Laboratory E analysed subsurface samples to a depth of 180 cm for nitrate. The recommendations for kind and amount of fertilizers varied widely as did the costs of the fertilizer, but no significant differences in root yield, sugar percentage or total sugar produced resulted. One can only speculate about the wide variation in recommendations that produced no significant differences in practical results.

Table 1 FERTILIZER RECOMMENDATIONS IN LB/ACRE FOR SUGAR BEETS MADE BY FIVE SOIL TESTING LABORATORIES AND COMPARISONS OF THE RESULTS IN A REPLICATED FIELD EXPERIMENT AT MITCHELL, NEBRASKA

Fertilizer recommendation	Laboratory				
	A	B	C	D	E(UNL)*
N	145	110	100	110	65
P	110	100	160	100	0
K	0	0	0	30	0
SO_4–S	20	30	0	0	0
Zn	0	3	8	0	0
Mn	5	4	3	0	0
Cu	0–1	2	2	0	0
Fe	0–6.5	0	0	0	0
B	1	0	0.5	0	0
Elemental S	0	0	80	0	0
Fertilizer cost $/acre	$56.73	51.93	62.80	40.27	13.83
Results					
yield tons/acre	24.90	25.04	23.39	23.84	26.09
Sugar percentage	15.9	16.3	16.1	15.8	16.0
Sugar lb/acre	7 890	8 150	7 520	7 490	8 320

* UNL – University of Nebraska Soil Testing Service.
From Daigger, L., Scientific analysis compares cost of fertility, Upbeet, 62, 10, 1974. With permission.

I have stressed the highly empirical nature of soil and plant tissue testing for guiding fertilizer practice and soil fertility management. When empiricism exists, there are great opportunities for making improvements through research and testing in practice. Because of the great complexity of the soil-water-plant system, soil and plant testing will probably always remain empirical. By this I mean that it will never reach the perfection of engineering that permits the design of new craft or landing of instrument packages on Mars.

This empiricism need not bother us for soil and plant tests have been developed that are reasonable in cost and serve well in the guidance of fertilizer practices in some regions and for the crops whose problems they were designed to solve. Perhaps at least two-thirds of the fertilizers used in the U S A is applied in accordance with some kind of soil test. This is not to say that all testing is adequate or even honest. There are instances of deliberate fraud wherein soil testing was claimed but recommendations called for larger amounts of fertilizer and even for elements not shown to be deficient by soil and plant tests. The regulation and policing of soil testing laboratories is another subject in itself.

As stated in the beginning we must place great hope on improvements in and extension of soil and plant testing if we are to achieve the needed food production with efficient use of fertilizers in a world becoming short of energy and more aware of pollution. Soil and plant testing represent the highest form of applied soil science and plant physiology for they are concerned with prediction.

Paper 2 PRESENT STATUS OF PLANT ANALYSIS AS A METHOD FOR PREPARATION OF FERTILIZER RECOMMENDATIONS

by

A. Cottenie
State University of Ghent, Belgium

1. INTRODUCTION

The theme 'Plant analysis and fertilizer problems' has been discussed in several congresses of the International Soil Science Society, the last time being in Hannover in 1974, after the Moscow Congress of the ISSS. These meetings have been oriented more to the physiological - theoretical aspect of the problem. In 1964 M. Lévy organized in Montpellier a 'Colloque sur le Contrôle de l'Alimentation des Plantes Cultivées', which was repeated later in Seville (1968), Budapest (1972) and Ghent (1976). The intention of these colloquia was to report practical experience, to estimate the possibilities of field application and to promote, where possible, the techniques of plant analysis in connection with fertilizer recommendations.

The idea of using the mineral content of plants as a criterion for the nutrient status of both plants and soil is most attractive. This principle was first put into practice by Lagatu and Maume (1934) and followed by many others. Important works were published by Lundegardh (1945), Goodall and Gregory (1947) and Chapman (1966).

At this moment, a large number of publications and reports describe as many applications and experiences in well defined conditions and with regard to particular crops, soils and local circumstances.

In view of this situation the question arises as to which part of the available information may be widely applicable and how can we introduce plant analysis as a method for determining fertilizer recommendations, making maximum profit from the existing information.

2. PRINCIPLES OF NUTRIENT DIAGNOSIS BY PLANT ANALYSIS

2.1 Relationship between Content in Plants and in the Growth Medium

Many experiments have shown the relationship between mineral element content in leaves and in the growth or substrate. Assuming that an essential element is acting as an isolated limiting growth factor, it is quite easy to show experimentally that a low mineral content indicates a deficiency or unavailability in the substrate and that a high content in the plant corresponds with a high level and availability in the substrate. However, in practice, such clear-cut situations are seldom encountered and an equally large number of papers describe all types of interferences and interactions. These are of course recognized when experimentally introduced, but their identification may be very difficult in practice when only the final effect of several simultaneously acting factors is observed.

Steenbjerg and Jakobsen (1962) analysed the complex relationship between available amounts of a nutrient element in the soil or substrate, its concentration in the plant tissues and the resulting growth or yield. This showed that:

- in cases of severe deficiency the leaf concentration decreases with the first application of the nutrient, due to stimulated growth and subsequent dilution of the particular mineral element by increased formation of organic matter (dilution effect).

- less severe deficiency may correspond with a situation where the nutrient content of the plant remains fairly constant despite increasing available amounts. This occurs when greater uptake is compensated by growth and formation of organic matter.

- the next stage consists of a regular response relationship until the optimum leaf concentration is reached, corresponding with maximum growth and yield.

- finally no further growth increase is obtained in spite of a continuing accumulation of the nutrient element in the plant, which is termed luxury consumption and which may be followed by an adverse effect or toxicity.

The practical observations of Prevot and Ollangnier (1957) were in conformity with these statements and stimulated further research.

2.2 Factors Influencing the Mineral Element Composition of Plants

There are many factors influencing indirectly the mineral element content of plants, which finally is the resultant of all acting parameters.

2.2.1 Soil parameters

Parameters such as texture, cation exchange capacity, humus content, soil density and aeration, oxidation-reduction potential and pH, all contribute to the availability of nutrient elements. This list could be extended to climatic and meteorological factors which influence the soil such as rainfall, temperature and light.

2.2.2 Plant species

Plant species behave in a somewhat characteristic way and this is clearly illustrated by the varying mineral composition of different plants growing together in the same soil or substrate.

The following observations have been generally confirmed: dicotyledons contain more Ca, Mg and B than monocotyledons, the latter showing higher levels of K.

Crucifers tend to accumulate sulphur, while rice, oats and spinach are known to be relatively rich in Fe. Sodium is quite easily accumulated by beets, rye, spinach, cotton and date palm, but remains at low level in maize, potato and sunflower (Mengel, 1972).

Nitrate accumulation in grass, as well as different other nutritional characteristics proved to be linked to species.

Many more plant-specific phenomena of nutrient uptake have been described and sometimes this is connected with the reaction to deficiency situations. Thus, different cereals have been found to be differentially sensitive to Cu deficiency in the following order: wheat > barley > oats > rye (Smilde and Henkens, 1967).

2.2.3 Physiological age and part of the plant to be sampled

During the early vegetative period, the rate of nutrient uptake is high and this consequently leads to high nutrient contents in the plant tissues. Increasing production of organic matter is responsible for a dilution effect in the middle of the vegetative cycle, corresponding to decreasing nutrient concentrations. This phenomenon is most pronounced with regard to NO_3^--nitrogen.

Thus, physiological age is an important factor of variability and young metabolically active leaves generally contain higher amounts of nutrient elements. Accumulation of proteins corresponds with higher levels of N and P, and several observations confirm that the highest P and N contents are found in cereals at the tillering phase.

During further growth phosphorus contents generally decrease less than N and K, the last mentioned being very mobile and is even partly returned by several crops to the soil at the end of the growth period. On the other hand, aging of plants may also correspond with increased contents of some elements such as Ca and Mg (Mengel, 1972).

Different parts or tissues of the plants also contain and accumulate varying amounts of elements and this of course is important with regard to the choice of the plant part to be analysed, which should be the best "index part". These observations illustrate the necessity to compile precise instructions for sampling. Several methods of foliar diagnosis specify a sample with the "latest mature leaves".

The well known Lundegärdh (1945) system of leaf analysis for characterizing the nutrient status of cereals is based on sampling just before flowering.

Though the term foliar diagnosis is used for the methods based on leaf analysis, other plant parts may also be taken and Routchenko and Soyer (1972) based a system of diagnosis on plant sap analysis, where element concentrations may vary in a proportion of 1 to 10.

Stalks and stems, which represent organs of the plant, generally contain large amounts of soluble nutrients, such as NO_3^- and NH_4^+-nitrogen, K^+ and phosphate ions. Due to the differences of ion mobility in the plant, their concentration in the stems is strongly influenced by external factors (e.g. soil moisture) which control their uptake. Fruits generally contain small amounts of mineral elements, because they mainly act as stores for organic matter such as carbohydrates, lipids, etc.

2.2.4 Interactions between nutrient elements

Interactions between elements may take place in the soil or substrate, as well as in the plant. When the uptake or transport of one element is inhibited by the presence of another, the interaction is called antagonism. This may be related to the formation of organo-mineral complexes or to the competition of cations for the exchange sites on soil colloids. Divalent cations are more strongly adsorbed than monovalent ions and this valency effect is favoured by increasing humidity (dilution effect). As a result, the element Mg may be so strongly retained by soil colloids in wet conditions that its availability becomes insufficient, while K becomes relatively much more accessible.

Different mechanisms have been described as being responsible for competition between elements at the level of plant roots, root free space, possible blocking in the transport system and internal ionic balance in plants and tissues.

The latter shows many different aspects and is often linked to metabolic phenomena. P deficient plants generally have a higher N content when N supply is sufficient. Increasing P supply results in a decrease of the N content in plants. Other examples are P-Zn, Fe-Mn, Ca-B. The favourable influence of an element on the uptake and assimilation of another is known as synergism.

PRACTICAL ASPECTS OF APPLIED PLANT ANALYSIS

Different authors have reviewed and compiled a large part of the available information concerning nutrient diagnosis using plant analysis. Not every report on foliar diagnosis was equally positive. Having studied the practical possibilities of the Lundegärdh-method, Scharrer and Lemme (1953) believed that their results did not confirm any possibility of generalized application. In spite of an existing parallelism between fertilization, element concentration in plants and yield in individual cases, the authors concluded that the element levels in plants were not fitted as a basis for nutrient diagnosis, owing to the fact that no reproducibility could be expected. In spite of such negative findings, an increasing interest has been shown in plant analysis and much work has been published on attempts to improve plant testing methods in different ways. The tendency at first is to experiment and study the behaviour of a particular crop in a particular situation and then to work out a detailed procedure for sampling, analysis and interpretation, suited for local use and application.

Many papers on the results so obtained have been published in the proceedings of the colloquia mentioned earlier.

Another approach consists in pooling data obtained under different circumstances and attempting to extrapolate and synthesize the maximum amount of generalizable information.

Goodall and Gregory (1947) were the first to compile a large quantity of data and their pioneer work was later completed by Chapman (1966, 1971). Extensive tables of analytical values were recently published by Bergmann and Neubert (1976). In principle the concentration ranges are split up into five levels : deficiency symptoms, low range, intermediate, high and toxic levels corresponding respectively.

In accordance with Finck (1968), the relationship between nutrient concentration in plant tissue and crop behaviour may be represented as follows:

Increasing content

E	Excess or toxicity	Yield decrease, possibly with visual symptoms	
			starting level of toxicity
D	Luxury consumption	Good growth, but internal element accumulation and possible interactions	
C	Optimal nutrient status	Good growth and generally good quality	
			limit of yield response
B	Latent deficiency	No visual symptoms, but better yield and quality by fertilization	
			limit of visual symptoms
A	Acute deficiency	Visual symptoms and direct effect of fertilization and leaf application	

Sampling is, of course, the first important step and it is necessary to standardize plant or leaf sampling techniques as completely as possible. Rigid observation of precise indications is essential for any plant analysis system.

The proper way to take a plant sample for tissue analysis was described by Benton Jones et al. (1971) who included directions for field crops, vegetables, fruits and ornamental plants. It is suggested that the laboratory provides mailing envelopes and forms, as well as a mailing kit with full instructions. Unless other instructions are given, the general rule is to sample upper recently matured leaves and the recommended time to sample is just prior to the beginning of the reproductive stage for many plants. When nutrient disorders are suspected, sampling may be done at the time at which the symptoms are observed.

As an example Table 1 gives the sampling instructions for field crops, as described by Benton Jones et al. (1971).

Many efforts have been made to eliminate causes of possible errors and different lines of thinking have been developed:

a) Considering that the skeletal or mechanical leaf tissue should not be included, either because only the mineral elements of the conducting tissues have any relation to growth and development, or because selected tissues show greater sensitivity, only softer green tissues should be analysed or extracting agents such as boiling water etc. should be used (Thomas, 1945).

Table 1 SAMPLING FIELD CROPS FOR TISSUE ANALYSIS

Stage of growth	Plant part to sample	Number of plants to sample
Maize		
1. Seedling stage (less than 30 cm)	All the aerial portion	20-30
or		
2. Prior to tasselling	The entire fully developed leaf below the whorl	15-25
or		
3. From tasselling and shooting to silking	The entire leaf at the earnode (or immediately above or below it)	15-25
Sampling after silking occurs is not recommended		
Soybeans or other beans		
1. Seedling stage (less than 30 cm)	All the aerial portion	20-30
or		
2. Prior to or during initial flowering	Two or three fully developed leaves at the top of the plant	20-30
Sampling after pods begin to set not recommended		
Small grains (including rice)		
1. Seedling stage (less than 30 cm)	All the aerial portion	50-100
or		
2. Prior to heading	The 4 uppermost leaves	
Sampling after heading not recommended		
Hay, pasture, or forage grasses		
Prior to seed head emergence or at the optimum stage for best quality forage	The 4 uppermost leaf blades	40-50
Alfalfa		
Prior to or at 1/10 blooming stage	Mature leaf blades taken about 1/3 of the way down the plant	40-50
Clover and other legumes		
Prior to blooming	Mature leaf blades taken about 1/3 of the way down from top of the plant	40-50
Sugarbeet		
Mid-season	Fully expanded and mature leaves midway between the younger centre leaves and the oldest leaf whorl on the outside	30-40

Stage of growth	Plant part to sample	Number of plants to sample
Tobacco		
Before blooming	Uppermost fully developed leaf	8–12
Sorghum, milo		
Prior to or at heading	Second leaf from top of plant	15–25
Sugarcane		
Up to 4 months old	Third or fourth fully developed leaf from top	15–25
Groundnuts		
Prior to or at blooming stage	Mature leaves from both the main stem and either cotyledon lateral branch	40–50
Cotton		
Prior to or at first blooming or when first squares appear	Youngest fully mature leaves on main stem	30–40

b) So as to eliminate the dilution effect and other factors interfering with element concentrations in plants, Finck and Schlichting (1957) proposed to judge the nutrient substrate on the basis of total uptake by small plants, e.g. the quantities of elements taken up by young cereal plants.

Bergman and Neubert (1976) also gave warning of short term variations in soluble concentrations, total contents being more constant and reflecting some "addition-effect".

The nutrient uptake, which is the product of concentration and produced mass, is the resultant of all active factors. Therefore, Bergmann and Neubert (1976) advised that uptake should be considered when the principal aim is to predict the expected yield. On the other hand, for diagnosing the nutrient situation relative to fertilizer requirements, they recommended working with concentrations which show the ratio between elements taken up and the already produced plant mass. This will show whether further absorption may give an increase in growth or not.

Indeed, even when the total uptake of an element is low, owing to restricted growth as a consequence of other limiting factors, its concentration may be sufficiently high to show that further treatment will no longer give better growth. In such a case it is necessary first to correct the real limiting factors. Moreover, it is clear that the determination of total uptake in field conditions would be technically very difficult.

Some years ago, different systems for quick field plant-tissue testing were developed, but Chapman (1966, 1971) stated that with the development of instrumental methods of analysis, there is little to be said in in favour of quick tests and the various extraction methods (of sap, by water, buffered acetic acid extractants, etc.). During recent years, the trend has indeed been to undertake quantitative analyses on a sufficiently large scale in central laboratories with good analytical equipment and skilled personnel, rather than to use semi-quantitative quick test methods in the field.

In spite of this, it seems "that there is still a place for rapid field tests on green plant tissue, even though much more development research, especially correlating nutrient content on specific plant parts at specific ages with yield or performance is needed for most crops" (Chapman, 1971). In practice, it seems possible that mobile, truck-mounted small-scale testing laboratories might be used for such tasks. Their major advantage would be to permit a nutrient diagnosis in the early stages of cropping with an eventual improvement in profit of the current crop. Early diagnosis of mineral deficiencies by means of plant analysis was studied by Broeshart and van Schouwenburg (1961), using oats as a test crop. Large fluctuations in the chemical composition of normal plants, however, represent a main difficulty. It is this variability, however, which is precisely the basis for any possible diagnosis by plant analysis. The variation range differs markedly from one element to another and it is therefore necessary to study the uptake pattern of mineral elements by various plant species.

The elements K, Na, Mg and Cl are highly variable and this means that different factors may influence their concentrations in the plants. The identification by plant analysis of their available levels in the soil needs isolation of this cause of variation by careful standardization of the methodology. The variations of N, P and Ca in the plants are mainly related to physiological age. Tserling (1971) stated that plants of the same species require the same amounts of nutrients for their normal growth and showed experimentally that their chemical composition should be brought to one and the same optimum value irrespective of the soil on which they grow. This "optimum level" corresponds with sufficient nutrition, while the so called "critical level" is indicative of serious deficiency and a sharp reduction in yield. The optimum contents of nutrients for cereal crops as determined by Tserling (1976) are close to those of Lundgärdh, while those for orchard trees and forest plants correspond with the optimum contents given in Chapman's book.

4. PARTICULAR PROBLEMS AND APPLICATIONS

It is impossible to review or to summarize the numerous publications on particular applications and problems related to plant testing for nutrient requirement evaluation. Locally employed techniques and experiences are neither always conclusive nor uniform. Walsh and Beaton's book (1973) "Soil Testing and Plant Analysis" contains ten chapters, treating separately the methodology for sugar beets, sugarcane, cotton, soybeans and groundnuts, small grains, maize and grain sorghum, vegetable crops, orchards, forage crops and forests, each of them written by a specialist. The best results have generally been obtained with perennial crops in the Mediterranean and tropical countries. Thus useful information is available concerning grapes, citrus crops, olives, banana, oil palm, rubber, cotton, papaya etc.

Clearly foliar diagnosis has been most successfully applied to fruit and industrial crops. Martin-Prevel (1976) reported international cooperation with a view to improving sampling methods and foliar diagnosis of banana, and bringing together nearly all scientists working in this field.

It is clear that the sampling procedure for banana leaves, with surface areas of 1 to 2 m^2, constitutes an important parameter of the method. Oil palm has proved to be an ideal crop for foliar diagnosis and its well defined phyllotaxis permits an easy standardization of leaf sampling (Bolle-Jones 1975).

Braud (1972) reported successful results with cotton for identifying N, S, P and K deficiences, based on a large number of experiments in different countries of tropical Africa. Analytical data from fertilizer experiments of the subtractive type were transformed into a "nutrition index", so allowing the comparison of results obtained in different regions. The nutrition index for a given element is determined as:

$$X = 100\ X_O / X_C$$

where X_O is the content of the element in the leaves

and X_C is the critical level of that element or the content below which the yield is less than 90% of that obtained with complete fertilization.

Sometimes plant analysis is not carried out to detect nutrient deficiencies but to observe the effect of fertilizer applications. In this event it is a practical tool for evaluating the behaviour of fertilizer elements as a function of soil characteristics. Besides the determination of immediate fertilizer requirements, analysis of plants at different stages of development has been used by Tserling (1976) to follow the uptake patterns of elements relative to organogenesis, with a view to elucidating the effect of mineral nutrition on the process of yield formation.

5. ANALYTICAL ASPECTS

Plants can be analysed in different ways and the distinction between precise laboratory analysis and field methods by means of quick tissue testing has already been mentioned. It is our feeling that field testing is liable to lack of reliability for different reasons, while modern instrumentation, which makes possible the expansion of plant analysis, can only be available in a laboratory, operating centrally for a given region. There are different possible levels of instrumentation and it seems inadvisable to start in a too sophisticated way. Major nutrient elements and the most important trace elements can accurately be determined with spectrophotometric, flame photometric and atomic absorption methods.

An international committee (Comité Interinstituts pour l'Etude des Méthodes du Diagnostic Foliare) has published analytical procedures, worked out and tested by more than 20 different European laboratories. These techniques are proposed to serve at least for reference, comparison and standardization purposes. The same committee has also established a set of standard samples, containing 13 different plant species, chosen in order to cover a large range of element concentrations (Pinta, 1968; 1972; 1975). Table 2 shows the range of concentrations of different major and trace elements found in plants, as well as in solutions of plant ash obtained after calcining 1 kg dry matter and bringing the solution to a final volume of 50 ml.

Conclusions concerning analytical nutrient diagnosis will only be valid if concentration differences as a result of nutrient deficiencies are large enough to overcome sampling errors.

For practical use the analytical methods must permit the demonstration of biologically significant differences between two samples, without pushing the analytical criteria to a useless degree of precision.

The maximum allowable standard error σ, in order to confirm a concentration difference δ, may be calculated using the formula

$$\sigma \leqslant \left(\frac{n}{2}\right)^{\frac{1}{2}} \cdot \delta \cdot (t_1 + t_2)^{-1}$$

where $\underline{t}_1$ and $\underline{t}_2$ are the critical $\underline{t}$ values of the Student distribution and $\underline{n}$ is the number of replications (Cottenie et al 1972).

Table 3 contains the calculated maximum standard errors σ, at the level $p = 0.05$, for three chosen levels of confidence (80, 90 and 95 percent) and with 2 and 3 analytical replications.

The same data may be graphically represented so that a continuous scale is obtained. Making use of such a graph enables one easily to state the required precision of the analytical method.

Analytical techniques have been considerably refined during the last few years and the number of elements being studied has also expanded from N, P, K to include Ca, Mg, S, Na, Cl and trace elements such as Fe, Mn, Zn, B, Cu, Mo.

Table 2 NORMAL CONCENTRATION RANGES OF MINERAL ELEMENTS IN PLANTS AND PLANT ASH SOLUTIONS

Element	Dry matter content (%)	Dry matter content (ppm)	ppm in ash solutions (1 g dry matter for 50 ml)
N	0.2 - 5	2 000 - 50 000	40 - 1 000
P	0.1 - 2	1 000 - 20 000	20 - 400
S	0.1 - 1	1 000 - 10 000	20 - 200
Cl	0.05 - 1	500 - 10 000	10 - 200
Ca	0.1 - 5	1 000 - 50 000	20 - 1 000
Mg	0.02 - 1	200 - 10 000	4 - 200
K	0.2 - 6	2 000 - 60 000	40 - 1 200
Na	0.02 - 4	200 - 40 000	4 - 800
Fe		10 - 500	0.2 - 10
Mn		10 - 800	0.2 - 16
Zn		5 - 400	0.1 - 8
Cu		2 - 40	0.04 - 0.8
B		2 - 80	0.04 - 1.6
Mo		0.01 - 10	0.002 - 0.2
Co		0.01 - 5	0.002 - 0.1
Al		10 - 500	0.2 - 10
Pb		1 - 20	0.02 - 0.4
Ni		0.01 - 10	0.002 - 0.2
Cr		0.0 - 8	0.002 - 0.16

Table 3 MAXIMUM STANDARD ERRORS (σ) PERMITTING DETECTION OF A GIVEN DIFFERENCE (δ) AT THE LEVEL $p = 0.05$

Number of replications(n)	2			3		
Confidence level(%)	80	90	95	80	90	95
Differences(δ)						
5 000	1 256	1 040	856.2	1 993	1 671	1 436
1 000	251.2	208.1	171.2	398.5	334.2	287.2
500	125.6	104.0	85.62	199.3	167.1	143.6
250	62.80	52.02	42.81	99.64	83.54	71.81
50	12.56	10,40	8.561	19.94	16.71	14.36
25	6.280	5.202	4.281	9.964	8.354	7.181
20	5.024	4.161	3.425	7.971	6.683	5.745
10	2.512	2.081	1.712	3.985	3.342	2.872
5	1.256	1 040	0.856	1.993	1.671	1.436
2	0.502	0.416	0.342	0.797	0.668	0.574
0.5	0.126	0.104	0.086	0.199	0.167	0.144
0.1	0.025	0.021	0.017	0.040	0.033	0.029

6. INTERPRETATION

The results obtained by one or another type of plant analysis need interpretation which may be made in different ways. Tables with critical values of N, P, S etc. for a number of crops are very useful, especially when deficiencies are strongly pronounced. However, variations from year to year and place to place as a result of soil-climate-plant interactions may be difficult to interpret. Transfer of interpretation tables is only possible after careful experimental verification. It is recommended that judgement be based on comparison with reputable known standards. Critical and optimum ranges should be developed and verified under regional and local conditions and carefully checked by comparison with the information available from other regions.

Plant analysis systems may be introduced in stages related to the number of samples and elements to be examined and to interpretation techniques and instrumentation. In order to assure the greatest future use of all data produced, it is advisable to standardize from the start a record keeping system suited to later expansion.

As a consequence of the increasing mass of data, more and more institutes make use of a computer in connection with interpretation. A computer also makes it feasible to:

- compare an individual result with all available information
- identify groups of variables which are correlated with each other
- estimate the quantitative influence of a particular variable factor
- group cases with behaviour in common and identify the factors which distinguish them from other groups.

The identification of an existing deficiency (or excess) is only the first step which must lead to the determination of nutrient requirements and fertilizer advice. The latter is established as a function of soil characteristics, experimental information and economic factors. Considering that "plant indices simply indicate the nature and degree of balance of the nutrients in the plant, from which one can establish what is demanded by the plant at a given site, but not give an automatic indication of the amount of a particular element which must be added to the soil", and that plant composition is influenced by soil composition, but that the correct interpretation of plant analysis can only give plant requirements, not soil requirements, Beaufils (1973, 1976) has proposed an original interpretation method called "Diagnosis and Recommendation Integrated System" (D R I S).

The author, who aims at the establishment of a calibration technique for the plant/environment system of general validity, that is to say applicable to a particular crop grown under any conditions, at any place and at any stage of its development, has the merit of proposing a system in which the final conclusions are based on as much information as possible. Thus plant analysis as a means of nutrient diagnosis must not be considered as an alternative to other existing methods and possibilities, but should be used in connection with soil characterization and other sources of information.

In a simpler way the analytical data are generally translated into a judgement, which can be formulated in various ways :

- for individual elements, five concentration classes are often distinguished;
- a "nutrition index" may be calculated, as mentioned under Section 3, provided that sufficient experimental information is available for knowing the "critical level" X_C ;
- in many cases interpretation is made using the ratios between elements. Another possibility consists of calculating the proportional amount of an element within a group to which it belongs, e.g. the % K present in the sum of a group of cations such as Ca + Mg + K (+ Na). In this connection it should be noted that combining elements in sums, ratios, etc. is clearly only permissible if their quantities are expressed as chemical equivalents and not as milligrammes.

7. FUTURE TRENDS AND CONSEQUENT NEEDS

The use of plant analysis as a tool in research and for the practical purpose of detecting nutrient anomalies and deficiencies has steadily been increasing. The number and volume of publications on these subjects has increased very greatly during the last decade. Many papers describe the results of local experience with all types of crop. Fortunately some authors have already reviewed and compiled much of this information (Chapman, 1966, 1971; Bergmann and Neubert, 1976), but there remains a need for integration and generalization. The question of possible transfer of key data in time and space remains to be solved. Meanwhile progress is being made in different aspects and the following trends can be identified:

i. Laboratory equipment and instrumentation is constantly becoming heavier and consequently more expensive. Automation and therefore centralization allow us to handle more samples, to determine more elements and to shorten the analysis time.

   On the other hand, field methods seem not to be completely abandoned, though organization and techniques may lead us towards mobile units in the form of small truck-mounted field laboratories.

   Skilled personnel is always a determinant factor for reliable work and maintenance of the laboratories.

   Centralization and increasing laboratory capacity require the setting up of an efficient system of sampling, identification, dispatching, transport and pre-treatment of plant material. These operations are of major importance in ensuring the ultimate efficiency and usefulness of the whole organization.

ii. The analytical programmes are not only spreading to the major elements N, P, K, Mg, Ca, S but more interest is also shown in different trace elements. Furthermore, there is a tendency to develop methods for distinguishing between the mineral fraction of an element and its incorporation in organo-mineral complexes. At the same time different organic plant tissue compounds are receiving increased attention. This is related to the biological characteristics and quality of the growing plant as an indication and a result of its nutritional status.

iii. New approaches are developing which deviate from the original "foliar diagnosis" in different ways:

a. analysis of plant sap (Jaime et al. 1976; Routchenko and Soyer, 1972);

b. biochemical testing methods based on the determination of enzymatic activities, which are specific for individual elements, have been proposed by Bar-Akiva (1969, 1972). For example, using leaf discs incubation, the following determinations were described:

- peroxidase-activity (low in Fe deficient plants)
- ascorbate oxidase (low if Cu is deficient)
- carbonic anhydrase (low when Zn is deficient)
- nitrate reductase (low if Mo and also N are deficient);

c. morphological changes, identified by microscopic examination, have been studied by Pissarek (1974) as a potential tool for nutrient diagnosis.

iv. Methods of interpretation require improvement and new ideas and procedures are progressively being developed (Beaufils, 1976). One may expect an increasing depersonalization in the sense that the interpretation should no longer be a matter of individual experience or intuition, but become fully objective and reproducible, irrespective of the person involved. Much work remains to be done in this respect and in order to progress, proper transfer of results and feedback of information is essential.

8. CONCLUDING REMARKS

Probably nowhere in the world are all optimal material, human and organizational conditions simultaneously present. Our knowledge, which is still very incomplete, is based on many scattered results, presented and discussed in the periodical colloquia on plant analysis. In 1971, Chapman wrote "it is evident that as we look to the future, there will be an increasing need to use plant and soil analysis methods to guide and optimize fertilizer usage, to conserve natural resources and decrease or prevent pollution", and this view is largely confirmed today.

Analytical techniques are sufficiently developed, but more work remains to do in order to achieve:

i. fully satisfactory standardization of sampling methods;

ii. better possibilities for the transfer of criteria and norms or guidelines for interpretation;

iii. improved interpretation systems based on objective, mathematical manipulation of analytical and agricultural data.

This comprises as well practical, fundamental and developmental aspects. Even when no large funds may be available for organizing these tasks, useful contributions may be within the limited means of agrochemical institutes. In doing so, it is important to be informed about the experience obtained with the same crops and analogous problems under different circumstances. Therefore good and lasting contact should be established between interested scientists.

REFERENCES

BAR-AKIVA, A. The use of the activity of metalloenzyme systems for the appraisal of
1969 nutritional requirements of citrus trees. Proc. 1st Intern. Citrus Symp. Vol. III. Ed. H.D. Chapman, Univ. of California, Riverside. 1551 - 1557.

BAR-AKIVA, A. Carbonic anhydrase Assay vs Zinc analysis in citrus leaves in nutrition
1972 studies. 3e Colloque Europ. et Médit. sur le Contrôle de l'Alimentation des Plantes Cultivées, Budapest. 463 - 468.

BEAUFILS, E.R. Diagnosis and recommendation system (DRIS). A general scheme for
1973 experimentation and calibration based on principles developed from research in plant nutrition. Soil Sci. Bull. 1, University of Natal.

BEAUFILS, E.R. Plant-soil-environment calibration (DRIS). 4th Intern. Colloq. on the
1976 Control of Plant Nutrition, Gent. Vol.I: 21 - 36.

BENTON-JONES, J. et al. The proper way to take a plant sample for tissue analysis.
1971 Soils and Crops. Am. Soc. Agron. Publ. 15 - 18.

BERGMANN, W. and NEUBERT, P. Pflanzendiagnose und Pflanzenanalyse. VEB Gustav Fisher Verlag Jena.

BOLLE-JONES, E.W. Limitations of foliar diagnosis in the oil palm. Trop. Agric.
1975 (Trinidad) 52: 13 - 18.

BRAUD, M. Le contrôle de la nutrition minérale du cotonnier par analyses foliaries.
1972 3e Colloque Eur. et Médit. sur le Contrôle de l'Alimentation des Plantes Cultivées, Budapest. 469 - 487.

BROESHART, H. and VAN SCHOUWENBURG, J. Early diagnosis of mineral deficiencies by means
1961 of plant analysis. Neth. J. Agric. Sci. 9: 108 - 117.

CHAPMAN, H.D. Diagnostic criteria for plants and soils, Univ. of California.
1966

CHAPMAN, H.D. Tissues testing : Current status. In : Proc. Internat. Sympos.
1971 Soil Fertility Evaluat., New Delhi, 1: 165 - 197

COTTENIE, A. et al. Précision, sensibilité et possibilité de discrimination des
1972 méthodes analytiques du diagnostic foliare. 3e Coll. Europ. et Médit. sur le Contrôle de l'Alimentation des Plantes Cultivées, Budapest. 47 - 57.

FINCK, A. and SCHLICHTING, E. Zur Beurteilung des Nährsubstrates mit Hilfe von
1957 Pflanzenanalysen. Zeitschr. für Pflanzenern., Düngung in Bodenk. 76: 97 - 102.

FINCK, A. Grenzwerte der Nährelemente in Pflanzen und ihre Auswertung zur Ermittlung
1968 des Düngerbedarfs. Z. Pflansenernähr. u. Bodenk. 119: 197 - 208.

GOODALL, D.W. and GREGORY, F.G. Chemical composition of plants as an index of their
1947 nutritional status. Imp. Bur. Hort. Plant Crops, East Malling, Tech. Commun. 17.

JAIME, S., AGUILAR, A. and ESTEBAN, E. Détermination de K, Ca et Mg dans les sucs
1976 végétaux. Correlation avec l'analyse foliaire. 4e Coll. Int. sur le Contrôle de l'Alimentation des Plantes Cultivées, Gent, Vol. I: 47 - 50.

LAGUTU, H. and MAUME, L. Le Diagnostic foliare de la pomme de terre. Ann. Ecol. Nat.
1934 Agric. Montpellier. 22: 50 - 158.

LUNDEGÄRDH, H. Die Blattanalyse, G. Fischer Verl. Jena.
1945

MARTIN-PREVEL P. Le groupe international sur l'analyse foliaire du bananier
1976 4e Coll. Int. sur le Contrôle de l'Alimentation des Plantes Cultivées, Gent, Vol. II: 571 - 576.

MENGEL, K. Ernährung und Stoffwechsel der Pflanze. VEB G. Fischer Verl. Jena.
1972

PINTA, M. Méthodes de référence pour la détermination des éléments minéraux dans les
1968 végétaux. 2e Coll. Europ. et Médit. sur le Contrôle de l'Alimentation des Plantes Cultivées, Sévilla.

PINTA, M. Méthodes de référence pour la détermination des éléments minéroux dans les
1972 végétaux. 3e Coll. Europ. et Médit. sur le Contrôle de l'Alimentation des Plantes Cultivées, Budapest. 143 - 158.

PINTA, M. Etalons végétaux pour l'analyse foliaire. Analusis 3: 345 - 353.
1975

PISSAREK, H.P. Possibilities of microscopic diagnosis of macro-nutrient elements of
1974 oats. Plant analysis fertilizer problems. Vol. 2: 569 - 587.

PREVOT, P. and OLLANGNIER, M. Méthodes d'utilisation du diagnostic foliaire. Analyse
1957 des plantes et problème des fumures minérales. IRHO, Paris. 177 - 190.

ROUTCHENKO, W. and SOYER, J.P. Dix annécs de recherches sur le diagnostic de la
1972 nutrition des plantes basé sur l'analyse des sucs extraits des tissus conducteurs. 3e Coll. Europ. and Médit. sur le Contrôle de l'Alimentation des Plantes Cultivées, Budapest. 173 - 181.

SCHARRER, K. and LEMME, G. Untersuchungen über die Brachbarheit des Blattanalyse von
1953 Lundegardh zur Ermittlung des Düngerbedürfnisses der Böden. Zeitschr. fur Pflanzenernährung, Düngung und Bodenk. 60: 125 - 148.

SMILDE, K.W. and HENKENS, Ch. H. Sensitivity to copper deficiency of different cereals
1967 and strains. Neth. J. Agric. Sci. 15: 239 - 257.

STEENBJERG, F. and JAKOBSEN, S.T. Plant nutrition and yield curves, Soil Sci. 95: 69.
1962

THOMAS, W. Present status of diagnosis of mineral requirements of plants by means of
1945 leaf analysis. Soil Science 59: 353 - 374.

TSERLING, V.V. Mineral plant nutrition in development phases in relation to yield
1976 structure components. 4th Intern. Colloq. in the Control of Plant Nutrition, Gent, Vol.I: 10 - 19.

WALSH, L.M. and BEATON, J.D. Soil testing and plant analysis. Soil Sci. Soc. Am.,
1973 Madison, Wisc. U.S.A.

Paper 3 THE OPERATION OF SOIL AND PLANT TESTING SERVICES IN THE USA

by

A. Mehlich
North Carolina Department of Agriculture
Agronomic Division, Blue Ridge Road Center,
Raleigh, North Carolina 27611, USA

Soil and plant testing in the United States of America continues to play an important part in providing growers of crops with valuable services in the evaluation of diagnostic problems, nutrient balance, lime and fertilizer requirements. To this end, increasing numbers of soil and plant samples are being tested with methodology that is constantly under surveillance on a state and regional basis for improved accuracy and uniformity in expressing test results and fertilizer recommendations.

1. ORGANIZATIONAL AND FINANCIAL ASPECTS OF SOIL AND PLANT TESTING SERVICES

Soil and plant testing services in the United States are offered by:

i. Landgrant colleges - a) Extension Service, b) Research Station

ii. Department of Agriculture, North Carolina

iii. Private commercial laboratories.

Funding for each group is (i) by public tax funds, which some states have and others do not, off-setting charges; (ii) by public tax funds and a tax on fertilizer (25 cents/ton), lime and gypsum (5 cents/ton); (iii) commercial operation, direct charge per sample, off-setting cost charges through dealers in fertilizer and lime when the laboratory is operated by fertilizer or related industrial companies, contract arrangements with large farms for complete services, including sampling, analysis, line and fertilizer recommendations.

Activities in landgrant colleges also include work on correlation, interpretation, uniformity of reporting systems and methodology by individuals concerned with improving sampling techniques, extraction reagents and other analytical procedures.

In North Carolina, the Agronomic Division provides services in soil testing, plant analysis and nematode assay. For the 1975-76 season these services were made available to 32 666 farmers and home owners by testing 146 422 soil samples (1 350 235 determinations), 838 plant samples (10 056 determinations) and 2 555 nematode samples (160 530 determinations) at a cost of $3.13 per sample. The cost of this service which included salaries for 33 permanent and 4 temporary personnel, all operational services, education, research and administration was covered by the special tax plus $1.00 per sample for nematode assay and $3.00 per sample for plant analysis. The cost per sample for the soil test service alone was $2.48.

The estimated numbers of soil samples tested in the USA for the years 1960, 1968 and 1973 were 2 059 280, 3 537 531 and 2 092 280, respectively. The dramatic decrease after 1968 was almost wholly due to the North Central Region where the decline between 1968 and 1973 was 1 383 709 samples as compared to 1 445 251 nationally. During this period the proportion of soils tested by commercial laboratories increased and those by government decreased. Routine soil samples tested by the North Carolina Agronomic Division under a computerized system increased from 75 228 in 1972/73 to 133 205 in 1975/76 or a total for all types of samples of 146 422.

The number of plant samples tested in 1968 was 149 800 by government and 177 109 by commercial laboratories. By far the largest number (115 000 samples) was tested in California, of which 100 000 were tested by commercial laboratories. Plant testing has tended to increase. The determinations routinely undertaken include the macronutrients, nitrogen, phosphorus, potassium, magnesium and calcium and the micronutrients iron, manganese, copper and zinc. Sulphur, boron and molybdenum are determined largely on a special request basis, and involve an extra charge. The charge levied per plant sample usually ranges from $2.50 to $16.00, the higher fees reflecting the larger number of determinations per sample.

2. METHODOLOGICAL PROBLEMS IN SOIL AND PLANT TESTING

2.1 Soil Testing

Selection of an extractant for soil test evaluation should be contingent on its ability to extract a representative portion of the plant-available-nutrients. In the case of phosphorus, this should include the water soluble and representative portions of plant-available calcium, aluminium and iron forms, while in the case of potassium, magnesium, calcium, and sodium (if desired) should include the water soluble and exchangeable forms. From the standpoint of economy and efficiency in mass analysis, these nutrients and possibly manganese, zinc and others should be evaluated in the same extract. From present evidence it appears that none of the extractants used in the U S A was considered fully suitable for the soil test evaluation of a large number of nutrients covering a wide range of soil properties in a single extract.

For the extraction of phosphorus the most widely used methods include Bray No.1 (0.025N HCl-0.03N NH_4F), Olsen et al. (0.5N $NaHCO_3$ at pH 8.5) and Mehlich double acid (DA) (0.05N HCl-0.025N H_2SO_4). The Bray and Olsen methods were also used in some laboratories for the potassium test, while the Mehlich DA method is used routinely for phosphorus, potassium, magnesium, calcium and manganese. The DA extractant has also been used for zinc, having been successfully correlated with 0.1N hydrochloric acid. For copper, particularly with Histosols, a stronger extractant (0.5N HCl-0.05N $AlCl_3$) developed by Mehlich and Bowling was found to correlate well with crop response to copper.

Since 1969, the North Central Region (NCR.13) Soil Testing Committee has been engaged in standardizing procedures of soil testing laboratories, based on numerous sampling exchanges and experiments to determine the influence of testing method, sample size, soil:extractant ratio, speed, time of shaking, type of container and other procedural techniques on soil test results. These results led, with the cooperation of the USDA, to the North Central Regional Publication No. 221 (February 1975) for recommended chemical soil test procedures for the region including Alaska. The North Dakota representative to the NCR-13 committee, W.C. Dahnke, stated in his introduction to the publication, "results of this exchange indicated that small and seemingly unimportant differences in procedure were causing significant differences in soil test results". The recommended procedures include soil pH, lime requirement, phosphorus, potassium and nitrate nitrogen. Use of these procedures by all public, private and industrial or commercial soil testing laboratories is advised in order to reduce confusion surrounding soil testing and to add to its credibility in fertility evaluation.

Considerable efforts were made by the 17 Southern and mid-Atlantic states region towards achieving uniformity in soil test procedure, volume vs. weight samples, soil:extractant ratio, expression of soil test results and fertilizer recommendations. The present writer advocated the measurement of soil by volume, a 1:10 soil:extractant ratio and that results should be expressed in terms of milligrammes of nutrient per cubic decimetre (1000 cm^3). Most of these suggestions have been acted upon, although implementation is as yet largely forthcoming.

A major problem in the quest for uniformity is the selection of a suitable extractant to meet the need for extracting representative portions of the largest number of plant-available nutrients in a single extract over a wide range of soil properties. The savings in time, increased efficiency and economy in laboratories with demands for testing large numbers of soil samples (at North Carolina in excess of 140 000 samples per annum) are irrefutable. A new extractant to meet most of these requirements in lieu of the existing extractants was developed by the author. The composition of the extractant is: 0.2N NH_4Cl-0.2N HOAc-(0.015N NH_4F-0.012N HCl), pH 2.5. Acetic acid contributes to the buffer capacity and together with NH_4Cl effectively extracts exchangeable cations; in conjunction with acidified NH_4F it controls extractability of rock phosphate and other calcium phosphate forms in calcareous soils, while it promotes extractability of aluminium and iron forms of phosphorus. Phosphorus determined by the new extractant was well correlated with P uptake by millet, as it was with extractable P by the Bray No.1 and Olsen methods using 122 soils having a wide range of soil properties and by the DA extractant using 72 neutral to largely acid soils. Potassium, magnesium, calcium and sodium determined by the new extractant on 122 acid to alkaline soils were highly correlated with the amounts extracted by neutral, normal ammonium acetate. The amounts of manganese and zinc extracted by the new extractant were likewise highly correlated with those of the DA method.

Suggestions for study by the various regional committees therefore include expanded investigations on the correlation between the new extractant and present procedures and crop response to suggested fertilizer nutrient rates based on the new method.

Collaborative studies through exchange of samples between member states of the Southern region (S-52) now in progress include methodology in assessment of lime requirement, soluble salts, nitrate-N and organic matter. For lime requirement the methods being compared are the rapid buffer pH procedures of Shoemaker, McLean and Pratt (SMP) calibrated mainly against pH, the Adams-Evans method calibrated against pH and percentage hydrogen saturation and the Mehlich method calibrated principally against exchangeable acidity, mainly aluminium. The results have led to the conclusion that the SMP method is well suited to heavy textured, high cation exchange capacity soils while the Adams-Evans and Mehlich methods are well suited to the lighter textured and medium to low cation exchange capacity soils. The Mehlich method is also suitable for Histosols and mineral soils high in organic matter. Linear correlation showed the Adams-Evans method to be more highly correlated with total soil acidity while the Mehlich method was more highly correlated with unbuffered salt exchangeable soil acidity.

2.2 Uniformity of Expressing Soil Test Results

The need for expressing soil test results on a uniform basis has been the subject of recent communications by Mehlich. It was concluded that the most reliable and reproducible expression was the volume. The relevant units suggested for use in any communication, including scientific literature, were: $\mu g/cm^3$, mg/dm^3, g/m^3 or kg/ha to a depth of 10 cm (1 000 000 kg). When corrected for weight/volume (g/cm^3), the equivalent unit on a weight basis is ppm. The results showed that mg/dm^3 was equal to mg/kg when W/V was unity, while mg/kg decreased with increasing W/V and it increased with decreasing W/V for bulk density (BD). When mg/kg was divided by BD, the results agreed more closely with mg/dm^3. Full agreement was, however, influenced by the wider differences in extraction efficiency when the extraction procedure was based on weight.

The deviations in results between soils of varying BD are also considerably greater on a weight than volume basis in greenhouse or field applications of lime and fertilizers. It is well recognized that the soil:root association is a volume relationship. This applies to systems in the field but is particularly obvious with pot cultures. When a series of vessels of appropriate capacity recieve 1 dm^3 (1000 cm^3) of soils having wide ranges in BD and each of these soils is homogeneously mixed with 100 mg/dm^3 of nutrient and the soils are subsequently sampled and analysed on a volume and weight basis, the following results may be obtained. Since all soils received 100 mg of nutrient/dm^3 the analyst using the volume procedure would be expected to report 100 mg of nutrient/dm^3. The analyst using the weight method would likewise report 100 ppm with the soil having a BD of unity since 1 dm^3 of the soil would weigh 1 kg. As the BD increases, the kg/dm^3 increase and at a BD of 1.32 and 1.64 the analyst would report 76 and 61 ppm or 24 and 39% less, respectively, than the 100 mg/dm^3 actually present in the vessel. With decreasing BD, for example 0.8, 0.5 and 0.2 g/cm^3, the analyst would report 125, 200 and 500 ppm respectively, or 1.25, 2 and 5 times the 100 mg actually present.

The relationships in the field are identical except that the volume boundary is the depth of the ploughed layer or more specifically the depth of sampling. In the interest of uniformity and the accuracy necessary for the evaluation of soil fertility, soil analyses based on a volume measure and a report based on volume are of highest priority.

2.3 Plant Analysis

Procedural techniques in plant analysis raise few problems, provided the analyses are carried out by competent personnel having access to suitable facilities for plant sample preparation, drying, digestion, ignition, spectrometry and photometry. There is however need for a control system involving exchange of samples of known and unknown nutrient composition. The main problems centre around the time of sampling during the growing period and portion of the plant selected. Many of these problems are, however, partly resolved by collecting and simultaneously submitting soil samples.

3. EXTENSION OF SOIL AND PLANT TESTING RESULTS TO THE FARMERS

3.1 Fertilizer Suggestions based on Soil Test Results

Suggested P fertilizer rates are generally based on plant requirements, optimum yield potential (notably climate and various other soil factors) and economic considerations. The interpretation of soil test results, as related to a computerized programme in Alabama, have taken into account various considerations including soil test ratings, fertility index (0-990) and relative crop yield without addition of the nutrient. In North Carolina where crop fertilizer recommendations are based on an index calibrated against the DA extractable nutrients, Hatfield (1972) and Hatfield et al. (1976) use linear or curvilinear equations depicting the relationships between the soil test index and fertilizer nutrient rate. The rates suggested incorporate the plant requirement and, where required, include larger applications for fertility improvement.

In place of the DA nutrient index, correlation and fertilizer suggestions are based on the new Mehlich extractant. The index scale of 0 to 100 is expressed relative to increasing concentrations of extractable nutrients. The index values equivalent to mg/dm^3 or $meq/100\ cm^3$ soil by the new extractant are given in Table 1. The data represent simple and convenient relationships between index and nutrients determined by the new extractant. In the case of P and Mg the index represents the amount expressed in mg/dm^3 while it varies for the other nutrients as shown. For indexes above 100 a dilution factor is provided in the procedure.

Table 1 NUTRIENT INDEX CONVERSION TO mg/dm^3 OR $meq/100\ cm^3$ EQUIVALENT OF NUTRIENTS BASED ON NEW MEHLICH EXTRACTANT

Index	P	K	Mg	Ca	Na	Mn	Zn
			mg/dm^3				
1–100	1–100	2–200	1–100	–	–	0.2–20	0.05–5
			$meq/100\ cm^3$				
1–100	–	0.005–0.5	0.008–0.8	0.1–10	0.01–1	–	–

3.2 Calibration and Fertilizer Suggestions for Phosphorus

The relationship between the index, P levels determined by several methods and expected response of the crop to P are given below.

Index or New Mehlich $mg\ P/dm^3$	P in 0.001N* Acid $\mu g\ P/ml$	Olsen and DA $mg\ P/dm^3$	Bray No.1 $mg\ P/dm^3$	Expected crop response to P
< 20	< .15	< 12	< 27	Definite
20–30	.15–.20	12–18	27–40	Probable
31–50	.21–.30	19–30	41–60	Less likely
> 50	> .30	> 30	> 60	Unlikely

* P in solution by extraction with 0.001N HCl and 0.001N H_2SO_4 in a 1:10 soil solution ratio and 5 min shaking. Data based on average of both extractants.

Correlation of the nutrient requirement and index based on the new extractant lends itself to the varying rates and objectives. If the calibration for P is considered valid, the desired fertilizer rate should be the quantity necessary to raise the P level, if needed, above the response range and into the range where response is unlikely, corresponding to the index >50. The calculated rate for P in kg/ha to a depth of 20 cm is then: P required (IR) less P observed by soil test (IO) multiplied by 2. For example, when IR required = 50 and IO = 10, then (50-10)x2 = 80 kg P/ha. The actual value for IR in practice is to be determined from information on crop response and related knowledge available to state and regional specialists in soil testing research and extension.

In order to achieve uniformity not only in the expression of soil test results but also in conversion to the field recommendation, all suggestions for P fertilizer should be on the basis of the element rather than its oxide. As long as the phosphate industry persists in selling their production under the non-conforming and archaic phosphorus pentoxide designation, the burden of supplying the farmer and other users of their products with the correct quantity of P, as given in the soil test report, remains with the marketing branch of the phosphate industry.

3.3 Calibration and Fertilizer Suggestions for Potassium and Magnesium

The relationships between the index, K levels determined by the new and two other extractants, and the expected crop response are given below.

Index	New Mehlich and NH_4OAc	DA	Expected crop response to K
	mg K/dm^3		
< 25	< 50	< 33	Definite
25–50	50–100	33–66	Probable
51–75	101–150	67–100	Less likely
> 75	> 150	> 100	Unlikely

Response for optimum yield may range between 40 and 120 ppm K (weight basis) as measured by DA, depending on soil group and crop. The optimum rate of K is within the range IR 25 to 75 corresponding to 50 to 150 mg K/dm^3 or kg K/ha to a depth of 10 cm. If, for example, IR = 50 and IO = 20, the rate of K fertilizer would be (50-20)x4 = 120 kg K/ha to a depth of 20 cm. Expression of K as the element rather than the oxide should be the rule and the comments pertaining to P also apply to K.

In view of the high correlation between Mg extracted by neutral normal NH_4OAc and the new extractant, including similar extraction efficiency, knowledge gained with NH_4OAc is equally applicable to the new extractant. The relationships between the index, the Mg level determined by these two extractants and DA, and the expected crop response are as follows:

Index	New Mehlich and NH_4OAc	DA	Expected crop response to Mg
	mg Mg/dm^3		
< 25	< 25	< 20	Definite
25- 50	25- 50	20–40	Probable
51–100	51–100	41–80	Less likely
> 100	> 100	> 80	Unlikely

The index correlations with Mg level by the new extractant and expected response to Mg largely agree with experience in the USA. Suggestions for Mg should be evaluated in conjunction with soil acidity and to the rate of Mg applied by liming with dolomitic limestone. The suggested rate should be Mg in the form of MgO or $MgSO_4$ when need for lime is not indicated and the rate should be calculated from the relationship (IR-IO)x2 to obtain the magnesium requirement in kg/ha to a depth of 20 cm.

3.4 Interpretation of Calcium and Sodium

Calcium varies greatly with CEC and percentage base saturation (BS) so that an index based on the level of Ca is not very useful. It is, however, valuable for the reasons cited above to adopt an index based on percentage Ca saturation. The requirements for this purpose include evaluation of CEC by rapid and simple procedures. This is afforded by allowing the equivalent sum of the metal cations, K, Mg, Ca and Na plus the buffer pH acidity (Ac) determined by the Mehlich method to represent CEC, where meq Ca/meq CEC (in meq/100cm^3) x 100 = percentage Ca saturation. Percentage saturation by this means can be obtained for any of the individual cations or of the sum of cations for BS percentage.

By using the proposed method for CEC, the relationships between the index and the percentage Ca and base saturation are as follows:

Ca Index or Ca saturation(%)	Base Saturation(%)	Deficiency designation
< 35	<45	Severe
36-55	46-65	Poor to moderate
56-70	66-85	Optimum for acid tolerant plants
> 70	> 85	Optimum for acid intolerant crops

Suggestions for the rate of liming should be based on the new Mehlich buffer pH method and should specify application of dolomitic lime when the Mg index is less than 50.

In addition to CEC obtained by summation of Ac and cations, determination of sodium is also useful in the estimation of salt injury, soils inundated with salt water and toxicity levels in alkaline soils.

3.5 Interpretation of Micronutrients Cu, Mn, Zn

The relationships between the index micronutrient levels and crop response by the new Mehlich and Mehlich-Bowling extractants are as follows:

Index	Cu	Mn	Zn	Response effects
		mg/dm^3		
< 14	< 0.7	< 2.8	<0.7	Definite
14-24	0.7-1.2	2.8-4.8	(<0.7)*	Probable
> 24	> 1.2	> 4.8		Unlikely

* probable to unlikely

Interpretative data for Cu are based on field observations while those for Mn and Zn require field response data before final acceptance of the suggested interpretation.

3.6 Conclusions with Reference to the Index Values

The nutrient index system as related to nutrient levels and fertilizer suggestions represents the most informative and simplest method of communicating soil test results to the farmer. The system conveys the concept of low, medium and high in terms of numbers ranked from 0 to 100. In addition to nutrient level, the indices reveal at a glance the existing state of nutrient balance. The success of this or any other system depends on the soil sample representing the area to be treated and the accurate judgement of local environmental and economic factors affecting crop yields.

3.7 Interpretative Guides to Plant Testing

The results of plant analysis are extensively used as interpretative guides to whether or not the plants represented by the sample were growing under optimal nutrient conditions. Judgement is based on a well established critical concentration range of nutrients of the designated tissue. These critical concentrations have been and continue to be experimentally established in the field and greenhouse on many cultivars within a state or region.

Using this type of information, laboratories engaged in plant analysis provide the following services: (1) assist, in conjunction with soil testing, in the identification and resolution of nutrient deficiencies or toxicities presenting problems in the field and greenhouse, (2) monitor during critical growth stages the nutrient concentration in plantation crops, and (3) monitor commercial greenhouse crops where frequent fertilizer applications are required to maintain an adequate supply and balance of essential nutrients.

SELECTED REFERENCES

COX, F.R. Development of a yield response predicition and manganese soil test interpretation for soybeans. Agron. J. 60: 521 - 524.
1968

DOLL, E.C. and LUCAS, R.E. Testing soils for potassium, calcium and magnesium.
1973 In L.M. Walsh and J.D. Beaton (ed), Soil Testing and Plant Analysis. Soil Sci. Soc. Amer., Madison, Wis. 133 - 152.

HANDBOOK ON REFERENCE METHODS FOR SOIL TESTING. Council on Soil Testing and Plant Analysis.
1974 Athens, Ga.

HATFIELD, A.L. Soil test reporting: A nutrient index system. Comm. Soil Sci. Plant
1972 Anal. 3: 425 - 436.

HATFIELD, A.L., HICKEY, J.M. and EADDY, D.W. Crop fertilization based on N.C. Soil Tests.
1976 Circular No. 1 (Revised).

ISAAC, R.A. and JONES, J.B. Autoanalyser systems for the analysis of soil and plant
1971 tissue extracts. In Technicon International Congress, 1970. Tarrytown, N.Y. 57 - 64.

ISAAC, R.A. and KERBER, J.D. Atomic absorption and flame photometry: Techniques and
1972 uses in soil, plant and water analysis. In L.M. Walsh (ed), Instrumental Methods for Analysis of Soils and Plant Tissue. Soil Sci. Soc. Amer., Madison, Wis. 17 - 38.

JACKSON, M.L. Soil Chemical Analysis. Prentice-Hall, Englewood Cliffs, N.J. 146 - 151.
1958

MEHLICH, A. Determination of P, Ca, Mg, K, Na and NH_4. North Carolina Soil Test Division
1953 (Mimeo 1953).

MEHLICH, A. Uniformity of expressing soil test results. A case for calculating results
1972 on a volume basis. Comm. Soil Sci. Plant Analysis. 3: 417 - 424.

MEHLICH, A. and BOWLING, S.S. Advances in soil test methods for copper by atomic
1975 absorption spectrophotometry. Comm. Soil Sci. Plant Analysis. 6: 113 - 128.

MEHLICH, A. New buffer pH method for rapid estimation of exchangeable acidity and lime
1976 requirement of soils. Comm. Soil Sci. Plant Analysis. 7: 637 - 652.

MEHLICH, A., BOWLING, S.S. and HATFIELD, A.L. Buffer pH acidity in relation to nature of
1976 soil acidity and expression of lime requirement. Comm. Soil Sci. Plant Analysis. 7: 253 - 263.

MEHLICH, A. New extractant for the soil test evaluation of phosphorus, potassium,
1977 magnesium, sodium, calcium, manganese and zinc. Comm. Soil Sci. Plant Analysis (in press).

MURPHY, J. and RILEY, J.P. A modified single solution method for the determination of
1962 phosphate in natural waters. Anal. Chem. Acta 27: 31 - 36.

PRATT, P.F. Potassium. In: C.A. Black, Methods of Soil Analysis, Part II. Amer. Soc.
1965 Agron., Madison, Wis. 1022 - 1030.

WATANABE, F.S. and OLSEN, S.R. Test of an ascorbic method for determining phosphorus in
1965 water and $NaHCO_3$ extracts from soils. Soil Sci. Soc. Amer. Proc. 29: 677 - 678.

WOODRUFF, J.R. and KAMPRATH, E.J. Phosphorus adsorption maximum as measured by the
1965 Langmuir isotherm and its relationship to phosphorus availability. Soil Sci.
Soc. Amer. Proc. 29: 148 - 150.

Paper 4 THE OPERATION OF SOIL AND PLANT TESTING SERVICES IN JAPAN

by

Satoru Motomura
National Institute of Agricultural Sciences
Nishigahara, Kita-ku, Tokyo, Japan

1. INTRODUCTION

Agriculture in Japan has made rapid progress since the second world war. There is no doubt that this progress has been due to the extension of advanced techniques to the farmers and also to the provision of national funds for improving farm land. The rapid growth of the economy in Japan, however, has resulted in marked changes in agriculture. The demand for agricultural products has expanded remarkably on account of the change in the pattern of food consumption. The traditional labour-intensive agriculture has been replaced with a labour-saving type of farming. Another important fact is that environmental problems have been spreading to agricultural production.

Consequently, the Government has been concentrating its efforts on the encouragement of agricultural production under a wide variety of farming systems. This paper outlines the soil and plant testing services carried out by government organizations in Japan.

2. ORGANIZATIONAL AND FINANCIAL ASPECTS OF SOIL AND PLANT TESTING SERVICES

Because of the marked changes in agriculture that have taken place, the Government has taken steps to improve agricultural production and maintain soil fertility according to the basic principles of the Soil Conservation Act, 1971, stressing mainly the following items:

i. Basic survey for soil conservation of fertility

a. Identification of major soil groups and/or soil series in arable land and preparation of a soil map at a scale of 1:50 000 with soil series as a mapping unit.

b. Analysis of physical and chemical properties of the soil in relation to soil fertility.

c. Field experiments for evaluation of soil fertility and improvement measures.

d. Evaluation of productive capability class based on limitations and hazards for crops and/or risks of soil damage.

e. Investigation of soil erosion and establishment of methods for the protection of arable land.

ii. Investigation of changes in soil fertility under different farming practices

To clarify the changes in physical, chemical and biological properties governing soil fertility under different farming practices including cropping system.

iii. Elucidation of soil deterioration process

To clarify the factors responsible for the deterioration of soils induced by changes in the farming system and agricultural environments.

iv. Estimation of content of harmful elements

To estimate natural levels of harmful elements such as cadmium, copper, zinc etc. in relation to their toxicity for soils and plants.

v. Soil and plant testing programme

Establishment of facilities for soil and plant analysis at local agricultural extension offices in each prefecture as a means of quickly providing the farmers with accurate information on improved practices.

vi. Promotion of campaign for advancement in soil fertility

To inform farmers accurately and quickly of any findings relevant to improvement of the fertility of their soil.

To interpret advanced agricultural techniques for higher crop production.

All of the above mentioned items have been promulgated by the overnment as national projects to be executed by the prefectural governments. Half of the total cost, including the expenses of about 280 scientific personnel, has been covered with subsidies from the national government. Staff members are stationed at prefectural agricultural experimental stations and are assigned to carry out these projects. The organizational chart for these projects is shown in Figure 1.

3. METHODOLOGICAL PROBLEMS IN SOIL AND PLANT TESTING

Through various soil survey projects, the morphological, physical and chemical characteristics of arable soils have been identified in the field and laboratory. Practical improvement measures based on soil characteristics have been established by field experiments carried out concurrently. The methods used in the basic survey for soil fertility conservation programme and the related projects are outlined below.

2.1 Soil Survey and Classification

In the soil survey, a soil pit for describing the profile and sampling is made at the rate of one to every 25 ha. A soil survey has been conducted according to the "Soil Survey Manual" authorized by the Ministry of Agriculture and Forestry. The procedure is fundamentally similar to that of the USDA, but with some modifications, i.e. benzidine solution is used for detection of manganese oxides, dipyridyl solution for detection of ferrous iron in the field investigation, and a cone-shaped penetrometer is used for measuring soil compaction.

Soil series are employed as a basic unit of classification and mapping. Soil series are defined as a group of soils developed from similar parent materials with a similar mode of deposition from the pedological point of view,

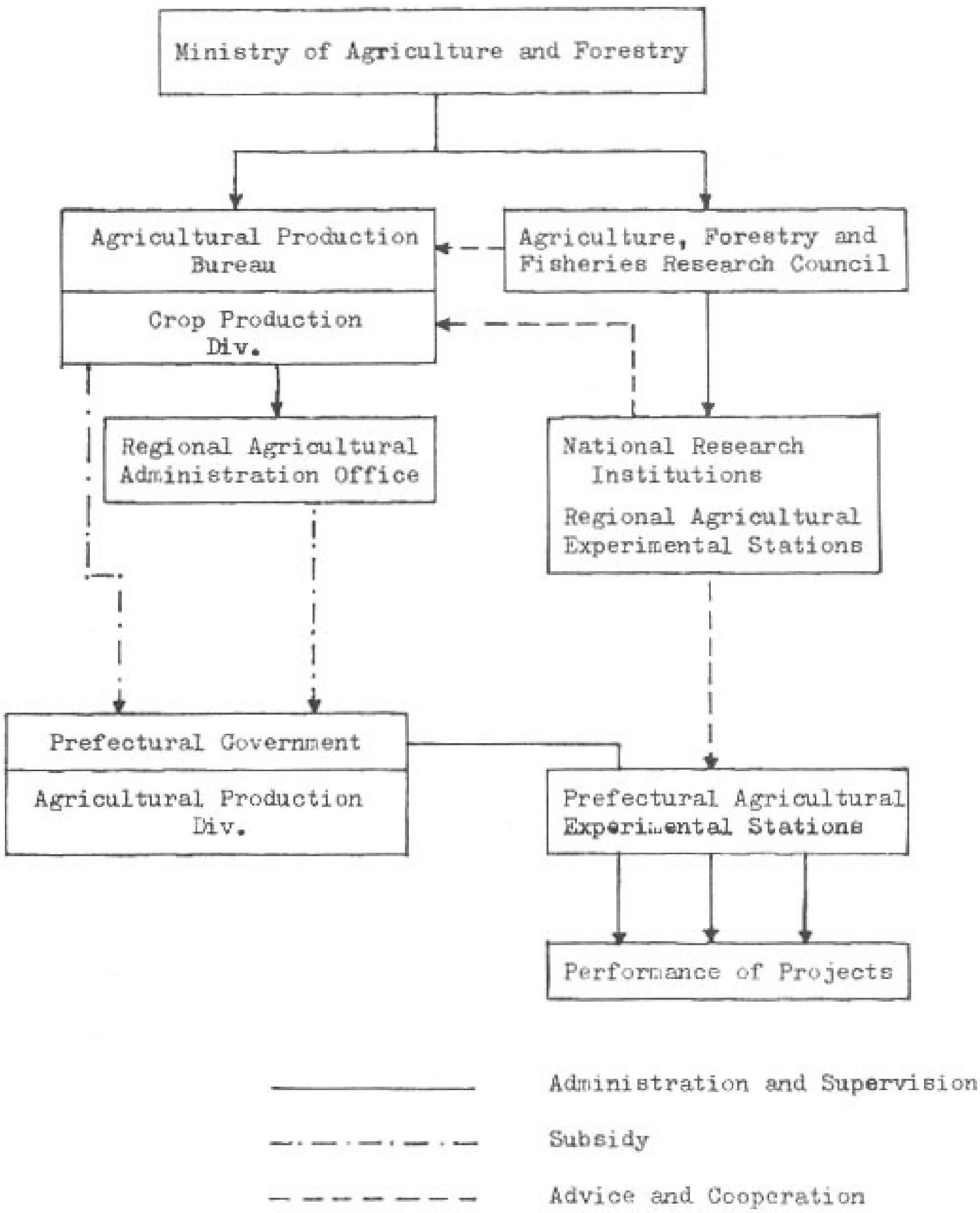

Fig. 1 Organizational Chart for Soil and Plant Testing

and having genetically similar characteristics differentiating the horizons which are arranged similarly in the soil profile. About 310 soil series have so far been identified in arable land. Soil series having the same diagnostic horizon(s) and a similar genetic process are grouped into a soil group.

3.2 Productive Capability Classification

Soil series identified through the basic soil survey are grouped into capability classes according to a productive capability classification so that the kind and degree of limitations and hazards for crop production may be easily distinguished. The productive capability classification in Japan started with one similar to the "Land Capability Classification" of the USDA, but special attention was paid to the establishment of practical measures for excluding limitations and hazards of soils for higher crop production in arable land. Therefore, in the Japanese system, arable soils are grouped into four capability classes, from class I to class IV. Based on the field and laboratory investigations, each class is defined as follows:

Class I : Soils that have almost no limitations or hazards for crop production and/or risks of soil damage. They are regarded as either being naturally fertile or of the greatest potential for crop production without any improvement practices.

Class II : Soils that have some limitations and hazards and/or risks of soil damage. They require some improvement practices for normal crop production.

Class III : Soils that have many limitations and hazards and/or risks of soil damage. They require fairly intensive improvement practices for normal crop production.

Class IV : Soils that have greater natural limitations and hazards than those in class III, but can be cultivated for some crops under very careful management.

The inherent soil characters (standard items) by which the capability of each soil is assessed are as follows :

For paddy rice	For upland crops
Thickness of top soil (t)	Thickness of top soil (t)
Effective depth of soil (d)	Effective depth of soil (d)
Gravel content of top soil (g)	Gravel content of top soil (g)
Ease of ploughing (p)	Ease of ploughing (p)
Permeability under submerged condition (l)	Wetness of land; wet condition (w), dry condition [w]
State of redox potential (r)	Inherent fertility (f)
Inherent fertility (f)	Content of available nutrients (n)
Content of available nutrients (n)	Hazards (i)
Hazards (i)	Frequency of accidents (a)
Frequency of accidents (a)	Slope of field (s)
	Erosion (e)

The capability class is determined by the evaluation of each standard item, some of which are determined by a combination of more detailed soil properties ranked into three or four grades. The capability class of a soil is judged by the lowest value of the enumerated standard items. Soil series are subdivided into several soil phases when clear differences in productive capability are recognized even in the same soil series.

3.3 Analysis of Soil and Plant

Analytical methods for the projects are specified by the Ministry of Agriculture and Forestry. Furthermore, laboratory manuals for analysis of physical properties of soil, analysis of plant nutrients in soil, and plant analysis have been edited by each committee under the direction of the Agriculture, Forestry and Fisheries Research Council of the Ministry.

3.3.1 Soil analysis

The representative soil samples of each soil series selected at the rate of one to every 100 ha are analysed for the following properties :

i. Physical properties

1. Mechanical analysis (particle size distribution).

2. Bulk density and distribution of the three phases (solid, liquid and gas).

3. Water-stable aggregate analysis (if necessary).

4. Water and/or air permeability (if necessary).

5. pF moisture value and available water content (if necessary).

6. Dispersion ratio and erosion ratio (if necessary).

ii. Chemical properties

1. Total organic carbon.

2. Total nitrogen.

3. Ammonium and nitrate nitrogen (if necessary).

4. Effect of air-drying and raised temperature on available nitrogen (paddy soil only).

5. Soil reaction (soil pH, exchange acidity).

6. Cation exchange capacity.

7. Exchangeable Ca, Mg, K and Na, and base saturation percentage.

8. Phosphorus adsorption coefficient.

9. Available phosphorus (if necessary).

10. Available silica (paddy soil only).

11. Free iron oxides (paddy soil only).

12. Easily reducible manganese (paddy soil only).

13. Active alumina and silica-alumina ratio (if necessary).

14. Chlorine (if necessary).

15. Sulphur (if necessary).

3.3.2 Plant analysis

Plant samples taken from the experimental fields at harvest time are analysed for the following constituents :

1. Total nitrogen, phosphorus and potassium.

2. Silica (rice plant only).

3. Calcium and magnesium.

4. Iron and manganese, and other minor elements (if necessary).

3.4 Field Experiments

Experimental plots for field trials are selected at a representative site in the surveyed area in order to develop recommendations which are fully valid under similar conditions. In general, experiments are mainly in the form of fertilizer trials (including those on three major elements, minor elements if necessary, and farmyard manure) and practical improvement tests based on soil characteristics. The details are decided by the prefectural government in consultation with the Regional Agricultural Administration Offices. Soils and plants are analysed when necessary.

3.5 Investigation of Polluted Soils and Measures for their Improvement

At present, cadmium, copper and arsenic have been recognized as harmful pollutants according to the "Law of Protecting Arable Lands from Pollution" enacted in 1970. There is, however, the further possibility that arable land might be affected by other heavy metals. To assess the actual condition of soils in arable land, a soil sample taken at the rate of one to every 1 000 ha, taking into consideration polluting sources, irrigation system and kind of soil, is analysed for cadmium, copper, lead, zinc, arsenic and other substances in cooperation with the Ministry of the Environment. In any arable land from which the agricultural products are recognized to be harmful to human health and where yields are depressed on account of heavy metals accumulated in the soils, field experiments should be conducted to establish practical methods for minimizing the harmful effects.

3.6 Soil Qualities in Relation to Crop Productivity and Measures for their Improvement

3.6.1 Paddy fields

Earlier investigations into higher rice production revealed the importance of a deep topsoil, adequate vertical percolation and the appearance of a gley horizon at a depth greater than 50 to 100 cm. These investigations also demonstrated that the texture of soils should be usually loam or clay loam with 2:1 types of clay minerals and that these soils should have a high nitrogen potentiality, and abundant available silica and exchangeable bases.

Formerly, the main emphasis had been placed on the ploughed layer only, but with the spread of mechanization, much attention has been directed to the importance of subsoil properties determining the depth and distribution of plant roots, and water regime of the soil. Thus the whole soil profile should be taken into consideration in soil management. Farm mechanization has also led to an increase in the application of rice straw and inorganic soil improving materials such as calcium silicates and fused magnesium phosphate in place of farmyard manure or compost to preserve and promote soil fertility.

The soil conditions generally accepted to be the most favourable for rice production and various means of improvement are listed in Table 1. However, it should be noted that a high yield is not always obtained in the fields wherever these conditions are fully met, because yield is also greatly

Table 1 SOIL CONDITIONS IN PADDY FIELDS AND MEASURES FOR THEIR IMPROVEMENT

Items	Limitations	Soil Factors	Favourable Conditions	Improvement Measures
Thickness of top soil	Shallow root zone, low supplying power for nutrients	Presence of excessive gravel, hard pan	>15 cm	Removal of gravel, soil dressing, subsoil breaking, deep ploughing
Effective depth of soil	Narrow root zone, leaking of irrigation water, low permeability	Presence of gravel layer, hard pan or bed rock	>50 cm	Soil dressing, subsoil breaking, soil layer mixing
Gravel content of top soil	Ploughing, thickness of top soil, effective depth	Presence of excessive gravel	<5%	Removal of gravel, soil dressing
Ease of ploughing	Efficiency of farm machinery, germination of seed	Texture of top soil, stickiness of top soil, moisture condition		Incorporation of organic matter, subsoiled drainage
Permeability under submerged condition	Need of much irrigation water, leaching of nutrients	Soil texture, compactness, presence of gravel layer	2-3 cm/day	Subsoil puddling, soil dressing, subsoil compaction
State of redox potential	Root damage, physiological disorder	Easily decomposable organic matter, free iron content, degree of gleying	Eh: 100-200mV Ground water table >70 cm	Incorporation of iron bearing materials, subsoil or tile drainage, intermittent drainage during growing period
Inherent fertility	Leaching out of nutrients, immobilization of nutrients	Nutrient holding capacity, nutrient fixing capacity, base status	CEC: > 20 me P_2O_5 absorption coeff. 1 000-1 500 mg/100g soil. Base sat. >50%	Soil dressing, incorporation of soil improving materials

Content of available nutrients	Poor growth, physiological disorders	Exchangeable Ca exchangeable Mg available K available P_2O_5 available N available Si minor elements acidity	300–600mg/100g 20– 50mg/100g 20– 30mg/100g 30mg/100g 10– 20mg/100g 20mg/100g pH : 5.5–6.5	Incorporation of organic matter and soil improving materials including Ca bearing materials, and fused magnesium phosphate
Hazards	Poor growth, lowering of nutrient uptake, physiological disorders	Harmful sulphur compounds, salt content, heavy metals, irrigation water quality	Cl : $<0.1\%$	Incorporation of soil improving materials, irrigation with fresh water
Frequency of natural disasters	Risk of severe flooding, landslides	Topography, geology		Consolidation of drainage system, pump drainage

Table 2 SOIL CONDITIONS IN UPLAND FIELDS AND MEASURES FOR THEIR IMPROVEMENT

Items	Limitations	Soil Factors	Favourable Conditions	Improvement Measures
Thickness of top soil	Shallow root zone, low supplying power for nutrients and water, extremes of moisture content	Presence of excessive gravel, hard pan or bedrock	>25 cm	Soil dressing, removal of gravel, deep ploughing, subsoil breaking
Effective depth of soil	Narrow root zone, extremes of moisture content	Presence of gravel layer, hard pan or bedrock	>100 cm	Soil dressing, removal of gravel, deep ploughing, subsoil breaking
Gravel content of top soil	Ploughing, thickness of top soil, effective depth	Presence of excessive gravel	5–10%	Removal of gravel, soil dressing
Ease of ploughing	Efficiency of farm machinery, germination of seeds	Texture and stickiness of top soil, moisture condition		Incorporation of organic matter, underdrainage
Wetness of land : wet condition dry condition	Extremes of moisture content, ploughing	Permeability, water holding capacity, moisture condition	Air phase: >18%, avail.water: >50mm, permeability: 10^{-3}–10^{-4} cm/sec	Surface and subsoil drainage, deep ploughing, subsoil breaking, soil layer mixing, irrigation
Inherent fertility	Leaching out of nutrients, immobilization of nutrients, poor growth	Nutrient holding capacity, nutrient fixing capacity, base status	CEC: >20 me P_2O_5 absorption coeff. 1 000–1 500 mg/100g, base sat. >50%	Soil dressing, incorporation of Ca-silicate materials and fused magnesium phosphate
Content of available nutrients	Poor growth, physiological disorders	Exchangeable Ca exchangeable Mg available K available P_2O_5 minor elements acidity	Ca/Mg >10 15–30mg/100g 5–20mg/100g pH: 6.0–6.5	Incorporation of organic matter and soil improving materials including Ca bearing materials and fused magnesium phosphate

Hazards	Poor growth, lowering of nutrient uptake, physiological disorders	Harmful sulphur compounds, salt content, heavy metals, irrigation water quality	Cl: $<0.1\%$	Incorporation of organic matter and soil improving materials, irrigation with fresh water
Frequency of natural disasters	Risk of flooding, landslides	Topography, geology		Consolidation of drainage system, pump drainage, terracing
Slope of field	Erosion	Gradient of slope, direction of slope	$<3^{\circ}$	Terracing
Erosion	Loss of top soil	Slope, geology, vegetation, dispersion ratio, infiltration, stability of soil structure		Terracing, mulching, consolidation of drainage system

affected by climatic conditions, varieties grown and control of pests and diseases.

3.6.2 Upland fields

Unlike paddy fields, it is very difficult to specify favourable soil conditions in upland fields owing to marked differences between crops in their requirements and uptake of nutrients. However, the soil conditions commonly required by plants are good permeability, optimum moisture regime, sufficient nutrients and absence of harmful substances. It has been generally accepted that highly productive soils should have more than 5% of non-capillary pores, more than 10% of air phase, more than 30 mm available water, base saturation more than 30%, a pH of 6.0 to 6.5, a Ca/Mg ratio less than 10, and as much available P_2O_5 as possible. Otherwise, a soil should be improved to meet these conditions. The favourable conditions for upland fields and practical measures for their improvement are listed in Table 2.

4. EXTENSION OF SOIL AND PLANT TESTING RESULTS TO THE FARMERS

The extension and recommendation of fertilization, soil improvement and management practices, and technical guidance in their operation are assigned to the national and local administrative agencies. Such extension work is undertaken with close cooperation between the administrative agencies, local agricultural extension offices and research institutions. The organizational chart for the extension service system is shown in Figure 2.

About 635 local agricultural extension offices throughout the country are staffed with farm advisers and subject-matter specialists help the administrative agencies so that newly developed practices may be successfully introduced. The farm advisers are engaged in extension and consultation services. Subject-matter specialists play a role in conveying the newly developed techniques to farm advisers and in securing closer liaison between the extension offices and research institutions or administrative agencies.

Research institutions and experimental stations have been making steady efforts to improve soil fertility and crop production. Particularly, prefectural experimental stations have been carrying out research and experiment on the techniques which directly help the extension and guidance services with which they keep in close touch.

Facilities for soil and plant analysis have been set up at several local extension offices in each prefecture so that any questions from farmers may be accurately and quickly answered. The total number of extension offices so equipped is 308. Soil pH, exchange acidity, exchangeable K, Mg and Ca, available P_2O_5, nitrate nitrogen, salinity etc. are measured there. The analysis of plant samples and more difficult determinations such as minor elements are undertaken at the Analysis Laboratory installed for this purpose at prefectural experimental stations. Farmers are given the results of analysis with practical recommendations for soil improvement and management. Furthermore, attempts are being made to convey to farmers through the press, radio, television, periodicals and lecture meetings accurate information not only on technical innovations but also on agricultural policies adopted by the national, prefectural and municipal governments. It is important that there should be two-way exchange of information and that matters arising among farmers are conveyed to policy makers and to quarters concerned with agriculture. The campaigns for advancement of soil fertility play an important role in the exchange of information between the administration or other public organizations and the farmers.

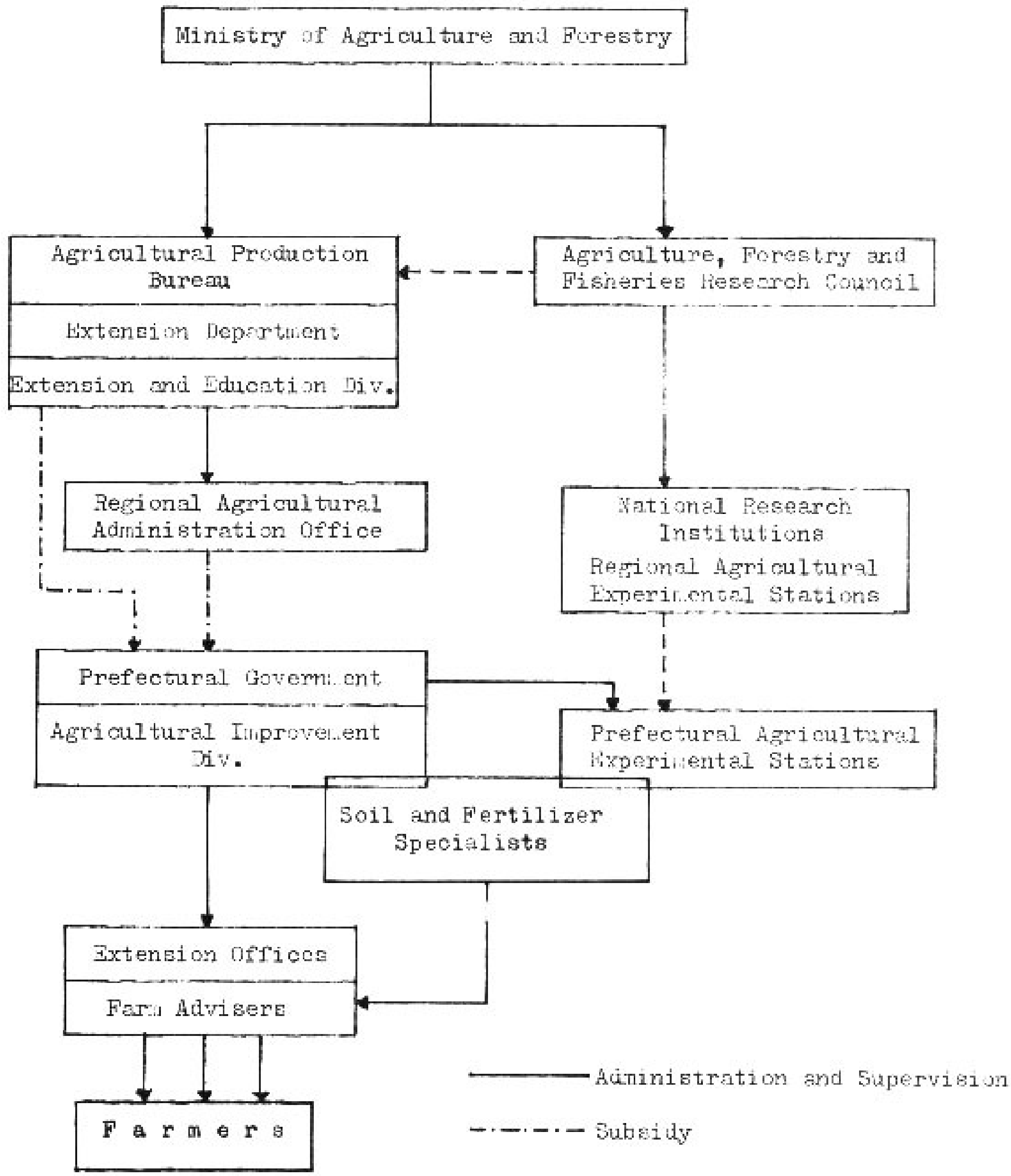

Fig. 2 Organizational Chart for Extension Work on Soil and Plant Testing

The extension services in Japan are characterized by being carried out not only jointly by the national and prefectural governments but also by the national federation system with city, town, and village agricultural cooperative associations. For example, standard fertilizer applications, including rate, time, placement and forms used are determined by a committee which is mainly composed of university professors, subject-matter specialists, researchers from agricultural experimental stations, advisers from the federation of prefectural economic associations and fertilizer dealers. The standards are established from field experiments for every crop, soil type and climatic region.

5. CONCLUSIONS

Fertilization and soil fertility have been closely connected not only with agricultural production but also with conservation of the environment. The solution to present and future fertilization and soil fertility problems, including soil improvement and/or management practices, can probably come only through a better fundamental understanding of soils and soil-plant relationships. It should be emphasized that there is a need for more interpretative data based on soil types with respect to yield estimation, productive rating and soil grouping for a specific purpose. Such data must be more quantitative and this will require a closer working relationship between specialists in different fields of soil science.

Paper 5 THE OPERATION OF SOIL AND PLANT TESTING SERVICES IN BULGARIA

by

I.P. Garbouchev
The N. Poushkarov Institute of Soil Science, Bulgaria

1. INTRODUCTION

The production of more food for the world population is assuming still greater international importance. The synthesis of foodstuffs in agriculture represents a transformation of solar energy and nutrients from soils and atmosphere into organic substances. The crops grown at present are improved cultivars of natural species. In their historical phyllogenetic development plants have made use of nutrients from the earth's crust, and therefore detailed analysis of plant tissue samples shows the presence of the same elements occurring in the soil, water and atmosphere. Science and technology have developed chemical compounds as an artificial source of plant nutrients to restore the necessary supply in the soil. Nowadays, we cannot imagine agriculture without fertilizer application. Nitrogen, phopshorus, potassium and trace elements used at present are taken up by plants after their introduction into the soil. Soils that have been used for thousands of years are now so poor in nutrients that if no fertilizers are applied the crops grown on them will be very low yielding. With the rapid increase of production and use of fertilizers in agriculture, science and practice faced the problem of development of methods for chemical control of soil fertility. A great amount of work has been done to develop analytical methods for the determination of crop fertilizer requirements in relation to soil type, and extension services are being organized in most countries for soil and plant tissue analyses as a guide to the most efficient use of fertilizers.

2. MAIN PROBLEMS

The first problem is related to the close study of soil properties and the detailed inventory of soils in the regions covered by soil testing and methods for fertilizer recommendations. Soils are a complex physico-chemical and biological system which develops under the influence of numerous factors. Therefore, various soils have inherited different abilities to supply plants with nutrients irrespective of management practices. To this end, methods of chemical control of soil fertility should be specifically developed for the particular soil.

The second problem is related to rates and ratios of nutrients in soils and plants, which vary considerably in soils and are relatively constant in plants. It is well known that crops are tolerant of variations in the concentration of nutrients in the soil, but when these are very large the crops grown either yield little or die. Therefore, when fertilizers are introduced into the soil, the most appropriate nutrient ratio should be established. Both crop and soil must be considered in this respect.

The third principal problem concerns methods for the identification of changes occurring in the soil and the determination of rates and ratios of nutrients in the fertilizers used to achieve the most favourable plant growth.

The fourth problem comprises organization and frequency of soil testing as well as criteria for maximum yields.

3. RESEARCH WORK AND EXTENSION SERVICE IN BULGARIA

The application of fertilizers has been studied since 1892, but until the end of the second world war the amounts of fertilizers used in Bulgaria were negligible. Up to 1965, about 50-60 kg/ha of N and P_2O_5 on average and insignificant amounts of K were applied annually. The research work carried out mainly at the N. Poushkarov Institute of Soil Science and the detailed soil survey made after 1947 have shown that Bulgarian soils were very poor in nitrogen and phosphorus, and comparatively well supplied with potassium. For the 1965-75 period, Bulgarian agriculture has made use of 140-160 kg/ha of NPK on average, of which about 100 kg/ha were N, about 50 kg/ha P_2O_5, and only about 10 kg/ha K_2O. In 1977, the amount of NPK fertilizers used will be about 180-190 kg/ha on an average, and by 1980 it will rise to about 250 kg/ha of NPK (140 kg/ha N, 80 kg/ha P_2O_5, and 30 kg/ha K_2O). 1/

Soil testing has been carried out since 1956. The first overall soil testing was accomplished in 1962. From 1962 to 1965, research work was expanded to solve the problems resulting from soil testing in the country. From 1965 to 1972, the second complete soil testing was accomplished using improved methods. For the 1970-72 period, a project was initiated to establish parameters and software for computerized fertilizer recommendations. After the two years of experimentation, since 1974, fertilizer recommendations have been given by computer. As a result of the experience gained three new problems have arisen. The first of these is related to the suitability of analytical methods and the capacity of facilities for routine analysis; the second concerns the methods for determination of rates and ratios of nutrients as regards changes in nutrient status in the soil, and the third is related to the creation of a system for the annual rather than periodical issue of computerized fertilizer recommendations.

So far, the following methods have been used in the country : hydrolysable N after Tjurin and Cornfield for nitrogen determinations, Egner-Rhiem for phosphorus determinations, and 0.2 N HCl for potassium determinations. In the course of the last few years, a new PK method has been developed (2% $NaHCO_3$ + 0.7% $(NH_4)_2SO_4$) with a wider range of application which markedly reduced the analytical work. A new semi-automatic line for routine analyses has been developed (with a capacity of 1 000 samples per day) and put into operation.

To solve some methodological problems that were expected to arise two kinds of field experiments were organized in 1965 in the geographical network of the country. The first kind served to test each element singly on the basis of 2-3 levels of the other nutrients as a blanket treatment. The second embraced experiments of the 4x3x3 types. These experiments have made it possible to establish an NFK balance sheet and new parameters for computerized fertilizer recommendations. The latter were introduced in 1973 on the basis of the data available from earlier research. Recommendations have been given with the aid of an ICL-1200 computer.

Pilot experimentation with the new parameters and approaches to the chemical control of soil fertility was initiated in 1977 for the introduction of a second improved approximation for computerized fertilizer recommendations. The system was developed within the framework of a UNDP/FAO Project (1969-1976) with the assistance of a number of outstanding experts and consultants.

4. OPERATION OF THE SYSTEM

4.1 Prerequisites

The detailed study of soil resources has proved to be a significant factor.

1/ See Note on page 1 regarding conversion factors for oxide to elemental form.

One hundred and fifty agro-industrial complexes (APK) cover the whole of the arable land in the country and all are provided with soil maps on a scale of 1:25 000. There are agro-chemical centres established at each APK with 5-7 well qualified specialists. The latter periodically attend special training courses at the N. Poushkarov Institute of Soil Science to improve their qualifications and familiarize them with the computerized system for fertilizer recommendations. Soil samples are collected according to the soil maps and crop rotations. Each field has its own code number. Special records are kept for each field including data for fertilizer application, yields, previous crops, tillage, and other management practices. Fertilizer recommendations are given for 45 days - from sampling until submission of computer print-outs. To this end, soil samples are taken when the previous crop is mature so that recommendations can be given prior to seed-bed preparation for the next crop. A cross communication between the central laboratory and the APKs will be established.

4.2 Fertilizer Recommendation Principles

Nitrogen fertilizer rates are determined on the basis of the balance sheet of available nitrogen compounds in the soil, nitrogen uptake by plants, and the coefficient of N utilization from fertilizers. The initial data for different soils have been obtained with the aid of stable N isotopes.

Data from soil testing are included as coefficients to characterize the N supplying ability of soils. In other words, the coefficient for a given soil is an average value and therefore the N-test should not be made annually, although field experiments must be carried out continuously to follow changes in the N supplying ability of soils.

4.3 Calculation of N rate

$$R^{(i)}{j_N m} = (a_0 + a_1 Z j_N + a_2 Y i m) \cdot C jm$$

where

R is the N fertilizer rate in kg/ha for a given field,

i is the code number of the field,

j_N is soil type or soil group,

m is the crop grown,

Z_N is the rate of N supplying ability,

Y is the target yield,

C is a correction coefficient, and

a_0, a_1, a_2 are regression coefficients.

Example:

(wheat grown on leached chernozem)

Z_N = 30

Y = 4 800 kg/ha

C jm = 1.02

R = (9.6743 - 0.0793 x 30 + 0.0122 x 4 800) x 1.02 = 134.4 kg/ha

Phosphorus and potassium rates are determined in relation to the establishment of appropriate phosphorus and potassium levels according to soil types. The real term for build-up of phosphorus and potassium levels in the soils is considered to be 12 years. Fertilizer application could be practised either annually or periodically, i.e. every third or fourth year. Thus, the rate is calculated by dividing the whole amount needed by 12, 3 or 4.

For phosphorus, an equilibrium concentration of 0.2-0.3 ppm in 0.01 M $CaCl_2$ is used as a criterion for optimal level.

4.4 Calculation of P_2O_5 rate

$$R^{(i)}{}_{j_p}m = \left(\frac{S_{P\ 0.2}}{T} + Uijm\right). Kag$$

where

R is the P_2O_5 fertilizer rate in kg/ha for a given field,

i is the code number of the field,

j_p is soil type or soil group,

m is the crop grown,

$S_{P\ 0.2}$ is the sorption capacity of soil - the amount required to reach an equilibrium concentration of 0.2 ppm,

T is the number of years necessary to build up a phosphate level,

U is the amount of P taken up by the crop, and

Kag is the ageing coefficient.

Example:

(wheat grown on leached chernozem)

$S_{P\ 0.2}$ = 81.6

T = 12 years

U = 1.0 for 100 kg dry matter

Y = 4 800 kg/ha

Kag = 1.101

$$R = \left(\frac{81.6}{12} + 4.8\right) \times 1.101 = \underline{127.6\ \text{kg/ha}}$$

Long-term studies of K forms and their availability to plants have been taken into consideration to determine K_2O rates. The equation comprises coefficients for textural and mineralogical composition and potassium uptake by plants.

4.5 Calculation of K_2O rate

$$R^{(i)}{}_{j_K}m = \frac{Uim}{k_1} + \frac{(Zl - Zs)k_2}{T \cdot k_3}$$

where

R is the K_2O fertilizer rate in kg/ha for a given field,

i is the code number of the field,

j_k is soil type or soil group,

m is the crop grown,

U is the amount of K taken up by the crop,

Zl is the level of K required,

Zs   is available K established with the aid of soil testing,

T   is the number of years needed to build up a potassium level,

k_1 is the coefficient of K utilization,

k_2 is the coefficient of calculation for bulk weight of plough layer per hectare given in tonne,

k_3 is the coefficient of the effect of the newly applied K fertilizers.

Example:

(wheat grown on grey forest soil)

Y = 3 500 kg/ha

Zl = 15

Zs = 12

T = 12 years

$$R = \frac{10.5}{0.80} + \frac{(15-12) \times 2600}{12 \times 0.26} = \underline{156 \text{ kg/ha}}$$

The rates determined in this way for NPK are corrected for organic matter content, depth of plough layer, thickness of AB horizon, annual precipitation, mean daily temperature, solar radiation, previous crop, residual effect of farmyard manure and fertilizers, depth of ploughing, specific requirements of the crops, etc.

The fertilizer recommendation is in fact a computer print-out.

4.6 Some Considerations for the Future of Soil Chemical Testing

The long-term studies made on different soil types under various conditions to follow up changes in the soil resulting from fertilizer application and other management practices afford the opportunity of establishing a mathematical equation to represent permanent characteristics of the soils. The studies include determinations of intensity, kinetics, and buffer capacity of nutrients for the quantitative prediction of nutrient supply in different soils. An efficient communication system between users and the central laboratory should be established to secure continuous updating of input information. This is considered to be the first condition needed, and the second is related to the maintaining of a well-coordinated network of fertilizer experiments to allow the follow-up of changes occurring in soils. Such a link between research and extension for fertilizer recommendations opens the way for the elimination of routine soil analyses and a reduction in work and expense.

5. PLANT TISSUE ANALYSIS

A considerable amount of research work has been done in Bulgaria concerning the use of plant tissue analysis for fertilizer recommendations. The main objectives of the studies made were to establish a correlation between data from soil and plant analyses. In practice plant tissue analysis is mostly used for orchards but it has recently been tested in connection with the correction of N rates for cereals in the spring. Optimum concentrations of NPK have been established for apples, pears, peaches, cherries, and vines. For example, the limit value for apples was found to be 2.4% for N, 0.35% for P_2O_5, and 1.8% for

K_2O. For peaches, 3.5% for N, 0.46% for P_2O_5, 2.2% for K_2O, and 0.8% for Mg. 1/

On the whole, the use of plant tissue analysis is rather restricted in the country. In a number of cases however, the yield of both orchard trees and cereals has been unsatisfactory, in spite of normal contents of NPK.

A new trend in plant tissue analysis that has been developed at the N. Poushkarov Institute of Soil Science is the determination of anion and cation content instead of the percentage contents of elements in plants.

From the results obtained the organic salt content is calculated as the difference between the equivalent sums of cations and inorganic anions.

$$(K + Ca + Mg + Na) - (NO_3 + H_2PO_4 + SO_4 + Cl)$$

During tillering of wheat the normal organic salt contents should be 900-1000 meq/1000g dry matter. Pilot experiments are being carried out at present to correct the organic salt contents by spraying with nutrient solutions.

6. CONCLUSIONS

In countries, where systems for fertilizer recommendations are being developed, consideration should be given to the following:

i. the results available from soil survey and soil chemical tests should be summarized as regards pH, anion and cation exchange capacity, soil texture, clay minerals, humus content, etc;

ii. a programme for field experiments should be developed to test the effect of increasing rates of NPK at 2-3 levels, depending on the data obtained from soil chemical tests;

iii. the most appropriate analytical methods should be selected according to the experience of other countries with similar conditions;

iv. soils should be classified into groups according to their properties from the management point of view. Field experiments should be used to establish limit values, as well as NPK application rates, according to crops and soil groups.

When all these preparatory activities have been completed, a routine soil chemical test could be introduced. The results obtained should be evaluated statistically. Parallel with the routine work a detailed study should be made of soil resources, their properties, soil processes and changes occurring as a result of fertilizer application and other management practices. The conclusions from practical work and scientific studies should be used for improvement of the system for chemical control of soil fertility. In some cases use should be made of the experience of other countries either through FAO, or by bilateral cooperation.

We hope that the present meeting for soil and plant testing organized by the Soil Resources, Development and Conservation Service of the Land and Water Development Division of FAO will play a significant role in improving the effect of soil and plant tissue analyses to increase the efficiency of fertilizers in all the countries facing that problem.

1/ See page 1 for conversion factors for oxide to elemental form.

Paper 6 THE OPERATION OF SOIL AND PLANT TESTING SERVICES IN KENYA

by

G. Hinga
National Agricultural Laboratories, P.O. Box 14733, Nairobi, Kenya.

1. INTRODUCTION

The services are provided at the National Agricultural Laboratories (NAL), Nairobi, which were established in 1908. A branch to deal with Agricultural Chemistry was established in 1924, whose work was mainly analytical. In 1931 a soil chemist was appointed to deal with soil fertility, particularly soil surveying. The unit provided valuable service and advice to Government and farmers on improved land usage but remained small and limited in its activities.

In the nineteen fifties the facilities of the Section were expanded and improved through the setting up of a soil physics laboratory and a clay mineralogy laboratory was established in the early sixties. The staff establishment was increased which enabled a major fertilizer programme to be expanded and basic crop nutrition studies to be started. With the expanded programme a need arose for an improvement in the soil and plant tissue analytical methods both in speed and accuracy. Consequently Dr. Mehlich and others were assigned the responsibility of developing suitable analytical methods, and this culminated in the production of Mass Analysis Methods for Soil Fertility Evaluation (Mehlich *et al*. 1960).

2. SOIL TESTING AND PLANT ANALYSIS

A fertile soil is one which has a good supply of plant nutrients in balanced proportions, adequate water holding capacity and infiltration rate and good physical structure. The best indicator of soil fertility is the yield and quality of the crops grown, hence the importance of field trials. Soils vary in their capabilities for supplying plant nutrients according to their parent materials and with past manuring and cropping. Soil analysis is useful, firstly in evaluating the ability of the soil to sustain good yields, secondly in determining specific conditions in the soil which can be improved by the additions of correctives or by introduction of other agricultural practices, and thirdly in predicting the probability of obtaining response to the application of fertilizers. In Kenya soil analyses form a basis for:

i. evaluating the fertility status of soils in areas earmarked for development;

ii. soil classification on the basis of analytical data by the soil surveyors;

iii. fertilizer recommendations , i.e. quantity, types or any other ameliorative measures necessary.

In using plant analysis as a tool for assessing fertilizer requirements of crops, it is assumed that within certain limits there is a positive correlation between the amounts of nutrient supplied, the leaf content of the element in question and yield. In this method of studying soil fertility problems, the plant itself is used as an extracting agent for its nutrients. The advantage of leaf analysis, if correctly used, is that it indicates the quantity of nutrients the crop is getting from the soil. In contrast, soil analysis can only show what the plant might obtain since other environmental factors influence the actual amounts taken up. Plant analyses have been useful in fertilizing perennial crops and tree crops. For these crops, results of soil analyses are difficult to interpret as a large mass of top and subsoil is explored by tree roots.

3. ORGANIZATION OF THE SERVICES

The testing of soil and plant samples is the responsibility of the Senior Soil Chemist assisted by Soil Chemists and a Soil Physicist. Until recently soil and plant samples were analysed at NAL for the whole country. However, about 3 years ago, the Soil and Plant Nutrition section of the Coffee Research Foundation, Ruiru, set up a routine leaf and soil analysis advisory service for coffee growers. The two laboratories follow the same methods of soil analysis while those of leaf analysis are dependent upon the facilities available at the respective laboratories. A fertilizer company based at Nakuru provides soil analysis services to farmers following NAL methods. At NAL the services are provided free of charge when the analyses are undertaken for advisory purposes, for government institutions and for farmers in general, provided they forward their samples through the extension staff or when the services are given in the interests of an industry as a whole. Private institutions and non-government agencies pay a small fee. The purpose of involving extension staff in the service is to make them aware of soil fertility and crop nutrition problems within their areas besides providing a link between the farmer and the soil chemist. Since technical knowledge of the great majority of the farmers is limited, the extension staff are required to explain to the farmers the results and recommendations that the soil chemist makes.

With increasing pressure on the available land for arable farming, farmers are tending towards continuous cropping with subsequent decline in yields where soil fertility is neglected. In some cases farmers obtain low yields or no harvest at all, and it is these kinds of farmer who send in soil samples for testing. The progressive farmers who are aware of the value of soil testing and the existence of the service, send in soil samples whenever they open new land or in cases where fertility of the soil is unknown. Agronomists and agricultural research workers at research stations send in soil samples from their experimental sites for soil fertility evaluation. Other samples are submitted by the Kenya Soil Survey. In the laboratory, the facilities available include reception and preparation rooms and a soil store nearby, a main laboratory for mass analysis, and soil physics and leaf analysis laboratories.

4. MASS ANALYSIS METHODS FOR SOIL FERTILITY EVALUATION

4.1 Introduction

Although field trials are accepted as the best method of evaluating soil fertility and such trials will continue to have an important role in the future, chemical and physical measurements of soils in the laboratory have the advantage of speed. The existence of such laboratory services allows for greater assistance to farmers, agricultural officers, soil surveyors and others concerned with land use problems.

An appropriate method of analysis is one involving a single extraction in which a number of elements can be determined. A single acid extractant employing a mixture of hydrochloric and sulphuric acids was selected after considerable experimentation. The method is similar to the North Carolina one except for the higher concentration of the hydrochloric acid. The acid replaces the bulk of the exchangeable cations. The acid soluble phosphorus available to plants may be held in exchangeable form and it is replaced by the sulphate anion in the acid mixture. The concentration of sulphuric acid is restricted to about 0.03$\underline{N}$ since this approaches the upper limit of calcium sulphate solubility. This concentration would be too weak to effect the desired replacement of cations, hence the inclusion of 0.1$\underline{N}$ hydrochloric acid in the mixture.

The elements determined in the extract are: P, Mg, Mn, Ca, K and Na. P, Mg and Mn are determined colorimetrically while Ca, K and Na are determined by flame-photometer. Soil pH, organic carbon and total nitrogen are also determined.

4.2 Organic Carbon and Total Nitrogen

In these analyses a sieved soil is used. Organic carbon is determined following the Walkley and Black (1934) procedure. In determining total nitrogen a micro-Kjeldahl digestion procedure is followed. The samples are digested in test tubes which are heated in an alimunium block.

4.3 Hp (Exchangeable Acidity)

This was defined by Mehlich (1960) as the exchange acidity arising from the depletion of bases from negatively charged permanent cation exchange capacity sites. It is determined by leaching the soil with $BaCl_2$ and the leachate titrated with NaOH to just above neutrality.

4.4 CEC and Exchangeable Cations

The determination of cation exchange capacity and exchangeable cations is carried out on selected soil samples, in particular Soil Survey samples for which the data are required for classification purposes.

Exchangeable cations are determined by leaching soil samples with IN ammonium acetate, pH 7.0, followed by the determination of individual cations in the leachate. Ca, K and Na are determined by flame photometer, while Mg is determined on an atomic absorption spectrophotometer.

The CEC is determined by saturating the soil with IN sodium acetate, pH 8.2. The excess NaOAc is washed with rectified spirit. The absorbed Na is replaced by NH_4OAc and the Na in the leachate determined.

pH in both water and KCl and electrical conductivity are determined on all these soil samples at a soil : water ratio of 1 : 1 or 1 : 2.5 depending on the clay content. Suspected saline soils (EC1 over 1 mmho/cm) are washed with rectified spirit prior to the determination of exchangeable cations. The prewash removes salts soluble in NH_4OAc which would interfere with the determination of exchangeable cations. Saturation pastes are also prepared for the suspected saline soils and electrical conductivity and pH determinations are carried out on the extracts. Conductivity cations and anions in the saturation extracts of only selected samples are analysed.

The method is not suitable for calcareous and saline-alkaline soils as high values of exchangeable Na and CEC are obtained, i.e. the prewashing with rectified spirit is not effective. When the total exchangeable cations exceed the CEC, the calcium value is corrected accordingly.

5. INTERPRETATION OF RESULTS OF SOIL ANALYSIS AND RECOMMENDATIONS

The interpretation of analytical results is based on pH and Hp, cations supply, available P, total N, organic matter content and texture. Soil samples for advisory purposes are usually accompanied by information sheets giving information on area, crops to be grown, previous crop, fertilizer/manure history, slope of the land, drainage, irrigation facilities, soil type and texture, colour of the soil, purpose of the analysis and any other information pertinent to the soil and the crop. The results of chemical tests and the above information are considered in the interpretation and recommendations.

As a guide, soils containing less than 20 ppm P are regarded as low or deficient depending on the crop to be grown. In general high responses are obtained from phosphatic fertilizers on most crops, particularly annuals. K is considered deficient when it is less than 0.2 meq% or 0.4 meq % for crops having low or high requirements for K respectively. The ratio of K to other cations, notably Ca and Mg, is also taken into account.

Calcium is considered deficient below 2.0 meq %. Ca is considered together with pH and Hp values. If the soil is too acid and low in Ca, basic fertilizers are recommended or in extreme cases liming is recommended as an ameliorative measure. Mg is considered deficient when it is below 1.0 meq % . Calcined magnesite or dolomitic limestone is recommended if both Ca and Mg are required. Total nitrogen gives an indication of the potentially available nitrogen. Organic carbon in the top soil is considered in relation to soil structure, particularly aeration.

Trace elements are considered in conjunction with pH and analysis of plant materials. More information is obtained from the bioassay tests in the greenhouse following the minus one element technique. Copper and zinc are particularly important in citrus production where the best indicator is the leaf analysis. Aerial sprays are generally recommended for micronutrient applications. Copper is of special significance in the wheat growing areas where deficiencies are frequently encountered. Seed dressing with copper oxychloride followed by aerial spray are recommended.

In recommending fertilizers for various crops reference is made to fertilizer recommendations made by agronomists. The level of technology, available resources and expected returns are taken into consideration in the recommendations.

Farmyard manure (well rotted) is frequently recommended for use by small holders. It is usually available from their own small bomas.

6. PHYSICAL MEASUREMENTS

6.1 Soil Texture - Hydrometer Method

Mechanical analysis of soils is carried out following the Bouyoucos method as described by Day (1950, 1953 and 1956). Ordinary 1 000 ml graduated cylinders are used. The reading for clay is obtained after six hours. Temperature corrections are applied. Selected soil samples are analysed by the pipette method as described by Kilmer and Alexander (1949).

6.2 Clay Mineralogy

Selected soil samples from soil survey areas are analysed for clay mineralogy. In the analysis organic matter is removed by treating the soils with hydrogen peroxide, dispersed with 'Calgon' and subsequently separated into sand, silt and clay fractions. Slides are prepared and analysed following the method of Theisen and Harward (1962). The identification of clay minerals is based on patterns obtained from standard clay minerals. In semi-quantitative analysis the method of Theisen and Bellis (1964) is followed except that peak area ratios are used instead of peak height ratios.

6.3 Other Analyses

These measurements are made on request and in cases where it is considered necessary:

i. soil moisture retention curve: in this analysis moisture tensions of 0.33 and 1.0 atmosphere are determined in pressure cooker apparatus and tensions of 5, 10 and 15 atmospheres are obtained using standard pressure membrane equipment;

ii. soil density and porosity: this involves the determination of bulk density and specific density from which porosity is calculated. Standard procedures are followed;

iii. hydraulic conductivity of soils.

7. PLANT TISSUE ANALYSIS

7.1 Preparation of Samples

Freshly taken plant tissues are dried in an oven at 75° to $80^{\circ}C$ overnight. The dry samples are ground in a large cutting Wiley mill for macronutrient determinations and in a microhammer mill whose grinding chamber, hammers and sieves are stainless steel, for samples destined for micronutrient analysis. The samples are passed through a 1 mm sieve.

7.2 Ashing of Plant Materials

Plant materials can be dissolved either by wet oxidation or by dry ashing. Wet oxidation is accomplished by treating the material with HNO_3 and $HClO_4$. Its main advantage is that both macro and micro nutrients can be determined on the same digest. Its main disadvantage is the problem of disposing the corrosive fumes of the acids and the potential danger of explosion. Ashing (ignition) is popular as a satisfactory alternative method for the release of mineral elements. However, significant amounts of K and P may be volatilized at the usual ignition temperature of 550 to $600^{\circ}C$. For this reason, ashing for P is generally carried out in the presence of an alcoholic solution of $Mg(NO_3)_2$.

At the NAL laboratory the dry ashing method is followed. The sample is ashed at 400 – $450^{\circ}C$ (to avoid the loss of K and P) for 3 h. The sample is then treated with conc. HNO_3 evaporated to dryness on a waterbath and placed back in the muffle furnace at $400^{\circ}C$ for 15 minutes. The ash is taken up in dilute HCl. The solution is used in the determination of P, K, Ca, Mg, Zn, Fe, Mn and Cu. For sulphur, ashing in the presence of $Mg(NO_3)_2$ is preferred. The method has proved satisfactory for macronutrients but somewhat low values are obtained for the trace elements. Wet digestion is preferred but the corrosive fumes of $HClO_4$ present a problem.

7.3 Determination of Individual Elements

Phosphorus is determined colorimetrically following development of the colour with nitric vanadomolybdate reagent. Potassium is determined by flame photometer while sulphur is determined by the turbidimetric method. Calcium, magnesium, iron, manganese, zinc and copper are determined on an atomic absorption spectrophotometer. Lanthanum chloride solution is added to the Ca and Mg standards and solutions alike.

The results of plant analysis are interpreted by taking into consideration the information supplied with the sample, such as fertilizers used, occurrence of the disorder in the field, results of soil analysis, comparison of results of healthy and unhealthy plants that are similar, and data given in the literature.

As a check on the accuracy of the analyses, membership of a scheme organized by the Netherlands Laboratory of Soils and Fertilizers, Wageningen, has been helpful. The central laboratory distributes six standard plant material samples every two months, to the participating laboratories. The member laboratories analyse the samples for those elements they are interested in, and send the results to Wageningen for compilation of the data which are sent to all member laboratories without comments.

8. CONSTRAINTS

i. It is generally recognized that field trials are the best indicators of soil fertility and capacity of soils to sustain yields. While such trials have demonstrated the value of fertilizers and manures through increased yields, particularly as a result of application of phosphatic fertilizers, the relationship between the soil test and yields has remained poor. Other factors such as climate, type of soil, management etc. account for the poor relationship. It has therefore not been possible to relate crop responses and the applied fertilizer to the soil test.

ii. Information and data on the critical nutrient levels for important crops is inadequate or non-existent, which is a hinderance to effective and efficient advisory services.

iii. The level of technology for the small scale farmers is generally low. This hinders them from making use of the service with a consequent drop in production. Few of them are in a position to take soil samples properly or implement the recommendations correctly. Communication between the soil chemist and the farmer through the extension is a weak point in the service.

iv. The service lacks feedback information on the performance of crops as a result of the recommendations, the difficulties that face farmers in implementing the recommendations and the socio-economic problems that farmers encounter.

v. Although farmers are encouraged to supply as much background information as possible when sending samples for analysis, some fail to do so. This creates difficulties in the interpretation of the results and in the recommendations.

vi. Some of the small scale farmers experience difficulties in implementing the recommendations owing to lack of cash or availability of fertilizers within their localities.

vii. Inadequate laboratory facilities such as drying ovens during peak periods, grinding mills, lack of spare parts and occasionally maintenance services, are some of the drawbacks in the running of the services smoothly and efficiently.

REFERENCES

DAY, P.R. Physical basis of particle size analysis by hydrometer method. Soil Sci.
1950 70: 363 - 374.

DAY, P.R. Experimental confirmation of hydrometer theory. Soil Sci. 75: 181-186.
1953

DAY, P.R. Report of the Committee on Physical Analyses. Soil Sci. Soc. Amer. Proc.
1956 20: 167 - 169.

KILMER, V.J. and ALEXANDER, L.T. Method of making mechanical analysis of soils. Soil
1949 Sci. 68: 15 - 24.

MEHLICH, A. Charge characterization of soils. Trans. Inter. Congr. Soil Sci. Madison,
1960 Wisconsin.

MEHLICH, A., PINKERTON, A. and ROBERTSON, W. Mass analysis methods for soil fertility
1960 evaluation. Dept. of Agric. K nya.

THEISEN, A.A. and HARWARD, M.E. A paste method for preparation of slides for clay
1962 mineral identification by X-ray diffraction. Soil Sci. Soc. Amer. Proc. 26:
90 - 91.

THEISEN, A.A. and BELLIS, E. Quantitative analysis of clay mineral mixtures by X-Ray
1964 diffraction. Nature 204: 1228 - 1230.

WALKLEY, A. and BLACK, I.A. An examination of the Degtjareff method for determining
1934 soil organic matter and a proposed modification of the chromic acid titration
method. Soil Sci. 37: 29 - 38.

Paper 7 THE OPERATION OF SOIL AND PLANT TESTING SERVICES IN INDIA

by

V.K. Mutatkar
Fertilizer Promotion and Agricultural Research Centre
Planning and Development Division
Fertilizer Corporation of India Limited
Sindri, Bihar, India

1. HISTORY OF SOIL TESTING

A soil testing programme was started in India during the years 1955-56 with the setting up of 16 soil testing laboratories under the Indo-US operational agreement for "Determination of Soil Fertility and Fertilizer Use". Eight more laboratories were added in 1958.

With the increase in fertilizer consumption from 1.2 million tonnes in 1966 to 2.7 million tonnes during 1975-76, the number of soil testing laboratories has also been increased progressively and now there are 260 soil testing laboratories, including 52 mobile soil testing vans, functioning all over the country.

The state governments, the Central Ministry of Agriculture and Irrigation, and institutions such as the Indian Council of Agricultural Research, agricultural universities and the manufacturers of fertilizer who advise farmers on fertilizer use are all engaged in soil testing programmes.

In spite of limited resources and various technical difficulties, good progress has been made in the soil fertility evaluation programme which has expanded considerably in the last decade. An important development was the setting up of soil testing laboratories by the fertilizer industry. The fertilizer industry has played a vital role in making the soil testing programme more effective and successful.

The total capacity of all soil testing laboratories is for the analysis of 4.0 million samples per year. Overall utilization of the soil testing facilities is about 70 percent. Considering that there are 70 million farm holdings and an estimated 50 million farmers needing soil testing services, the total capacity of soil testing services developed is still small. More laboratories working at a higher degree of efficiency are required.

2. ORGANIZATION

The soil testing laboratories are operated by government agencies, universities and fertilizer manufacturers, while some are private. Most of these, with a total capacity of 3.1 million samples, are in operation in the government sector. The total capacity of all the laboratories run by the Fertilizer Corporation of India Ltd. (FCI) throughout the country is 0.5 million soil samples per year. The FCI is placing more emphasis on mobile soil testing laboratories because by bringing the soil testing service to the doorstep of the farmer the farming community is motivated towards the scientific and economic use of fertilizers. The contribution of the FCI through mobile soil testing laboratories is 44 percent of the total capacity of mobile soil testing laboratories in the country. Details regarding the total capacities of soil testing facilities in each state rendered by different organizations are given in Tables 1A and 1B.

2.1 Size of Laboratory

The rated capacities of individual laboratories run by government and universities range from 5 000 to 84 000 samples per annum. The average laboratory capacity of 10 000 samples per year is exceeded by only a few laboratories.

Table 1A CAPACITY OF STATIC SOIL LABORATORIES BY STATES (million samples/year)

States	Govt.	University	Fertilizer Manufacturers		Total
			FCI	Others	
A.P.	0.144	–	0.010	–	0.154
Assam	0.055	–	0.025	–	0.080
Bihar	0.130	0.016	0.075	–	0.221
Gujarat	0.160	–	–	0.010	0.170
Haryana	0.222	0.040	–	–	0.262
H.P.	0.050	0.010	–	–	0.060
J.K.	0.049	–	–	–	0.049
Karnataka	0.460	–	0.010	0.040	0.510
Kerala	0.151	–	–	0.037	0.188
M.P.	0.080	0.030	–	0.005	0.115
Maharastra	0.036	0.015	0.040	N.A.	0.091
Manipur	0.010	–	–	–	0.010
Meghalaya	0.010	–	–	–	0.010
Nagaland	–	–	–	–	–
Orissa	0.070	–	–	–	0.070
Punjab	0.100	0.060	0.010	–	0.170
Rajasthan	0.090	–	0.001	–	0.091
T. Nadu	0.576	–	–	0.061	0.637
Tripura	0.010	–	–	–	0.010
U.P.	0.355	0.069	0.025	0.007	0.456
W. Bengal	0.055	–	0.075	–	0.130
A.N.	0.003	–	–	–	0.003
Delhi	0.001	0.001	–	–	0.002
Goa	0.010	–	–	–	0.010
Pandichari	0.028	–	–	–	0.028
TOTAL :	2.855	0.241	0.271	0.160	3.527

Source : Fertilizer statistics, 1974-75, F.A.I.

The smaller units (10 000 samples per year or less) cannot be operated efficiently and economically on an assembly line production basis. The laboratory best suited to Indian conditions has a capacity of 30 000 samples per year, as also recommended by Muhr <u>et al</u>. (1965). Perur <u>et al</u>. (1975) showed that a laboratory having a capacity to analyse 30 000 samples per year could double its output with slight modifications in staffing pattern and work technology. However, the design of any laboratory for maximum efficiency depends on the maximum daily capacity, projections of future needs and number of determinations carried out on each soil sample.

The soil testing laboratories of the FCI, most of which were established during the last 10 years, were designed for a capacity of 30 000 soil samples per year. The mobile soil testing vans, each with a capacity to analyse 18 000 soil samples per annum, were built to a design suggested by the Ministry of Food and Agriculture, Government of India.

Table 1B CAPACITY OF MOBILE SOIL LABORATORIES BY STATES
(million samples/year)

States	Govt.	Universities	Fertilizer Manufacturers		Total
			FCI	Others	
A.P.	0.008	-	0.015	-	0.023
Assam	-	-	0.030	-	0.030
Bihar	0.020	-	0.030	-	0.050
Gujarat	0.070	-	-	-	0.070
Harayana	-	-	-	-	-
H.P.	-	-	-	-	-
J.K.	-	-	-	-	-
Karnataka	0.010	-	0.015	-	0.025
Kerala	0.015	-	-	0.010	0.025
M.P.	0.010	-	0.015	-	0.025
Maharastra	-	-	0.030	-	0.030
Manipur	-	-	-	-	-
Meghalaya	-	-	-	-	-
Nagaland	N.A.	-	-	-	-
Orissa	0.010	-	0.030	-	0.040
Punjab	0.020	-	-	-	0.020
Rajasthan	0.010	-	-	-	0.010
T. Nadu	0.036	-	-	-	0.036
Tripura	0.010	-	-	-	0.010
U.P.	0.060	-	0.015	-	0.075
W. Bengal	-	-	0.045	-	0.045
A.N.	-	-	-	-	-
Delhi	-	-	-	-	-
Goa	-	-	-	-	-
Pandichari	-	-	-	-	-
TOTAL :	0.279	-	0.225	0.010	0.514

Source : Fertilizer statistics, 1974-75. F.A.I.

To establish one static soil testing laboratory with a capacity of 30 000 samples per year requires a capital expenditure of about Rs.0.35 million for the building with a floor area of about 185 m^2, instruments and furniture. The operational cost of such a laboratory, inclusive of salaries, wages and materials etc., would vary between Rs. 4 and 6 per sample analysed. Similarly, a mobile soil testing van can be constructed at an initial cost of Rs. 0.30 million, but the cost of analysis would be 1.5 times that in the static laboratory. The van would be moving from place to place and the effective working time would be less.

2.2 Staff

In the light of experience gained from the routine determinations which are carried out in most of the laboratories, the staff requirement for a laboratory analysing 100 samples per day (or 30 000 samples per year) would be 18 persons. They would comprise one Soil Chemist (in charge), two Research Assistants (one chemist in charge of analytical work and one agronomist in charge of fertilizer recommendations), five Analytical Assistants, six Laboratory Attendents, three typists and one driver.

3. ORGANIZATION OF LABORATORY OPERATIONS

3.1 Collection of Soil Samples

It has been the practice in India to collect soil samples from the cultivators' fields through the extension staff of the State Department of Agriculture, namely, the village level workers or agricultural officers of the districts.

The soil testing laboratories run by fertilizer manufacturers use their own field staff who are engaged in promotional activities or fertilizer dealers as agents for collecting soil samples. Special campaigns are organized to encourage farmers to draw samples two or three months before each planting season, viz. kharif, rabi and summer.

Soil samples are collected having regard to the uniformity of the area, topography, colour, texture, cropping pattern, drainage etc. As far as possible a truly representative sample of the area is taken. On despatch, the sample is accompanied by an information sheet which is used when interpreting the data and making the fertilizer recommendation.

3.2 Laboratory Equipment

In soil testing laboratories accuracy and speed are equally important and an appropriate choice of laboratory equipment is therefore essential. Criteria for selection include: (1) a degree of sensitivity and precision to meet the required standard of accuracy, (2) simple operation, (3) rugged construction to avoid frequent failures, (4) availability of spares and after sales service from the manufacturer.

Soil testing laboratories use pH meters, conductivity meters, photo-electric colorimeters and flame photometers of Indian manufacture, the performances of which are quite satisfactory. As 80-90 percent of equipment breakdowns are mostly of a minor nature due to mishandling, they can be remedied by the laboratory staff. Thorough training of the laboratory personnel and a good after sales service from the manufacturers are of the greatest importance.

3.3 Time Saving Devices

A number of time saving devices such as soil samplers, multiple sampling spoon assembly, multiple racks for flasks and washing devices were designed and described in detail by Muhr et al. (1965) and Perur et al. (1975). These have been found quite useful and in modified form are being used extensively. Madras Fertilizer Ltd. have introduced a new type of multiple dispenser, an automatic suction and drawing device for colorimeters and an extension of the atomizer capillary in flame photometers (Verma and Bennet, 1971). All these and other innovations such as a multiple stirrer based on a model suggested by the International Soil Fertility Evaluation and Improvement Programme are coming into use. Verma (1975) has estimated that the saving in time afforded by these devices is 30-80 percent. They also reduce the risk of human error.

3.4 Analytical Procedures and Quality Control

All the soil testing laboratories are equipped to analyse soil samples for pH, electrical conductivity, availability of macronutrients, and lime and gypsum requirements, while some government laboratories also estimate the availability of micronutrients in soils. Most laboratories also have facilities for analysis of irrigation water and plant samples. Standard procedures as described by Muhr et al. (1965) are used in all laboratories for pH, electrical conductivity, organic carbon, available phosphorus, available potassium, and lime and gypsum requirements.

The correct choice of analytical method centres around extraction of nutrients proportionate to the amount which a plant can obtain from the soil during its lifetime. Since the nutrient availability depends on soil type and management practices, the suitability of a method for estimating the fertility of soil must be determined from its correlation with the crop response under various agroclimatic conditions.

For assessing nitrogen availability in soil, the alkaline potassium permanganate method (Subbiah and Asija, 1957), calcium hydroxide method (Prasad, 1965) and organic carbon percentages in soil (Kalbande, 1964; Singh and Brar, 1973) have been found to be highly correlated with crop response, although Pathak et al. (1976) did not find any correlation of organic carbon and total nitrogen in soil with percentage yield. No uniform method for all soil testing laboratories can yet be adopted, and because the distillation process is time consuming, nitrogen availability in soil is still assessed by estimation of organic carbon.

Studies have been made with different extractants viz. Olsen, Bray No.1, Bray No.2, Truog, Morgan, Bingham, Spurway and Al-Abbas to evaluate a suitable soil test method for phosphorus (Datta and Khera, 1969; Dubey et al. 1973; Khera and Datta, 1969; Meelu and Bhumbla, 1969; Pathak et al. 1975; Singh and Brar, 1973; Ramamoorthy and Hasan, 1977; Ramamoorthy and Bajaj, 1969). Of these the Olsen method was the most suitable for neutral and alkaline soils, while the Bray No.1 method was found suitable for maize, wheat and vegetable crops on acid soils. Datta and Kamat (1959) developed a method for extraction with a mixture of ammonium fluoride and EDTA for available phosphorus which was highly correlated with yield in several soil associations.

For estimation of available potassium in soil neutral normal ammonium acetate was found to be a suitable extractant (Dubey and Khera, 1974). Datta and Kalbande (1967) found potassium extractable with 6 N sulphuric acid to be highly correlated with the crop response, while research at Orissa Agricultural University showed extraction with N HNO_3 to be the most suitable for available K in laterite and red soils.

Research data are still insufficient to enable unified methods of analysis to be adopted. Moreover, the soils on which paddy, the most important crop in India, is grown present special problems because prolonged waterlogging creates a reducing environment in which the dynamics of nutrient availability differ from those of arable soils (Chang, 1964). Further research is necessary for the development of suitable soil testing methods for waterlogged soils, as also for a suitable common extraction procedure for all macronutrients. A modified Olsen's method (Hunter, 1972) has given encouraging results for estimation of available P, K and micronutrients.

3.5 Quality Control

To ensure the accuracy of analysis, all laboratories provide for the analysis of one check sample for each set of 10 samples, for which purpose one extra space is provided in the racks to take this sample.

The laboratories of the FCI operate in addition a system of cross-checking for one percent of total samples taken from the different laboratories of the Corporation.

3.6 Interpretation of Analysis

The value of soil test data in the prediction of crop response to application of any specific nutrient is dependent on accurate analysis of representative samples that are backed by sound correlation studies. During the early period of soil testing service in India, limited pot culture correlation experiments and a few field trials were conducted by the Indian Agricultural Research Institute, the outcome of which was the grouping of soil test data in three ratings , low, medium and high (Table 2). Later, with the availability of more data the departments of agriculture in each state, agricultural universities and the FCI collaborated to revise the earlier classification system to include five ratings, namely, very low, low, medium, high, very high (Table 3). Most of the soil testing laboratories now follow this rating chart.

Table 2 RATING CHART FOR SOIL TEST DATA 1/

Organic carbon (as a measure of available nitrogen)	Below 0.5%	0.5 – 0.75%	Above 0.75%
Available P_2O_5	Below 20 lb/acre	20–50 lb/acre	Above 50 lb/acre
Available P	Below 9 lb/acre	9–22 lb/acre	Above 22 lb/acre
Available K_2O	Below 125 lb/acre	125–300 lb/acre	Above 300 lb/acre
Available K	Below 105 lb/acre	105–250 lb/acre	Above 250 lb/acre
	Soil Reaction (pH)		
Acidic	pH below 6.0	Tending to become alkali	pH 8.6 – 9.0
Normal	pH 6.0 – 8.5	Alkali	pH above 9.0

Conductivity (Total soluble salts) (mmho/cm)

Below 1	–	Normal
1 – 2	–	Critical for germination
2 – 3	–	Critical for the growth of salt-sensitive crops
Above 3	–	Injurious to most crops

1/ Source: Muhr et al. (1965)

Using the critical test level approach of Cate and Nelson (1965), Goswami et al. (1971) studied the relationship between soil test value of phosphorus and percentage yield through 489 simple fertilizer trials on cultivators' fields over a two year period. The authors calculated the critical soil test level of phosphorus for rice in six soils and for wheat in three other soils (Table 4). Pathak et al. (1975) calculated the critical soil test value of phosphorus (P) as 12.3 kg/ha (28 kg P_2O_5/ha) in the alluvial soils of U.P. for wheat. Work by the FCI at Sindri showed the critical level for phosphorus (P) to be 13 kg/ha in the red laterite catenary soils of Bihar under waterlogged conditions (Mukherjee et al, personal communication). Rao (1975) found the critical limits for phosphorus (P) and potassium (K) as 15.4 kg/ha (35 kg P_2O_5/ha) and 124.5 kg/ha (150 kg K_2O/ha) in the soils of Andhra Pradesh district.[2]

Table 3 MODIFIED RATING CHART FOR SOIL TEST DATA 1/

Nutrient	Very low	Low	Medium	High	Very high
Organic carbon (as a measure of available nitrogen %)	>0.25	0.25 -<0.50	0.50 -<0.75	0.75 -<1.0	1.0 and >1.0
Available P (kg/ha)	<5	5 - <10	10 -<20	20 -<50	50 and >50
Available K (kg/ha)	<55	55 -<115	115 -<280	280 -<465	465 and >465

Soil Reaction (pH)

Very acidic	pH < 5.0	Alkaline	pH 8.0 -<9.0
Acidic	pH 5.0 -<6.0	Very alkaline	pH 9.0 ->9.0
Neutral	pH 6.0 -<8.0		

Conductivity (Total soluble salts) (mmho/cm)

Below 1	- Normal
1 - 2	- Critical for germination
2 - 3	- Critical for the growth of salt sensitive crops
Above 3	- Injurious to most crops

1/ Followed in the soil testing laboratories of Bihar.

Since the availability of any nutrient in soil is governed by various physicochemical soil factors such as pH, sesquioxides, calcium carbonate, clay and also other nutrient elements present in soil, attempts are now being made to develop soil test calibration equations in relation to other soil factors. The FCI have undertaken a research programme on soil test crop response correlation with a dynamic computer model on the principle of Colwell (1967).

3.7 Fertilizer Recommendations

A fertilizer recommendation should indicate the type and quantity of fertilizer and time and method of application for a particular crop and soil. Therefore, it is necessary to have soil test values supplemented with the information on drainage, physical properties, depth of the soil, alkalinity etc., which is normally supplied on the information sheet accompanying the soil sample. The cultivar, plant population, standard of farm management and the economics of fertilizer use are normally also taken into consideration. With the aid of the foregoing, an experienced agronomist can make a fertilizer recommendation by increasing or decreasing the rate of nutrient suggested in the general recommendation for an area. For certain crops and areas, detailed guidelines are available (Table 5).

Table 4 CRITICAL LEVEL FOR SOIL PHOSPHORUS AND YIELD RESPONSE OF RICE AND WHEAT TO FERTILIZER PHOSPHORUS 1/

Soil group	Year	No. of trials	Critical level (kg P_2O_5/ha) (Olsen value)	Response to phosphorus (kg/ha) at 60 kg P_2O_5/ha over 120 kg N/ha	
		RICE		Below C.L.	Above C.L.
Red					
Coimbatore	(1968-69)	33	20	420	380
Shimoga	(1969-70)	25	15	2078	140
Chittoor	(1969-70)	17	18	3187	684
Deep black					
Nizamabad	(1969-70)	38	30	1102	711
Coastal Alluvial					
Alleppey	(1969-70)	39	67	521	104
Thanjavur	(1968-69)	33	69	1811	525
Laterite					
Palghat	(1969-70)	44	18	747	127
Medium black					
Nasik	(1969-70)	32	46	292	33
Mixed red and black					
West Godavari	(1969-70)	30	33	1954	760
		WHEAT			
Black					
Hoshangabad	(1968-69)	32	49	1373	340
Alluvial					
Karnal	(1968-69)	23	20	1453	412
Ludhiana	(1968-69) and (1969-70)	84	17	1839	1056
Grey brown					
Mehsana	(1969-70)	59	17	788	238
Bray No.1 method.					

1/ Source: Goswami *et al*. 1971

Table 5

RATING CHART FOR WHEAT IN BIHAR

Sl. No.	N_2		P_2O_5		K_2O	
	Soil test value % organic carbon	Recommendation N_2 in kg/ha + FYM in t/ha	Soil test value Average P_2O_5	Recommendation P_2O_5 kg/ha	Soil test value Av. K_2O/kg/ha	Recommendation K_2O kg/ha
1.	0.0 - 0.15	130 + 8	0.0 - 10	80		
2.	0.16 - 0.30	120 + 6	11 - 20	70		
3.	0.31 - 0.45	110 + 4	21 - 30	60	0 - 125(L)	40
4.	0.46 - 0.60	100 + 2	31 - 40	50		
5.	0.61 - 0.75	90 + 2	41 - 50	40	126 - 300(M)	30
6.	0.76 - 0.90	80 + 2	51 - 60	30	301 and above(H)	20
7.	Above 0.91	70 + 2	Above 60	20		

1. For unirrigated tracts fertilizer recommendation for N will be 50% of above and 25% for other nutrients.

2. P_2O_5 recommendation may be raised by 50% in acid soils of Chotanagpur and Santhal Parganas.

Source: Proceedings of the meeting of Technical Coordination Committee, Bihar held at Patna on 17.11.75.

These recommendations are entered on a form which is taken to the farmer by local field staff or village level workers of the extension service who explain and interpret the recommendations.

According to the wishes of a farmer, fertilizer use can be aimed at obtaining the maximum yield per hectare or the maximum profit per rupee invested in fertilizer. The fertilizer recommendation for different circumstances can be made using Ramamoorthy's (1975) technique for the desired yield.

4. EXTENSION OF SOIL AND PLANT TESTING RESULTS TO THE FARMERS

The results of soil tests and the fertilizer recommendations must be communicated to the farmers in such a way that they will understand and make effective and profitable use of the information (Perur et al. 1975).

Recommendations are usually communicated to farmers by the extension worker, but the line of communication is a long one with many weak links. Even if a farmer receives a recommendation, he needs persuasion to invest in costly fertilizer and accept the risk of financial loss. In this respect the role of the extension service is a critical one.

The fertilizer industry has a programme of demonstrating the use of fertilizer on farmers' fields and carries out about 7 000 such demonstrations annually. These are supplemented with field days and promotion through film shows and the radio.

Some states have indicated that even after demonstrations most farmers do not use the quantity of fertilizer recommended. A study carried out by Punjab Agricultural University, Ludhiana, indicated that only 4 percent of the farmers who had had their soil tested fully implemented the fertilizer recommendation, 48 percent partly implemented the recommendation while the remaining 48 percent took no action (Makhan, 1975). Experience in the state of Maharastra has been similar. The individuals who make most use of the soil testing service and fully implement the recommendations are the progressive farmers, and those with irrigation facilities or who grow cash crops. The farmers in the second category are more sceptical, perhaps because of the financial risk, but are usually willing to use 25 percent of the recommended dressing. Failure to take any action on recommendations is attributed to delayed receipt of reports, lack of credibility of recommendations and incorrect sampling.

5. PREPARATION OF SOIL FERTILITY MAPS

Summarized soil test data can be used in conjunction with the nutrient index concept introduced by Parker et al. (1951) for preparing soil fertility maps. These maps should eventually be used for deciding the types and amounts of fertilizer most suitable for each area and for determining the policy for fertilizer production, distribution and consumption in different regions. Maps of this type covering all of India for N, P and K have been prepared by Ramamoorthy and Bajaj (1969). Many others for blocks and districts have been prepared by various soil testing laboratories. The FCI soil testing laboratory at Trombay has prepared a soil fertility map for the districts of Jalgaon and Kolhapur and a detailed district map for the state of Bihar is also developed by the soil testing laboratory at Sindri.

6. PLANT TESTING SERVICES

Plant testing services are rare, and plant testing is not done on a routine basis for lack of sufficient basic research.

An attempt was made very recently to introduce tissue testing through the mobile soil testing service with recommendations based on ad hoc norms obtainable from field experiments.

REFERENCES

CATE, R.B. and NELSON, L.A. Int. Soil Test Serv. Tech. Bull. 1.
1965

CHANG, S.C. The mineral nutrition of the rice plant. John Hopkins Press, Baltimore.
1964 373.

COLWELL, J.D. Aust. J. Soil Res. 5: 275.
1967

DATTA, N.P. and KHERA, M.S. J. Indian Soc. Soil Sci. 17: 191.
1969

DATTA, N.P. and KALBANDE, A.R. J. Indian Soc. Soil Sci. 15: 1.
1967

DATTA, N.P. and KAMATH, M.B. Indian J. Agric. Sci. 29: 81.
1959

DUBEY, S.M., KHERA, M.S. and OOMMEN, P.K. Fert. News, 18(11): 38.
1973

DUBEY, S.M. and KHERA, M.S. Fert. News, 19(2): 33.
1974

GOSWAMI, N.N., BAPAT, S.R. and PATHAK, A.N. Proc. Int. Symp. Soil Fert. Evaluation,
1971 1: 351.

HUNTER, A.H. Rep. North Carolina Agric. Expt. Sta.
1972

KALBANDE, A.R. J. Indian Soc. Soil Sci. 12: 62.
1964

KHERA, M.S. and DATTA, N.P. J. Indian Soc. Soil Sci. 17: 133.
1969

MAKHAN, D.S. Proc. Workshop Soil Testing, F.A.I., 59.
1975

MEELU, O.P. and BHUMBLA, D.R. J. Indian Soc. Soil Sci. 17: 133.
1969

MEHROTRA, C.L., SINGH, B. and PANDE, R. J. Indian Soc. Soil Sci. 23: 500.
1975

MUHR, C.R., DATTA, N.P., SANKRASUBRAMONEY, H., LELEY, V.K. and DONAHUE, R.L. Soil
1965 Testing in India. USAID, New Delhi.

PATHAK, A.N., TIWARI, K.N. and MISRA, M.P. Fert. News, 21(5): 17.
1976

PATHAK, A.N., TIWARI, K.N. and PRASAD, J. J. Indian Soc. Soil Sci. 23: 207.
1975

PARKER, F.W. et al. Agron. J., 43: 105.
1951

PERUR, N.G., SUBRAMANIAN, C.K., MUHR, G.R. and RAY, H.E. Soil fertility evaluation to
1975 serve Indian farmers. Mysore Department of Agriculture.

PRASAD, R. Pl. Soil., 23: 261.
1965

SINGH, R. and BRAR, S.P.S. J. Indian Soc. Soil Sci., 21: 213.
1973

SUBBIAH, B.V. and ASIJA, G.L. Curr. Sci. 25: 259.
1957

RAO, S.V. Proc. Workshop Soil Testing, F.A.I. 51.
1975

RAO, T.M.V. and RAO, K.K. J. Indian Soc. Soil Sci. 11: 165.
1963

RAMAMOORTHY, B and HASAN, R.U. Intern. Symp. on Improving Crop and Animal Productivity -
1977 Nuclear and Allied Techniques.

RAMAMOORTHY, B. and BAJAJ, J.C. Fert. News 14(8): 25.
1969

RAMAMOORTHY, B. All Indian Co-ordinated Scheme for Investigations on Soil Test - Crop
1971 Response Correlation. Report 1970-71 (unpublished).

RAMAMOORTHY, B. Proc. Workshop Soil Testing, F.A.I. 39.
1975

REPORT on All India Co-ordinated Scheme on Soil Test Crop-Response Correlation.
1968

SOIL TEST WORK. Group of National Soil Research Committee Tech. Bull. N. Carol. Agric.
1956 Exp. Stn. 121.

VERMA, Y.S. and BENNET, J. Fert. News 16(2): 37-39.
1971

VERMA, Y.S. Proc. Workshop Soil Testing, F.A.I. New Delhi. 27.
1975

Paper 8 THE OPERATION OF SOIL AND PLANT TESTING SERVICES IN THE DOMINICAN REPUBLIC

by

G.A. Tirado
Soils Department, CNIECA, San Cristóbal, Dominican Republic

1. INTRODUCTION

The Dominican Republic occupies an area of 48 442 km^2 lying in the eastern two-thirds of Hispaniola Island (La Española) in the Caribbean and has a population of about 5 million Spanish speaking people. Normal temperatures range from 25 to 35°C and although the average precipitation is 1 600 mm per year, it varies according to sectors from less than 300 mm to over 2 500 mm per year.

The first government soil testing service was started in 1936. Today there are seven test centres operating, excluding university testing laboratories.

2. ORGANIZATION AND FINANCIAL ASPECTS OF SOIL AND PLANT TESTING SERVICES

2.1 Soil and Plant Testing Laboratories

Of the seven laboratories, three are privately owned. The objectives of these laboratories differ.

Name	Ownership	Objective
National Centre of Research, Extension and Training (CNIECA), San Cristóbal	State	General soil and plant testing services
Centre of Agriculture Development in the North Region (CENDA), Santiago	State	General soil and plant testing services
State Sugar Centre (CEA), near Santo Domingo	State	Testing for sugar plantations only
Romana, Gulf and Western	Private	Testing for sugar plantations only
FERQUIDO, Santo Domingo	Private	Selling company products
COINPESA, Santo Domingo	Private	Selling company products
National Institute of Hydraulic Resources, Santo Domingo	State	Testing for irrigation projects mainly

The first two laboratories are technically under the Soils Department of the Secretary of State for Agriculture, and this paper refers to them alone as being the only ones which perform a public service to farmers and general agricultural research. Santiago is in the north and San Cristóbal in the south of the country, 150 km and 30 km distant from Santo Domingo. Until recently there has been FAO technical cooperation in Santiago and at times, AID, through a North Carolina U.S. private company, has supported the laboratory in San Cristóbal.

The average annual budgets of these laboratories are distributed as follows:

Laboratory	Personnel			Materials and chemicals	
	No.	US$	%	US$	%
CNIECA, San Cristóbal	13	43 440	74.0	15 000	26.0
CENDA, Santiago	8	24 600	59.0	17 000	41.0

The operation is financed by the government through its general budget. Recently there has been support from an Inter-American Development Bank loan for equipment, chemicals and salaries of personnel. The laboratory in Santiago obtains additional funds by charging a fee for each analysis to cover basic costs.

2.2 Coordination between Laboratories

The two laboratories, although having good relations, find it difficult to coordinate methodologies, equipment or personnel. Thus, services are not standardized and interpretations and recommendations are not made with the same criteria. An explanation for this could be the different sources of funding and technical assistance.

2.3 Supply of Equipment, Materials and Chemicals

Most equipment is imported and was obtained through OAS, FAO, AID, BID, by means of loans or grants. It is very difficult to obtain materials and chemicals since these must also be imported, and government procedure for acquisition is slow and complicated. At the present time some chemicals are supplied by the International Coffee Organization since the Department is doing a soil survey in areas where coffee is planted.

2.4 Functioning of the Soil and Plant Testing Service

Users learn of the service from other users and from extension personnel. The service can be obtained by taking soil samples on the farms, filling in an information sheet and sending the samples with the form to the laboratory.

Samples are drawn by the farmers, by extension agents or personnel of the Soils Department. The Soils Department is trying to arrange carriage of samples by mail.

Once in the laboratory, the samples are registered, coded, and stored for analysis after drying and sieving. Space available is sufficient for six months of storage. All laboratory premises are air conditioned.

For fertilizer recommendations, the basic analyses performed are: pH, organic matter (OM), electric conductivity, phosphorus and potassium. In special cases tests are made for exchangeable calcium, magnesium, copper, iron, manganese, zinc, sulphur and boron. Molybdenum and aluminium are not determined yet, although equipment and well trained technicians are available.

For soil classification, basic analyses are pH (in water at two ratios and with calcium chloride), electric conductivity, moisture percentage, organic carbon, nitrogen, calcium carbonate, calcium, magnesium, potassium, exchange capacity and texture. In special cases, phosphorus, carbonates, bicarbonates, sulphates, chloride etc. are determined.

For research in soil fertility, analyses are similar to those undertaken for farmers or for soil classification. Analyses for plant samples are: P, K, Ca, Mg, Na, Cu, Fe, Mn, Zn, S, B and N. Water for irrigation is tested for pH, electric conductivity, CO_3, HCO_3, Cl, SO_4, Ca, Mg, Na and K. Samples of fertilizer are tested for N, P, K and by arrangement with the suppliers, Mg, moisture percentage, particle size and physical condition.

2.5 Interpretation and Recommendations

Results of analysis are reported on printed forms. Interpretation is made by technical personnel of the Department and recommendations are based on the following previously established critical levels and research results obtained in countries with similar conditions.

Element	Critical Level of the Element
K	0.2 meq/100 cm^3 of soil
Ca	2.2 meq/100 cm^3 of soil
Mg	0.8 meq/100 cm^3 of soil
P	12.0 $\mu g/cm^3$ of soil
S	12.0 $\mu g/cm^3$ of soil
B	0.2 $\mu g/cm^3$ of soil
Fe	16.0 $\mu g/cm^3$ of soil
Zn	3.0 $\mu g/cm^3$ of soil
Cu	1.0 $\mu g/cm^3$ of soil
Mn	5.0 $\mu g/cm^3$ of soil

Additional information for recommendations includes that supplied by the information sheet, soil classification reports and soil fertility research results obtained on specific crops and soils in this country.

Results and recommendation reports are delivered by mail or personally to the user when possible. The Department hopes that local extension personnel will assume responsibility for conveying the results to farmers. Local centres for distribution of agricultural supplies are also a source of technical assistance for this purpose.

3. PROBLEMS OF METHODOLOGY

3.1 Brief Description of the Soil and Soil Fertility Status in the Dominican Republic [1/]

The soils of the Dominican Republic vary widely. They range from being sandy to very high in clay; from strongly acid to alkaline (pH 3.8 - 8.7); and from infertile to fertile /0.2% - 11.4% OM, 0 - 53 ppm P (121 ppm P_2O_5), 4 to over

1/ Source: Free, J., Conrad, K. and Foster, T.H. Dominican Republic Fertilizer Situation. National Fertilizer Development Centre, Tennessee Valley Authority. Bulletin Y-103, 1976.

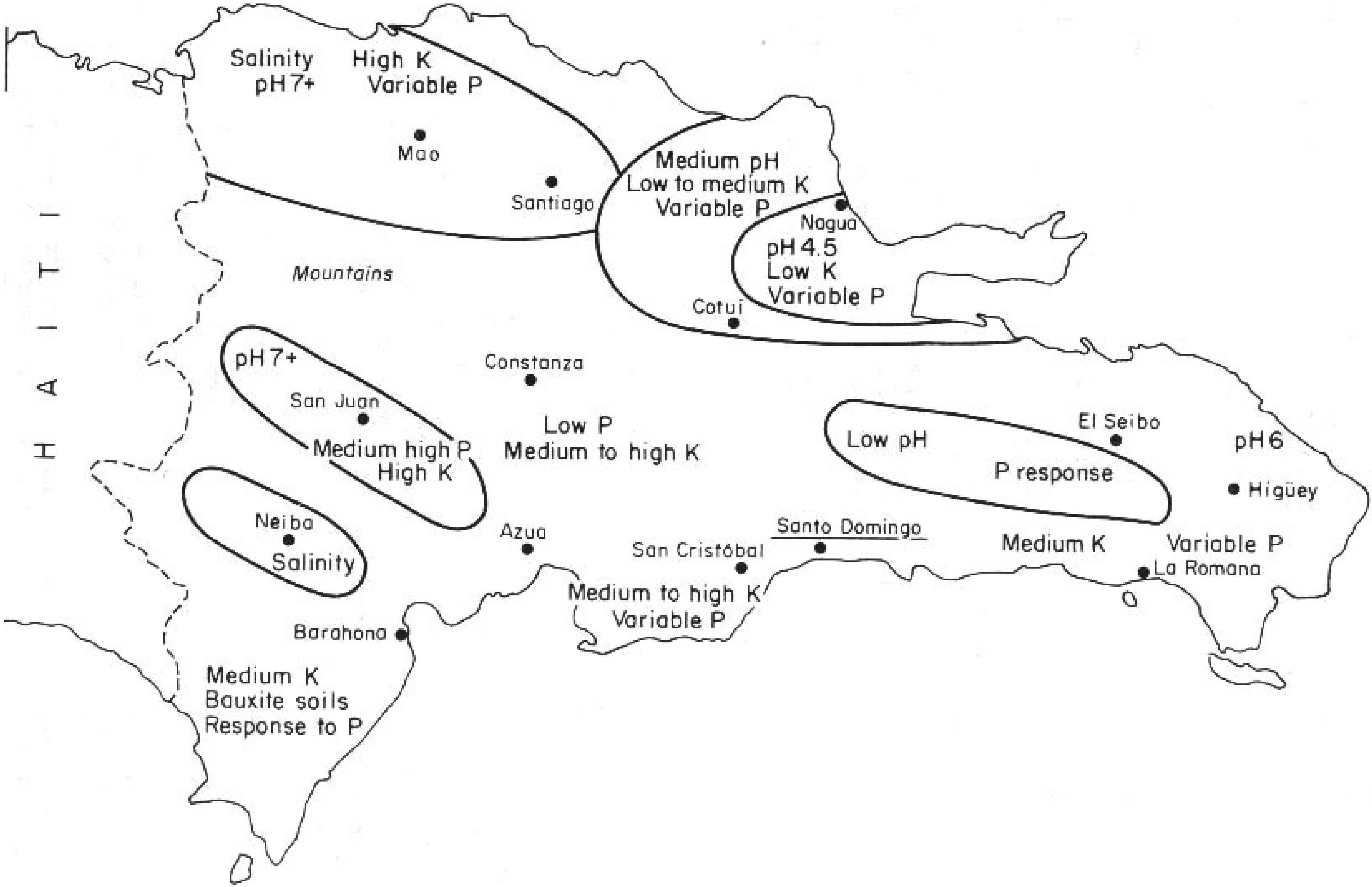

Fig. 1 General map of soil fertility status in the Dominican Republic

830 ppm K (5 to over 1 000 ppm K_2O) 7. Most of the soils are not highly weathered; they are developed on residual rock or alluvial materials and are relatively young. The soils in the Cibao Valley show that clays are predominantly of the 2:1 type and are largely montmorillonite. Thus, they have a large cation exchange capacity and the Cibao Valley soils have a high saturation of calcium, magnesium and potassium. Soils in the southeast coastal plain and the acid savanna soils are low in cation exchange capacity.

Although soils in the Cibao Valley have been evaluated more thoroughly than those of the remainder of the Republic, the entire country has been mapped according to land capability classes.

According to the OAS land capability report, only 12.6% of the land in the Dominican Republic is in classes I, II or III, the classifications of soils best suited for cultivation. Land capability classification is based largely on topography and physical factors which influence erosion and drainage. Although certain soils may possess textural and other physical characteristics favourable to crop production, soils in class I, II or III are not necessarily highly fertile or free of production problems. The report indicates that soils in the Dominican Republic are extremely variable. Knowledge of the chemical characteristics of most soils is incomplete. A very rough approximation of the soil fertility status and expected general crop response to fertilization in major agricultural areas can be seen in Figure 1. The Dominican Republic Tobacco Institute has published a general soil fertility status map of tobacco growing areas.

More information is needed on soil chemical characteristics and various crop responses to fertilization to delineate accurately crop response to fertilizer and the effect of adverse conditions, such as soil acidity, on crop production.

3.2 Methodological Problems related to the Nature of the Soils

The traditional Kjeldahl method is used for nitrogen. The modified Olsen method of extraction is used for phosphorus, K and micronutrients. Then, colorimetric methods are used for P and atomic absorption spectrophotometry are used for the remainder.

In general, few problems of methodology have been found. However, there is little experience of handling problems such as those arising from soils with excess calcium, sodium, manganese, iron and aluminium (the last is not determined). Exchangeable calcium is not determined for soils with an excess of calcium carbonate. Recently, problems with Mn determinations have arisen as successive analyses of the same sample have given significantly different results. Some samples of apparently non-sodic soils show large amounts of exchangeable sodium. Another problem that is being studied is the improvement of textural analysis for soils high in $CaCO_3$ and organic matter.

4. EXTENSION TO FARMERS ON THE RESULTS OF SOIL AND PLANT TESTING ANALYSIS

At the moment there is no effective extension support to the farmers on this subject. Some of the reasons are:

i. extension service personnel are sometimes unaware of the soil testing services available and agronomists lack the knowledge to give advice to the farmers;

ii. local extension service personnel are loaded with functions other than those pertinent to extension, such as credit, supplying agricultural inputs, marketing, etc.;

iii. the general belief of individuals that the knowledge they have about soils is sufficient; hence, no interest is shown in results and information that the Soils Department can release or offer.

Paper 9 PROBLEMS IN SETTING UP SOIL TESTING LABORATORIES IN DEVELOPING COUNTRIES

by

R.G. Menon
National Soil Service, Tanga, United Republic of Tanzania

1. INTRODUCTION

In many developing countries very scanty information is available regarding the soils and their agricultural potential. The land is cultivated in the traditional way, crop yields depending entirely on the vagaries of nature. However, with the introduction of commercial fertilizers, irrigation systems and high yielding carieties of crops, farming is gradually becoming more of a scientific discipline, though to a large extent it still remains a gamble. With the high cost of inputs and the small return from his investment, the farmer cannot afford to take chances with his fertilizer applications. Therefore, to guide the farmer in soil fertility management, soil testing services are being established in almost all developing countries of the world.

Though soil testing has been in vogue in industrialized countries for a long time, in most developing countries soil testing is in an infant stage. Soils laboratories do exist attached to research stations and universities, but these are mainly concerned with the analysis of a few samples for research purposes, soil characterization, or for teaching. Establishment of routine soil testing laboratories has lagged behind due to various problems.

The main difficulties faced while setting up laboratories in different countries are more or less the same: personnel, equipment, finance and facilities.

2. PERSONNEL

Recruiting qualified personnel who can be trained to operate a laboratory is one of the serious problems in establishing and operating successfully a soils laboratory. Each soil testing unit will need a director who should at least be a university graduate in chemistry with specialization in soil testing. He has to supervise the work of the staff, train them, ensure quality control, interpret the results of the analyses and issue recommendations. Besides the director, a number of technicians are required to do the actual analysis. These should be dilpoma holders from analytical institutes or at least high school graduates with enough background in basic sciences who, with competent training, can become proficient in carrying out individual tests. People belonging to the same group can be trained to collect soil samples. Besides these, workers are needed to receive the soil samples, check them for damage and contamination, register and keep records and prepare the samples for analysis.

While in certain less developed countries there is no scarcity of qualified people, even those with post graduate qualifications, in most developing countries, to secure the services of a high school graduate, let alone a university degree holder, is often very difficult. With the expansion of industries, bilateral aid projects and so on, there is a keen competition for securing the services of the few students who come out of the schools and universities every year. Often, given a choice, the graduates prefer to work in better paying private organizations.

In some developing countries, the university graduates have a feeling that having passed the few courses on the subject, they have acquired whatever knowledge they need. Most of them prefer to sit in the office and supervise the work rather than do the laboratory work themselves.

The frequent transfer of personnel from one research station to another is another common problem in many developing countries. People sent abroad on fellowships to study soil chemistry find on their return that they have been transferred to fields completely unrelated to their training.

3. EQUIPMENT

The necessary equipment and chemicals is very difficult, if not impossible, to obtain in most of the developing countries. All the instruments have to be imported from industrialized countries. This generally takes from six months to a year or more, provided sufficient foreign exchange is made available. Instances are known where the delay in getting the equipment was so great that by the time the goods came, the person who had ordered them had already left the country and the instruments remained in their packing cases for years.

Replenishing the consumable goods is another problem. This applies especially to chemicals. The work in the laboratory comes to a standstill due to lack of the necessary reagents.

Maintenance of instruments is also a serious problem. Owing to the high humidity and temperature, the instruments start deteriorating rapidly. Spare parts are not available in most places, and even if they are imported, no expertise exists to repair the instruments. In many laboratories, one can see expensive pieces of machinery lying idle because of some minor defects. Repairs to a pH meter or spectrophotometer become such a costly and time-consuming affair that it is often easier to order a new one.

The purchase of complicated instruments in developing countries is to be discouraged. While autoanalysers, atomic absorption instruments and so on may be standard equipment in industrialized countries, the developing countries need simple instruments which can be operated and maintained easily. Certain laboratories set up with foreign collaboration have been show-pieces as long as the foreign experts remained, only to become museum pieces afterwards.

Another problem, though minor, is that when instruments are obtained from abroad, they often arrive without the connecting wires, plugs, etc. and at times it may be difficult to find these in the local markets.

4. FINANCE

Money can be a big problem everywhere. If the laboratory is to be set up under bilateral or multilateral assistance programmes, the initial foreign exchange requirements will be easily met, but not so if the soil testing laboratory is to be set up by the local department concerned.

Even after the initial capital expenditure, sufficient budgetary provisions have to be made for the operating expenses, for the purchase of locally available goods and services. Arranging a transport or field allowance for the persons collecting the soil samples can often become a big bottleneck.

5. FACILITIES

The first prerequisite for the establishment of a laboratory is an adequate building to house it. The size of the building will depend on the expected volume of work. Though it would be ideal to plan a building to meet requirements precisely, this is usually not possible and the laboratory has to be housed in some existing laboratory building or at times in a few rooms or a shed.

The supply of adequate running water and electricity has been a major problem in many laboratories. In some countries, the main source of water has been stored rain water, but such supplies will last for only a few days once a laboratory starts functioning. Even where a limited town supply is available, there will often be strong competition between the local residents and the laboratory to utilize it and more often the laboratory is the loser. In one particular instance, for example, a special pipeline to supply water to the laboratory was laid by the water supply department. It worked perfectly for some time until the house owners along the route discovered it and started to tap it for water. In about two months, the water supply was such that water had to be carted in by trucks. In another place, there was a long line of women and children with buckets near the outside tap, with the result that the distilled water still could seldom be operated because of the low water pressure.

Erratic electric supply is another common problem. The power supply fluctuates so much and the voltage becomes so low at times that even with stabilizers, it becomes difficult to operate the instruments.

In many places it is also difficult to get gases for instruments such as a flame photometer, especially gases like acetylene and oxygen.

6. LIBRARY FACILITIES

In several countries, library facilities are very limited. No catalogues, textbooks or scientific publications may be available. Unless a person goes armed with the necessary current catalogues, it will not be possible to place an order for equipment to suit local conditions.

7. LACK OF ADEQUATE INFORMATION

Though a great deal of work has been done in advanced countries on soil testing in relation to fertilizer recommendations, the soil test interpretations developed in these countries cannot be transferred to developing countries. Research work on the analytical methods and their correlation with crop response must be carried out in each country.

The establishment of the soils laboratory is often the first step. With little or no data existing regarding the soils, climatic conditions, management practices and so on, the soil chemist finds it very difficult to issue any recommendations.

Requests are often received from individuals or firms to send someone to collect the samples and test them. Educating the public about what the soils laboratory can and cannot do is important. Soil testing is no remedy for all soil fertility problems.

8. CO-ORDINATION OF WORK

In some countries, soil testing laboratories have been set up at different centres by different foreign aid programmes. Since the equipment, money, and experts are supplied by the donor countries, each such centre becomes a scaled-down version of the institutions existing in the donor country. This often results in the various laboratories in the same country following different methods of analysis and using different terminologies. Uniformity in methodology and reporting systems is very important; however, as each laboratory works independently of the others, it becomes rather difficult to introduce this uniformity.

Paper 10 PROBLEMS CONNECTED WITH SOIL TESTING FOR PHOSPHORUS AND POTASSIUM

by

H.W. Fassbender
Institut für Bodenkunde und Waldernährung der Universität Göttingen
D-3400 Göttingen-Weende, Büsgenweg 2

1. INTRODUCTION

More than 100 years ago, Justus von Liebig, a well known German chemist and soil-plant scientist, expressed "A rational system of agriculture cannot be established without the application of scientific principles, for such a system must be based on an exact knowledge of nutrition of plants and the influence of soils and action of manure upon them". Such thoughts from Liebig pointed out the importance of plant and soil analysis as a measure of the needs of plants.

In general the objectives of soil testing for the evaluation of nutrient availability can be defined as:

- to classify the soils into availability groups for recommendations of fertilizer and lime practices;

- to predict the economically possible yield response to applied fertilizers and lime;

- to develop some soil parameters for evaluation of its productivity.

Many chemical techniques have been proposed for measuring nutrient availability. Early work on soil testing for phosphorus availability in the USA was reviewed by Bingham (1962); Chapman's book on "Diagnostic Criteria for Plants and Soils" (1965) reviews the different methods of soil and plant analysis used worldwide for all important chemical elements. The methods tested in French-speaking Africa were presented by Pichot and Roche (1972). Recent research in soil testing was summarized in the proceedings of international congresses in Latin America (Bornemisza and Alvarado, 1975) and India (Kanwar *et al.* 1971; Biswas, 1976). A survey of soil laboratories for 64 FAO country members showed the range of variations in the different methods used for P and K determinations (Brogan *et al.* 1965).

For the selection of chemical methods the following criteria are very important:

- the extractant should extract all or a part of the "available" nutrient from soils of variable characteristics; the available nutrient is an ambiguous term; it is only important that:

- the amount extracted should correlate with the growth and response of many crops under varying conditions. Under greenhouse conditions, the environment can be controlled, whereas field experiments relate to the natural growing conditions;

- the interpretation of soil test data should allow the division of soils into groups (deficient and sufficient or low, medium, and high) based on the field calibration of the method, when plants are grown to maturity;

- the extraction and measurement of nutrients should be reasonable accurate and quick.

This paper will deal with the basic aspects of soil-plant relationships in order to choose chemical methods and will present some examples of the work done in this field in tropical soils.

2. SOIL-PLANT RELATIONSHIPS FOR PHOSPHORUS AS A BACKGROUND TO SOIL TESTING FOR P

The growth of plants requires the continuous movement of ions of nutrients from the soil to the plant. The ions pass through the soil solution where they are in contact with the root surface and are finally absorbed by the plants. Figure 1 presents a model of such a soil-plant system for phosphorus. The calcium, iron and aluminium phosphates can liberate P ions to the soil solution by dissolution or exchange processes. Organic phosphorus compounds can also be mineralized, so supplying $H_2PO_4^-$ ions to the soil solution. These phosphate fractions can be considered as the phosphorus reserve in the soil. The reductant-soluble occluded phosphorus forms are not completely defined chemically; they are supposed to be related to concretions of hydrated iron and aluminium oxides and are not immediately available to the plants.

Several methods have been proposed for the chemical fractionation of soil phosphorus using selective extractants to differentiate between the specific chemical form or groups of compounds. The method of Chang and Jackson (1957) is used worldwide, although the separation of aluminium and iron phosphate is not very accurate. Many authors have proposed variations of the method by changing the pH of the extractant for Al-phosphate. The results presented in Figure 1 were obtained by Fassbender et al. (1968, 1969, 1972) for 110 soils from Central America using the Chang and Jackson method, extracting aluminium phosphate with 1 N NH_4F adjusted at pH 8.5.

The phosphate soluble in NH_4Cl is a very small fraction and represents the water soluble and weakly bound phosphates. In these soils this fraction reached an average of 3.2 ppm. The average amount of iron phosphates was 62 ppm, those of aluminium and calcium phosphate were 70 and 131 ppm respectively.

The solubility product principle has also been used to interpret the possible phosphate forms and their availability in soils. From the solubility product of chemically well defined phosphate the product of ion activities can be calculated. Under equilibrium conditions of soil solution, the ion activities can be calculated and compared with those phosphorus forms and their presence can be predicted. This approach has been demonstrated by Fassbender et al. (1969) and Ulrich and Khanna (1968). The phosphorus potential, calculated as pH + pH_2PO_4, was well correlated (r = −0.80) in the 110 Central American soils with the P uptake of tomato plants grown in the greenhouse (Fassbender et al. 1969). This term describes the actual availability of phosphorus. Results obtained for Australian soils (White and Haydock, 1967; Dalal and Hallsworth, 1976), Rhodesian and Zambian soils (Salmon, 1966) and Indian soils (Saxena, 1971) confirms the suitability of ionic activities as an intensity parameter for the phosphorus availability determination.

The correlations of the phosphorus potential with the phosphorus forms in Figure 1 indicated which fraction supplies P to the soil solution. The NH_4Cl fraction is the one best correlated (r = −0.579***), but the quantity is too small to cover the needs of actively growing plants. The phosphorus supplied by those soils came from the calcium and aluminium-bound fractions (r = −0.508*** and −0.455*** respectively).

From the point of view of plant nutrition, this P model has some limitations. Figure 1 shows that the soils have a considerable reserve of organic phosphates which in time and through mineralization can supply large amounts of phosphorus,

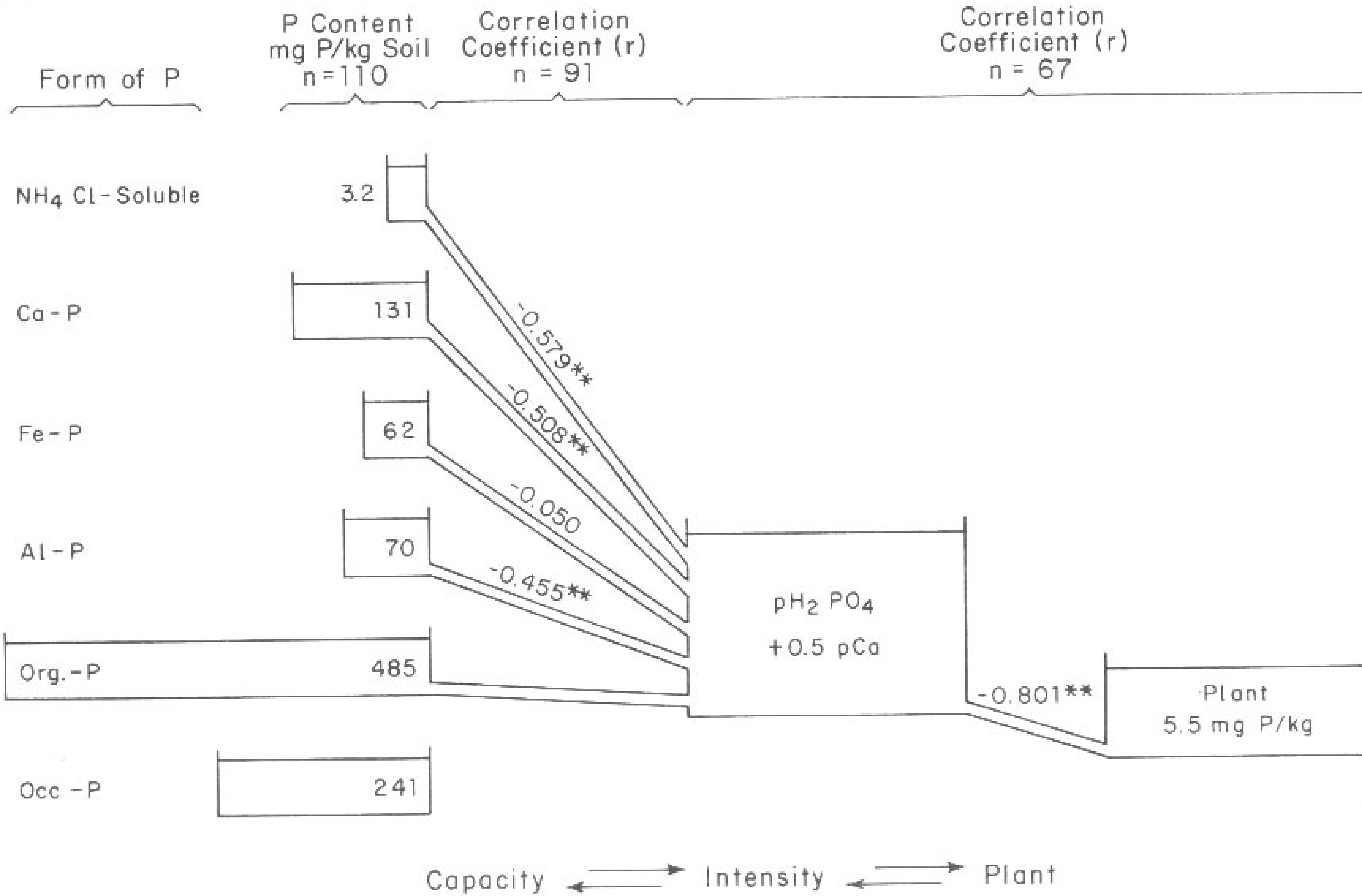

Fig. 1 Phosphorus soil-plant system (recalculated from Fassbender *et al* 1968, 1969, 1972)

but no correlations have been calculated. On the other hand, the determination of the phosphorus potential refers only to an instant in time; in the soil there must be continuous changes and the establishment of new equilibria. A model representing the real soil-plant system should consider varying fluxes and a mathematical resolution of the system based on simulation techniques (Ulrich et al. 1973).

From the point of view of routine soil testing for the prediction of phosphorus availability, the model has severe limitations. Fractionation of the phosphorus requires the use of at least 6 extractants and it is a costly and time consuming technique. On the other hand, the implications of the use of complicated physico-chemical terms for describing P availability as P ionic activities are beyond the understanding of non-specialists. It can only be understood by specialists. For the assessment of phosphorus availability in routine laboratories other techniques should be developed. The diagram shows that the chosen extractant for a group of soils should extract accurately the actually available phosphorus (intensity) and a representative part of the reserve phosphorus (capacity) from the different fractions with an acceptable correlation with the phosphorus uptake of a given crop.

The distribution of the inorganic phosphorus in the profile varies considerably and clearly depends upon many factors such as pH, weathering intensity, age and cultural treatment. In neutral and calcareous soils Ca phosphate predominates. During soil development Fe- and Al-P are formed of which Al-P initially predominates. With time, however, there is a change from Al-P to Fe-P, which is more stable. Additional weathering results in the formation of occluded, sesquioxide bound phosphorus. Table 1 presents a summary of results obtained in many soils from Latin America. From the results obtained in the above mentioned soils from Central America, Fassbender et al. (1968, 1969) proposed the classification of soils in accordance with the predominance of Ca-P or Al-Fe-P, the distribution of which is determined by the pH value (Figure 2). From the soil testing point of view, the classification of the soils into two general groups means that the selected extractant has to be reasonably specific for the predominant phosphorus form.

SOIL PHOSPHORUS TESTING IN NEUTRAL AND CALCAREOUS SOILS

In Table 2 are summarized ten of the most important routine methods of determination of available phosphorus used worldwide. They have been partly tested in several programmes to select one suitable for routine analysis of agricultural soils.

The methods requiring large volumes of extracting solution have limitations for routine analysis due to equipment and glassware. Methods with a very short time of shaking are also inappropriate because of the lack of reproducibility of the results.

These extractants can be differentiated by their mechanisms of bringing P into solution. In NH_4F methods (Bray Nos. 1 and 2), F^- complexes the Al and so releases P, and these methods are appropriate in Al-P dominant soils. $NaHCO_3$ (Olsen) at pH 8.5 promotes the hydrolysis of Al and Fe phosphates, and activates the release of P in Ca phosphates; it therefore releases very specifically these three P forms. Very alkaline solutions (Saunder) extract large amounts of Al- and Fe-P and the organic P. Acidic solutions at low pH (Truog, Bondorff, Mehlich, North Carolina) dissolve some of the Al- and Fe-P and large amounts of Ca phosphates. Salts of organic acids at medium pH (Morgan, Egner) remove specially Ca phosphates. The resin method is based on the surface exchange of phosphorus through SO_4^{--} or HCO_3^- (Cooke, 1966; Cooke and Hislop, 1963; Marttingly and Talibudeen 1967).

Table 1 CONTENT AND FORMS OF PHOSPHORUS IN SOME SOILS FROM LATIN AMERICA

Source	Country, region	No. of Samples	Total P	Al-P	Fe-P	Ca-P	Occlu-ded P	Orga-nic P	% Org-anic P
			ppm						
Garcia (1963)	Mexico	7	-	11	18	175	-	-	-
Dahnke et al. (1964)	El Salvador	17	601	25	47	75	61	73	12
Chaverri (1958)	Costa Rica	16	1444	218	176	51	147	-	-
Fassbender et al. (1968)	Central America								
	(Ca-P predominant)	80	889	58	40	161	251	370	41
	(Al, Fe-P predominant)	30	1241	104	120	50	214	752	52
Fassbender (1975)	Central America (volcanic ash)	34	1142	92	55	124	274	496	43
Tafur and Blasco (1969)	Colombia, Valledupur	11	415	27	49	67	151	114	27
Bastidas and Blasco (1970)	Colombia, Putumayo	45	1270	226	189	40	431	379	30
Blasco (1969)	Colombia, Narino, Altiplano		1442	155	177	138	858	123	8
	Medio		534	57	48	53	301	74	
Blasco and Bohorquez (1968)	Colombia, Cauca	11	591	32	54	36	344	120	20
Westin and Brito (1969)	Venezuela	23	204	21	28	18	-	80	39
Fassbender and Diaz (1970)	Brazil, Maranhao	8	600	17	21	15	107	437	73
Cabala and Fassbender (1970)	Brazil, Bahia	8	713	11	42	31	200	432	61
Vieira and Bornemisza (1968)	Brazil, Amazonas, Latosol	7	369	52	37	10	-	147	40
	Non-Latosol	5	[illegible]	28	88	12	-	216	39
Coulot and Bolanos (1967)	Argentina, Buenos Aires	3	646	19	19	49	3	305	4[illegible]
Ahmad and Jones (1967)	Barbados	6	1725	185	128	413	322	-	-
Fassbender (unpubl.)	Puerto Rico, Oxisol	29	541	9	82	14	322	-	-
	Ultisol	31	362	4	73	9	256	-	-

Table 2 EXTRACTION METHODS FOR AVAILABLE SOIL PHOSPHORUS

Method	Reagent	Weight of soil (g)	Volume of solution (ml)	Time of shaking	pH
Truog	0.002N H_2SO_4 (buffered with ammonium sulphate at pH 3)	1	200	30 min	3
Bondorff	0.2N H_2SO_4	1	50	16.5 h	~ 1
Bray and Kurtz No.1	0.03N NH_4F in 0.025 N HCl	3	20	1 min	2.5-2.6
Bray and Kurtz No.2	0.03N NH_4F in 0.1 N HCl	3	20	1 min	1.5-1.6
Olsen	0.5N $NaHCO_3$ (adjusted to pH 8.5 with NaOH)	2.5	50	30 min	8.5
Morgan	0.5N acetic acid in 0.75 N sodium acetate, pH 4.8	5	25	15 min	4.8
Mehlich, North Carolina	0.05N HCl + 0.025 N H_2SO_4	5	20	5 min	1.7
Saunder	1N NaOH	1	50	30 min	~ 14
Joret and Herbert	0.2N ammonium oxalate	4	100	2 h	—
Egner *et al*.	Ammonium lactate-ammonium acetate (0.1N ammonium lactate, 0.4N acetic acid)	5	100	5 h	4.0
Amer *et al*., Cooke	Anion resin, Dowex 2X8 and water	1	100	2 h	—
Van der Paauw	Water				

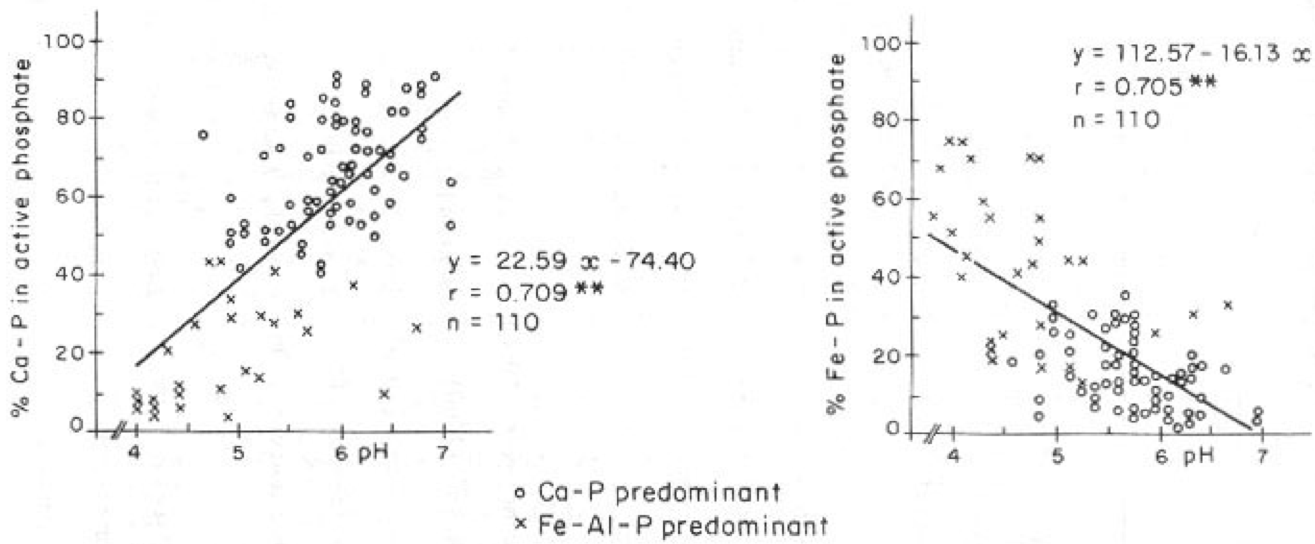

Fig. 2 Relationships between pH and Phosphorus forms
(Fassbender *et al* 1968)

Nine of the 10 methods presented in Table 2 were tested by Walmsley and Cornforth (1973) on 155 West Indian soils. The soils from twelve Caribbean islands of widely varying conditions are characterized specially by their neutral pH values (28 % with pH >7, 48 % with pH 5.5-7.0, 24 % with pH <5.5) and calcareous origin (Cornforth and Walmsley, 1971). They correlated the amount of P extracted with P uptake by maize plants and with the relative yield of dry matter production from the NK treatment expressed as a percentage of the NPK treatment in the greenhouse experiment. Correlations with P uptake were better than those with percent yield.

From Table 3 it can be seen that Olsen's method gives the best correlation with P uptake (r = 0.73 ***). After differentiation of the three pH groups, as mentioned above, higher correlations were reached (r = 0.75** to 0.82***). The resin method also yielded good results (r = 0.73***), although at lower pH values (5.5) the correlation coefficients were lower. All other methods tested yielded lower correlations. Olsen's method has been recommended by many authors as giving the best indication of crop yield response and P uptake both in greenhouse and field experiments for South Africa (Du Plessis and Burger, 1965), Taiwan (Tseng and Wang, 1964), Central America (Fassbender et al. 1968), India (Saxena, 1971), Australia (White and Haydock, 1967), Venezuela (Bascones and Lopez-Ritas, 1961), Chile (IIAP, 1966), Bolivia (Fitts, 1972). Olsen's method is widely used in many tropical countries (Brogan et al., 1965; Kanwar et al. 1971; Sanchez, 1972).

Table 3 SOIL PHOSPHORUS EXTRACTED BY DIFFERENT METHODS OF ANALYSIS AND CORRELATION COEFFICIENTS WITH GROWTH OF MAIZE

Method	Phosphorus extracted ppm P		Correlation coefficient (155 soils) Soil test value	
			%	P
	Mean	Range	Yield	Uptake
Total	457	40 - 10 333	0.22**	0.46***
Organic	266	7 - 2 733	0.12	0.28***
Truog	54	2 - 764	0.32***	0.33***
Bray No.1	10	1 - 186	0.32***	0.59***
Bray No.2	32	1 - 569	0.35***	0.45***
Olsen	11	1 - 111	0.46***	0.73***
Bondorff (modified)	174	10 - 1 150	0.37***	0.51***
Morgan	7	1 - 305	0.20*	0.25**
Amer	13	1 - 111	0.49***	0.72***
Joret and Herbert	43	2 - 430	0.37***	0.43***
Egner-Riehm	45	1 - 680	0.40***	0.45***

Source: Walmsley and Cornforth (1973).

4. SOIL PHOSPHORUS TESTING IN ACID AND HIGHLY WEATHERED SOILS

In acid soils Al-P and Fe-P predominate (Figure 2) as a result of weathering processes. Most of these soils are P-deficient because they have been cropped for centuries without fertilization and have high phosphate fixing capacities due to the large amounts of iron and aluminium oxides. The extractant to be used under these conditions should be selective for Al- and Fe-P. Table 4 presents the results obtained by Enwezor (1976) for 30 soils from southeastern Nigeria. He tested seven methods for soil P, and correlated their P values with the percentage yield of maize in greenhouse experiments after applying 112 kg P/ha. *Anion exchange resin, 0.02 N H_2SO and dilute acetic acid were least effective in extracting available phosphorus.* On the other hand, 0.01 N NaOH was very effective in extracting both inorganic and organic P. Dilute acid fluoride was intermediate, but gave the highest correlation with percentage yield (r = 0.71***). The fluoride ion displaces phosphate from iron and aluminium phosphates and the dilute hydrochloric acid in the mixture dissolves calcium phosphates; the more concentrated the hydrochloric acid (Bray No.2), the larger the amount of phosphorus extracted by the acid/fluoride solution. Bray's method has found a wide use in some tropical soils (Brogan et al. 1965; Sanchez, 1973; Kanwar et al. 1971).

Table 4 P EXTRACTION AND CORRELATIONS BETWEEN AVAILABLE PHOSPHORUS WITH PERCENT YIELD OF MAIZE IN 30 ACID SOILS FROM NIGERIA

Method	Extractant	P range (ppm)	Mean	Correlation coefficient (n = 30)
Bray No.1	0.03N NH_4F + 0.025N HCl	3.6-137.0	22.4	0.68**
Bray No.2	0.03N NH_4F + 0.1N HCl	4.3-140.0	27.1	0.74**
Resin	De-acidite FF II P	0.2- 21.0	3.8	0.72**
Morgan	10% NaAcO in 3% HAcO	0.4- 10.8	2.7	0.68**
Truog	0.002N H_2SO_4	1.3- 43.8	8.9	0.60**
Olsen	0.5N $NaHCO_3$	3.1- 63.0	11.3	0.67**
William	0.1N NaOH	8.8-460.0	55.8	0.58**
NaOH-total P	0.1N NaOH	32.8-806.0	158.1	0.56**

Source: Enwezor (1976)

5. FORMS OF POTASSIUM AND THEIR AVAILABILITY TO PLANTS

One can differentiate between four different kinds of potassium in the soil:

a) potassium in the soil solution,

b) exchangeable potassium,

c) "fixed" potassium, and

d) potassium in the crystalline mineral matrix.

Fixed potassium is located in the inner surfaces of clay particles of illite, vermiculite; potassium of the crystalline matrix is a part of minerals, such as micas, feldspars, hydrated micas and illitic clays. These two forms represent the largest proportion of total potassium and are not directly available to plants. Their distribution depends on parent material, state of weathering, clay content and clay type. Greenhouse experiments with intensive exhaustive cropping of the soil have given some evidence of extraction of fixed potassium by plants (Ahenkorah, 1970; Martini and Suarez, 1977). Its determination with boiling 6N HCl or other strong acid solutions is not appropriate for routine laboratories, especially if one considers that other K forms are primarily available to plants. In recent years there has been increasing interest in giving a complete description of the ion exchange processes, considering all ions present in the soil solution which are directly available to plants and those adsorbed by the soil which represent the reserve of cationic nutrients for the plants. This equilibrium between the solid phase and the liquid, can be expressed by the equation:

$$\sigma^{+}/\sigma^{2+} = f\left[(a^{+})/(a^{2+})^{\frac{1}{2}}\right]$$

Where: σ^{+} and σ^{2+} represent the amount in milliequivalents of monovalent ions and divalent ions, respectively, absorbed on the exchange complex, a^{+} and a^{2+} are the ionic activities of the same elements in the soil solution, and f is a constant of proportionality, or Gapon constant (Gapon, 1933).

Determination of exchangeable cations is widely used in the characterization of soils. Determination of the ionic activities of the elements in the soil solution is relatively simple. The soil is equilibrated with water or a weak solution of an electrolyte, such as 0.01M $CaCl_2$.

The cations K, Na, Ca, Mg and Al are determined in the solution equilibrated against soil, and from these concentrations the ionic activities are calculated, taking into account the Debye-Hückel laws. Cation equilibria such as these, presented on their own, give information on the momentary situation within the soil (intensity).

It is even more interesting to know the long-term behaviour of the soil potassium, in terms of its liberation or fixation consequent to an addition of potassium, or a loss through leaching or uptake by the plants (capacity). The idea of the determination of intensity/capacity relationships for cations is widely accepted today (Beckett, 1972). The associated technique consists of equilibrating the soil against solutions containing KCl and $CaCl_2$ and determining the ionic activities, and thus the gains or losses of the element from the equilibrium solution. The suitability of the use of cationic activities K, Ca and Mg as activity ratio or buffer capacity for the description of the available potassium has been widely demonstrated (Boyer, 1972; Beckett, 1972), also in tropical and subtropical soils from Ghana (Acquaye et al. 1967), Australia (Barrow, 1966; Barrow et al. 1965), South Africa (Leroux and Summer, 1968), Nigeria (Tinker, 1964) and Central America (Fassbender, 1972).

6. METHODS FOR K DETERMINATION

Although the ionic activities and buffering capacity describe accurately the availability of K to plants, they, as in the same method for P, cannot be used widely for routine analysis. According to the postulated criteria of suitability of a routine method for nutrient availability, the method selected for K determination should extract a large part of the available K and be well correlated with the plant response expressed as dry matter production, K uptake or percentage yield.

Table 5 shows the correlation coefficients between K extracted by different solutions and K uptake by tomato plants when no K had been applied to seven latosols and seven andosols from Costa Rica (Martini and Suarez, 1975).

Table 5 K EXTRACTION BY DIFFERENT METHODS AND ITS CORRELATION WITH K UPTAKE BY TOMATO PLANTS GROWN UNDER GREENHOUSE CONDITIONS IN LATOSOLS AND ANDOSOLS FROM COSTA RICA

Soil and method	K uptake Horizon A	Horizon B
LATOSOLS		
Mehlich $0.05N\ HCl + 0.025N\ H_2SO_4$	0.786**	0.923**
Morgan NaAcO + HOAc, pH 4.8	0.779**	0.880**
1N NH_4-AcO	0.867**	0.928**
HNO_3 (boiling)	0.899**	0.900**
ANDOSOLS		
Mehlich	0.732**	0.878**
Morgan	0.755**	0.745**
NH_4AcO	0.780**	0.870**
HNO_3	0.863**	0.402

Source: Martini and Suarez (1975)

Table 6 gives results obtained by Ahmad et al. (1973) on the evaluation of estimating available soil potassium for 151 soils in the West Indies with widely varying soil properties. In general, correlation coefficients between soil test values and K uptake were superior to those with percentage yield. Total K gave no significant correlations in any of the comparisons. The NH_4AcO (exchangeable) and cold H_2SO_4 were the most successful methods of all and the least sensitive to changes in soil properties. The range of soil characteristics (pH <5.5, 5.5–7.0, >7.0; percentage base saturation, <60, 60–79, >80 ; cation exchange capacity <10, 10–30, >30 meq/100 g soil and texture (clays, clayloams, loams and sand) reinforced the conclusion that NH_4AcO affords an accurate method for the routine determination of available K.

7. CALIBRATION OF METHODS

The calibration of the methods for P and K availability is the most important phase in soil testing. The classification of the soils into classes for the purpose of suggesting fertilizer practices has to be associated with a determinate crop and related to a certain soil group (genetical and geographical distribution). The information on calibration of chemical methods for P and K in tropical areas is still limited, although there is a very large amount on calibration under greenhouse conditions. It is essential to calibrate the methods in the field, where plants are grown to maturity under natural environmental conditions. As criteria for calibration one can use the:

a) nutrient concentration,

b) nutrient uptake, and

c) crop response as percent yield $\left\{\frac{\text{yield without nutrient}}{\text{yield with nutrient}} \times 100\right\}$.

Table 6 SOIL POTASSIUM EXTRACTED BY DIFFERENT METHODS OF ANALYSIS AND CORRELATION COEFFICIENTS BETWEEN LABORATORY ESTIMATES OF SOIL K AND PLANT GROWTH FOR 151 SOILS FROM THE WEST INDIES

Method of soil K analysis 1/	Mean	Range	Correlation Coefficient Soil test value	
			% Yield	K Uptake
Total K	11 400	700 - 52 000	0.14	0.02
NH_4OAc	199	4 - 1 197	0.36***	0.79***
CH_3COOH	318	16 - 2 399	0.28**	0.40***
H_2SO_4 (cold)	218	16 - 1 158	0.40***	0.81***
HNO_2 (boiling)	479	43 - 2 640	0.41***	0.63***

1/ See Pratt, 1965.

Source: Ahmad et al. 1973.

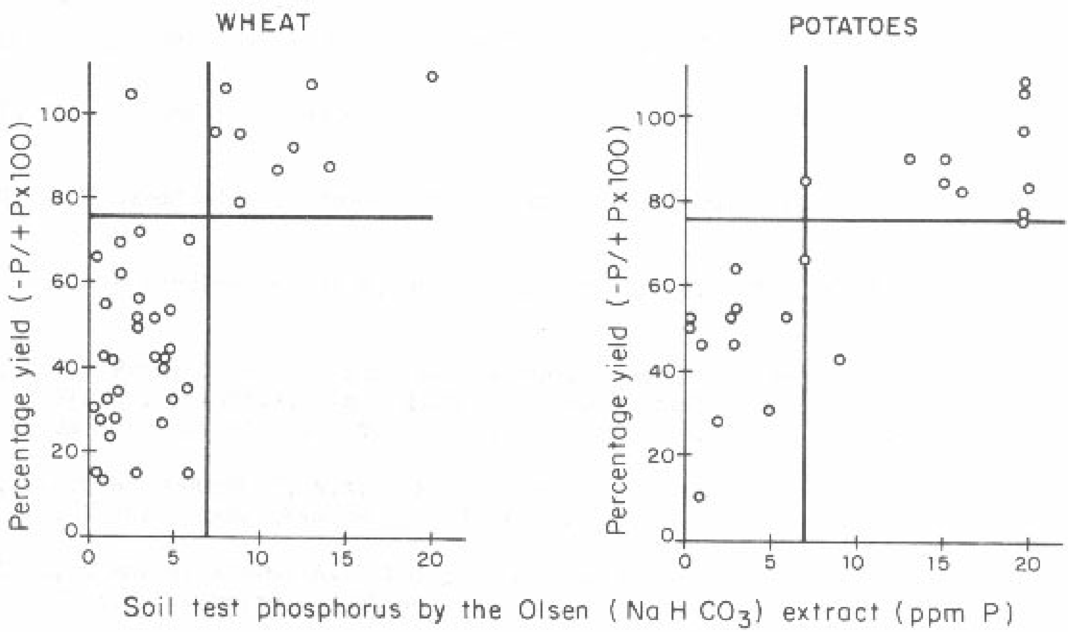

Fig. 3 Correlation studies (field trials) for phosphorus with wheat and potatoes in Bolivia (Waugh and Manzano, 1971; Fitts, 1972)

As an example of such a calibration, Figure 3 shows the results obtained in Bolivia for wheat and potatoes in a large group of soils using Olsen's method for P (Waugh and Manzano, 1972; Fitts 1972). Using the proposition of Cate and Nelson (1965) the critical level is determined by drawing two lines - one parallel with the X axis and the other with the Y axis - in such positions that there are a minimum number of observations in the upper left-hand and the lower right-hand quadrants. The intersection with the X axis is the critical level. This method can be regarded as being only the first stage of soil calibration, and is a possible way of separating deficient from non-deficient soils.

For fertilizer recommendations it is necessary to classify the soil nutrient contents in different groups such as low, medium and high. To separate these groups one has arbitrarily to fix the size of the expected response to applied fertilizer, which should be based on economic considerations. The levels of P or K availability are related to a specified crop in certain environmental conditions.

In the tropics there are a few countries or areas in which soil testing has been widely used in order to prepare fertility maps. Evaluating 4.5 million soil samples analysed during 1968 to 1974, Ghosh and Hasan (1976) presented a K availability map of India. The level of available potassium (NH_4AcO-extractable) has been found to be low in 20, medium in 42 and high in 38 percent of the districts covered. Such maps can be used for fertilizer planning purposes.

REFERENCES

ACQUAYE, D.K. et al. Potential and capacity of potassium in some representative soils of
1967 Ghana. Soil Sci. 103: 79–89.

AHENKORAH, Y. Potassium supplying power of some soils of Ghana cropped to cacao. Soil
1970 Sci. 109: 127–135.

AHMAD, N. et al. Methods of measuring available nutrients in West Indian soils. III
1973 Potassium. Plant and Soil 39: 635–647.

AHMAD, N. and JONES, R.L. Forms and occurrence of inorganic phosphorus and its chemical
1967 availability in the limestone soils of Barbados. Soil Sci. Soc. Amer. Proc.31: 184–188.

BALERDI, F. et al. Estudio del fosforo en suelos de America Central. III Comparación de
1968 cinco metodos quimicos de analisis de fosforo disponible. Turrialba 18: 348-360.

BASCONES, L. and LOPEZ-RITAS, J. Ensayo de calibración de metodos para la determinación
1961 de fosforo "asimilable" en suelos de la colonia agricola de Turen. II Journadas agronomicas 1961. Caqua, Venezuela.

BASTIDAS, O. et al. Formas de fosforo en suelos volcanicos del valle de Sibundoy, Putumayo.
1970 Turrialba 20: 434-438.

BARROW, N.J. Nutrient potential and capacity. II Relationship between potassium potential
1966 and buffering capacity and the supply of potassium to plants. Austr. J. Agric. Res. 17: 849–861.

BARROW, N.J. et al. Nutrient potential and capacity. I The concepts of nutrient potential
1965 and capacity and their application to soil potassium and phosphorus. Austr. J. Agric. Res. 16:61–76.

BECKETT, P.H.T. Studies on soil potassium I and II. J. Soil Sci. 15: 1–9, 9–24.
1964

BECKETT, P.H.T. Critical cation activity ratios. Advances in Agronomy 24: 379–412.
1972

BINGHAM, F.T. Chemical soil test for available phosphorus. Soil Sci. 94: 87–95.
1962

BISWAS, T.D. Potassium in soils, crops and fertilized. New Delhi, India. 345 p.
1976

BLASCO, L.M. Propiedades quimicas de los suelos derivados de cenizas volcanicas de
1969 Nariño, Colombia. In: IICA Panel sobre suelos derivados de cenizas volcanicas de America Latina. Turrialba. Costa Rica. B 8. 1–10.

BLASCO, L.M. and BOHORQUEZ, N.A. Fractionation of phosphorus in tropical soils of
1968 Colombia. Agrochimica 12: 173–178.

BORNEMISZA, E and ALVARADO, A. Soil management in tropical America. North Carolina
1975 State University. 565 p.

BOYER, J. Soil potassium. In: Committee on Tropical Soils: Soils of the Humid Tropics.
1972 National Academy of Sciences, 102–135.

BROGAN, J.C. et al. A Survey of Soil Laboratories in sixty four FAO member countries.
1965 FAO Soils Bulletin 2: 30.

CABALA, P. and FASSBENDER, H.W. Formas del fosforo en suelos de la region cacaotera de
1970 Bahia, Brazil. Turrialba 20: 439-444.

CATE, R.B. and NELSON, L.A. A rapid method for correlation of soil test analyses with
1965 plant responses data. Tech. Bull. Nr. 1. ISTP Series, North Carolina State Univ. Agric. Exp. Stat.

CHANG, S.C. and JACKSON, M.L. Fractionation of soil phosphorus. Soil Sci. 84: 133-144.
1957

CHAPMAN, D. (ed.) Diagnostic criteria for plant and soils. Riverside. Univ. of
1965 California.

CHAVERRI, J. Fraccionamiento del fosforo en 16 suelos de Costa Rica. STICA Informe
1968 Anual 1968. 16.

CHILE, I.I.A. Calibración de la necesidad de fertilizante con las caracteristicas del
1966 suelo. Segunda Memoria Anual 1965-66, 47 - 48.

COOKE, I.J. A kinetic approach to the description of phosphate status. J. Soil Sci.
1966 17: 57 - 64.

COOKE, I.J. and HISLOP, J. Use of anion exchange resin for the assessment of available
1963 soil phosphate. Soil Sci. 96: 308 - 312.

CORNFORTH, I.S. and WALMSLEY, D. Methods of measuring available nutrients in West Indian
1971 Soils. I Nitrogen. Plant and Soil 35: 389 - 399.

COULOT, J. and BOLAÑOS, A.A. Estudio del estado del fosforo en suelos del sudeste
1967 bonarense, Argentina. INTA. Boletin tecnico 61: 12.

DAHNKE, W.C. et al. Phosphorus fractions in selected soil profiles of El Salvador as
1964 related to their development. Soil Sci. 98: 33 - 38.

DU PLESIS, S.F. and BURGER, DU T. The availability of different phosphate fractions.
1966 South African J. Agric. Sci. 9: 331 - 340.

DALAL, R.C. and HALLSWORTH, E.G. Evaluation of the parameters of soil phosphorus
1976 availability factors in predicting yield response and phosphorus uptake. Soil Sci. Soc. Amer. Proc. 40: 541 - 546.

EGNER, H. et al. Untersuchungen über die chemische Boden-analyse als Grundlage für die
1960 Beurteilung des Nährstoffzustandes der Böden. K. Lander Hogsk. Ann. 26: 199 - 215.

ENWEZOR, W.O. Soil testing for phosphorus in some Nigerian soils. I Comparison of
1976 methods of determining available phosphorus in soils of southeastern Nigeria. Soil Sci. 122: 48 - 53.

FASSBENDER, H.W. et al. Estudio des fosforo en suelos de America Central. II Formas y
1968 su relación con las plantas. Turrialba 18: 333 - 348.

FASSBENDER, H.W. Deficiencia y fijación de fosforo en suelos derivados de cenizas volcanicas
1969 en America Central. In: IICA Panel sobre suelos derivados de cenizas volcanicas de America latina. Turrialba B 4, 1 - 10.

FASSBENDER, H.W. et al. Physikalisch-chemische Interpretationen der Phosphatformen und
1969 ihre Beziehungen zur Pflanze in Böden Zentralamerikas. Geoderma 3, 147 - 155.

FASSBENDER, H.W. and DIAZ, N. Contenido y formas de fosforo de algunos suelos de la
1970 region amazonica del estado de Maranhao. Brazil. Turrialba 20: 372 - 374.

FASSBENDER, H.W. Chemisches Verhalten der Hauptnährstoffe in Böden der Tropen insbesondere
1972 in Latinamerika. Göttinger Bodenkundliche Berichte 23: 1 - 182.

FASSBENDER, H.W. Equilibrios cationicos y disponibilidad de potasio en suelos de America
1972 Central. Turrialba 22: 388 - 397.

FASSBENDER, H.W. Quimica de suelos, con enfasis en suelos de America latina. IICA,
1975 Turrialba, Costa Rica. 398 p.

FITTS, J.W. The farmer needs specific information relative to soil fertility needs.
1972 Phosphorus in Agriculture 59: 1 - 6.

GAPON, E.N. On the theory of exchange absorption in soils. J. Gen. Chemistry 3:
1933 144 - 163.

GARCIA, R. Phosphorus fractionation and phosphorus fixation capacity of calcareous soils
1963 in Mexico. 11th. Proceedings Congress Sugar Cane Technology. p 111 - 115.

GHOSH, A.B. and HASAN, R. Available potassium status of Indian soils. In: Biswas, D.T.
1976 Potassium in Crops, Soils and Fertilizers. New Delhi. p 1 - 5.

JORET, G. and HERBERT, J. Contribution à la détermination du besoin des sols en acide
1955 phosphorique. Ann. Agron, 6: 233 - 300.

KANWAR, J.S. et al. International Symposium on Soil Fertility Evaluation. Indian Soil
1971 Sci. Soc. 1117 p.

LEROUX, J. and SUMMER, M.E. Labile potassium in soils. I and II. Soil Sci. 106: 35 - 41,
1968 331 - 337.

MARTINI, J.A. and SUAREZ, A. Potassium status of some Costa Rican latosols and andosols
1975 and their response to potassium fertilization under greenhouse conditions.
Soil Sci. Soc. Amer. Proc. 39: 74 - 80.

MARTINI, J.A. and SUAREZ, A. Potassium supplying and fixing capacity of some
1977 Costa Rican latosols and andosols determinated by successive cropping,
extractions and incubation. Soil Sci. 123: 37 - 47.

MARTTINGLY, G.E.C. and TALIBUDEEN, O. Progress in the chemistry of fertilizer and soil
1967 phosphorus. In: Greysen, M. and Griffith, E.J. Topics in phosphorus
chemistry. Vol. 4. Interscience. New York. 157 - 290.

MEHLICH, A. Determination of P, Ca, Mg, K and Na and NH_4 by the North Carolina Test
1953 Laboratory. Raleigh, North Carolina. mimeo. s.p.

MORGAN, M.F. The universal soil testing system. Univ. Connecticut Agric. Exp. Sta.
1937 Bull. 392: s.p.

OLSEN, S.R. et al. Estimation of available phosphorus by extraction with sodium
1954 bicarbonate. US Dept. Agric. Circ. 939: 19 p.

OLSEN, S.R. and DEAN, L.A. Phosphorus. In: Black, C.A. Methods of Soil Analysis.
1965 ASA Monographs 9: 1035 - 1048.

OLSEN, R.A. and ENGELSTAD, O.P. Soil phosphorus and sulphur. In: Committee of Tropical
1972 Soils. Soils of the Humid Tropics. National Academy of Sciences. pp 82 - 102.

PAAUW, F. van der, et al. An improved method of water extraction for the assessment of
1971 availability of soil phosphate: PW-value. Versl. Landbouwk. Onderzek. 749 p.

PICHOT, S. and ROCHE, A. Phosphorus in tropical soils. Agron. Trop. 27: 939 - 965.
1972 965.

PRATT, P.F. Potassium. In: Black, C.A. Methods of Soil Analysis. ASA Monographs 9: 1022-
1965 1030.

SALMON, R.C. Relations between intensity level and quantity of soil phosphate and its
1966 availability. Soil Sci. 101: 450-454.

SANCHEZ, P.A. A review of soil research in tropical Latin America. North Carolina
1972 State University. 263 p.

SAUNDER, D.H. Determination of available phosphorus in tropical soils by extraction with
1956 sodium hydroxide. Soil Sci. 82: 457-463.

SAXENA, S.N. Characterization of soil available phosphorus. In: Kanwar, J.S. et al.
1971 International Symposium on Soil Fertility Evaluation. Indian Soil Sci. Soc.
New Delhi. 361-369.

TAFUR, V.N. and BLASCO, L.M. Fosforo en los suelos de Valldupar (Cesar). Agricultura
1969 Tropical 25: 151-159.

TINKER, P.B. Studies on soil potassium. III Cations activity ratios in acid Nigerian
1964 soils. J. Soil Sci. 15: 24-35.

TRUOG, E. The determination of the really available phosphorus in soils. J. Amer. Soc.
1930 Agron. 22: 874-882.

TSENG, H.D. and WANG, C.H. Correlation between available phosphorus in slate alluvial
1964 soils and response of rice. J. Taiwan Agric. Res. 13: 20-26.

ULRICH, B. and KHANNA, P.K. Schofield'sche Potentiale und Phosphatformen in Böden.
1968 Geoderma 2: 65-77.

ULRICH, B. et al. Modelling of bioelement cycling in a beech forest of Solling district.
1973 Göttinger Bodenkundliche Berichte 29: 1-54.

VIEIRA, L.S. and BORNEMISZA, E. Categorias de fosforo en los principales grandes grupos
1968 de suelos en la Amazonia de Brasil. Turrialba 18: 242-248.

WALMSLEY, D. and CORNFORTH, L.S. Methods of measuring available nutrients in West
1973 Indian soils. II Phosphorus. Plant and Soil 39: 93-101.

WAUGH, D.L. and MANZANO, A. In: Kanwar, J.S. et al. International Symposium on Soil
1971 Fertility Evaluation. Indian Soil Sci. Soc. New Delhi, 377-383.

WESTIN, F.C. and BRITO, J.G. de. Phosphorus fractions of some Venezuelan soils as
1969 related to their stages of weathering. Soil Sci. 107: 194-202.

WHITE, R.E. and HAYDOCK, K.P. An evaluation of the phosphate potential, Troug, Olsen
1967 and Morgan methods for measuring the availability of soil phosphate. Austr. J.
Soil Res. 5: 215-224.

Paper 11 SOIL AND PLANT DIAGNOSIS IN POTASSIUM NUTRITION AND FERTILIZATION

by

A. Loué and J. Quémener
Agromony Department, Société des Potasses et de l'Azote, Mulhouse, France

1. INTRODUCTION

Field experiments with fertilizers form the basis for the establishment of fertilization standards. Numerous authors have stressed the limits and difficulties of extrapolating the results. Analytical controls at the soil and plant levels should increase the precision of the extrapolation and make it less hazardous.

The present paper deals only with the use of soil or plant analysis as a means of diagnosis. It is restricted to problems of analytical methods based on the results of experiments and is confined to potassium.

2. SOIL ANALYSIS IN RELATION TO POTASSIUM STATUS

In France, the determination of K is traditionally based on the exchangeable K extracted by ammonium acetate at pH 7. It is known, however, that this sole determination even when complemented by the ratio of exchangeable K to exchange capacity does not allow the correct classification of soils relative to their response to K and, indeed, the classification is improved if it is done according to types of soil.

K balances are fairly widely studied by the Agronomy Department of the Société des Potasses et de l'Azote (SCPA). Generally, when the balance is clearly positive part only of the increase is found as exchangeable K owing to fixation, while when the balance is negative there is little or no reduction in exchangeable K because of release of K (Garaudeaux, 1965; Hebert and Remy, 1964).

The most recent studies have primarily been concerned with developing a better method of K diagnosis and, to a less extent, with a better interpretation of K balances. We shall examine here the two main tests developed during the last ten years at the SCPA Experimental Station at Aspach, Mulhouse, of which the first is a biological extraction technique akin to the Stanford - de Ment method (de Ment et al. 1959) and the second is extraction by sodium tetraphenylboron (NaTPB).

2.1 Biological Extraction Technique (Stanford)

After several years of exhaustive studies with Italian rye-grass (Lolium multiflorum Lam.) in pot experiments, the method now used is one of biological extraction of potassium by a modified Stanford method (Quémener, 1976). The principle of the method and its adaptation to K have been described by Quémener and Rolland (1970) and some results have been published by Garaudeaux and Quémener (1968). In brief, this method consists of starving a plant of K before placing it in contact with the soil to be studied. Barley (Hordeum vulgare L.) chosen for its genetic homogeneity, is well suited to the purpose; its ability to extract K seems to be fairly good compared with potato (Solanum tuberosum L.) which is especially poor in this respect and with rye-grass which is particularly efficient.

The studies carried out with this technique at the Station have concerned two main categories of samples: (i) soils of the permanent experiment fields of the SCPA in order to correlate the Stanford results with the K response curves of field experiments (Loué, 1973; Quémener, 1969), (ii) certain types of local soils situated around, or at a distance from, the experimental fields (Loué, 1972a).

2.1.1 Definition of 'Stanford' terms

- Potassium absorbed (by the barley seedlings during microculture) represents the amount of K removed by the aerial portions of the plants placed in contact with the soil under study less the amount of K removed by the plants grown on sand.

- Exchangeable potassium is the amount of K determined by extraction with neutral, normal ammonium acetate solution before and after the Stanford culture.

- Variation of exchangeable K in the course of the microculture is the amount of exchangeable K after culture less the exchangeable K before culture.

2.1.2 Interpretation of 'Stanford' results

i. Relationship between exchangeable K, Stanford K and response in field

In the present example there were 49 experimental soils, classified into four categories according to their response to applied K determined from all the results of four consecutive years of experimental cropping. The results obtained from cereals, maize and pasture have been more especially used. A difficulty has been to qualify the response of each experimental field to applied K, and responses have therefore been expressed as percentages of the yield of control plots (no K applied) rather than in absolute values. The statistical significance of the experimental results has been almost wholly disregarded. The Stanford data were interpreted and related to the results of the field experiments mainly with the help of two graphs.

Figure 1 shows the relationship between K absorbed in Stanford microculture and exchangeable K, the points being also distinguished by the response to applied K in the field experiments. For low values of exchangeable K (below 80 ppm), the classification given by absorbed K by the Stanford method agrees better with the nature of the responses. For an absorption of about 200 ppm, however, the field experimental response may be very variable and therefore the absorbed K (Stanford) cannot constitute by itself a sufficient guide to response in the field.

Figure 2 shows the relationship between absorbed K and the variation (reduction) in exchangeable K during the course of microculture. It associates the removal of K by the seedlings with changes in the amount of the so-called resulting available K. In this figure, five zones have been marked according to the field response: zone 1 covers an area where there were no field experiments and the response to applied K is unknown; zone 2 is an area where there were no or low responses; zone 3 where responses were low, moderate or good; zone 4 where responses were variable, and zone 5 where responses were large. It appears that the soils are better classified in this way than only on the amount of exchangeable K (Figure 2) and that the zone delimitation should become more precise when more data are obtained.

It should be noted that a soil with high immediate availabilities, i.e. high exchangeable K and absorbed (Stanford) K, can, however, respond to applied K after some lapse of time if its K availability is renewed only slowly, as shown by a marked decrease in exchangeable K.

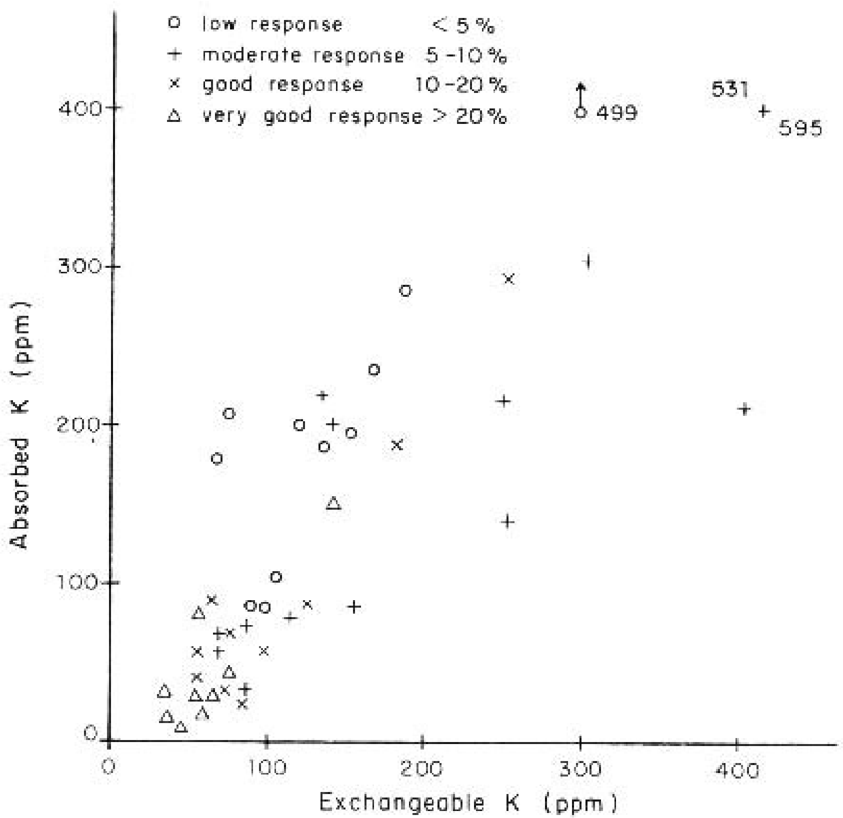

Fig. 1 Relationship between absorbed K (in Stanford pots), reduction in exchangeable K during microculture and response to applied K in field experiments

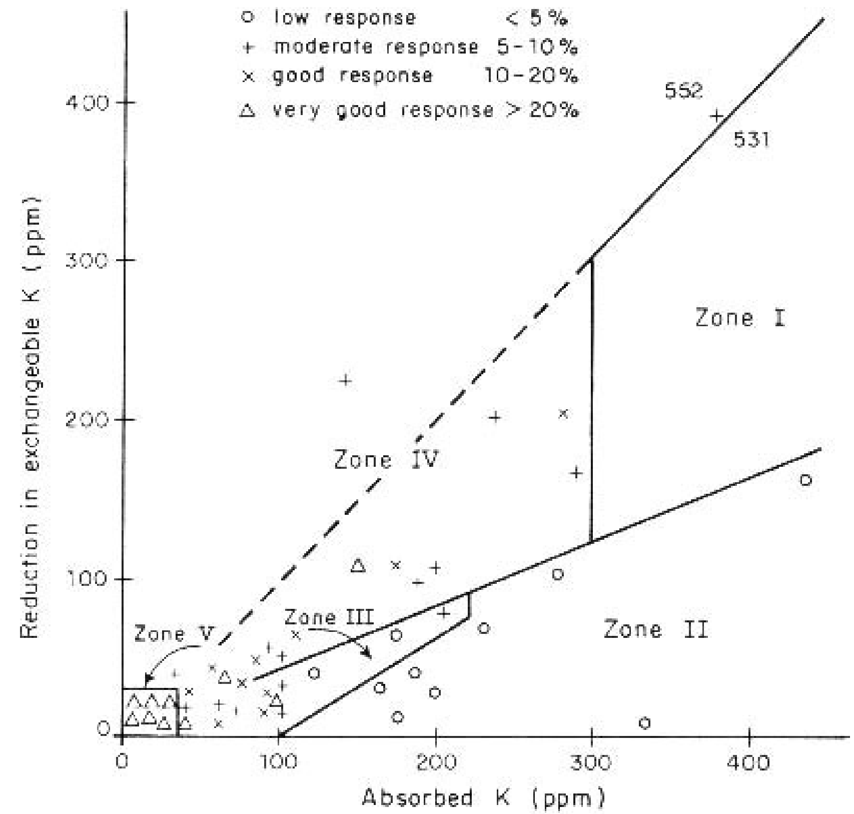

Fig. 2 Relationship between absorbed K (in Stanford pots), exchangeable K and response to applied K in field experiments.

Conversely, a soil with average immediate availability but with quick renewal, i.e. showing a small decrease in exchangeable K , can show weak and variable field responses according to the crop.

ii. <u>Application of method</u>

The application of the method can be illustrated by a comparison between two of the main types of soil of southwestern France, the Boulbenes and the terreforts (Loué, 1972a).

The exchangeable K in a sample of 14 boulbene soils varied from 22 to 141 ppm. The K absorbed by the Stanford cultures varied from 13 to 135 ppm, thus closely corresponding to the range of exchangeable K in the soil before culture. The ratio of absorbed K to exchangeable K, one of the main values calculated by this method, varied from 0.49 to 1.38 (mean 0.98).

Figure 3 shows the relationship between absorbed K and the initial exchangeable K and indicates that the boulbenes are a fairly homogenous family with a ratio close to unity. The exchangeable K thus seems to reflect properly the ability of these soils to supply K.

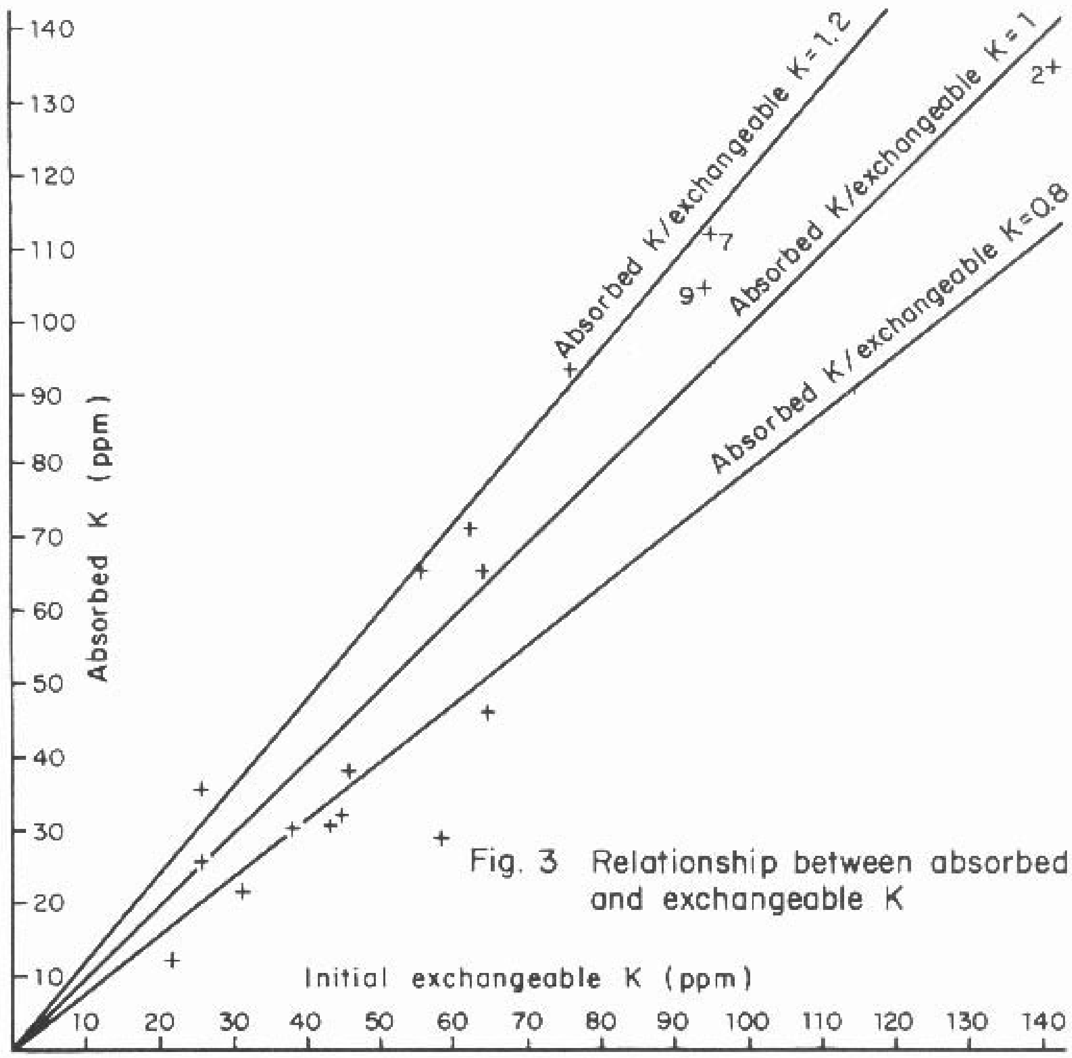

Fig. 3 Relationship between absorbed and exchangeable K

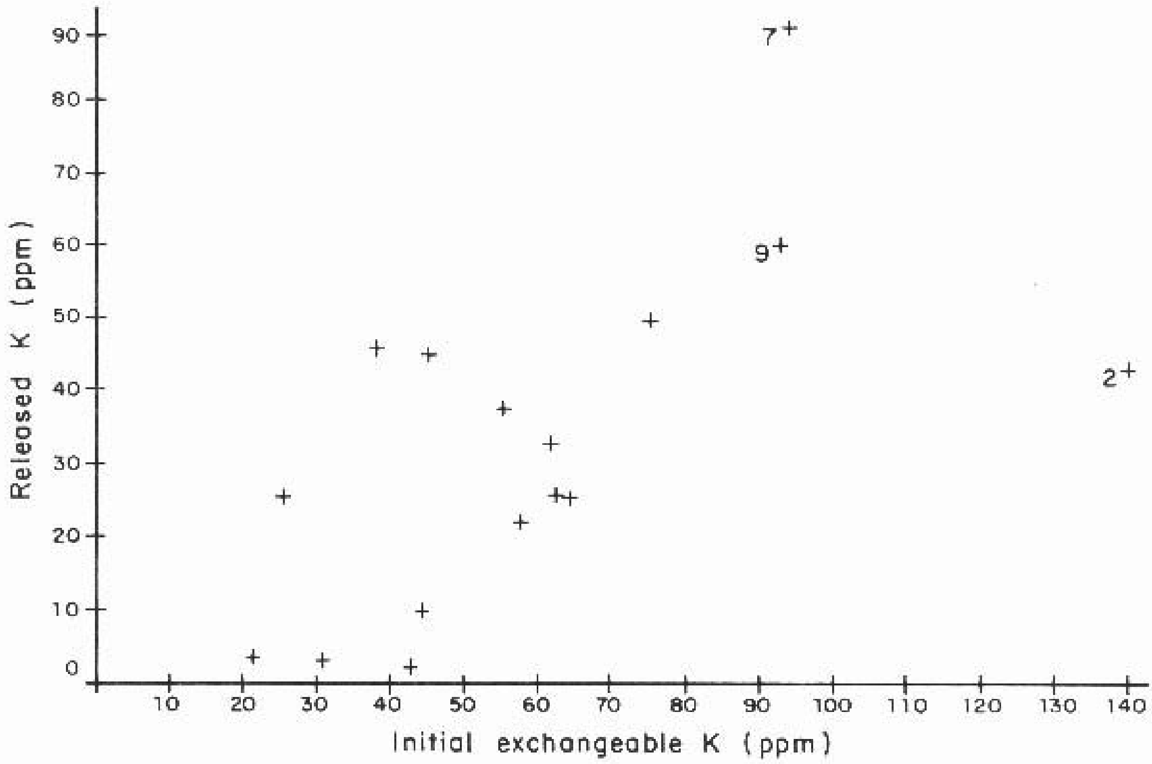

Fig. 4 Relationship between released K and initial exchangeable K

This method also enables the amount of released K to be gauged, since released K equals absorbed K plus exchangeable K after culture minus exchangeable K before culture. This release has varied from 2 to 91 ppm with a mean of 34 ppm. The released K has some relationship, albeit imprecise, with the exchangeable K before culture (Figure 4). The boulbenes, which are very low in exchangeable K, release also very small amounts of K. The mean results from the foregoing 14 boulbene and 14 terrefort soils from the same area are given below.

	Boulbenes	Terreforts
Clay (%)	14	29
CEC (meq %)	9.6	23
Exchangeable K before culture (ppm)	64	134
Absorbed K Stanford (ppm)	62	261
Absorbed K/exchangeable K	0.97	1.94
Exchangeable K after culture (ppm)	36	84
Released K (ppm)	34	211

The results obtained by this method therefore give supplementary data to improve the K diagnosis.

2.2 <u>Studies on K with Extractants containing NaTPB</u>

Studies by Quémener (1974) at Aspach on the use of reagents containing sodium tetraphenylboron were prompted by studies made in the USA and the work of Cabibel (1971, 1972), Duthion and Grosman (1970) and Studer and Guyot (1969) in France. They concerned in particular: (i) a study of the changes in the K balance sheet and (ii) the classification of soils in relation to the results of pot and field experiments on K.

2.2.1 <u>Application of NaTPB to studies of K balance sheets</u>

Quémener (1974) used 0.1N NaTPB plus 1.9N NaCl with an extraction time of 24 hours. Figure 5 gives an example of the results obtained with a terrefort clayey soil for this extractant in comparison with 0.05N NaTPB and neutral 1.0N ammonium acetate.

With 0.05N NaTPB the shapes of the curves are similar to those obtained for exchangeable K with neutral normal ammonium acetate. With 01N NaTPB + 1.9N NaCl, the points lie close to a straight line which suggests that the relationship is independent of differences between soils, i.e. enrichment or depletion of K.

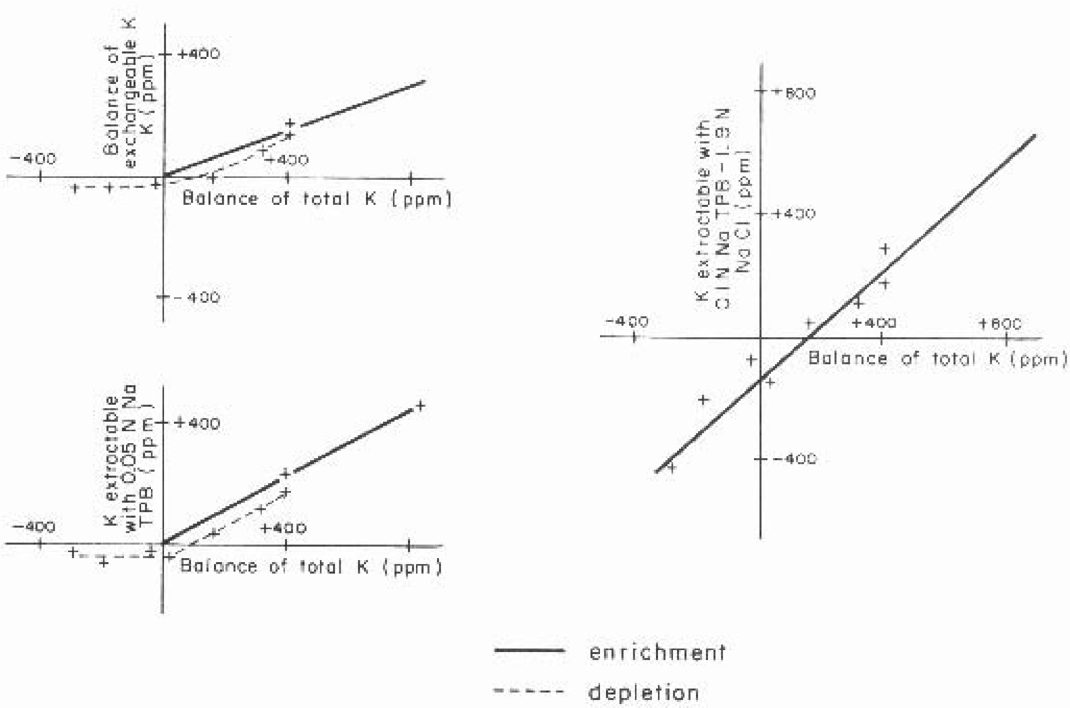

Fig 5 Comparison of balances of total K with balances of exchangeable K and K extracted with 0.05 N and 0.1 N NaTPB

2.2.2 Application of NaTPB to K diagnosis

i. Relationship between K extracted by NaTPB and pot cultures

Work at Aspach compared the biological Stanford extraction with extraction by 0.05N NaTPB for 24 hours at a soil:solution ratio of 1:20. Two sets of soil samples were compared, the first representing the full range of variations in the absorbed K:exchangeable K ratio as measured in the Stanford cultures and the second consisting of 70 soils from fields under SCPA experiments.

Figure 6(a) shows the relationship between absorbed K as measured in the pot experiments and exchangeable K, the correlation coefficient for which was 0.44. Of the 57 soils in this set, ten had a ratio of over 2.0. Figure 6(b) represents the relationship between K extracted by NaTPB and exchangeable K; the correlation coefficient was 0.963. This extractant evidently was more like the Stanford method than the ammonium acetate method in the amount of K determined, and it is therefore better for use on soils in which actual K uptake is disproportional to exchangeable K. A very good correlation ($\underline{r}$ = 0.95) was found between K extracted by NaTPB and the total K absorbed by the plants + exchangeable K after culture. The correlation between the amounts of non-exchangeable K extracted by the NaTPB and by the Stanford micro-cultures was less high ($\underline{r}$ = 0.698).

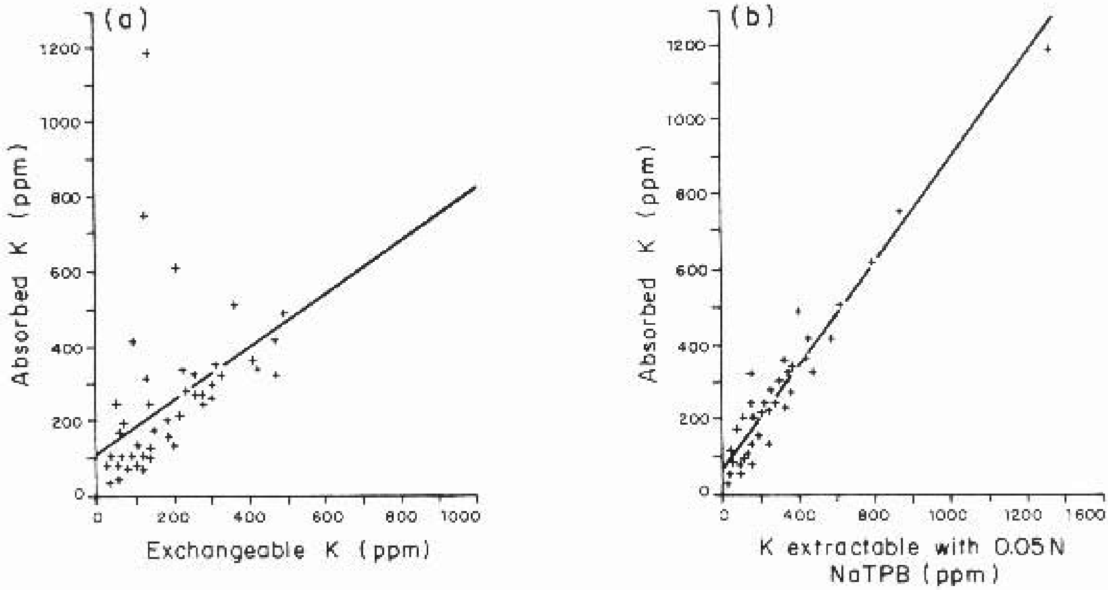

Fig. 6 Relationship between K absorbed in microculture and (a) exchangeable K and (b) K extracted by 0.05N NaTPB

In the set of soils from the experimental fields, three soils only showed a ratio of absorbed K to exchangeable K higher than 2.0. The correlations were: exchangeable K: absorbed K, $\underline{r}$ = 0.898; K extracted by NaTPB:absorbed K, $\underline{r}$ = 0.953. In this case the improvement due to NaTPB was much less.

ii. Relationship with field response to applied K

The data obtained by the use of 0.05N NaTPB were thus very well correlated with extractions made in microcultures in Stanford pots but it appeared that this reagent did not bring a clear cut improvement in prediction of the field response to applied K. Attention was therefore given to the use of a slightly more concentrated reagent.

The use of 0.1N NaTPB without addition of NaCl and with an extraction time of 7 days improved the correlation between the amounts of released K determined by the two methods (NaTPB and Stanford), i.e. $r = 0.820$ instead of $r = 0.698$, and the amounts were rather higher than those estimated by pot culture (whereas it was the contrary with 0.05N NaTPB).

Figure 7 shows the field response to applied K in relation to exchangeable K (by ammonium acetate) and supplementary K extracted by 0.1N NaTPB. Field responses to applied K are indicated by different symbols according to the mean percentage increase in yield of K plots in comparison with control (without added K). Rates of applied K were 83 to 166 kg/ha (100 to 200 kg/ha of K_2O) per year for the 40 trials on cereals and 166 kg/ha (200 kg/ha of K_2O) per year for the 20 trials on pasture. Although the points in Figure 7 show a narrow range of variation more especially for the trials on cereals, it appears that soils with a large response (over 20%) to applied K are also low in exchangeable K and very low in supplementary K determined by 0.1N NaTPB, and that for a given amount of exchangeable K the magnitude of the response in the field sometimes corresponds to very clear cut differences in the amount of supplementary K extracted by 0.1N NaTPB. It seems, therefore, that the technique used can give data capable of improving the K diagnosis in certain soils for which the exchangeable K is inadequate.

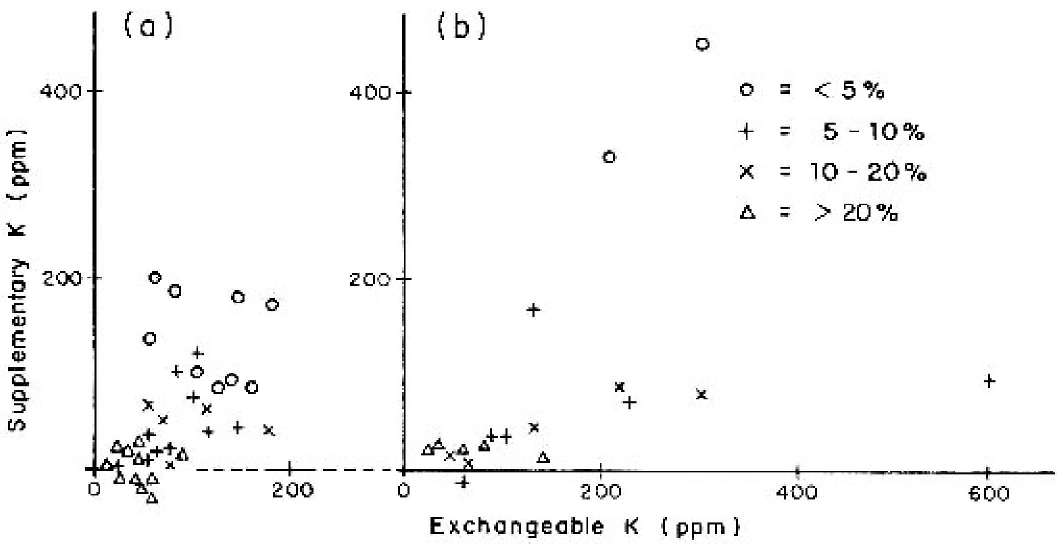

Fig. 7 Comparison between supplementary K (K extracted by 0.1N NaTPB less exchangeable K) and exchangeable K. Responses to applied K as a percentage of control treatment yield

3. PLANT ANALYSIS AND POTASSIUM

Knowing the difficulties met by agronomists attempting to assess the ability of soils to supply K, it is clear that there is a possible means of avoiding the difficulty by measuring the actual K status of a plant by analysing part or the whole of the plant.

Plant analysis is perhaps most useful as a means of determining K nutrition for the following reasons:

i. K is fairly often the major element most abundant in the plant and plays a fundamental role in the anion-cation equilibrium;

ii. many plants preferentially absorb K;

iii. K translocates readily in the plant from old leaves towards younger leaves, according to the stage of growth. The problem of selection of a suitable foliar sample can be resolved fairly correctly for K;

iv. K is an element whose uptake is much influenced by the soil and by the rates of applied K. It follows from this and (i) and (ii) that there are good correlations between the K content of the plant and K applied;

v. on account of (iv), there is the possibility of correlation between K contents of the plants and yields if there are correlations between yields and K in the soil, K supplied or the sum of the two.

For tissue analysis it is necessary to identify the portion of the plant whose K content is most closely related to the amount of K applied. For some plants the leaf petiole is more susceptible than the lamina.

3.1 K and K/Ca/Mg Diagnosis

Figure 8 illustrates the relationship between the K content of the ear-leaf of maize and the yield of the crop (Loué, 1962, 1963a, b, 1965) and suggests that it is curvilinear. It would, however, be unwise to specify a particular K content as the critical level and it would be preferable to indicate a critical zone say from 1.8 to 2.0% K. This critical zone would, itself, fluctuate; when water is deficient, it could fall to about 1.30 to 1.40% K and the zone of very high yields would then correspond to K contents of 1.9 to 2.2% K.

The K/Ca/Mg foliar equilibria can be studied after expressing K, Ca and Mg individually as percentages of the total amount of all three elements. Data of this type covering numerous K/Ca/Mg equilibria ranging from K deficiency to moderate Mg deficiency are plotted in Figure 9.

Maize strengthens the case for plant diagnosis if it is borne in mind that there is a strong positive correlation between the dry matter weight of the ear-leaf (tissue sampled) and yield.

Loué has also studied foliar analysis in wheat by using the whole of the second and third leaves below the ear. The results were difficult to interpret particularly on account of the tillering habit of the plant and because K levels must be related to the rate of applied N. Barley presents much the same difficulty.

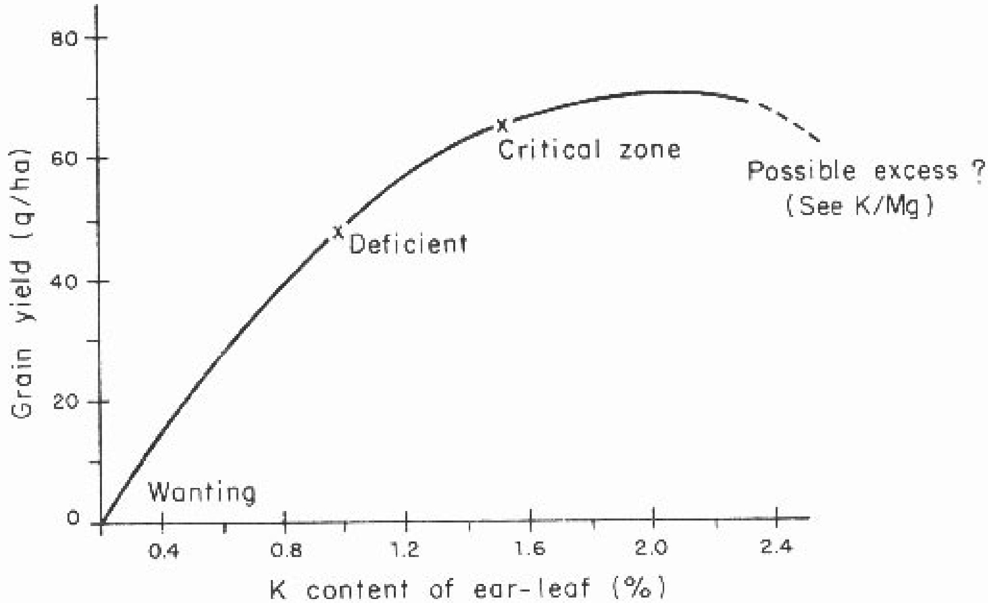

Fig. 8 Relationship between yield of dry grain and K content of the ear-leaf of maize at tasseling

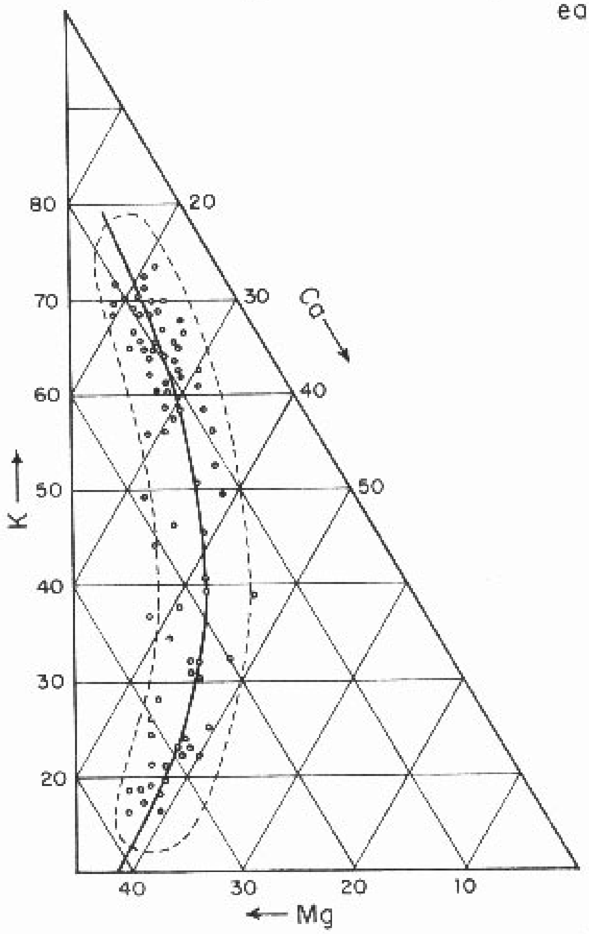

Fig. 9 K/Ca/Mg equilibria in the ear-leaf of maize

It is probable that experiments will enable the choice to be made of the leaf best suited to serve as a sample for analysis and the stage of growth at which the sample should be taken. Already, study of the lower portion of the curve in Fig. 8 (K contents associated with some or severe deficiency) presents little difficulty. Numerous plants are known, the K contents of which are associated with the appearance of very clear, less clear and even slight symptoms of deficiency, e.g. maize, sorghum, beet, vine and apple, but determination of the critical zone remains most difficult.

3.2 Petiolar Diagnosis

For some crops, the petiole appears to be more sensitive than the lamina in expressing nutritional differences and the use of this tissue is more highly developed in the USA (vine, sugar beet etc.). We usually use this technique in vine experiments to compare the results with those from conventional foliar analysis and also in the surveying of vineyards (Loué, 1965, 1976). Fertilizer experiments on potato have also been studied by petiolar analysis with fairly satisfactory results (Loué, 1972b).

4. RELATIONSHIP BETWEEN SOIL AND PLANT ANALYSES

Statistical processing of data can be used to establish a link between foliar and soil analyses as the following example shows. A survey on the nutrition and fertilization of the vine in the southeastern part of France dealt with 82 vines. Data were obtained for complete analyses of the soil profile at three levels (0–40 cm, 40–80 cm and sometimes 80–120 cm) and for foliar analysis at flowering and at fruit ripeness. Relationships between soil and plant were studied by means of single correlations between foliar N, P, K, Mg and the variables of soil analysis.

Multiple relations between foliar and soil data were examined by means of stepwise regression analysis in which the most highly correlated variable is chosen in step 1. At step 2 the variable is chosen that contributes most to the improvement in percentage explanation already obtained and so forth for subsequent steps. When the additional improvement is small, it is tested for its significance, failing which no further steps are taken.

The following equations were found to relate soil variables to the K content of the leaf. Soil variables are shown by their usual abbreviations standing alone for the soil depth 0–40 cm but followed by S for the first subsoil (40–80 cm) and SS for the second subsoil (80–120 cm).

(a) Leaf K at flowering

Step	Coefficient of multiple correlation	Explanation (%)
1. $K = -0.0839\ MgS + 1.29$	0.397	15.8
2. $K = -0.085\ MgS + 0.372\ KS + 1.16$	0.495	24.5

At step 3 the silt of the second subsoil brought 3.6% of explanation, at step 4 the total lime of the soil brought 3.5%, at step 5 exchangeable Ca of the soil brought 3.8%, at step 6 the clay of the soil brought 3.0%, at step 7 the exchangeable sodium of the second subsoil brought 3.7%, at step 8 the lime of the first subsoil brought 3.1% and at step 9 the very fine sand of the soil brought 3.5% of explanation. Overall, r was found to be 0.699 and 48.9% of the variation had been accounted for.

(b) Leaf K at fruit ripeness

Step	Coefficient of multiple correlation	Explanation %
1. $K = - 0.11\ MgS + 1.1$	0.432	18.7
2. $K = - 0.11\ MgS + 0.631\ KS + 0.879$	0.598	35.8
3. $K = - 0.10\ MgS + 0.781\ KS + 0.0441\ Ct/100 + 0.673$	0.655	42.8
4. $K = - 0.068\ MgS + 0.02\ KS + 0.0051\ Ct/100 - 0.0356\ CS + 0.76$	0.694	48.2

At step 5, the exchangeable sodium of the first subsoil brought 3.6% of explanation. At step 6, the exchangeable calcium of the first subsoil brought 3.7% of explanation. The value of r was thus 0.745 bringing 55.5% of explanation.

Exchangeable Mg and K of the first subsoil were chosen in each of the above two cases as the main explaining variables but the proportion of explanation reached was clearly higher when the fruit was ripe than at flowering. The exchangeable bases (CaO, MgO, K_2O and Na_2O) of the first subsoil can alone explain 43% of the variation at fruit ripeness (negative influences for Ca and Mg and positive for K and Na).

Soil analysis can therefore explain an appreciable percentage of the variation, the non-explained part being under the influence of other variables such as cropping pattern, cultivar, rootstock and age of vine. In the case of K in particular, differences between species in their nutrient requirements can be considerable, and in this respect plant analysis can be helpful. In the present stage of knowledge it is, however, necessary to conduct analyses of both soil and plant, and use the results jointly.

REFERENCES

CABIBEL, B. Libération du potassium par les fractions granulométriques du sol en présence
1971 de tétraphényl borate de sodium. Ann. Agron. 22: 6.

CABIBEL, B. Mobilisation du K des sols par le NaTPB en relation avec le comportement des
1972 cultures. Ann. Agron. 23(3): 355-367.

DE MENT, J.D., STANDFORD, G. amd BRADFORD, B.N. A method of measuring short term nutrient
1959 absorption by plants. II - Potassium. Soil Sci. Soc. Amer. Proc. 23: 47-50.

DUTHION, C. and GROSMAN, Ruth. Potassium lentement libérale - Quelques essais de bilans
1970 culturaux. Ann. Agron. 21: 57-73.

GARAUDEAUX, J. and QUEMENER, J. Etude de la libération du potassium en culture en pots.
1968 9th Inter. Congress of Soil Science. Vol. II: 639-647.

GARAUDEAUX, J. Etudes sur la fumure potassique réalisées à la Station agronomique
1965 d'Aspach le Bas (Haut-Rhin). 122 p.

HERBERT, J. and REMY, J.C. Effets de doses croissantes répétées de sels de potasse.
1964 C.R. Acad. Agric. Fr. pp 946-954.

LOUE, A. La nutrition cationique du maïs et le diagnostic foliaire. Ann. Physiol. Vég.4
1962 (2): 127-148.

LOUE, A. Maize nutrition, cation requirements and potash demand. World Crops 15: 373-
1963a 379.

LOUE, A. Contribution à l'étude de la nutrition cationique et plus particulièrement
1963b potassique du maïs. Fertilité 20: 57.

LOUE, A. Le diagnostic foliaire du maïs (méthodologie, état actuel des connaissances,
1965 utilisation). Inst. Int. Potasse, 4ème Colloque Belgrade, p.105-116.

LOUE, A. L'intérêt du diagnostic pétiolaire dans les études sur la nutrition et la
1968 fertilisation potassique de la vigne. 2ème Colloque - Contrôle de la fertilisation des plantes cultivées, Seville. p.283-294.

LOUE, A. Etudes sur la fertilisation et le problème du potassium des sols de boulbènes
1972a du Sud-Ouest de la France (1961 à 1971). p.61-68.

LOUE, A. L'analyse végétale (pétioles, feuilles, tubercules) en vue d'apprécier la
1972 nutrition minérale et plus particulièrement potassique de la pomme de terre. 3ème Colloque - Contrôle de la fertilisation des plantes cultivées, Budapest. p.18.

LOUE, A. L'analyse du sol et de la plante pour le contrôle de l'expérimentation. 10ème
1973 Colloque - Inst. Intern. Potasse, Abidjan, Côte d'Ivoire. p.375-398.

LOUE, A. Etude des liaisons entre le diagnostic foliaire et l'analyse du sol dans le
1976 traitement d'une enquête sur la nutrition de la vigne. 4ème Colloque - Contrôle de la fertilisation des plantes cultivées, Gand. p.255-268.

QUÉMENER, J. Utilisation des résultats des micro cultures de Stanford pour la détermination
1969 de la fertilité potassique des sols - note non publiée. 13 p.

QUEMENER, J. and ROLLAND, D. Application de la technique de Stanford et de Ment à
1970 l'extraction du potassium des sols. Ann. Agron. 21(6): 819-844.

QUÉMENER, J. The use of reagents containing sodium tetraphenylboron for the extraction
1974 of soil potassium : applications to the study of fertility problems. 10th Congress Inter. Potash Institute, Budapest. p.65-73.

QUEMENER, J. Analyse du potassium dans les sols. Dossier K_2O. SCPA. 26 p.
1976

STUDER, R. and GUYOT, J. Etude de l'alimentation potassique des plantes et de la
1969 régénération du potassium des sols calcaires. C.R. Acad. Sci. Paris, série D. 268: 2076-2078.

Paper 12

SCOPE AND POSSIBILITIES OF SOIL TESTING FOR NITROGEN

by

C.M. Smith
Department of Soils, North Dakota State University
Fargo, North Dakota, USA 58102

1. INTRODUCTION

Food requirements of people in the world are increasing rapidly and man's capabilities to harvest enough crop products are challenged. Soil and plant testing coupled with use of fertilizers, water and other management practices can help to optimize efficient use of soil resources. How much fertilizer to use depends on the crop, the soil, the availability and cost of fertilizers or other needed soil additives, and the value of the crop products to the consumers.

The yields of crops increase as farmers learn more about the soils and as they use improved crop production methods. As the attainable yields go higher, the need increases even more for knowledge of soil and crop requirements. It is not very difficult to grow a crop giving a small or even average yield. However, when large yields are produced more nitrogen (N), phosphorus (P), potassium (K), and other plant food nutrients are removed from the soil. The capability of the soil to provide enough nutrients may then be exceeded. Soil testing is one way of obtaining better information about the capacity of the soil to supply enough nutrients to the plants at a fast enough rate.

Soil testing to determine amounts of N fertilizer needed for the crop has been used in some areas with good results. However, many failures have occurred, some of which may be caused by lack of useful correlation or field calibration data. With nitrogen, poor results may be caused in part by a combination of climate and mobility of N compounds in the soil-water system.

Much of the N in soils exists in organic compounds. This N is not absorbed by plants, at least not in sufficient amounts to supply the needs of the crop. Changes to NH_4^+ or NO_3^- depend on temperature, oxygen, water, pH, energy source for microorganisms and chemical and physical properties of the organic materials and soils. Products of mineralization most readily utilized by plants are NO_3^- and NH_4^+. The relative impacts of factors affecting N transformations and movement within soils influence the choice of tests and usefulness of the data obtained from them.

2. INORGANIC N SOIL TESTING

Nitrogen fertilizer recommendations for several crops in the USA are now based on soil tests for inorganic N particularly in many states of the Great Plains and West. Nitrate (NO_3^-), and ammonium (NH_4^+) in some areas, measured on soil profile samples taken before crops are planted or in early stages of growth, is useful in N fertilizer management for cereal grains, maize (*Zea mays* L.), sugar beets (*Beta vulgaris* L.), potatoes (*Solanum tuberosum*) and certain other irrigated and non-irrigated crops. Areas where most success has occurred are in general semi-arid with less than 400-500 mm of annual precipitation. The acceptance of these test procedures is moving very slowly into areas of greater precipitation as systems are improved for soil sampling, sample treatment or handling, and calibration of test data with results of fertilizer experiments.

In general, NO_3^- moves in soils with water, can be leached beyond the rooting depth of plants, is subject to denitrification and volatilization under certain conditions, and can be immobilized by microorganisms. Although NH_4^+ does not move readily in most soils, it converts to NO_3^- rapidly if the conditions are favourable for nitrification. Because of NO_3^- mobility, traditional soil sampling to ploughing depth has usually produced inadequate data for N fertilizer recommendations.

Considering the dynamic nature of N compounds in soils and the mobility of NO_3^-, it is not surprising that soil test and recommendation programmes for N have been difficult to develop. A thorough review of the history of biological and chemical soil testing procedures developed to determine N availability indices has been made by Dahnke and Vasey (1973). Most of those procedures did not take into account initial or residual NO_3. Bartholomew (1972) has also discussed advantages and problems of various soil tests for N.

A major purpose of this paper is to discuss the N soil testing and interpretation procedures now being used by state and private laboratories in several states. Soil sampling and handling, available water data and problems of many aspects of soil testing for inorganic N are also presented. Because the most current information on present practices is desired, many of the source references are extension circulars, semi-technical magazines, and personal communications from research or extension personnel. Some of the information was summarized by Smith (1977).

Correlation of soil test data with plant responses to N fertilizers and subsequently calibration of laboratory tests with experiments on rates of N in the field are recognized as essential for the success of a soil testing programme. Information is presented about successful programmes that will be applicable to some aspects of soil testing in developing countries.

2.1 Soil Sample Depth

Depth of soil sampling needed to evaluate inorganic N can vary with soil texture, soil depth, climate, irrigation, and crops to be grown. In general, it is best to sample to the maximum depth at which the roots of the crop are expected to remove water and nutrients.

2.1.1 Non-irrigated crops

If the goal is to evaluate NO_3^- and available water supply to the depth of significant water removal, for example by a dryland winter wheat (Triticum aestivum L.) crop, it may be necessary to take samples to a depth of 180 cm according to research in the states of Montana and Washington (Brown, 1971; Leggett, 1959). However, there is evidence in areas of the Great Plains from Oklahoma to Saskatchewan, Canada, that a 60 cm soil sampling depth usually produces data that evaluate inorganic N with acceptable precision for their soil and climatic conditions for cereal grains (Smith, 1977). All states agree that NO_3^- analysis of a sample taken to ploughing depth only has little value for making N recommendations.

Nebraska (Sander et al. 1973) has a preference for a sample depth of 180 cm for winter wheat. However, sampling to 180 cm is very difficult for farmers because they usually do not have access to hydraulic equipment or commercial services. In practice, because soil samples received in the laboratory have been taken to variable depths, data are adjusted for purposes of recommendations to a common soil depth of 180 cm. This adjustment is based on an average of NO_3^- distribution data in soil profiles of numerous field experiments conducted in areas of similar soils. It is believed that any resulting errors are less than if no adjustments are made. This method would have merit in some developing countries.

Data about distribution of NO_3^- in soil profiles exist for many areas and for different management systems. In general, in a given climatic region, limited fertilization and relatively uniform soil and crop management result in similar amounts of NO_3^- in soils below 60 cm. However, exceptions do exist and as use of N fertilizers increases, coupled with some NO_3^- movement into subsoils, a greater need develops for deeper soil sampling. Variability in NO_3^- distribution is further emphasized especially where precipitation is relatively non-uniform within farming areas and over the years.

Daigger et al. (1972) in an experiment in western Nebraska incorporated ammonium nitrate into a fallowed soil. At the N rate of 180 kg/ha, for example, and after 220 mm of rain in 127 days, NO_3^- concentration increased by 10 ppm N between zero and 15 cm deep, and by 9 ppm N between 60 and 120 cm deep. The smallest change of about 4 ppm N was between 15 and 60 cm deep. A different amount of precipitation probably would have changed the profile distribution of NO_3^-. Ammonium in the soil samples changed significantly only in the zero to 15 cm depth, but not until rates of N fertilizer application reached 180 kg/ha. In this experiment zones of maximum and minimum concentrations of NO_3^- were independent of N fertilizer rate.

In a field in eastern Montana that had never been fertilized with more than 4 kg/ha N for each 2 crop years, the author measured NO_3^- concentrations greater than 100 ppm N between 120 and 150 cm deep, within reach of winter wheat roots. However, in the upper 60 cm of depth this same soil averaged less than 4 ppm N as NO_3^-. This NO_3^- originated from mineralization of organic matter (OM) and the many years of shallower rooted spring planted wheat not removing deep NO_3^-. Distribution patterns with significant increases in NO_3^- concentration below 60 cm of depth are not uncommon in some areas. Knowledge of the expected profile distribution of NO_3^- is essential before recommending a sampling depth to a farmer or soil sampling technician. The location of plant available N within the profile can have a major effect on the sufficiency or deficiency of N at certain stages of physiological development of plants.

Deep sampling is especially important in well drained soils. If concentrations of NO_3^- are found at any depth within the root zone, the plants will make use of some of it at least. Failure to take account of the N compounds occurring deep within the soil will result in errors of correlation interpretation.

2.1.2 Irrigated crops

Soil sampling depths recommended for irrigated sugar beets, maize, or other grain crops are usually 120 to 180 cm (Carter et al. 1974; Giles et al. 1975; Smith, 1977). Some accept or use 60 cm or less (Ludwick et al. 1975; North Dakota Cooperative Extension Service, 1975), but data are being collected that may justify deeper sampling.

Because of the shallow rooting of potatoes, recommended soil sampling depths are 60 to 90 cm (Dow et al. 1969). Sampling soils below the rooting depth of crops such as potatoes does not improve the data needed to assess the amount of NO_3^- N available for the crop, but these deeper samples can provide valuable data about NO_3^- movement in the soil and about water and N fertilizer management. For example if excessive NO_3^- N from fertilizers has moved beyond the root zone, reduced amounts of irrigation water per application and more frequent irrigations may be necessary. Also, a change from single to split applications of N could be practised to reduce leaching. Knowledge of large concentrations of N compounds below the depth of rooting for shallow rooted crops can permit the farmer to use a cereal, maize, or other deeper rooted crop to use that N.

Experiments in Nebraska (Anderson et al. 1972) using labelled N (^{15}N) produced data showing that sugar beets absorbed N from the deepest placement of 135 cm. Also sugar beets grown in a soil shown by test to be high in NO_3^- absorbed less deep NO_3^- than from a soil with a low test value. Deep NO_3^- not accounted for can result in excessive NO_3 absorption by the sugar beet plants late in the growing period. Deep sampling is also useful for identifying fields with high levels of NO_3 so crops such as malting barley (*Hordeum vulgaris* L.) and soft wheats requiring low protein can be grown elsewhere.

2.2 Taking and Handling Soil Samples

The greatest problem associated with farmer participation in deep soil sampling concerns ability to take and subsequently handle the samples. Farmers in the USA are willing to employ someone for soil sampling services, but this may not be so in countries where the government might provide the service. Fertilizer dealers in some states provide a sampling service to customers which is sometimes free if the fertilizer is purchased from that dealer. In North Dakota, soil sampling is a profitable sideline business for many people. One reason for an extremely rapid increase in soil testing for NO_3^- in North Dakota is availability of custom sampling.

Deep samples are not difficult to collect with vehicle-mounted hydraulic soil samplers. Such equipment is used for sampling to depths of 120 to 180 cm or more Special designs of slotted and larger diameter tubes make sampling easier if soils are high in clay content and sticky when wet, or when soils contain gravel that can easily plug small diameter probes. Open faced hand probes are widely used in medium to moderately coarse soils, but extreme care is required to avoid contamination. Augers are also available but should be used only under extremely difficult conditions as contamination is a serious problem. Sampling to a depth of 60 cm is relatively easy and equipment is inexpensive. Although sampling by hand is practical, the number of soil samples taken is likely to be inadequate to represent the field correctly.

Consider the area of a field to be represented by a composite set of profile samples as a "sampling unit". Each sampling unit must represent areas of similar soil types with past crop and fertilizer management that has been nearly constant for a minimum of 3 to 5 crop years. For a composite sample (Northwest Soil and Plant Test Work Group, 1974; Smith, 1972) representing the surface to 15, and 15 to 30 cm depths, 15 to 25 cores should be mixed together. Fewer cores are needed from greater depths. Unless the subsoils are extremely variable, the number of cores for the second sample depth or to 60 cm can usually be reduced by one-third or to 10 or 15 cores. Generally, less variability in inorganic N occurs at depths greater than 60 cm so a composite of 5 to 7 cores per sample is sufficient. Most states advocate separate analysis for each 30 cm to obtain NO_3^- distribution. Usually they suggest plough depth or 15 cm as one sample and from that depth to 60 cm for the second, then each 30 cm to the full depth of sampling. In addition to NO_3^- the plough depth sample may be analysed for pH, P, K, sometimes NH_4^+, other elements, OM and soluble salts.

Soluble salts, including nitrates, are not uniformly distributed in soil after rill or furrow irrigation, and special procedures are recommended to avoid non-representative samples (Smith, 1972). If the row direction is known, a set of three cores per depth should be taken in a direction parellel to the row or ridge and spaced at one-fourth the distance between ridges as shown in Figure 1. This procedure should be repeated for each 0.8 to 1.2 ha (2 or 3 acres) and the sets of three cores should be bulked by depths to make up a sampling unit. Each set of three cores can be bulked and analysed separately if desired.

After taking samples for inorganic N analysis biological activity in the soil must be stopped or retarded. If this is not done analysis for NO_3^- and NH_4^+ may yield incorrect data. The author subdivided soil samples and measured increases in NO_3^- of 10 ppm N or more in field-moist soil samples that were transported 2 days for comparison with counterpart samples that were frozen after being taken. To avoid significant changes, samples should be spread in a thin layer and drying initiated within a few hours after sampling, or samples can be frozen or refrigerated until drying can be done. When drying the soil samples, forced air and temperatures at less than 50°C should be used. Plastic-lined bags set into an oven retard drying rate so much that microbial activity can produce significant changes in the samples. High clay content of soil, large samples, and not using forced air may cause incorrect NO_3^- or NH_4^+ data because of a slow drying rate.

Contamination in the field can occur as for samples taken for any soil tests. However, if analytical tests include NH_4^+, measures must be taken to avoid contamination of samples by ammonia (NH_3). Samples held in storage, even though dry, can adsorb enough NH_3 to produce large errors.

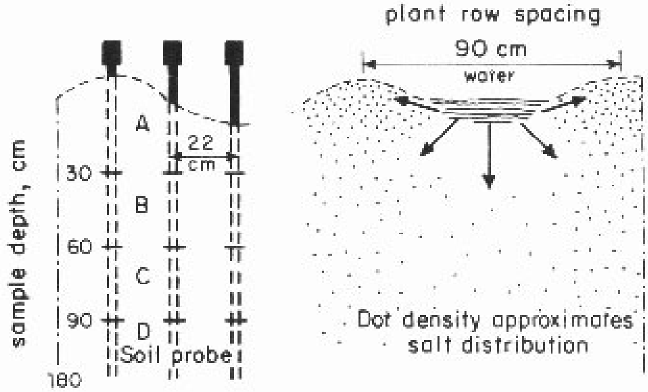

Fig. 1 Soluble salts, including nitrates, are not uniformly distributed after furrow irrigation. Arrows show direction of water movement from the furrow. Rainfall or sprinkler irrigation produces less pronounced effects. To take soil samples, combine three cores by 30 cm depths spaced at 1/4 the distance between ridges or rows, and in a line perpendicular to them. Repeat this procedure for each hectare (Smith, 1972)

3. SOIL WATER AND PRECIPITATION

The success of non-irrigated crop production is dependent on precipitation during the crop growing season and plant available water stored in the soil. It is possible to determine plant available soil water content in late winter or early spring before planting or soon thereafter. It is not easy for farmers to measure stored soil water quantitatively. Expected precipitation is estimated from long-term records. Farmers are encouraged to keep precipitation records and to compare them with the official data. They soon realize how their farming areas differ from government weather stations.

Brown (1971) in Montana has shown the interrelationship of soil water, growing season precipitation, and N levels for producing high yields of grain. He related wheat plant development to a continuous water budget during its growing season. Adequately fertilized winter wheat grown on a silt loam (medium textured) soil extracted more water from intermediate soil depths than when N was deficient. Sufficient N also caused root extension and water extraction to take place to depths greater than 180 cm. This emphasizes the need to know the soil water status for the potential crop rooting zones.

In practice, special effort is needed to obtain soil water data, adequate equipment being required for deep sampling. Soil samples can be collected by a farmer or a researcher using any one of various tools such as spades, augers, tubes and probes. For the data to be useful the best time to assess soil water status in near fertilization, and preferably as near the growing season as is practicable. Gravimetric determinations of water are usually made on the same samples as NO_3^-; however, if sampling is done in the autumn, an estimate of water stored in the soil from winter precipitation will be needed. Measuring plant available water in soils to a high degree of precision is difficult on a field scale. However, when considering the level of precision associated with predicting growing season precipitation, assessing other variables that affect yield, and the difficulty of obtaining accurate soil bulk densities to represent the soil profile sampled, adequate estimates of soil water can be practicable.

An alternative method for estimating soil water is to use a probe (Brown, 1959) to measure depth of moist soil. It consists of a rod with a short piece of drill bit for wood welded to the end. When the depth of moist soil is known an estimate of plant available stored water can be made by determining texture and by applying appropriate factors. This gives useful "approximate" values for estimating potential yields and potential response to N.

Another procedure for estimating the effect of probable available water for a dryland crop is to establish a yield goal with adequate fertilization. A "yield goal" is the yield one should expect from a given soil and climate. If a yield goal is realistically set it should serve as an integrator of expected precipitation and stored soil water that the farmer believes will occur for his soils under his management.

Farmers' yield records can be a guide for establishing goals but should be used carefully. Expected yields should not be disproportionate to yield potentials based on experimental data. Used wisely, this system can be a major improvement over using NO_3^- as a single variable. Many states use yield goals in combination with inorganic N by soil test as a basis for adjusting N fertilizer rates. This, in effect, becomes a budget approach to recommendations whereby one calculates N fertilizer needed to produce an expected yield.

4. USING INORGANIC N SOIL TESTING SYSTEM

There is no single best approach to obtaining or using data about inorganic N for N fertilizer recommendations. Nitrogen availability to crops and its effectiveness in producing yield increases is linked so closely to plant available soil water, precipitation, temperature, and to other factors that one should expect system modifications in different regions. If the amount and distribution of NO_3^- were reasonably constant in a soil management system, which it seldom is, soil testing would be needed only frequently enough to check the status.

4.1 Analysis and Reporting Test Results

States and provinces differ in their use of NO_3^-, or both NH_4^+ and NO_3^-, as a measure of plant available N in soil samples. Reports from Kansas (Whitney, 1974), Idaho (Painter *et al.* 1975), and Saskatchewan, Canada, (Read and Warder, 1973) indicate that NH_4^+ is of sufficient quantity in soils, especially in the spring, to be considered significant for recommendations. Generally when both ionic forms of N are measured they are considered as equal in availability to plants and are summed when making recommendations. Most states that only test for NO_3^- have had experiments where NH_4^+ was of significance. However, NH_4^+ concentrations were reasonably constant and are not used as a variable when making recommendations.

Reporting of data is not consistent among laboratories. The concentrations of NO_3^- and NH_4^+ measured in extractions from soil samples are apparently always expressed as N. Differences of expression caused by calculation procedures and factors are imposed subsequently. Some soil test reports show N as parts per million, while others convert concentration (ppm) to quantity (kg/ha) before reporting, or both may be given.

Some states use a soil density of 4.5 million kg/ha per 30 cm of soil depth and convert ppm of N to kg/ha. This means that they assume the soil bulk density is constant for all depths and for all soils, but perhaps errors introduced in this way are not as serious as others in the system.

Various reporting procedures are intended for easier use of soil test data. Attempts to oversimplify have in some instances contributed to computation steps that are not only confusing but sometimes erroneous. If NO_3^- and NH_4^+ concentrations are reported as ppm of N for the specific sample depth, a simple equation can then convert the data to quantity (kg/ha) if bulk density is known. Alternatively, N in both ppm and kg/ha can be shown on the report for each depth. Providing correct information for each depth gives the user of the soil testing service the best data.

4.2 Interpretations and Recommendations

Much of the reason why some researchers do not have success with N soil testing is their unwillingness to try combinations of data from various factors affecting crop yield. Making N fertilizer recommendations from soil test data for inorganic N, ranges from using equations that incorporate several variables to availability index ratings of very low, low, medium, and high with associated N fertilizer rates for different crops. Most widely used procedures fall in between, but variations in simplicity can even occur among crops within a state. Examples of procedures show different techniques being used and some of these may be soon out-of-date.

Many researchers have examined relationships between soil test data for inorganic N measured before the crop was grown and yield responses to N fertilizer. A general summary is that high correlations are not uncommon for single experiments, but the correlations become poorer as experimental data from more soils and climatic conditions are added.

In the mid nineteen fifties Leggett (1959) in Washington showed a good relationship between dryland wheat yields and available water and nitrogen. This research plus additional more recent data has evolved into the present fertilizer guide for dryland winter wheat in eastern Washington. It is a budget type of approach.

This budget method utilizes a computation of the amount of N required to produce an estimated potential yield based on response data from experiments. Then an inventory of the plant available N from all sources other than fertilizers is made. The fertilizer N required is represented by the difference between the plant available N and the total N required for the potential yield. There are several modifications of this system in use.

Washington dryland winter wheat recommendations (Engle et al. 1975) are developed in four steps: (i) estimate potential yield from plant available water, (ii) calculate N needed to obtain that yield, (iii) inventory the soil N, and (iv) calculate N fertilizer rate needed. More specifically this is done as follows:

i. Potential yield = (yield/unit of water) x (expected precipitation plus available soil water minus water to grow plant)

Yield(hl) = 0.97 hl/cm (ppt in cm + soil water in cm - 10 cm)

Note: For soft white winter wheat use 0.97 hl/cm and

0.83 hl/cm for hard red winter wheat.

Precipitation (ppt) is that expected for wheat growing season.

Soil water is plant available water to 180 cm or to a root restricting layer. (Some states use 120 cm depth.)

10 cm of water is used to grow the plant, without fruiting.

ii. N needed (kg/ha) = (i) hl/ha x 3.5 kg/hl

Note: Use 3.5 kg/hl of N for soft white winter wheat and 3.9 kg/hl of N for hard red winter wheat

iii. Soil N inventory = soil test NO_3^- as kg/ha of N to 180 cm plus expected N mineralized during the growing season, previous crop if legumes, and other sources minus expected loss of available N by immobilization, volatilization, denitrification, and leaching.

iv. N fertilizer rate = (ii) - (iii)

North Dakota recommendations for N fertilization of non-irrigated small grains are determined by a modification of the budget approach. A yield goal is provided by the producer who is asked to consider the highest yield he has had for the particular field. He can make adjustments in yield goal depending on data from N-rate experiments, stored soil water, expected precipitation, and other management factors. A warning is given that unrealistic yield goals will result in incorrect N recommendations.

The N required to produce a crop depends on crop yield, at least within certain limits. A chart of yield goals and N requirements for wheat, durum, rye (*Secale cereale*), feed barley, and oats (*Avena sativa* L.) was developed from numerous field experiments. The difference between total N required to produce the yield (based on experimental data) and N available in the soil to 60 cm is the N fertilizer recommendation. Also a circular (Wagner and Vasey, 1971) relates soil water and precipitation to expected yield responses to fertilizers. Instructions are given on how to estimate plant available soil water by depth of wet soil and soil texture. A map is also provided that shows percentage probabilities of receiving more than 150 mm of precipitation for the period 3 May-1 August, a 13 week period during which precipitation has a major influence on grain yield. North Dakota's use of yield goals lays the responsibility for determining a realistic yield on the farmer. In developing countries greater assistance would need to be provided by advisers, but the farmer should still be involved.

Montana irrigated sugar beet recommendations for N fertilizer are given in a fertilizer guide (Christensen et al. 1974) and are based on budget inputs of: (i) total N requirements, (ii) soil test NO_3^-, (iii) estimated mineralized N, (iv) N from manure, and (v) N from previous crop. These are combined to obtain the N rate to apply, as follows:

i. Data from several N-rate experiments indicate an N requirement for sugar beets of about 4.5 kg/t. The yield goal is the 5 year average for the field. Note that these farmers have used fertilizer for many years and the average should reflect their management, soil potential and the average growing season conditions. The sugar beet producer is reminded that excessive N, whether residual or from fertilizer, can reduce total sugar production.

ii. Soil test data are reported as N for each soil depth sampled. An equation is given for the quantitative calculation of N from concentrations (ppm) given in the soil test report and any depth of sample.

iii. N mineralization is estimated as about 34 kg/ha per 1% OM, during the growing season. This is an average of data from several experiments and could be different in other climatic areas.

iv. Manure contributions to N supply are based on long time experiments in the state (Halvorson and Hartman, 1975). The available N per ton of manure is credited as 4 kg/t for the first year and half that amount for the second.

v. Adjustment for the previous crop reduces the needed N fertilizer if that crop was leguminous and increases the N rate when straw or maize stover is to be ploughed down. The adjustment for rate of N fertilizer per ton of crop residue is 10 kg/t.

4.3 Direct Response Method

Some states have related crop yield response to N fertilizer to soil test N, soil water and precipitation; others have developed different tables of N rates for different climatic and soil regions.

Montana dryland winter wheat N fertilizer recommendations (Christensen and Smith, 1973) take into consideration soil test NO_3^- and expected plant available water. Plant available soil water is determined either by gravimetric soil analysis or estimated from depth of moist soil and soil texture. The grain producer is encouraged to keep precipitation records and relate them to those for the nearest weather station.

A two-way table gives the N fertilizer rates for each of several ranges of NO_3^- in the soil profile, at different amounts of plant available water from 20 to 36 cm or more. Plant available water is the sum of soil water and expected growing season precipitation. The highest N rate recommended is 134 kg/ha for a very low NO_3^- soil test level and 36 cm or more of soil water plus expected growing season precipitation.

5. ANALYSING ORGANIC N

Analysing soils for either the OM content or the net mineralization resulting from incubation of samples under standard conditions of temperature and moisture are two other techniques being used. They have their advantages and disadvantages (Dahnke and Vasey, 1973 ; Bartholomew, 1972). Because availability of N has been related quite well to total soil N for single soil types and for local climate zones (Bartholomew, 1972), these determinations can sometimes provide useful data.

Predicting N fertilizer needed for rice production is difficult. There are problems with soil tests for N, especially for paddy soil conditions. Hsi and Su (1972) reported work of Wang in 1966 in Taiwan. He calculated percentage increase in rice growth due to added N, $[(N-N_o)/N \times 100]$ and correlated this with percentage soil organic matter. In greenhouse experiments the correlation coefficient r was -0.82, which was significant at the 1% probability level. However, the relationship determined in the greenhouse was not very good in the field. They concluded that soil tests are not very accurate for rice. M. Sudjadi (personal communication) has also indicated little success in testing paddy soils in Indonesia.

Under Korean conditions Park found a relationship between the "available silica", organic matter contents of paddy topsoil, and the physical conditions of the soil. He showed OM percentages of over 2% to be of little value for predicting N supplying capacity in soils if Si levels are low (78 to 130 ppm). However, with Si levels in the range of 520 to 1040 ppm, the influence of over 7% OM was detectable. Nevertheless, he indicated that a minimum rate of 100 kg/ha of fertilizer N is needed for rice regardless of the calculated relationships.

6. SUMMARY

Nitrogen fertilizer recommendations are being made for several crops based on soil tests for inorganic N in soil profile samples, plant available water for non-irrigated crops, and other management factors. N soil tests on samples taken to 60, 120, or 180 cm depth appear to be used most in the Great Plains and the West of the United States.

Procedures may have been developed earlier for dryland crops in most of these areas because of the strong interdependence of plant growth response to N and to plant available water. Also, in these areas conditions are favourable for a build-up of residual NO_3^- because of summer fallow practices and the infrequent flushing of water through the soil profile. Sugar beets and oil seed crops, where quality as well as yields of sugar and oil are closely related to available N supply, have received much attention in development of inorganic N testing. Not only is it important to determine quantity of NO_3^- in the soil but its distribution is needed as well. Nitrate-N deep in the soil can be absorbed by sugar beet roots late in the season, for example, and can reduce total sugar production. Soil testing for NO_3^- has proved useful for N and water management on irrigated potatoes and other crops.

There is much variation among states and Canadian provinces as to depth for sampling, methods of reporting test data, variables used for making recommendations, and inclusion of NH_4^+. Regional efforts are underway in the Northwest and in the Great Plains to resolve some of these differences. Generally the approaches vary because of soil and climatic conditions that existed when experiments were conducted in each area. It is more difficult to integrate approaches when climatic and management factors are involved in recommendations.

There are major efforts underway to improve field calibrations for inorganic N soil testing, and to examine carefully whether a system can be developed for more crops in areas of present use and for certain soil and crop conditions in more humid areas.

Testing soils for N under high precipitation or paddy conditions includes additional problems as compared to well drained soils in the semi-arid to sub-humid areas.

Collection and refinement of additional data on soil testing for inorganic N, and imagination in its use, are needed to combine measureable and predictable factors into the most convenient and useful N fertilizer management techniques. Opportunities exist to improve N recommendations for many crops through timely soil testing for NO_3^- and NH_4^+ in soil profile samples. Testing soils for NO_3^- and NH_4^+ should not be overlooked in programmes of developing countries. However, definite limitations exist for many crop production areas. Goals are to improve crop product yield and quality in addition to optimizing N fertilizer use efficiency for energy conservation and environmental quality.

REFERENCES

ANDERSON, F.N., PETERSON, G.A. and OLSON, R.A. Sugar beet quality, soil testing can help. 1972 Nebraska Coop. Ext. Ser. QR 7-72.

BARTHOLOMEW, W.V. Soil nitrogen supply processes and crop requirements. Intl. Soil Fert. 1972 Eval. and Impr. Prog. Tech. Bul. 6. North Carolina State Univ., Raleigh, NC.

BROWN, P.L. Soil moisture holds the key! Crops and Soils. 11(9): 16-17. 1959

BROWN, P.L. Water use and soil water depletion by dryland winter wheat as affected by 1971 nitrogen fertilization. Agron. J. 63: 43-46.

CARTER, J.N., JENSEN, M.E. and BOSMA, S.M. Determining N fertilizer needs for sugar beets 1974 from residual soil nitrate and mineralizable N. Agron. J. 66: 319-323.

CHRISTENSEN, N.W., BALDRIDGE, D.E., HARTMAN, G.P. and HALVORSON, A.D. Sugar beets - 1974 Irrigated. Montana Coop. Ext. Ser. Fertilizer Guide. AG55.610:60.

CHRISTENSEN, N.W. and SMITH, C.M. Winter Wheat - Non-irrigated. Montana Coop. Ext. Ser. 1973 Fertilizer Guide. AG55.610:21.

DAHNKE, W.C. and VASEY, E.H. Testing soils for nitrogen. In: L.M. Walsh and J.D. Beaton (ed) 1973 Soil Testing and Plant Analysis. Soil Sci. Soc. of Amer. Madison, Wis. p. 97-114.

DAIGGER, L.A., SANDER, D.H. and PETERSON, G.A. Applied nitrogen - Where is it? Univ. of 1972 Nebraska Coop. Ext. Ser. QR 5-72.

DOW, A.I., JAMES, D.W. and NELSON, C.E. Interpretation of soil test N for irrigating 1969 crops in central Washington. Washington Coop. Ext Ser. Cir. E.M. 3076.

ENGLE, C.F., KOEHLER, F.E., MORRISON, K.J. and HALVORSON, A.D. Dryland wheat nitrogen 1975 needs for eastern Washington. Washington Coop. Ext. Ser. Fertilizer Guide. FG34.

GILES, J.F., REUSS, J.O. and LUDWICK, A.E. Prediction of nitrogen status of sugar beets 1975 by soil analysis. Agron. J. 67: 454-459.

HALVORSON, A.D. and HARTMAN, G.P. Manure good source of N for beets. Mont. Farmer 1975 Stockman. 62(9): 21-23.

HSI, L.C. and SU, N.R. Soils of the ASPAC region. The fertility status of Taiwan soils.
1972 Tech. Bul. No.8 Food and Fert. Tech. Centre, Taipei.

LEGGETT, G.E. Relationship between wheat yield, available moisture and available nitrogen
1959 in eastern Washington dryland areas. Washington Agric. Exp. Stn. Bull. 609.

LUDWICK, A.E., SOLTANPOUR, P.N. and REUSS, J.O. Guide to fertilizer recommendations in
1975 Colorado. Colorado Coop. Ext. Ser.

NORTH DAKOTA COOPERATIVE EXTENSION SERVICE. 1977 Crop Production Guide: Diagnostic methods
1976 and fertilizer recommendations. North Dakota Ext. Ser. Cir. A-592, 44-61.

NORTHWEST SOIL AND PLANT TEST WORK GROUP: Subcommittee on Soil Sampling. Principles of
1974 soil sampling for Northwest agriculture. In A.I. Dow (ed.) Proceedings Twenty-fifty Annual Pacific Northwest Fertilizer Conference. Richland, Washington, 16-18 July. Northwest Plant Food Assn., Portland, Oregon. p. 115-126.

PAINTER, C.G., JONES, J.P., McDOLE, R.E., JOHNSON, R.D. and OHMS, R.E. Potatoes: Idaho
1975 fertilizer guide. Idaho Coop. Ext. Ser. and Agric. Exp. Stn. Current Information Series 261.

PARK, C.S. Practice of fertilizer application for the rice under the shortage of chemical fertilizers in Korea. Institute of Agr. Sci. Suweon, Korea.

READ, D.W.L. and WARDER, F.G. Influence of soil and climatic factors on fertilizer
1973 response of wheat grown on stubble land in southwestern Saskatchewan. Agron. J. 66: 245-248.

SANDER, D.H., DAIGGER, L.A. and PETERSON, G.A. How much fertilizer on wheat? Nebraska
1973 Coop. Ext. Ser. Neb Guide. G 73-37.

SMITH, C.M. Diagnostic Methods. In: W.C. White and D.N. Collins (ed.) The Fertilizer
1972 Handbook. The Fertilizer Institute, Washington, D.C. p. 115-141.

SMITH, C.M. Interpreting inorganic N soil tests: sample depth, soil water, climate and
1977 soil. In: T.R. Peck, J.T. Cope Jr., D.A. Whitney (ed.) Soil Testing: Correlating and Interpreting the Analytical Results. ASA Spec. Publ. No.29. Am. Soc. Agron., Madison, Wisconsin.

WAGNER, D.F. and VASEY, E.H. Refining fertilizer recommendations by state areas, stored
1971 soil moisture conditions and rainfall probabilities. North Dakota Coop. Ext. Ser. S & F No.1.

WAGNER, D.F., DAHNKE, W.C., BAUER, A., and VASEY, E.H. Fertilizing small grains.
1974 North Dakota Coop. Ext. Ser. Cir. S-F 2.

WHITNEY, D.A. Soil test interpretations and fertilizer recommendations. Kansas Coop.
1974 Ext. Ser. Cir. C-509.

Paper 13

SOIL TESTING FOR SOLUBLE NITROGEN AS AN AID FOR CALCULATING NITROGEN FERTILIZER REQUIREMENTS

by

J. Dressel
BASF Agricultural Research Station
Limburgerhof, Federal Republic of Germany

1. INTRODUCTION

Because of the intensification of agriculture, a level of N application has been reached in Central Europe (the Netherlands 208 kg/ha; Belgium 114 kg/ha; the Federal Republic of Germany 90 kg/ha; France 48 kg/ha; England 52 kg/ha) 1/ which makes it necessary that the rate required should be precisely calculated. This is important since nitrogen as a growth promoter not only has the greatest visible effect on plant growth, but can also adversely affect the maximum economic yield when applied too generously (lodging of cereals, loss of quality with sugar beets, potatoes, etc.) as well as when applied insufficiently (reduction of yield with all plant types, loss of quality). For this reason an exact calculation is not only interesting from the scientific standpoint but is also a necessity for profitable farming.

The increasing yield level of the past few years has brought us within the reach of the highest possible yield for many plant varieties. Contributions to this yield are made by both the newly applied fertilizer and the long-term improvement in soil fertility due to decades of using fertilizer under skilled land management. Evidence of this can be shown by field trials conducted on farmers' fields over many years where on constantly changed sites the control plots have produced steadily rising yields from about 2 t/ha of wheat in 1925 to 3.8 t/ha in 1970. It can be assumed that some 50% of this yield increase is the result of advances in plant breeding, plant protection and agricultural engineering, and the remaining 50% is due to improved plant nutrition. Similarly, equal shares in the increased yield can be attributed to the current use of fertilizer and to the residual effect through increased soil fertility. This also means, however, that under Central European conditions a high yield level can only be achieved after several years of intensive crop husbandry. This is particularly true for the high-yielding varieties which require much better soil conditions than the former native varieties. The realization that in many places yields nearing the maximum are being produced under present-day production methods makes it necessary to be informed on the current nutrient supply level of a soil. This is especially so for nitrogen since the nitrate and readily soluble ammonium nitrogen present in the soil are fully available to the plants.

2. SOIL ANALYSIS

Unlike the nutrients P, K, Mg and the trace elements, for which a study of only the topsoil normally suffices, an analysis for soluble nitrogen necessitates a study of most of the soil space that can be penetrated by roots. Usually a soil sample down to a soil depth of 1 m is enough. It is also advisable to subdivide the profile into 20 cm or 30 cm soil layers in order to find out at which depth the main nitrogen supplies are located. Table 1 presents some examples showing the varying

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1/ Yearbook of Agricultural Statistics 1976.

distribution of NO_3^- nitrogen in soil profiles from several farms in the spring of 1977. This table shows that it is not only important to know the total amount; one should also know the distribution in the profile. The nitrogen at 80 - 100 cm depth is available to the plants much later than that in the upper layers.

Table 1 DISTRIBUTION OF NO_3-N IN SPRING 1977 IN SOIL PROFILES ON VARIOUS FARMS (kg/ha)

Farm No.	0 - 20	20 - 40	40 - 60	60 - 80	80 - 100	Total
1	8	12	5	4	6	35
2	5	11	14	16	12	58
3	10	10	12	23	40	95
4	10	16	17	34	38	115
5	19	32	73	47	11	182
6	74	92	83	58	27	334

3. DIFFICULTIES THAT ARISE WHEN ANALYSING SOIL FOR SOLUBLE NITROGEN

Problems are caused less by the analysis itself than by incorrect soil sampling and storage of the samples until they reach the laboratory. The soil must be cooled immediately to 2 - 4°C, screened in its natural state (without drying) and analysed. This requirement is easy to fulfill in areas neighbouring the laboratory but not so when many farmers living a great distance away desire such a soil study. The farmers also demand that the results of the study be in their hands within 10 - 14 days. This demand is justifiable since the tests can only be made in the spring and the values can change owing to percolation of the nitrogen downwards to lower layers if the interval between the soil sampling and the fertilization date is too long (Figure 1).

Another problem is nitrogen mineralization which intensifies as the growing season progresses. Figure 2 shows that N in the green manures of the previous autumn was mineralized due to sudden high precipitation with high soil temperatures after a long dry period (March, April and May 1975: 55 mm), and the liberated nitrogen acted like a late dressing of N for the wheat. This points to still another difficulty for the advisory service since without knowledge of the case history of a field it is impossible to foresee a sudden liberation of N. We use in addition a checklist (Figure 3) enumerating all the criteria that could influence the soluble nitrogen. With its use the adviser or farmer can increase or decrease the application in order to adjust appropriately the values found by the soil study.

It is our belief that now and in the immediate future soil studies for nitrogen that are conducted annually can only be carried out at sites representative of a uniform climatic region. It is not possible to analyse several plots for many or all of the farmers within the short period allowed, since the logistic prerequisites are non-existent. The results of the soil tests at representative sites will be made public and advisers or farmers can determine the amount of the nitrogen application with the aid of the checklist.

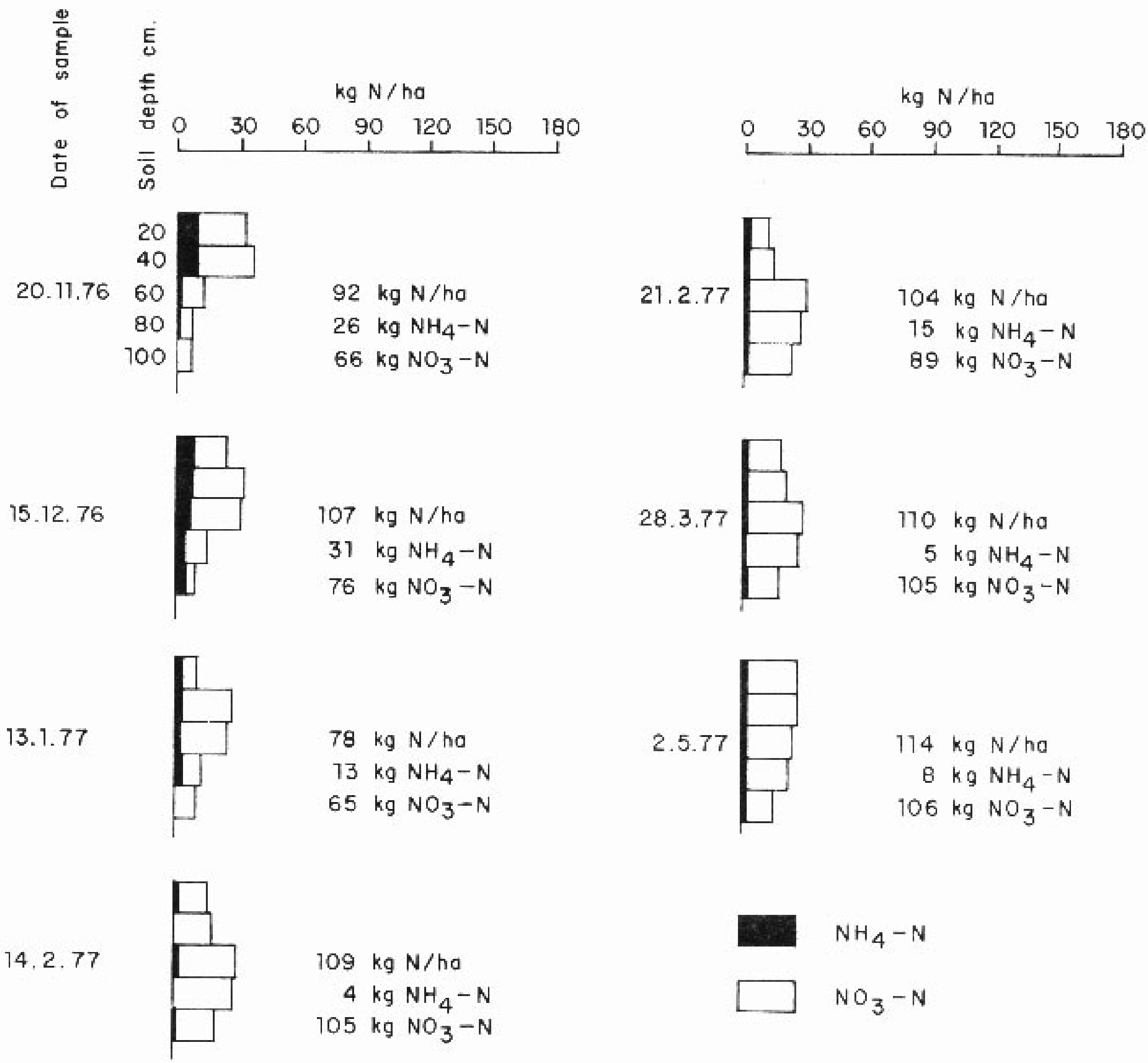

Fig. 1 Transport of N_{min} during winter six months 1976 - 77 (at Ruchheim)

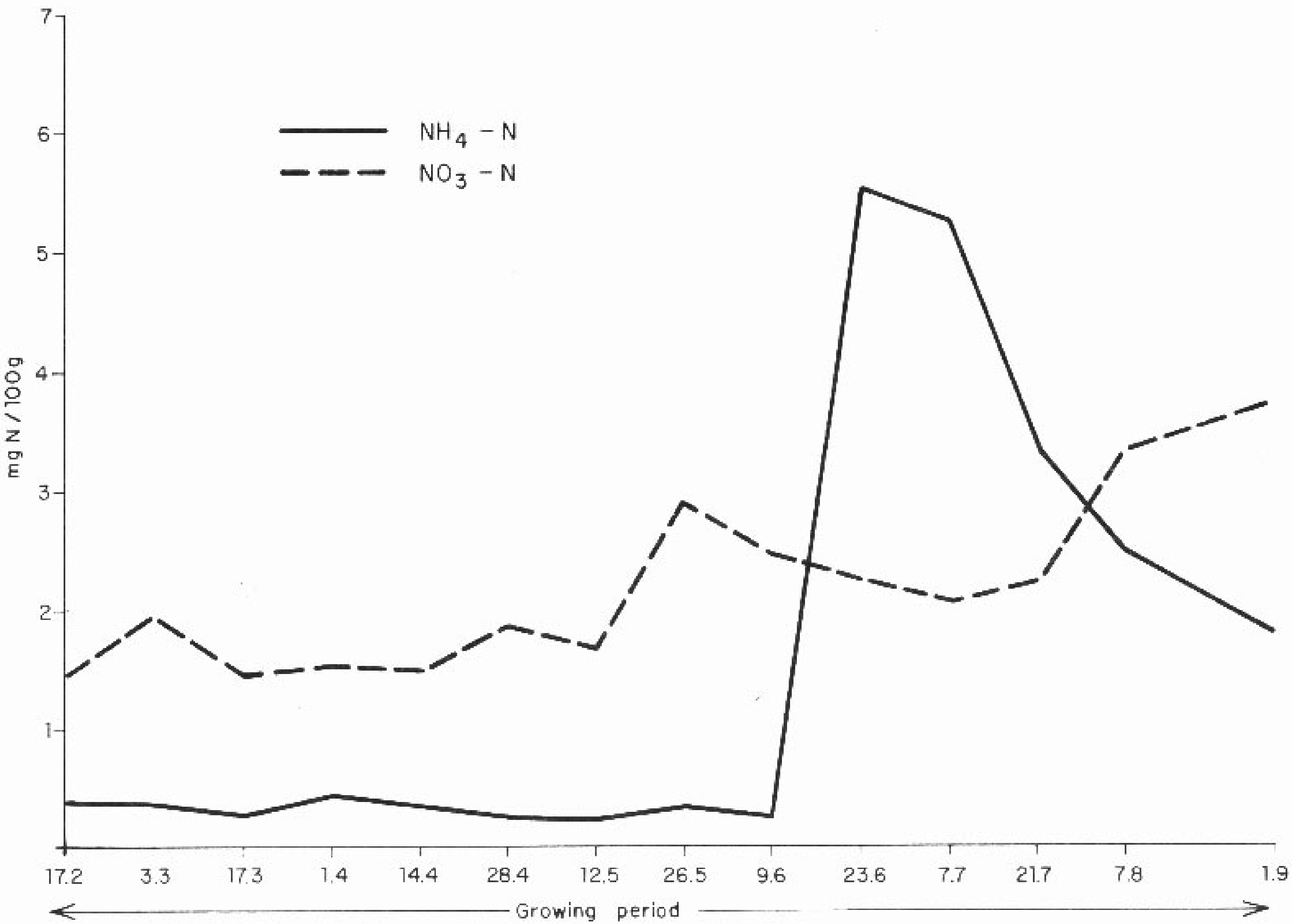

Fig. 2 Nitrogen mineralization in the growing period of 1975 under fallow (0 - 40 cm. soil depth, at Ruchheim)

Figure 3 - CHECKLIST FOR N FERTILIZATION OF CEREAL CROPS

	Spring application			Intermediate application	Late application
	Single dose	Split 1st dose	2nd dose	(on good soils generally not recommendable)	
Recommendation according to type of cereal and site kg/ha N	50-100	50-80	50-30	0-30	40-80
FARMING EXPERIENCE kg/ha N					
WINTER WEATHER: a) little permeable soils					
dry, mild					
dry, cold					
normally humid, mild					
wet, cold					
wet, mild					
b) permeable soils					
dry, mild					
dry, cold					
normally humid, mild					
wet, cold					
wet, mild					
ORGANIC FERTILIZATION: (manure, gülle, green manure, beet leaves, straw with complementary N)					
1 year before (on the crop)					
2 year before (on preceding crop)					
Without organic matter					
Straw without supplementary N					
PREVIOUS CROP: beets/potatoes					
rape/maize					
cereals					
CROP DENSITY: high (foreseeable $\geq$ 550 ear-carrying stems/m^2)					
low (foreseeable $\leq$ 400 ear-carrying stems/m^2)					

	Spring application			Intermediate application	Late application
	Single dose	Split 1st dose	Split 2nd dose	(on good soils generally not recommendable)	
Recommendation according to type of cereal and site kg/ha N	50–100	50–80	50–30	0–30	40–80
WEEDS: higher weed/grass density in winter in early spring					
SOIL TILLAGE: unsuitable soil structure (e.g. after wet beet harvest)					
very good soil structure (tillage at ideal soil conditions)					
SPRING WEATHER: favourable to growth					
unfavourable to growth					
PRODUCTION PURPOSE: cereals for forage					
quality wheat					
brewery barley					
Numbers Numbers					
Total of additions and substractions					
N-FERTILIZATION IN CURRENT YEAR					

PROBLEMS INVOLVED IN ESTIMATING THE MICRONUTRIENT STATUS OF SOILS

by

M. Sillanpää
Institute of Soil Science, Vantaa, Finland

1. INTRODUCTION

Micronutrients are not regularly applied to soil by the use of the common fertilizers. Their removal from the soil has been going on for centuries without any systematic replacement. It is apparent that hidden micronutrient deficiencies are far more widespread than is generally estimated. Micronutrient problems, which today may be considered only local, may well become more serious in the relatively near future, occuring over extensive new areas and creating widespread and complicated production restrictions if they are not properly studied and diagnosed in time.

The amounts of micronutrients removed yearly with normal crop yields vary greatly depending on the crop, yield level, soils and factors affecting uptake and availability. The quantity removed represents only a very small proportion of the various micronutrients present in soils, generally less than one percent of the total. Thus, it is obvious that even in the most serious cases of deficiency the total amounts far exceed the requirements of crops.

2. METHODOLOGICAL PROBLEMS

Micronutrient concentrations in plant tissue usually reflect the fractions of the respective elements available in the soils. Therefore, both plant analyses and soil tests have been used to diagnose the micronutrient status of soils. Opinions differ, however, as to the value of these two techniques. An advantage of plant analyses compared with soil tests is that uniform methodology can be used over a wide range of varying soil and climatic conditions. Also the pretreatment of samples as well as analytical procedures are to a certain extent common or vary little from one element to another. The disadvantages include e.g. the wide variation in concentrations of micronutrients found in different plant species, varieties and plant parts and at the different stages of growth, which make it difficult to interpret the results. For example, the B content of the couple of dozen plants grown on the same soil varied between 2.3 (barley) and 95 (poppy) ppm in dry matter (Bertrand and de Waal, 1936). Since all species do not indicate all elements equally well and the most indicative species do not grow in all fields, sampling possibilities are quite limited. Also the timing of sampling may cause practical difficulties because in order to obtain comparable results samples should be taken at the same stage of plant growth. However, chemical analyses of well chosen indicator plants provide valuable information about the micronutrient status of soils, especially in extreme nutritional conditions and, in addition, data on the nutritional quality of the crops can be obtained simultaneously (Cottenie and Kiekens, 1974). Obviously, a combination of plant and soil analyses offers an excellent tool for controlling crop nutrition.

Estimation of the status of various micronutrients in soils by chemical soil tests is difficult because of the great number and low contents of these elements and their varying functions in respect to chemical, physical and biological factors affecting their behaviour and availability to plants. Although the total content of a micronutrient may have an essential influence on its soluble or plant available content, availability may be dominated by other factors such as pH, organic matter, texture, clay minerals, moisture content, redox-potential, temperature and interrelations between other elements etc. Thus total content is seldom a reliable index of the available micronutrient status of the soil.

The loosely bound and easily mobile amounts which are immediately available for biological and geochemical processes are important, i.e. the amounts dissolved in the soil solution and the exchangeable fractions adsorbed to the particle surfaces. Also of particular interest, especially in pedology, are the fractions that have been mobile in the past, i.e. the fractions now found in the humus and those precipitated or accumulated in soil horizons. Finally, there is a third fraction of interest, namely the one which will be released relatively easily and become mobile due to weathering, i.e. primarily the contents of minerals with the lowest resistance to weathering (Andersson, 1975).

Viets (1962) has suggested the hypothesis that various pools of micronutrients exist in the soil. He proposes that these be grouped into five pools: (i) H_2O-soluble; (ii) exchangeable; (iii) adsorbed, chelated or complexed; (iv) secondary clay minerals and insoluble metal oxides; and (v) primary minerals. The first three pools are thought to be in equilibrium, and change in one of them would result in changes in the other two. These three pools are the ones important in supplying micronutrients for the plant during the growing season. Soil tests for micronutrients should, therefore, extract a portion or all of these three pools.

The improvements in analytical equipment made during recent years, in particular the introduction of advanced atomic absorption techniques, have made it possible to determine several microelements in very dilute solutions.

A great number of extractants have been developed for determining the contents of various micronutrient. The use of universal extractants for simultaneously determining the availability to plants of all the known micronutrients is ideal. Such a practice has already been applied for years. Morgan's acid sodium acetate (pH 4.8) has been used as a micronutrient extractant in various countries. Baron (1955) recommended a mixture of ammonium acetate, ammonium sulphate and acetic acid (pH 4) for the determination of boron, iron, cobalt, copper, manganese, molybdenum and zinc. Mitchell (1957, 1964) has used N neutral ammonium acetate and 0.5 N acetic acid (pH 2.5) as well as 0.05 M EDTA for extracting several trace elements from soils. Viro (1955a, b) proposed the use of this chelating agent for the simultaneous determination of plant available copper, zinc and molybdenum in forest soils. Acid ammonium acetate (pH 4.65) is used in Finland in soil testing for K, Ca, Mg and P (Vuorinen and Mäkitie, 1955). The same extraction method was tested and used for the determination of plant available Mn, Zn, Cu, Mo, Co, Ni and Pb (Lakanen, 1962; Sillanpää and Lakanen, 1966). This extractant, however, was found unsatisfactory for some elements and was later strengthened by combining it with 0.02 M EDTA (Lakenen and Erviö, 1971).

Many other combinations of salts and acids of various strengths have been used and tested with other methods of soil and plant analysis. Weak solvents such as water, CO_2-charged water or weak acids are often considered too weak to extract enough of the labile solid phase, and therefore these solvents do not reflect the soil's ability to replenish nutrients removed by plants, while strong acids may release too much of the solid phase nutrients (Viets and Lindsay, 1973). At present it seems that chelating agents, if carefully selected, offer one of the most promising means of assessing the power of soils to supply nutrients (Lakenen and Erviö, 1971; Lindsay, 1974; Viets and Lindsay, 1973). An example of the relative efficiency of nine soil extractants to dissolve five different elements is given in Figure 1.

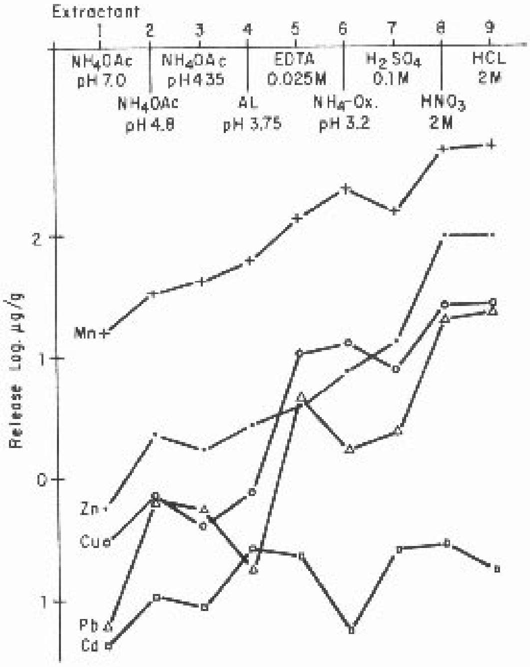

Fig. 1 Amounts of Mn, Zn, Cu, Cd and Pb dissolved by nine different soil extractants (3)

One of the advantages of the chelating agents as extractants is that the amount of metal ions that combines with the chelating agents is a function of both the initial activity of the metal ions (called intensity factor) and the amount of readily replenishable nutrient (capacity factor). In addition, the pH of the extracting media can be carefully selected to avoid many undesirable side reactions (Viets and Lindsay, 1973).

The best known chelating agents are EDTA (ethylenediaminetetra-acetic acid) introduced by Viro (1955a, b) and DTPA (diethylenetriaminepentaacetic acid) by Lindsay and Norwell (1969). Both of these have been widely used as such or in slightly modified forms for extracting cationic micronutrients.

For anionic micronutrientes such as B, Mo and Cl numerous extracting methods have been used. By far the most widely used assay for available B is the hot water extraction originally suggested by Berger and Truog (1940). Available Cl is also commonly measured in water extracts of soils and for Mo Tamm's solution (acid ammonium oxalate) or its modifications may be more extensively used than other extractants such as water, acid ammonium acetate, anion exchange resins or microbiological assay with *Aspergillus niger*.

3. SAMPLING, STORAGE AND PREPARATION OF SAMPLES

Selecting the best possible extraction method for determining various micronutrients in soils is one of the problems involved in estimating the micronutrient status of soils, but it is not the only one.

Misleading results may be obtained because of the heterogeneity of the soil in the area sampled, variation in sampling procedures, sample storage and preparation.

Soil sampling is usually done to the depth of plough layer, but there are no generally accepted rules concerning the number of samples to be taken per unit area. Therefore, previous knowledge of local conditions and soils to be sampled is of practical value.

Drying and storage of samples may have different effects depending on the element in question. Mn, for example, is particularly sensitive to dehydration, and it has therefore been suggested that Mn should be analysed, in field-moist condition before drying and storage (Adams, 1965) or, if this is not possible, drying should be done as slowly as practicable.

Special precautions should be taken to avoid contamination of the sample at all stages from sampling to the end of the analytical procedure. Materials such as brass, bronze, galvanized steel or any metal equipment containing elements to be analysed should not be used in sampling, preparing or storing the samples.

CALIBRATION OF SOIL TESTS AND INTERPRETATION OF RESULTS

Soil tests are empirical and need to be calibrated in order to create a basis for interpretation of the results. Correlation studies with crop responses on a large number of soils varying from low to high nutrient levels are needed to obtain a general picture of the situation and to establish the critical limits. Response experiments both in greenhouse and field conditions have been used for this purpose. Greenhouse studies are often preferred because they offer better opportunities to control the growing conditions and because of the difficulties encountered in finding field sites where crops will respond to micronutrients. Also correlation of extractable soil concentrations with concentrations in crops or plant uptake have been used in calibrating soil tests. In such studies all nutrients except the one being tested must be present in non-limiting amounts (Mortvedt, 1976).

Interpretation of micronutrient soil tests requires more than just the analytical results. As available Mn, for example, is closely related to soil pH and Cu to soil organic matter content, these factors should be considered in soil test interpretations. Further, environmental factors such as soil temperature, moisture, and aeration affect the availability of micronutrients. Cropping history, the crop to be grown as well as cultivar differences are all factors to be considered in interpreting the analytical results and making fertilizer recommendations (Mortvedt, 1976).

Excellent reviews concerning micronutrient analyses, their calibration and interpretation of results have been published. Among the recent ones are those by Viets and Lindsay (1973), Reisenauer _et al_. (1973), Mortvedt (1976) and Cox and Kamprath (1972).

WHERE TO SUSPECT MICRONUTRIENT DISORDERS

In cases of micronutrient deficiency it is not always enough to know which element is the deficient one; further knowledge about the reasons for the deficiency is needed in order to correct it effectively. Where disorders due to different elements are suspected, general knowledge of soil characteristics and other conditions are of considerable importance. Therefore, a short review of conditions where these disorders have been reported may be appropriate.

5.1 Boron

Low soil values for B have been reported from almost all European countries (Ryan et al., 1967). Its deficiency is most often associated with soils of high base status derived from calcareous parent materials and with coarse textured, leached soils. It occurs under extreme climatic conditions ranging from semi-arid in Greece to humid in Ireland. In Great Britain B deficiency occurs most often on light textured, sandy soils low in organic matter, and is more common in dry summers and on limed and heavily fertilized fields (Hull, 1960). In humid regions of the USA B deficiency occurs most often on sandy and highly weathered soils, where the available B is readily leached from the soil (Berger et al., 1967; Nelson and Barber, 1964; Sauchelli, 1969).

Toxicity of B has been reported in Germany from areas where excessive B has been applied in fertilizers, and in Israel in waterlogged bog soils, in Cyprus in alluvial and Red Mediterranean soils which have been irrigated with waters enriched with B (Ryan et al., 1967). Also in the USA in desert and semi-arid regions, certain soils and irrigation waters may contain toxic concentrations of B (Wilcox, 1960). One ppm in irrigation water is injurious to some plants and 4 ppm is injurious to most dicotyledons (Madison, 1971). Irrigation waters containing 2 ppm B are reported to be undesirable, e.g. sea water contains more than twice this amount (Mitchell, 1964). Natural B toxicity is relatively rare except in arid regions and toxicity from added B is more likely on acid, sandy soils, even on those previously B deficient.

Since the commonly employed salts of B are water-soluble it seems apparent that toxic soil levels of B, resulting from over-application, will be quite readily leached from the majority of soils and, therefore, rarely persist for more than one season (Hodgson, 1963; Purvis and Carolus, 1964).

5.2 Chlorine

Cl is usually found in soils in highly soluble forms and is subject to losses by leaching. Deficiency, however, develops only in extreme conditions, but leaching, e.g. from sandy hill soils, may cause accumulation of Cl in adjoining depression areas. Seashore soils in humid regions and saline soils in arid regions often contain toxic amounts of Cl. For instance, soils prevalent in Japan contain relatively large amounts of Cl, apparently due to the fact the Japan is surrounded by sea (Yamasaki, 1968). White alkali soils contain a high proportion of chlorides and sulphates of sodium.

5.3 Cobalt

While Co deficiency is not limited to any particular type of soil or parent rock, many incidences in Great Britain and Ireland are associated with calcareous sands, old red sandstone and granite (O'Moore, 1961). Similar relationships have been reported from other European countries, (e.g. Austria, Greece and western Germany) and, in addition, Co deficiency has often been observed to occur in areas of podzols or podsolized soils (Poland, Spain, Scotland, Ireland, western Germany, England and Wales), of light sandy soils or other coarse textured soils (Netherlands, Norway, Finland, Israel, Sweden) and of peat soils (Ireland, Finland, Poland). In the Netherlands especially, sands with low organic matter and low clay content and in Sweden all soils, except clays, may be susceptible to Co deficiency (Ryan et al., 1967; Wallace, 1961).

As for other trace elements, such soil factors as texture, pH and soil moisture content are related to the amounts of Co in soils and to its availability to plants. As mentioned above, Co deficiency often occurs on coarse textured soils and correlations between the Co content of soils and their textures have been reported.

In 160 Finnish soils the total content of Co significantly decreased as soil texture became coarser. A similar relationship existed between the content of Co soluble in acid ammonium acetate and texture, but since the relative solubility was not found to be affected by texture, the latter was considered to be due mainly to the former (Sillanpää, 1962). Similarly, a linear positive relationship between the Co and the clay contents of 32 Pakistani soils has been reported (Wahhab and Bhatti, 1958) and in another study the clay fraction of a soil was found to contain up to seven times as much Co as the sand (Hill et al., 1953).

5.4 Copper

Organic soils have often been found deficient in Cu, apparently because of their low total Cu content and partly due to their high capacity to fix Cu. This is especially true in the northern countries where, for example in northern Sweden, half the organic soils but only one-fifth of the mineral soils, have been estimated to be Cu deficient (Agerberg, 1959). In the United States Cu deficiency in field crops occurs mainly on organic soils including peat and muck (Berger, 1962) and similarly in Finland a deficiency in Cu has usually been found to be associated with peat soils or coarse mineral soils (Tainio, 1953). Here the average total contents of Cu in fine mineral, coarse mineral and organic soils were reported to be 33, 16 and 14 mg and soluble contents (acid ammonium acetate) 0.61, 0.29 and 0.19 mg per litre of soil, respectively (Silanpää, 1962). Also Ryan et al. (1967), when summarizing the occurrence of Cu deficiency by country and soil, state that Cu deficiency is most common in peats and podsolized soils in zones of high precipitation. It is also associated with granite, calcareous sandstone, basalt, red sandstone and carboniferous limestone parent materials. Furthermore, in their list of Cu deficient soils, peats or peaty soils are mentioned in 11 out of 14 countries, podzols or podsolized soils in nine countries and in cases where soil texture is specially pointed out reference is always made to sands or coarse textured soils.

5.5 Iodine

One of the most widespread micronutrient deficiencies is that of I, the symptoms of which are known as goitre in mammals. In spite of the high solubility of most I compounds, appreciably higher concentrations of I exist in soils than in the rocks from which the soils are derived (Goldschmith, 1954). This cannot be explained without taking into consideration the external sources of I. The additional I in soils is likley to be air-borne oceanic from rain and snow or carried by oceanic winds in a gaseous state or adsorbed on floating particles of dust. It has been estimated that 22 to 50 mg of I per acre (54 to 124 mg/ha) will fall annually in the rain on the Atlantic coast, while only 0.7 mg per acre (1.7 mg/ha) will fall in the Great Lakes Region of North America (Hercus et al., 1925; Mitchell, 1955). Thus, the annual precipitation and distance from the sea are important factors determining the I content of soils. This explains the lower I content of inland soils than coastal soils.

The above factors are in close agreement with the geographical distribution of goitre areas found in a number of countries in Europe, North America and elsewhere (Goldschmith, 1954). This is apparently because most I compounds are highly soluble and plant uptake closely follows the soil I content even though there are differences between the plant species.

5.6 Iron

Fe deficiency problems are most often associated with soils derived from calcareous materials. In Europe Fe deficiencies were recorded on the following soils: calcareous soils on chalk and marl formations in England and Wales, Xerorendzinas and calcareous "Raw Soils" in Cyprus, Rendzinas and Brown Calcareous soils in France, Rendzinas and Brown Forest soils in Greece, over-irrigated calcareous soils in Israel, clay soils in the Netherlands, swamp soils in Norway, sandy podzolic soils and peats in Poland, Brown and Red calcareous alluvial soils in Portugal, Sierozems, Reddish Brown and alluvial soils in Spain and Rendzinas, Brown Forest and Grey-Brown Podzolic soils in Sweden (Ryan et al., 1967). In the same report Fe toxicity problems were recorded only in Spain on acid soils derived from granite.

The amount of plant available Fe in soils depends largely on soil pH and redox potential. In acid soils Fe usually exists in ferrous forms which are available to plants, but in neutral or alkaline soils it is oxidized to ferric iron which may be so insoluble that plants have difficulty in absorbing enough. Increasing oxidation potential leads to the oxidation of Fe from ferrous to ferric forms and, therefore, decreases its availability. The oxidation potential increases with increasing pH and with increasing aeration, so that the reaction $Fe^{2} \longleftrightarrow F^{3}$ due to both of these factors is likely to proceed toward F^{3} and to decreasing Fe availability. Improvements in soil structure may have a similar influence (De Kock, 1955; Mokady, 1961; Wiklander, 1958). Increasing acidity as well as depletion in soil structure are likely to cause a reaction towards the reduction of iron. Therefore, the proportion of ferrous Fe of the total Fe usually increases towards the lower soil horizons due to the decreasing aeration. In poorly drained soils the reduction of ferric to ferrous iron may be affected by decomposing organic matter, and some wet soils may contain so much ferrous iron at low pH values that they are toxic to plant roots (Bear, 1965). Several authors have reported disorders in Fe uptake caused by high contents in soils of heavy metals such as Mn and Cu.

5.7 Manganese

Several field experiments have shown that the relationship between the availability of Mn and soil pH, and pH values around 6-6.5 appear to be critical, the lower values favouring reduction and higher values oxidation (Bould and Hewitt, 1963). In Norway no response to Mn fertilization was observed in soils with pH values below 6.3 (Semb and Øien, 1970) and significant negative correlations have been found to exist between soil pH and exchangeable Mn in Punjabi and West Bengali soils (Bandyopadhya and Adhikari, 1968; Randhawa et al., 1961), and between pH and ammonium acetate-extractable Mn in Indiana soils (Tisdale, 1949). Similar results have been presented from a number of locations and it is therefore obvious that Mn deficiency is usually associated with alkaline or neutral soils and its toxicity with acid soils. Liming of soils decreases the availability of Mn and in several cases it has been reported to cause deficiency (Ryan et al., 1967).

5.8 Molybdenum

Soil pH is apparently the principal regulator of the solubility of Mo. Unlike other micronutrients, Mo becomes increasingly available with increasing pH.

When reviewing trace element problems in relation to soil units, Ryan et al. (1967) stated that there is an apparent association between an excess of Mo and heavy textured soils that are generally hydromorphic and derived from calcareous materials, while Mo deficiency problems occur over so wide a range of Great Soil Groups that little correlation can be made. However, deficiency is most commonly associated with acidic soils.

5.0 Zinc

Zn deficiency has been recorded in a dozen European countries (Ryan et al., 1967). The data were not sufficient to establish clear soil relationships, but in some countries the deficiency seems to be associated with Red Mediterranean, Reddish-Brown, Brownish-Yellow Sandy, some loess-derived, certain alluvial and bog soils.

Zn deficiency is found in a wide range of soil textures but most often in sandy soils. This may be due to the same reason as for many other micronutrient deficiencies, i.e. that most rocks and minerals containing Zn are easily weathered and thus likely to form fine textured soils. Zn is accumulated in surface soils where it is absorbed by clay particles and organic matter. Removal of the surface soil, e.g. by erosion, may lead to Zn deficiency in soils low in its content.

Zn is generally more readily available in acid than in alkaline soils, the range of least availability being about pH 6.0 - 7.0. Viets et al. (1957) found that the Zn uptake of plants was almost halved when the pH of the soil was increased from 5 to 7. At high pH the formation of insoluble calcium zincates is favoured and Zn may be less available. Therefore, liming acid soils decreases the availability of Zn and may produce Zn deficiency (Thorne et al., 1951). On the other hand, Zn toxicity may result if soils are acidified or when Zn fertilization is continued over a long period with Zn rich materials such as sewage sludges (Bear, 1955; Janick et al., 1968).

There are indications that Zn deficiency is more pronounced in cool wet weather than in warm dry weather. For example, in California winter grown sweet-corn showed severe Zn deficiency on soils where no such deficiency occurred when the same crop was grown in summer (Van Maren, n.d.). In some cases the soil temperature - Zn uptake interaction seems to concern only the uptake of applied but not the native soil Zn (MacMillan and Hamilton, 1971).

Zn deficiency has also been reported on high phosphate soils or on soils where P content has been accentuated by heavy or excessive phosphate fertilization (Bowan and Leggett, 1964; Brown et al., 1970; Burleson et al., 1961; Ellis et al., 1964; Keefer and Singh, 1969; Ward et al., 1963).

Especially in earlier literature, the view was presented that the fixation of micronutrients, including Zn, by organic matter might be strong enough to cause the deficiencies often found in organic soils. However, in peat soils, in spite of the high fixing capacity of organic matter, micronutrients are apparently less effectively bound than in mineral soils. This view is supported, e.g. by Dobrovolskii (1961) who found that the maximum contents of water soluble forms of almost all micronutrients occur in the humus horizon and by Dolar (1970) who stated that Zn uptake is closely related to the organically bound soil reserves. Sorensen et al., (1971) also reported a positive correlation between extractable Zn and OM content and the relative solubility of Zn has been found to be much higher in organic than in mineral soils (Jensen and Lamm, 1961; Sillanpää, 1962). This may be partly due to the generally lower pH of organic soils.

6. POSSIBILITIES FOR ROUTINE TESTING FOR MICRONUTRIENTS

One of the main purposes of this consultation is to evaluate the possibilities of routine use of soil testing systems in the developing countries. As far as the main nutrients and pH are concerned, it is highly desirable that soil testing services be established in countries where such activities still do not exist and that those already functioning be strengthened.

In the foregoing, some of the problems and difficulties in estimating the micronutrient status of soils including some comments on chemical soil tests have been pointed out. Too many problems still remain unsolved. Therefore, routine soil testing for micronutrients in general is not recommendable, at least not before soil testing for the main nutrients is well established and positive results from it have been obtained. Many developing countries already have well equipped laboratories with qualified personnel and much valuable work on micronutrients has been done. However, for the time being, more attention should be given to increasing general knowledge on micronutrients, their functions and behaviour, relationship to various soils and plants, visible symptoms of disorders and where appropriate local field and pot experimentation should be recommended.

REFERENCES

ADAMS, F. Manganese. Methods of soil analysis, Part 2 (ed. C.A. Black et al.).
1965 Agronomy 9: 1011-1018.

AGERBERG, L.S. Bor-och kopparhalt i några norrländska åkerjordar. III. Wästernorrland.
1959 Kungl. Skogs. Lantbr. Akad. Tidskr., 98: 343-351.

ANDERSSON, A. Relative efficiency of nine different soil extractants. Swedish J. Agric.
1975 Res. 5: 125-135.

BANDYOPADHYA, A.K. and ADHIKARI, M. Trace element relationships in rice soils:
1968 I. Alluvial soils of West Bengal. Soil Sci. 105: 244-247.

BARON, H. Gemeinsame Extraktion und chemische Bestimmung des leichtlöslichen Anteils der
1955 Mikronährstoffe Bor, Kobalt, Mangan, Molybden und Zink in Boden. Landw. Forsch. 7: 82-89.

BEAR, F.E. Chemistry of the Soil. Reinhold, New York. 373 p.
1955

BEAR, F.E. Soils in Relation to Crop Growth. Reinhold, London. 297 p.
1965

BERGER, K.C. Micronutrient deficiencies in the United States. Agric. Food Chem. 10: 178-
1962 181.

BERGER, K.C. Introductory Soils. MacMillan, New York.

BERGER, K.C. and TRUOG, E. Boron deficiencies as revealed by plant and soil tests.
1940 J. Amer. Soc. Agron. 32: 297-301.

BERTRAND, G. and DE WAAL, H.L. Sur la teneur comparative en bore des plantes cultivées
1936 sur le même sol. C.R. Acad. Sci. Paris 202: 605-609.

BOWAN, L.C. and LEGGETT, G.E. Phosphorus and zinc concentrations in Russet Burbank potato
1964 tissues in relation to development of zinc deficiency symptoms. Soil Sci. Soc. Amer. Proc. 28: 229-232.

BOULD, C. and HEWITT, E.J. Mineral nutrition of plants in soils and in culture media.
1963 Plant Physiology (ed. F.C. Steward) Vol. III: 15-133.

BROWN, A.L., KRANTZ, B.A. and EDDINGS, J.L. Zinc-phosphorus interactions as measured by
1970 plant response and soil analysis. Soil Sci. 110: 415-420.

BURLESON, C.A., DOCAS, A.O. and GERARD, C.J. The effect of phosphorus fertilization on zinc
1961 nutrition of several irrigated crops. Soil Sci. Soc. Amer. Proc. 25: 365-368.

COTTENIE, A. and KIEKENS, L. Quantitative and qualitative plant response to extreme
1974 nutritional conditions. Proc. 7th Intern. Coll., Hanover 1974. pp. 543-556.

COX, F.R. and KAMPRATH, E.J. Micronutrient soil tests. Micronutrients in Agriculture
1972 (Ed. J.J. Mortvedt, P.M. Giordano and W.L. Lindsay. Soil Sci. Soc. Amer., Madison, (Wis.) 289-317.

DE KOCK, P.C. Iron nutrition of plants at high pH. Soil Sci. 79: 167-175.
1955

DOBROVOLSKII, V.V. (Characteristics of the distribution of minor elements in the soils and
1961 plants of Ustyurt). Pochvovedenie 2: 65-70. Ref. Soils and Fert. 24: 1769.

DOLAR, S.G. Availability of copper, zinc and manganese in a Wisconsin soil catena. Diss.
1970 Abstr. 31 B: 468-469. Ref. Soils and Fert. 34: 2746.

ELLIS, R. Jr., DAVIS, J.F. and THURLOW, D.L. Zinc availability in calcareous Michigan
1964 soils as influenced by phosphorus level and temperature. Soil Sci. Soc. Amer. Proc. 28: 83-86.

GOLDSCHMITH, V.M. Geochemistry, ed. by A. Muir. Clarendon Press, Oxford. 730 p.
1954

HERCUS, C.E., BENSON, W.N. and CARTER, C.L. Endemic goitre in New Zealand and its
1925 relation to the soil-iodine. J. Hyg., Camb. 24: 321-402.

HILL, A.C., TOTH, S.J. and BEAR, F.E. Cobalt status of New Jersey soils and forage plants
1953 and factors affecting the cobalt content of plants. Soil Sci. 76: 273-284.

HODGSON, J.F. Chemistry of the micronutrient element in soils. Adv. Agron. 15: 119-159.
1963

HULL, R. Sugarbeet diseases. Min. Agr. U.K., Fish and Food Bull. 142: 55.
1960

JANICK, J., SCHERY, R.W., WOODS, F.W. and RUTTAN, V.W. Plant science: An introduction to
1968 world crops. W.H. Freeman, San Francisco. 629 p.

JENSEN, H.L. and LAMM, C.G. On the zinc content of Danish soils. Acta Agric. Scand. 11:
1961 63-80.

KEEFER, R.F. and SINGH, R.N. Residual effect of zinc sources on plant growth and on P-Zn
1969 interaction in soybeans. Proc. W. Va Acad. Sci. 41: 27-38.

LAKANEN, E. On the analysis of soluble trace elements. Ann. Agric. Fenn. 1: 109-117.
1962

LAKANEN, E. and ERVIÖ, R. A comparison of eight extractants for the determination of
1971 plant available micronutrients in soils. Acta Agr. Fenn. 123: 223-232.

LINDSAY, W.L. Role of chelation in micronutrient availability. In: The Plant Root and
1974 its Environment, ed. E.W. Carson. Univ. Press of Virginia, Charlottesville. p. 507-524.

LINDSAY, W.L. and NORWELL, W.A. Development of a DTPA micronutrient soil test. Agron.
1969 Abstr., p. 84.

MACMILLAN, K.A. and HAMILTON, H.A. Carrot response to soil temperature, and copper,
1971 manganese, zinc and magnesium. Canadian J. Soil Sci. 51: 293-297.

MADISON, J.H. Principles of Turfgrass Culture. Reinhold, New York. 420 p.
1971

MITCHELL, R.L. Trace elements. Chemistry of the Soil, ed. F.E. Bear. Reinhold, New York,
1955 ACS Monograph No.126: 253-286.

MITCHELL, R.L. The application of spectrochemical methods of agricultural problems.
1957 Appl. Spectrosc. 11: 6-12.

MITCHELL, R.L. Trace elements in soils. Chemistry of the Soil, ed. F.E. Bear.
1964 Reinhold, New York. p. 320-368.

MOKADY, R. The effect of partial pressure of oxygen in field soils on lime-induced
1961 chlorosis. Plant and Soil 15: 377-386.

MORTVEDT, J.J. Micronutrient soil test correlations and interpretations. Mimeograph.
1976 31 p.

NELSON, W.L. and BARBER, S.A. Nutrient deficiences in legumes for grain and forage.
1964 Hunger Signs in Crops, ed. H.B. Sprague. David McKay, New York. p. 143-179.

O'MOORE, L.B. Status of research on copper, molybdenum and cobalt: Summary and
1961 discussion of the papers. Co-op. Res. Project on Trace Elements. Sub-Comm. Agric. Res. of ECA. Meeting, Dublin, May 1959. FAO, Rome.

PURVIS, E.R. and CAROLUS, R.L. Nutrient deficiencies in vegetable crops. Hunger Signs
1964 in Crops, ed. H.B. Sprague. David McKay, New York. p. 245-286.

RANDHAWA, N.S., KANWAR, J.S. and DIJHAWAN, D.S. Distribution of different forms of
1961 manganese in the Punjab soils. Soil Sci. 92: 106-112.

REISENAUER, H.M., WALSH, L.M. and HOEFT, R.G. Testing soils for sulphur, boron, molybdenum
1973 and chlorine. Soil Testing and Plant Analysis, ed. L.M. Walsh and J.D. Beaton. Soil Sci. Soc. Amer. Inc., Madison, Wis. p. 173-200.

RYAN, P., LEE, J. and PEEBLES, T.F. Trace element problems in relation to soil units in
1967 Europe. World Soil Resources Report 31. FAO, Rome.

SAUCHELLI, V. Trace Elements in Agriculture. Reinhold, New York. 248 p.
1969

SEMB, G. and ØIEN, A. Orienterande undersøkelser over mangarmangel i relasjon till pH
1970 og manganinnholdet i jorda. Forskn. Forsøk i Landbr. 21: 125-138.

SILLANPÄÄ, M. On the effect of some soil factors on the solubility of trace elements.
1962 Agrogeol. Publ. 81: 1-24.

SILLANPÄÄ, M. and LAKANEN, E. Readily soluble trace elements in Finnish soils. Ann. Agric.
1966 Fenn. 5: 298-304.

SORENSEN, R.C., OELSLIGLE, D.D. and KNUDSEN, D. Extraction of Zn, Fe and Mn from soils
1971 with 0.1 N hydrochloric acid as affected by soil properties, solution : soil ratio and length of extraction period. Soil Sci. 111: 352-359.

TAINIO, A. Hivenaineiden puutteesta Suomen kasvinviljelyssä. Suom. Kemistilehti 26: 192-
1953 196.

THORNE, D.W., WANN, F.B. and ROBINSON, W. Hypotheses concerning lime-induced chlorosis.
1951 Soil Sci. Soc. Amer. Proc. 15: 254-258.

TISDALE, S.L. Ph. D. Thesis, Purdue University. Ref. Tisdale and Nelson 1966 in "Soil
1949 fertility and fertilizers". Macmillan, New York. 694 p.

VAN MAREN, A.F. Unpublished data Univ. of Calif. Agr. Extension Service, Riverside. Ref. Kranz and Melsted 1964 in "Hunger Signs in Crops". David McKay, New York. p. 25-57.

VIETS, F.G. Chemistry and availability of micronutrientes. J. Agr. Food Chem. 10: 174-
1962

VIETS, F.G., BOWAN, L.C. and CRAWFORD, C.L. The effect of nitrogen and types of nitrogen
1957 carrier on plant uptake of indigenous and applied zinc. Soil Sci. Soc. Amer. Proc. 21: 197.

VIETS, F.G. and LINDSAY, W.L. Testing soils for zinc, copper, manganese and iron. Soil
1973 Testing and Plant Analysis, ed. L.M. Walsh and J.D. Beaton. Soil Sci. Soc. Amer. Inc., Madison, Wis. p. 153-172.

VIRO, P.J. Use of ethylenediaminetetraacetic acid in soil analysis: I. Experimental.
1955 a. Soil Sci. 79: 459-465.

VIRO, P.J. Use of ethylenediaminetetraacetic acid in soil analysis: II. Determination
1955 b. of soil fertility. Soil Sci. 80: 68-74.

VUORINEN, J., and MÄKITIE, O. The method of soil testing in use in Finland. Agrogeol.
1955 Publ. 63: 1-44.

WAHHAB, A. and BHATTI, H.M. Trace element status of some West Pakistan soils. Soil Sci.
1958 86: 319-323.

WALLACE, T. Report on replies to questionnaire. App. III, Co-op. Res. Project on Trace
1961 Elements. Sub-Comm. Agric. Res. of ECA. Meeting, Dublin, May 1959. FAO, Rome.

WARD, R.C., LANGIN, E.J., OLSON, R.A. and STUCKENHOLZ, D.D. Factors responsible for poor
1963 response of corn and grain sorghum to phosphorus fertilization. Soil Sci. Soc. Amer. Proc. 27: 326-330.

WIKLANDER, L. The soil. Handbuch der Pflanzenphysiologie, ed. W. Ruhland. Springer-
1958 Verlag, Berlin. p. 118-169.

WILCOX, L.V. Boron injury to plants. Agr. Inform. Bull. 211, U.S. Gov. Printing Office.
1960 7 p.

YAMASAKI, T. "Secondary fertilizer elements" and micro-elements. Agric., Asia, Special
1968 Issue No.6: 99-111.

PRINCIPLES AND PRACTICES IN PLANT ANALYSIS

by

B. Evenhuis and P.W.F. de Waard
Royal Tropical Institute, Amsterdam

1. INTRODUCTION

For growth, development and production crop plants require a continuous, well adjusted supply of essential mineral nutrients to the roots for uptake and transport to the aerial parts. These nutrients are subdivided into a group of macro-elements (N, P, K, Ca, Mg and S) and micro-elements (Fe, Mn, B, Cu, Zn and Mo); macro and micro prefixes refer to quantitative requirements. If any of these elements is in limited supply crop performance decreases and ultimately results in nutritional disorders. Shortages of mineral nutrients manifest themselves in terms of reduced crop yields and/or poor quality of produce.

In the early stages of deficiency development there may be considerable reductions in yield. In severe cases deficiencies are qualitatively reflected by the presence of single or multiple visual and characteristic symptoms, such as discolouration, chlorosis and malformation of plant parts. Evidently, chemical processes in plants become deranged. This in turn adversely affects physiological processes and production mechanisms.

Ultimate deterioration of the productive capacity of crop plants should be prevented by early intervention through adjustment of the mineral nutrition by addition of fertilizer. Over the past 2-3 decades plant analytical techniques have been developed to aid the appropriate use of fertilizers. Generally speaking, leaves proved to be the most appropriate plant parts and chemical foliar analysis was developed and refined for qualitative and quantitative adjustments of mineral nutrition.

This paper presents main lines of research on chemical analysis of leaf samples of tropical and subtropical tree crops, recently completed at the Royal Tropical Institute. The work was aimed at establishing a set of simple, rapid and reliable procedures for the determination in a single digest of N, P, K, Ca, Mg, Na, Fe, Al and Mn in leaf material, and providing detailed background information on relevant instrumental and analytical aspects. These methods have been developed especially for conditions frequently met in developing countries. Major attention is also paid to sampling procedures; the use of analytical data in interpretation and formulation of fertilizer policies is outlined.

2. PLANT ANALYSIS AND FOLIAR DIAGNOSIS

Leaves are considered as the focus of physiological activities. Changes in mineral nutrition appear to be reflected in the concentrations of leaf nutrients. Motivation for determination of nutrient concentrations in leaves for diagnostic purposes arises from the assumption that a significant relationship exists between nutrient supply and levels of elements, and that increases or decreases in concentrations relate to higher or lower yields, respectively. In general these assumptions are valid, but much error, for example, may be introduced during sampling.

The utilization of leaf nutrient levels for reliable diagnosis and interpretation in terms of fertilizer requires a wide knowledge of agronomic, ecological and physiological influences. This reliability depends also on continuity of crop stands in time and place and on seasonal patterns. Continuity permits establishment of natural equilibria between nutrient supply and uptake and crop performance over extended periods of time, and gives the opportunity of determining optimal, critical and deficient ranges for specific crops. Effects of fertilizer applications may be monitored by periodic analysis, so permitting timely intervention to correct oncoming nutritional disorders. Significant success with foliar diagnosis has been obtained with perennial bush and tree crops e.g. coffee, tea, cocoa, pepper, citrus, banana, oil palm and rubber.

The concentrations in the leaves are determined by chemical analysis. Many methods have been developed, differing in degree of sophistication, complexity and reliability. For routine application in developing countries, methods and procedures have been pursued at the Royal Tropical Institute, combining speed, simplicity and reliability. In this context simplicity refers to both instruments and auxiliary equipment used, and to ease of manipulation. Reliability refers to the degree of accuracy needed for interpretation, precision and the validity of analytical methods under varying experimental conditions.

It is evident that systematic, standard procedures for leaf sampling are essential to warrant the cost and efforts involved in the use of analyses and subsequent interpretation. Such procedures can be established by systematic standardization of sub-procedures for component sampling variables, and subsequent integration into a single overall procedure. Essential aspects of these individual variables involved will be broadly discussed in separate sections.

3. SOURCES OF ERROR

Practical considerations constrain routine sampling of individual trees in large commercial areas. An alternative approach involves bulk sampling of leaves. Concentrations in these samples are considered as representative for the mean of the tree population. Reliability of this method demands uniform sample areas and a minimum number of sampled trees to reduce to a minimum error from interplant variation.

Other major sources of variability also affect actual leaf concentrations. Age of plants, species, cultivars or varieties, physiological age of leaves, morphological position on plants, internutrient effects as well as seasonal variation, time of sampling, time of day, collection, weather conditions and climate contribute to error and ultimately to analytical results. Often neglected sources of variation include handling of samples, cleaning methods, drying and grinding procedures and storage conditions and, finally, use of indiscriminate and uncalibrated analytical methods. This kind of error may partly neutralize the favourable effect of careful sampling procedures.

Interpretation of the leaf levels is always carried out on a comparative basis, using reference values. This implies that the inclusion of reference samples of usually healthy trees as a standard is essential to reduce error in interpretation. Utilization of absolute values of leaf concentrations alone is less interesting; these levels depend on too many unknown systematic and random errors introduced by external and internal influences.

4. SAMPLING PROCEDURES

4.1 Choice of leaves

While leaves are considered the major manufacturing sites of organic substances and therefore indicators sensitive to changes in mineral supply, the physiological processes involved are sources in their own right of considerable variability with regard to concentrations of the respective elements. Concentrations are systematically influenced by, among others, physiological leaf age, growth in sun or shade, morphological and chronological position, portion of the leaf, presence or absence of fruit/flowers and aspect of the plant. For highest sensitivity and increased precision in comparing leaf concentrations, each crop requires a specific, detailed standard procedure for leaf sampling. Careful picking of prescribed leaves from precise positions is essential. For rubber, leaves growing at low level in the shade should be sampled, whereas for pepper the second fully mature leaves on primary branches are selected. In oil palm in some areas the ninth leaf is sampled while in other areas the seventeenth leaf is more representative. In tea the auxiliary leaf of the first pluckable shoot is the most representative.

Under similar ecological conditions the same procedure may be followed. In a first approximation, a successful procedure in one region may be used in another region or even country. For several crops, however, the sensitivity of positions as indicators of mineral substances tends to vary with regions or countries and in due course precision should be tested and adjusted accordingly.

4.2 Sampling Area

Cropping areas may be inconveniently large for sampling activities. Also within a given crop area considerable variability may usually be observed from place to place due to the net effect of several external influences. Formal subdivision into conveniently homogeneous sample units is an essential preparation prior to actual sampling activities.

Features on which appropriate subdivision could be based include uniformity of topography, type of soil, crop appearance, drainage conditions, irrigation conditions, varieties planted, age of crop, and maintenance practices.

Each of the stratified units is sampled separately. A large area may therefore yield several leaf samples representing homogeneous portions of the total heterogeneous area. The data of the respective sub-units permit more relevant interpretation as compared to those obtained from a single representative sample for the entire area. Yet, a balance between practicability and reliability should be duly considered.

4.3 Number of Trees

The number of trees to be included in a representative bulk-sample depends on the tree to tree variation for each of the respective elements. Estimates of this variability from the population mean value can be obtained by sampling and analysis; from these data the variance can be calculated. By assuming an allowable difference between population mean and sample mean (the permissible error), and by setting a confidence level ($P = 0.05$) to ensure that the sample mean falls within the range of the permissible error, the corresponding number of sample trees may be calculated. The permissible error usually adopted is 10–15% for adequate representation of the population mean value (Shorrocks, 1964).

In day to day field practice this calculation of the number of trees may be impracticable. Research workers have investigated this problem and have been able to determine the number of sample trees for a range of tree crops. Although these numbers are strictly speaking only valid for the respective conditions of investigation, they provide reasonable estimates of the order of magnitude. For rubber the sampling of 40 trees over 26 ha proved adequate to estimate levels of 5 major elements within the permissible error of 15% (Shorrocks, 1964). In the case of oil palm 25 trees over 50–100 ha proved adequate to make up a representative bulk sample (Turner and Gilbanks, 1964). For pepper, however, 150-175 vines per hectare were needed (de Waard, 1970). As a rule of thumb no more than 10% of trees or bushes of a homogeneous sample area should be sampled, depending on density of planting.

4.4 Time of Sampling and Collection of Leaves

Plants respond to distinct changes of conditions related to physiological phenomena of active growth, onset of floral development and fruit growth. The net effect of one or several of these phenomena is reflected by changes of the nutrient levels in the leaves. In addition, other external influences, in particular seasonal variations, exercise their effect on leaf nutrient levels. The actual effect of nutrient supply on concentrations is interwoven with this complex of interacting factors. Yet, critical periods may be established associated with optimal, critical and deficient values, indicative of expected crop performance. Accordingly, proper times of sampling may be fixed.

4.5 Practices in Sampling

Selective sampling of individual trees is utilized usually for analysis of leaves showing visual deficiency and for other special activities. Reference samples are also collected while extra samples showing intermediate symptoms may be helpful in interpretation.

As a rule, bulk sampling is applied in cases of routine collection of leaf samples over extended areas of crop stands. A predetermined, representative number of trees contribute to the composition of the bulk sample. The selected trees should be systematically distributed over the planted area. Reference samples should be obtained from standard healthy reference plots, located in the same area.

Detailed information with regard to the sample areas should be assembled with regard to meteorological conditions, soil type and composition, topography and drainage, maintenance practices, fertilizer applications and crop performance. This information will greatly enhance the ultimate reliability of interpretation and recommended treatments.

Actual leaf collection is an important activity. Precision of the chemical results depends a great deal on the correct execution of established procedures. Collection itself should take place preferably between 07.00 and 10.00 hours and should not be carried out during or directly after rainfall. Personnel selected for leaf collection should be well trained and work under close supervision.

The number of leaves actually collected from each tree may vary from one to four. Preferably 4 leaves should be sampled representing each aspect of the tree with equal frequency in the bulk sample. If only one leaf is taken, aspects of subsequent sample trees should be systematically represented in turn. A similar system can be devised for two and three leaves per tree. The ultimate size of the bulk sample should contain sufficient representative leaves to obtain 25-50 g of air-dry material. Should too many leaves have been included, the bulk sample may be reduced accordingly by random quartering.

4.6 Sampling Frequency

The number of samplings depends on desired precision of recommendation, the nature of the crop and on economic considerations. A good compromise for most crops constitutes 3 samplings per year; the first in a critical period of the dry season, a second in such a period of the rainy season, and a third at an intermediate control date. In this way the state of mineral nutrition can be minitored and adjusted when necessary. It is evident that increased frequency of sampling entails a correspondingly more accurate control. As a rule of thumb, frequency should be increased with greater instability of climatic patterns, but an economic balance should be struck considering all determinants.

4.7 Sample Handling

4.7.1 Cleaning

Within some six hours after collection leaves should be cleaned to remove dust or residues. Wiping with a damp cloth, soaked in 0.1% detergent solution, followed by rinsing twice in distilled water is recommended. If this procedure is done quickly there is no danger of leaching of nutrients. After rinsing, excess water is removed and leaves are transferred to small muslin bags.

4.7.2 Drying

The muslin bags are placed in a stainless steel, forced-draught oven and dried at 70°C for 48 hours. If drying is delayed, considerable loss in dry weight may occur, as well as an undue increase in concentrations, due to enzymatic respiration. At temperatures over 90°C significant losses of N may occur by thermal decomposition.

4.7.3 Grinding, packing and storage

The dried material may be pre-crumbled, sealed in polyethylene bags and sent to the laboratory for grinding, or alternatively, it may be directly powdered. Preferably, grinding is carried out in an all-stainless steel mill to avoid contamination. The desired fineness of the powdered sample is obtained by fitting a 1 mm sieve in the mill. This ensures a homogeneous sample. Immediately after grinding the powder is thoroughly mixed, packed in polyethylene bags, sealed and stored under dry and cool conditions to await analysis.

5. CHEMICAL ANALYSIS

5.1 Concept of Simplified Methods

5.1.1 General considerations

In recent years advanced instrumental methods and equipment have been introduced for routine analytical purposes, including plant analysis. These (semi) automated, highly capital intensive techniques reduce analytical work considerably and increase the reliability of laboratory data output. Prerequisites for operating these instruments are the availability of skilled laboratory assistants and well-trained analysts on the one hand, and the availability of instrument supplies and rapid repair services on the other. In many developing countries where these conditions may not be fulfilled and manpower is abundant, reliable, rapid manual techniques may be considered as a good alternative to meet the need for the analysis of a continuously growing number of samples.

Instruments well suited to reliable, rapid manual techniques (RRMT) are spectrophotometers and flame photometers. These instruments have proved to be reliable partners in analysis for many years. In particular, when out of order they can be repaired locally provided an adequate stock of spare parts is being maintained.

Methods suitable for RRMT should have a wide scope of application to ensure analysis of different types of leaf samples in a single analytical series, permit straight calibration curves within the expected element concentration ranges to facilitate calculations, and include colour systems with a high stability.

As to procedures, reactions should be carried out in test tubes and the number of reagent additions should be kept to a minimum. Auxiliary equipment includes analytical balances for accurate weighing of leaf material, hotplates for digestion, automatic pipettes for taking aliquots of sample solution, top-loading balances for rough weighings of reagent chimicals, dispensers for the addition of reagents, test tube mixers for homogenization, draincells for spectrophotometric determinations and a calculating machine for data processing.

Aware of the demand for reliable, rapid manual techniques, a scheme has been developed for the determination of 9 elements - N, P, K, Ca, Mg, Na, Fe, Al and Mn - in a single digest. This digest is obtained by destruction of organic matter with concentrated H_2SO_4 and H_2O_2. K, Ca and Na are determined flamephotometrically; for the determination of the remaining elements spectrophotometric methods are used.

Successful application of rapid manual techniques requires sufficient background information on relevant analytical and instrumental aspects. For plant analysis, this information is scattered throughout the literature, but it has been gathered and described in detail by Evenhuis et al., (1976). Some aspects of the work and tests made are described in the following paragraphs.

5.1.2 Methods of ashing

Destruction of organic matter for dissolution of mineral elements may be accomplished either by dry oxidation, "ashing", or wet oxidation, "digestion". Ashing is carried out in many laboratories because traditional wet digestion is a tedious and lengthy process. However, using hotplates and volumetric flasks, wet oxidations are simpler to perform on a large scale and they could prevent possible losses of elements during dissolution. A major advantage of digestion with concentrated H_2SO_4 and H_2O_2 is the inclusion of the determination of N in the same digest.

5.1.3 Instrumental methods

i. General remarks

Requirements for spectrophotometric and flamephotometric equipment for routine analysis are reliability and simplicity of operation; digital read-outs are preferred to alternative devices in order to help avoid reading errors.

A high sensitivity and accuracy are less important, for these instruments have to be used by relatively unskilled workers. Moreover, the sensitivity and accuracy as provided by high-grade equipment is not essential for the purposes of plant analysis under discussion.

Condensation, caused by large fluctuations in temperature and humidity, may have serious damaging effects on electronic circuits, causing haphazard malfunctioning. Therefore, electronic equipment should be installed in permanently air-conditioned rooms.

When voltage supplied to the laboratory fluctuates within fairly wide limits, it is necessary for reliable performance of electronic instruments to include an external voltage stabilizer in the electrical circuit.

ii. Spectrophotometric methods

At present a variety of reliable and rugged instruments, equipped with draincells and digital read-out to speed up analytical work, is commercially available. Spectrophotometric methods should give straight calibration curves, at least in the normal working range. Straight calibration curves are more convenient to use - e.g. for calculation and checking purposes - and permit greater accuracy than non-linear systems. In addition the methods used should be checked with respect to: time of colour development and colour stability; interferences; influence of pH, temperature and light, and accuracy and precision.

iii. Flamephotometric methods

Flamephotometry permits a rapid, simple and reliable method for the determination of Na, K and Ca. A prerequisite is a reproducible and steady flame obtainable by proper gas pressure regulation. The premix burner has a better performance than the total consumption device, mainly because of its stability.

Particular attention should be paid to: interferences; ionization; self absorption; matrix effects, and accuracy and precision.

iv. Calibration

The necessary calibration for spectrophotometric and flamephotometric methods is achieved by means of solutions of known concentrations, termed standard solutions. If the solutions prepared for analysis contain fixed or variable quantities of other components, the standards must be prepared in such a way that their composition will be closely similar to the samples with which they are to be compared. Accuracy of instrumental methods ultimately depends on the reliability of standard solutions. These should be prepared with the greatest care, using an analytical balance, analytical grade reference chemicals and distilled water for dissolution in volumetric flasks.

When stored, reference chemicals are affected by temperature and humidity, i.e. they may lose or absorb water. Anhydrous chemicals, e.g. $(NH_4)_2SO_4$, KH_2PO_4, KCl, $CaCO_3$ and NaCl, can be safely freed from water by drying at 105°C for at least two hours. Reference chemicals containing water of crystallization, such as $MgSO_4 . 7 H_2O$, $NH_4Fe(SO_4)_2 . 12 H_2O$, $KAl(SO_4)_2 . 12 H_2O$ and $MnSO_4 . 1 H_2O$, however, must be standardized before being used in reference solutions. Standardization of these chemicals is easily performed with standard EDTA, using pyrocatechol violet as an indicator. When grinding reference chemicals, agate mortars should be used because porcelain dust may invalidate standardization results.

RFMT requires pre-prepared standard series solutions. When stored in polyethylene flasks at about 20°C, reference solutions up to 1 ppm in dilute sulphuric acid are stable for at least two months. At higher temperatures these solutions should be stored in the refrigerator.

5.2 Laboratory Procedures

5.2.1 Digestion

0.5000 g of oven-dry leaf material is digested in a 50 ml volumetric flask with 2.5 ml of conc. H_2SO_4 on a hotplate at approximately 270°C. Standardized additions of H_2O_2 are repeated until the digest remains clear. Depending upon the origin of the sample, 0.5-1 ml (mean 0.75 ml) of conc. H_2SO_4 is consumed during digestion. Standards for element determinations, therefore, are made in aqueous solutions containing 3.5 ml of conc. H_2SO_4 per 100 ml.

5.2.2 Analytical methods

i. Analytical methodology

Both flamephotometric and spectrophotometric determinations were developed from established methods. Major attention was paid to potentially interfering elements present in digests in varying quantities. It has been shown that, calculated on oven-dry material, simultaneous presence of 4% N, Ca, K and Cl, 0.5% P, Mg and Na, 0.25% Al and Mn, 1000 ppm Fe and 100 ppm B, Cu, Zn, Co and Mo, did not interfere 1/ with any of the particular element determinations. Although the composition of the majority of digests falls well within these limits, in some cases individual elements may be present in excessively high concentrations which may interfere. Provisions for elimination are given in the procedures.

The influence of sulphuric acid concentrations, ranging from 0-5 ml of conc. H_2SO_4 per 100 ml of solution, was studied. It appeared that within concentrations of 2-5 ml of conc. H_2SO_4 essential elements could reliably be determined.

In spectrophotometric determinations the effect of temperature, light and time on colour stability was investigated. It showed that after full colour development, colours were stable for at least 3 hours; light and temperature (between 20 and 35°C) did not affect colour stability.

Some details of the determinations are shown in Table 1; with the relative standard deviations, the mean is given within brackets.

The methods so developed were successfully applied to perennial tree crops such as coffee, tea, cocoa, pepper, citrus, banana, oil palm and rubber, and have been checked with standard reference samples.

ii. Determination of K, Ca and Na

Aliquots of digests are diluted with distilled water and concentrations are determined by flamephotometer, using a mixed standard of K, Ca and Na. Propane is used as a fuel for the determination of K and Na, whereas acetylene is employed for Ca. For some details see Table 1.

1/ Interference for major elements was defined as deviations larger than ± 5% of the standard value; for micronutrients, as ± 10% of this value.

iii. Determination of N, P, Mg, Fe, Al and Mn

Mixed-reagent solutions are added to measured aliquots of digests. Concentrations are determined spectrophotometrically. See Table 1 for some details.

Table 1 PRECISION OF DETERMINATIONS OF ELEMENTS BY RAPID MANUAL TECHNIQUES

Element	Aliquot (ml)	Method	Mixed reagents solutions	Test range oven-dry material	RSDa 1/ (%)	RSDb 2/ (%)
N	0.1	Indophenol	2	0.4–4%	1.0 (2.7%)	3.5 (1.8%)
P	1	Molybdenum blue	1	0.05–0.5%	1.0 (0.18%)	2.0 (0.14%)
K	1	Flame photometer	1	0.5–5%	1.5 (3.1%)	3.5 (1.1%)
Ca	1	Flame photometer	1	0.5–5%	1.1 (2.6%)	3.6 (0.53%)
Mg	1	Titan yellow	2	0.05–0.5%	2.0 (0.25%)	3.2 (0.36%)
Na	5	Flame photometer	–	0.04–0.4%	1.0 (0.20%)	4.0 (0.30%)
Fe	5	Orthophenanthroline	1	50–500 ppm	2.0 (114 ppm)	9.0 (60 ppm)
Al	1	Pyrocatechol violet	1	50–500 ppm	2.4 (111 ppm)	–
Mn	5	Formaldoxim	1	50–500 ppm	1.0 (224 ppm)	4.0 (83 ppm)

RSD : relative standard deviation is the standard deviation as a fraction of the mean, expressed as a percentage.

1/ RSDa : RSD determined by analysing duplicate samples ten times each in the same analytical series.

2/ RSDb : RSD determined by analysing duplicate samples two times each in 5 different analytical series at two months intervals.

From the RSD data presented it may be concluded that the methods have a high degree of precision. The RSDb data are more representative for daily work.

5.3 Laboratory Quality Control

A quality control programme is concerned with establishing and maintaining a fair level of accuracy and precision within the laboratory. Such a programme provides for optimization and standardization of: analytical methods and procedures; analytical instrumentation; glassware and auxiliary equipment; standard solutions and reagents, and working mode of analytical personnel.

To reveal analytical discrepancies, a blank and one or two standard samples should be included in each analytical series.

Problems concerning quality of output may be detected by participation in laboratory sample exchange schemes, the so-called round-robin tests.

6. PRINCIPAL ASPECTS OF INTERPRETATION

Objectives of interpretation broadly include both direction of the mineral nutrition of the crop and treatment of acute symptoms of malnutrition. A basic assumption is that optimization of the vegetative crop condition is an essential precondition for improved productivity. Reference values usually represent a system of excess, optimal, critical and deficient values. Comparison of field values with the respective references provides an insight into the state of crop health at that moment. In principle these values should be universally valid (for specific crops and cultivars) under similar conditions and use of standardized procedures. However, in practice these values appear to be specifically related to environmental peculiarities and ranges differ correspondingly (Table 2). In this respect much information has already been obtained for the major elements N, P, K, Ca and Mg; for minor elements such as Mn, B, Cu and Zn considerable research is still required.

A first impression of the magnitude of differences from the reference values is obtained by comparison of the assumed permissible error with the difference of the estimated population mean value and the reference value. If this difference exceeds the permissible error, the difference is considered significant at a given probability and vice versa. This emphasizes the importance of the choice of a permissible error vis-à-vis the need for high or low precision of estimated population values; a lower permissible error demands a higher precision of estimates of field values. Yet, economic considerations may call for compromises in this respect.

For ease of interpretation detailed agronomic, physiological, yield and performance data, as well as meteorological records are essential attributes. Qualitative interpretation presents relatively minor problems in the region of deficiencies; confidence may be placed in recommendations in terms of quantitative dressings with regard to prospective effects. Towards the optimal levels, interpretation in qualitative and quantitative terms becomes more complicated and requires more detailed background information and empirical data to permit equally confident recommendations. Unfortunately, in practice such information is rarely supplied.

In recent years, research has indicated that further standardization of autonomously acting factors on leaf levels is possible. Investigations involving the soil/root interface suggest that variability of nutrient uptake can be improved by application of techniques aimed at "feeding of the plant" (Barber, 1974; Fried and Broeshart, 1967). Some important facets in this respect constitute establishment of steep nutrient gradients to the root surface, maintenance of near optimal water and oxygen supply conditions, and maximum concentration of active roots near a balanced supply of fertilizers (Summer, 1977). Use of drip irrigation combined

With mineral nutrition systems, placement of fertilizers and mulching appear to have a stabilizing effect on autonomous variability of nutrient levels (de Taffin and Daniel, 1976). Overall results seem to suggest that areal, regional or country effects on interpretation may be further reduced, simplifying interpretation and improving foliar diagnosis as a steering tool for fertilizer programmes in perennial tropical crops.

Table 2 COMPARISON OF REFERENCE VALUES FOR THE 3rd AND 4th LEAF PAIR FROM THE APICAL BUD OF *Coffea arabica* IN 3 COUNTRIES

Element	Costa Rica (Chaverri *et al.*, 1957)	Colombia (Machado, 1956)	New Guinea (Southern, 1966)
	%	%	%
Nitrogen			
High	> 2.80	> 3.00	> 3.4
Medium	2.30–2.80	2.50–3.00	2.6 –3.4
Low	2.00–2.30	2.00–2.50	2.2 –2.6
Deficiency	< 2.00	< 2.00	< 2.2
Phosphorus			
High	> 0.20	> 0.15	> 0.19
Medium	0.12–0.20	0.11–0.15	0.13–0.19
Low	0.09–0.12	< 0.11	0.10–0.13
Deficiency	< 0.09	-	< 0.10
Potassium			
High	> 2.70	> 1.80	> 2.6
Medium	1.70–2.70	1.50–1.80	1.8 –2.6
Low	1.00–1.70	1.10–1.50	1.4 –1.8
Deficiency	< 1.00	< 1.10	< 1.4
Calcium			
High	> 1.70	> 1.30	> 1.6
Medium	1.10–1.70	0.70–1.30	0.6 –1.6
Low	0.80–1.10	-	0.4 –0.6
Deficiency	< 0.80	-	< 0.4
Magnesium			
High	> 0.35	> 0.39	> 0.7
Medium	0.20–0.35	0.35	0.4 –0.7
Low	0.10–0.20	0.16	0.3 –0.4
Deficiency	< 0.10	< 0.16	< 0.3

Source: de Geus (1973).

REFERENCES

BARBER, S.A. Properties of the plant root that influence fertilizer practice. In: Plant
1974 Analysis and Fertilizer Problems. 1: 25-35. German Society of Plant Nutrition.

DE GEUS, J.G. Fertilizer guide for the tropics and subtropics. Centre d'étude de l'azote,
1973 Zurich.

DE TAFFIN, G. and DANIEL, C. Premiers résultats d'un essai d'irrigation lente sur palmier
1976 à huile. Olegineux 31(10): 413-421.

DE WAARD, P.W.F. Foliar diagnosis and yield stability of black pepper (Piper nigrum L.)
1970 in Sarawak. Communication 58. Royal Tropical Institute, Amsterdam.

EVENHUIS, B. et al., Simplified methods for foliar analysis, Parts I-VII. Internal
1976 report, Royal Tropical Institute, Amsterdam.

FRIED, M. and BROESHART, H. The soil plant system in relation to inorganic nutrition.
1967 Monograph, Academic Press, New York.

SHORROCKS, V.M. Some problems related to the choice of a leaf sampling technique for
1964 mature Hevea brasiliensis. Plant analysis and fertilizer problems IV. Amer.
Soc. Hort. Sci., Humphrey Press, New York. p.306-331.

SUMNER, M.E. Application of Beaufils' diagnostic indices to maize data published in the
1977 literature, irrespective of age and conditions. Pl. Soil 46(2): 359-371.

TURNER, P.O. and GILBANKS, R.A. Oil palm cultivation and management. Incorporated
1964 Society of Planters, Kuala Lumpur, Malaysia.

Paper 16 PLANT ANALYSIS AS AN AID IN THE FERTILIZATION OF THE OIL PALM

by

H.C. Okoye
Nigerian Institute for Oil Palm Research, Benin, Nigeria

1. INTRODUCTION

Plant tissue analysis is used for basic studies on the nutrient requirements of the oil palm, diagnosis of nutrient deficiencies in the field and as an adjunct to fertilizer trials and soil analysis as a regular means of assessing the fertilizer requirements of the oil palm in particular areas. These studies have led to procedures and practices which are now applied routinely together with soil analysis for the assessment of the fertilizer requirements of the oil palm. The discussion that follows will centre on the details of the plant analysis procedures and their adequacy in guiding rational use of fertilizers in plantation palms.

2. METHODS OF PLANT ANALYSIS IN USE

Two main approaches have been used in assessing the mineral requirements of the oil palm by plant analysis:

i. total plant analysis in which the component tissues of the palm are analysed to determine the quantities of nutrient elements immobilized, and,

ii. leaf analysis in which only a selected leaf tissue is analysed.

2.1 Total Plant Analysis

Several studies have been carried out in the different oil palm zones of the world to estimate the quantities of nutrients immobilized by palms of different ages (Ferwerda, 1955; Tinker and Smilde, 1963; Ng and Thamboo, 1967, 1968). Comparative estimates of the quantities of major nutrients immobilized in the trunk, leaves, roots and bunches in these areas have been compiled by Werkhoven (1965), Hartly (1967), Ollagnier, Ochs and Martin (1970), Ng (1970) and Turner and Gillbanks (1974).

The use of total plant analysis or nutrient removal as a diagnostic technique, though useful as a first approximation, has the limitations of being tedious to establish, entails destructive sampling, ignores the regular contribution from soil reserves and cannot be extrapolated from one environment to another. In practice, therefore, the method does not provide an expeditious direct guide for current fertilizer use. It is now mainly used in nursery and pot culture work where total quantities of nutrients absorbed may correlate better with plant performance than tissue concentration.

2.2 Leaf Analysis

In the last 3-4 decades, the use of leaf analysis as a guide to fertilizer requirements of crops in preference to total plant or soil analysis has been widely accepted. Leaf analysis as a diagnostic tool is based on a certain defined relationship between the concentration of a specific nutrient element or ratios in a specified leaf (or leaves) on the one hand, and growth and/or productivity on the other. The tissue selected should not only accurately reflect the nutrient status of the plant by varying with the conditions of nutrient supply in the medium but should correlate well with plant performance. These properties may be termed sensitivity criteria.

Although leaf nutrient concentration is controlled primarily by nutrient supply, a number of non-nutritional factors are known to affect the nutrient status of a plant tissue or organ. These factors are notably plant age, position of leaf, seasonal and climatic factors, soil physical characteristics and availability of water, and genetic make up of the plant. It therefore becomes necessary not only to select an organ to be sampled on the sensitivity criteria but also on its stability to the non-nutritional external and internal factors causing variation in leaf nutrient level. Any sampling procedure adopted would endeavour to minimize the effects of these variations.

3. SAMPLING

3.1 Tissue Sampled

It has been shown that the leaf nutrient composition of the oil palm is affected by all the variational factors listed above (Chapman and Gray, 1949; Scheidecker and Prevot, 1954; Broeshart, 1955; Coulter, 1958; Smilde and Chapas, 1963). Considerable variations occur in the composition of a single leaflet and between leaflets on the same frond, between fronds on the same palm, between palms in the same field and between samples taken at different periods of the year. The first problem with oil palm leaf analysis was therefore how to obtain a sample which is representative of the nutrient status of a palm, and then to determine the minimum number of palms that will reflect the nutrient status of a given area. Smilde and Chapas (1963) have discussed in detail and critically the work done on tissue selection and sampling procedures. In these studies, the influence of frond age on chemical composition received considerable attention. Gradients in frond composition with frond position were found with N, P, K generally decreasing and calcium increasing with frond age. The trend in magnesium appears controversial but seems to depend on the initial levels of K and Ca in the organ. From the work of Smilde and Chapas (1963) and Chapman and Gray (1949) frond 17 was chosen because of its low variability and correlation with yield. Frond 1 for similar reasons was recommended for special studies on K and Mg nutrition (Smilde and Chapas, 1963) and for routine diagnosis (Broeshart, 1955). In young palms without frond 17, the 9th frond could be sampled (Bachy, 1964).

The use of frond 17 appears now to be the standard practice everywhere in the routine diagnosis of the nutrient status of the oil palm. Apart from low variability, frond 17 appears to satisfy the sensitivity criteria as it shows readily the deficiency symptoms of the more common deficiencies (K and Mg), its nutrient status has often been positively correlated with fertilizer responses and with yield and it appears usually to be physiologically active in adult palms. It is also easier to reach for sampling than inner fronds. Frond 17 will continue to be sampled until a more sensitive tissue is found.

Research on the use of alternative tissues such as the root and petiole for specific elements is now going on. Use of a combination of fronds, depending on the known physiological movements of some elements, e.g. boron and magnesium, has been suggested, but the feasibility of sampling more than one frond in routine advisory work in plantations is still questionable.

3.2 Sampling Procedure

Sampling procedures for collecting homogeneous samples from a frond differ from place to place. In Malaysia, following the work of Chapman and Gray (1949), samples are taken from the central 10 cm of the central pairs of pinnae of a frond.

Others, like the IRHO[1/], take samples from the central part of the frond and use the central part of these leaflets after discarding the margins and the mid-rib. In Nigeria, the sampling procedure is after Hale (1946) who did not find the variation in composition along the length of the frond statistically significant and therefore used bulked samples of leaflets picked from both sides of the rachis at intervals of about 10 leaflets.

This practice entails cutting down from adult palms the frond to be sampled and exercising care in the field to include leaflets from all sections of the frond. This is time consuming and leads to considerable delay in collecting the large number of samples that normally come from plantations. An investigation on variation of leaflet composition in different sections of a frond showed that sampling could be confined to leaflets from the central portion of frond 17 only (NIFOR, 1963, 1968) thereby saving time in sampling.

3.3 Sampling Time

3.3.1 Time of year

The criteria for judging the best sampling season are similar to those for selecting a tissue for sampling (Leaf, 1973) but with consideration given to a period of lowest variability of nutrient contents. Important environmental factors in Africa are the climate, which varies from one region to another, and weather changes which affect the nutrient concentration at the time of sampling or responses to fertilizers (Bates, 1971). An ideal sampling time would correspond to a period of minimum variability (including palm-to-palm variability) for most nutrients. Broeshart (1955), Scheidecker and Prevot (1954), Smilde and Chapas (1963), and Smilde and Leyritz (1965), Coulter (1958) and Ferwerda (1961) have shown that the leaf composition of the various elements varies seasonally and monthly, and that the magnitude of the variations depends on the element, plant tissue and age or stage of development of the palm.

The NIFOR investigations in 1960/61 and 1962/63 show clearly how seasonal variations in the concentration of nutrient elements make it difficult to recommend a definite sampling time (Figure 1). The practice of sampling for all elements early in the dry season is based mainly on expediency and to a limited extent on the principal objective of using a repeatable period of minimum variability for most elements. The assessment of the effects of weather on nutrient content requires data collected over a very long period from adequately fertilized plants in a given area in order to estimate the errors arising from this source. Information of this type could also be collected from calibration trials covering the economic life span of palms in the different oil palm growing areas.

3.3.2 Time of day

It has been recommended that sampling of the oil palm should be restricted to the morning hours (07.00 to 11.00 hours) only because levels of N, Mg and Ca have been observed to be lower in the evening than in the morning samples (Scheidecker and Prevot, 1954; Coulter, 1958). This restriction implies that either a large labour force is required to complete the sampling within one day or that sampling must be spread over several days. Apart from the economic implications, Smilde and Chapas (1963) observed that when making the recommendation insufficient consideration had been given to analytical errors which are usually of the same magnitude as the observed diurnal differences (2-8%). They further remarked that for full assessment of this type of error, a knowledge of the day-to-day

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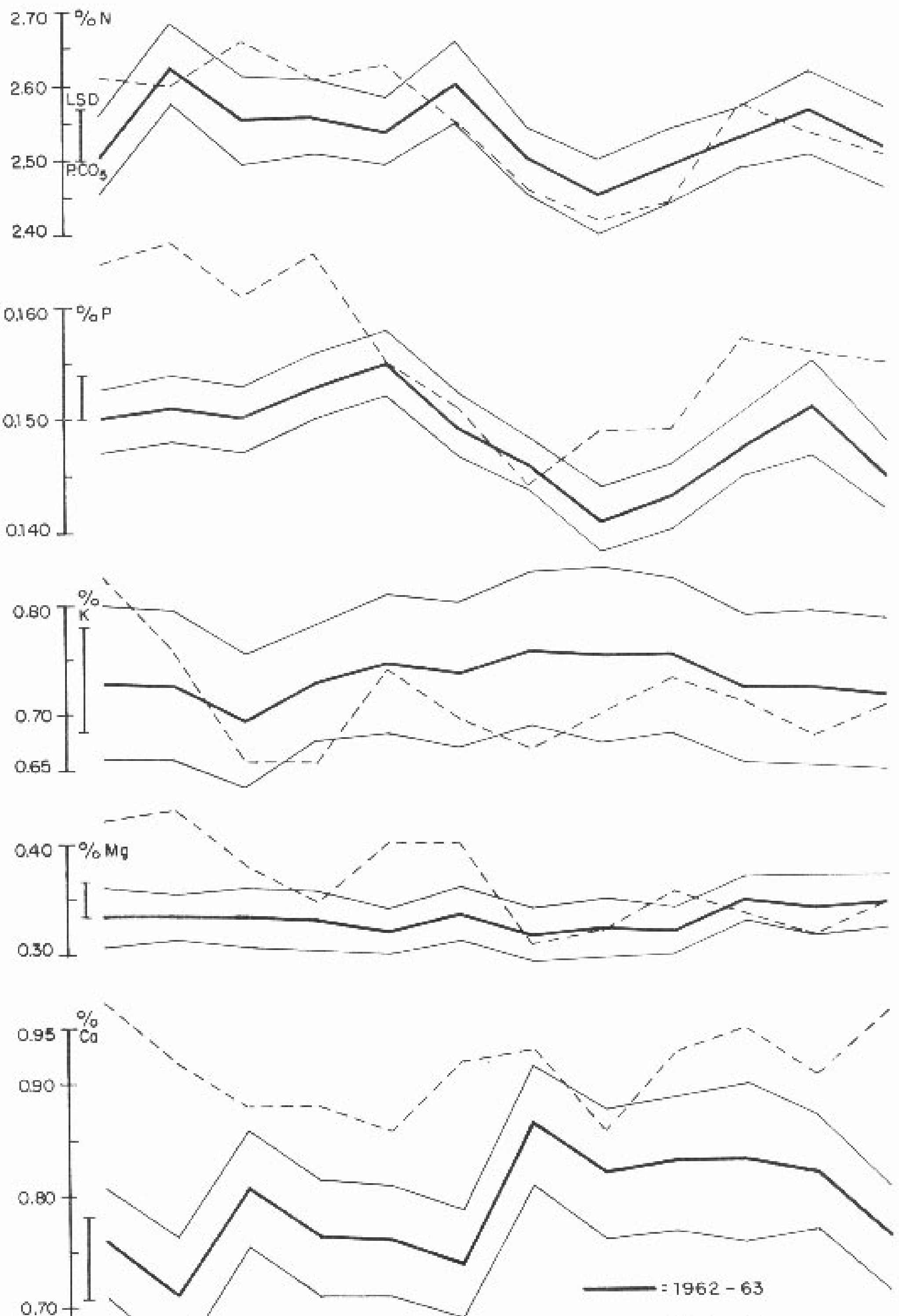


Fig. 1 Errors involved in leaf sampling of oil palms

Mean nutrient concentrations, month by month for 1960-61 (Expt. 1) and 1962-63 (Expt. 2) for the 17th. leaf of 32 palms, 95% confidence limits for 1962-63 data (Source: Smilde and Leyritz, 1965) variation is also required as sampling normally takes several days to complete.

This aspect of diurnal variation was investigated in NIFOR by Leyritz (NIFOR 1966/67) taking into consideration possible day-to-day variation. Five replicates of five palms each from palms of the same genetic origin were sampled daily at 08.00, 11.00, 14.00 and 17.00 hours for five consecutive days by taking two leaflets from the central portion of frond 17 on either side of the rachis each day.

No significant hourly variations were found for any element but the calcium level varied from day to day ($P=0.05$). Therefore sampling can take place any time of the day under Nigerian conditions. Error introduced by sampling over a five day period was considered negligible for most elements. This implies that a considerable saving in costs of sampling could be achieved by not restricting sampling to morning hours only.

3.4 Sample Size and Intensity of Sampling

The variation in the tissue nutrient concentration raises the practical problem of obtaining a leaf sample representative of the nutrient status of a given population of palms.

Opinions differ considerably on the minimum number of palms which should be included in a composite sample from an experimental plot or a plantation. There is also disagreement on the size of area units and the number of palms to be sampled per unit (sampling intensity) or the percentage of palms to be sampled in a given population of palms (sampling fraction). The minimum number of palms contributing to a composite sample ranges from 10-30 palms (Smilde and Chapas, 1963). For sampling intensity, the IRHO recommended one composite sample per 30 hectares for young palms (1-4 years old) or one per 50 hectares in subsequent years (Ollagnier et al., 1970) whereas in Nigeria sampling of 30 palms per 300 palms (10%) in a homogeneous two hectare unit is recommended (Smilde and Leyritz, 1965). Ward (1966) suggested sampling units of 25 hectares (based on frond 1 of Nigerian palms) and 1% sampling intensity.

The matter of choosing the right number of palms to characterize the nutrient status of palms in a given area is of economic importance. There is always need to strike a balance between the demands of correct diagnosis of mean nutrient status and the cost of labour involved in sampling and subsequent chemical analysis. There is also the practical aspect of evolving a sampling scheme, and a resulting fertilizer recommendation, that is workable. A sampling scheme that is most precise may not be the most expedient having regard to the time and labour involved in sampling. Similarly, if the size of sampling units as determined from statistical considerations is too small, indicating different fertilizer decisions per unit, the cost of implementing such a decision in terms of labour and material must be weighed against the income from anticipated increase in yield.

The sampling scheme recommended for Nigeria, for example, is of very high sampling intensity and generates a large number of samples. Moreover, in the absence of a detailed soil survey of some of the plantations it is difficult to delineate homogeneous blocks. Differences in topography, field practices (including levels of maintenance), heterogeneity in genetic source of planting material, ages and stages of growth or development due to supplies are also factors not fully considered in the studies on which the recommendation is based.

As the estimation of the minimum number of palms to be sampled is based on the variance of the population studied, and also as the block size depends on the uniformity of variance between contiguous area units, it is clear that a practical recommendation can only come from a study of variance and factors effecting it within a plantation. Thus, the extrapolation of the result of a sampling exercise completed on a uniform but limited population of palms, no matter how precise, may lead to wrong decisions. More information on the nature of variation of nutrient contents of palms in plantations on different locations is badly needed before a general principle of fertilization based on foliar diagnosis can be determined. A useful approach is that of control plot technique used in Malaysia by Knecht et al., (1974). Meanwhile, where plantations are managed in blocks of about 16.2 ha the sampling of 30 palms selected randomly (excluding runts, diseased and very abnormal palms) diagonally across the block is recommended.

4. PRE-TREATMENT OF SAMPLES

4.1 Cleaning

It is usually necessary to clean samples harvested during the dry season because of surface dust deposits. Leaflets are wiped on both surfaces with moistened cotton wool or muslin cloth dipped in 2% 'Teepol' detergent solution. This cleaning procedure has been found to be good enough for trace element analysis (NIFOR, 1967, 1968).

After cleaning, the mid-ribs are removed and the lamina is cut into pieces of about 2-3 cm and transferred into a labelled paper bag for oven drying.

4.2 Drying

The standard recommendation is oven drying (forced draught) at 70-80°C for 36-46 hours. The drying process should commence within 24-48 hours of collection from the field. Dried samples are placed in thin polyethylene bags and securely tied to prevent moisture absorption and stored in an air-conditioned room until they are milled.

When a laboratory is handy, drying presents no problem but when sampling is carried out at distant locations a suitable drying method prior to laboratory drying presents a big problem. This problem exists in many plantations.

Some practical means of overcoming the drying problem have been sought in the past. Kenworthy's (1973) suggestion that samples could be air-dried initially and oven-dried later was tried. The problem with air-drying in the dry season is dust contamination of the already cleaned samples. An alternative procedure which has been tried in plantations with processing mills is the use of the kernel dryer. These are steam-heated concrete platforms on which kernels are spread for drying. The platform surface is covered either with clean wooden planks, asbestos or iron sheets and paper bags containing the samples are then placed on these covers before the platform is heated by passing super-heated steam into a steam chamber beneath. Quick drying has been obtained by this method but temperature control is difficult. A very low nitrogen level in a sample so dried was attributed to this method of drying. Another drying method which has been tried is the use of wood-fired seed germinators. The temperature of the germinator chamber is normally maintained at about 40°C but it can be increased for leaf sample drying.

For sampling on a large scale, some thought should be given to the drying problem. It may be necessary to create sample preparation stations in each of the states now planning to develop large-scale plantations. Plantations of 5 000 or more hectares should have processing laboratories attached. For smaller and more remote estates, kerosene heated ovens or a solar-heated oven may be designed, if the cost is not prohibitive.

Cold storage (0–5°C) of samples prior to oven drying has not been studied. As kerosene heated refrigerators are more common in the tropics than heated ovens, this may afford a temporary stop gap measure before the samples reach a laboratory for drying.

4.3 Milling

Oven dried samples are milled to pass a 1mm sieve using either a Wiley or a micro-hammer mill.

4.4 Storage

Milled samples are stored in an air-conditioned room (temperature about 21°C) in either bottles or polyethylene tubes, or when these are not available in sealed polyethylene bags. The period of storage varies but seldom exceeds 24 months.

4.5 Errors in Sample Preparation

From the foregoing, the possible sources of error in the sample preparation phase are:

i. losses in dry weight as a result of delays before oven-drying of samples from distant places;

ii. over-drying of samples with improvised equipment and inadequate temperature control;

iii. possible changes in composition with storage over a long time.

5. ANALYTICAL METHODS

For the oil palm, total laboratory analysis of oven-dried leaf samples appears to be the standard practice in preference to quick field tissue tests. This may be due to greater convenience of analytical procedures offered by the former as field sampling operations could be tedious.

5.1 Analytical Procedures

Both wet and dry ashing methods have been used for the routine analysis of the major element contents of oil palm lamina tissue. In NIFOR, dry ashing is currently preferred because of uncertainty about the purity of some of the reagents used for wet ashing - particularly phosphate impurities in some batches of hydrogen peroxide. The routine analytical procedures adopted are as follows.

Finely ground subsamples are re-dried at 105°C for two hours and are ashed at 550°C for three hours in a muffle furnace and the ash further digested in a hot water bath for 30 minutes with 25 ml of 20% HNO_3, filtered and made up to 250 ml with distilled water. Aliquots from this are used for the estimation of K, Ca, Mg and Na after suitable dilution. Potassium, calcium and sodium are determined by flame photometry using an EEL flame photometer. Phosphorus is determined colorimetrically with the auto-analyser (as vanadate yellow) or spectrophotometrically as molybdenum blue. Magnesium is determined colorimetrically by the titan yellow method but an atomic absorption spectrophotometer can be used for the routine determination of Mg and Ca.

A separate micro-Kjeldahl digestion is carried out using 120 mg of dried leaf powder in 2 ml of conc. H_2SO_4 and 1 g of sodium sulphate - selenium catalyst. The digest is made up to 100 ml and 50 ml aliquot is distilled for 10 minutes into a mixture of 40 ml of 2% boric acid and 10 ml of bromophenol blue and titrated with 0.05N HCl. Alternatively, total N is determined on the auto-analyser using the indophenol blue method.

The concentration of elements determined by these methods is usually expressed as percent (%) of dry weight.

5.2 Analytical Error

The analytical methods in use, which are fairly rapid and dependable, are usually tested for both accuracy and precision (reproducibility) at the time of establishment. Error variance from this source is, however, expected to be small compared with the total sampling error. A coefficient of variation of less than 5% is normally considered satisfactory. The use of more modern equipment such as auto-analysers and atomic absorption spectrophotometers is expected to increase the rate of chemical analysis of samples with lower analytical errors. Nevertheless, the need to keep a constant check on analytical errors cannot be over-emphasized especially as the dearth of instrument service technicians and very poor after-sales-service result in poor instrument precision coupled with frequent breakdowns.

One method of frequent check on analytical error which may be adopted is the use of an international test-sample exchange scheme. In such a scheme run by the Agricultural University, Wageningen, Netherlands, 6 samples of various plant tissues, including oil palm leaves, are analysed bi-monthly for as many elements as possible. Duplicate analysis of such samples enables a statistical test of reproducibility of the analytical methods to be made over a wide range of nutrient concentrations, while the mean values for each sample are used for test of accuracy and recovery. The usefulness of this scheme depends on the prompt availability of statistically analysed results indicating trends of bias in methods of analysis.

Experience with this scheme shows that for plant tissues high in phosphate, calcium levels determined by flame photometry are unreliable because of the quenching effect of phosphate. For tissues high in potassium errors arise mostly from inaccurate recording of the actual dilution made by assistants. Good agreement is often obtained for N and P.

A regional or local standards scheme of this nature would undoubtedly be rewarding as it is not certain how far conditions of transportation and handling introduce further errors.

5.3 Laboratory Services

Unlike Malaysia where there are several laboratories, NIFOR is the only laboratory servicing the oil palm industry in Nigeria. The demand for laboratory services from plantations is increasing and with the projected scheme for the development of the oil palm industry, the present rate of analysis will be inadequate for quick results. This problem can be solved by either creating more laboratories in each big plantation or greater automation in the analytical facilities of a few central laboratories manned by well trained staff. With the present level of technology, experience with instrumentation may favour decentralized laboratories with simple, less sophisticated, rugged and easily maintained equipment. As the main problem is one of shortage of experienced and trained manpower for servicing and maintaining laboratory equipment, a service and maintenance body might be created on an international level to service analytical laboratories within a zone.

6. INTERPRETATION OF DATA

6.1 Yield Responses in Fertilizer Trials

For most crops the relationship between leaf nutrient concentration and growth or yield is established in fertilizer trials in which changes in crop yields or growth, resulting from increases of a fertilizer nutrient element, are related to changes in the chemical composition of pre-selected leaf tissues. From these yield - nutrient response curves, reference standards for judging crop performance are derived. For diagnostic use, leaf nutrient concentrations are usually put into zones associated with deficiency, marginal, sufficiency and excess. A prime objective in this zoning is a knowledge of the 'ideal' or 'normal' composition associated with maximum growth or yield.

The many fertilizer experiments of this type which have been carried out have contributed greatly to knowledge on the use of foliar analysis in plants and the oil palm in particular.

The general nature of responses to fertilizer application in Nigeria has been reviewed by Chapas and Bull (1956), Forde et al., (1968), Hartley (1967), and yearly in NIFOR Annual Reports on the various fertilizer programmes. A brief summary of the nature of these responses will help to assess the possible effectiveness of plant analysis in guiding the present and future fertilizer practice. The early fertilizer experiments included fairly massive doses of fertilizer in a single application so as to demonstrate effects. Rates as high as 4.5 to over 10 kg of each fertilizer salt were given per palm, either as a single dose or repeated over several years. The early results showed responses to potassium and magnesium where visible deficiencies already existed before treatment - otherwise, responses were very small. Nitrogen, phosphate and lime applications gave no significant responses. Lime applied at 2 510 kg/ha caused about 20% decrease in weight and number of bunches (Chapas and Bull, 1956). With potash showing a dominant effect the frequency of application of potassic fertilizer was also investigated. It was shown that potassium deficiency was corrected by a dressing of only 5.44 kg of potassium sulphate per palm over a seven-year period, i.e. a mean of about 0.78 kg K_2SO_4 per palm per annum. Higher rates of potassium fertilizer did not produce further significant yield increases. Applying the fertilizer in a single dose gave higher yields than split doses in three or six applications throughout the rainy season. There was very little economic advantage in applying the fertilizers annually instead of every two or three years (May, 1956).

6.2 Fertilizers and Leaf Nutrient Levels

The general nature of effect of applied fertilizer treatments on leaf nutrient composition can be summarized as follows.

6.2.1 Nitrogen leaf content

The differences in leaf nitrogen concentration at the various levels of nitrogenous fertilizer application are barely significant in spite of the fact that nitrogen is consistently applied annually in all the treatments. Various explanations have been offered including dilution effect as a result of growth (Green, 1972).

6.2.2 Leaf phosphorus

Generally, there is an increase in leaf P following phosphate fertilizer application but it is only in the basement complex soils that these increases have been associated with increased bunch yield. There is very little effect of other fertilizer elements on leaf P.

6.2.3 Leaf potassium

Application of potassium fertilizer, even at the lowest level increases leaf K very significantly. In Calabar fasc soils a mean increase of over 75% in leaf potassium was obtained for fertilizer plots and about 50% in the Benin faso soils but little response in the potassium rich basement complex soils, where the mean leaf potassium level is over 1%. The application of magnesium, nitrogen and superphosphate fertilizers reduced leaf K by about 5-15%.

6.2.4 Leaf magnesium

Generally, application of magnesium fertilizers increased leaf magnesium levels with a significant reduction in potassium levels but with either positive or little effect on calcium levels.

6.2.5 Leaf calcium

Lime is rarely applied in oil palm agronomy as the early trials showed decreases in yield with lime. The calcium concentration of the oil palm tissue ranges from about 0.4-0.9%, depending on the relative values of K and Mg levels.

6.2.6 Leaf nutrient and yield

Yield responses are attributed to a few of the applied fertilizer elements - principally potassium and phosphate. From the trend of current fertilizer responses it appears that positive correlations can be established between yield and leaf analyses for potassium in the acid sand soils (Table 1) and for phosphate in the granitic basement complex soils.

Table 1 CORRELATION COEFFICIENTS OF LEAF NUTRIENT ELEMENTS WITH BUNCH YIELD ON ACID SANDS

Expt. No.	Bunch yield Period	Leaf elements (% dry weight) N	P	K	Ca	Mg
508-1	1971-74 vs. 1973 Leaf elements	-0.133	-0.152	0.378***	0.159	0.023
2-15	1971-74 vs 1971 Leaf elements	0.211*	0.039	0.610***	-0.271**	-0.433***

The significant but negative calcium and magnesium relationships with yield can be regarded as a consequence of the high positive relation of potassium with yield ($r^2 = 37.2\%$) and the known antagonism between these elements (Ca and Mg) and potassium.

A possible deduction from these results is that either the levels of other nutrients showing no yield responses to graded levels of appropriate fertilizer elements are adequate or that from Prevot and Ollagnier's (1961) principle of the law of minimum factors, the primary deficiencies of K or P may be limiting responses to these other nutrients. The factorial design of the experiment tested these non-responding elements at some levels of adequacy of the deficient elements. It then seems that the leaf levels of these other elements could be assumed to be adequate under the prevailing environmental conditions.

6.2.7 Critical levels

Unlike most of the classical yield response curves used in establishing critical nutrient concentrations, which show curvilinear responses with a transitional zone around the critical level (Ulrich, 1961; Hartley, 1967), our responses were predominantly linear and seem to indicate that the optimal leaf K level was not reached at the levels and frequencies of applied K (Figure 2). Possible criteria for judging nutrient requirements could be derived from these and other experiments not reported here. For example, no response was obtained for potassium where leaf K was over 1% and it could be assumed that the optimal level of K lies in the region of 1%.

These data show that relative to optimum yield the leaf nutrient level varies widely for each element including those for which no direct correlation was established. Therefore, it would be better for the time being to consider the adequacy of an element over a range of values associated with optimal growth or yield rather than a single value. These values should be strictly regarded as concentrations found in 'normal' plants of good yield in a given environment and do not as they stand afford a basis for positive statements on yield responses to fertilizer application. Smilde (WAIFOR 1962/63) has given tentative 'critical' values from earlier fertilizer trials. These values, together with the classical reference values given by the IRHO, now used as standard values, are given in Table 2.

Table 2 OPTIMAL VALUES FOR MAJOR ELEMENTS

Element	IRHO	Smilde (WAIFOR 1962/63)	Optimal Range
N	2.50	2.50 (approx)	2.3 -2.8
P	0.15	0.145-0.155	0.14-0.18
K	1.00	1.0 -1.10	0.8 -1.2
Ca	0.60	-	0.4 -0.8
Mg	0.24	0.28 -0.30	0.2 -0.5

Within the ranges given responses are still possible depending on various interacting factors. As the upper limits are approached, yield increments decrease until no further response is obtained (luxury consumption level). Below the lower limits there is certainty of response to fertilizer.

The use of a single value for the critical point as proposed by the IRHO has led to some confusion in the interpretation of foliar analysis data in oil palm nutrition. Several anomalies have been observed and responses have been obtained where leaf levels appear sufficient when judged by the critical level. Ideally, these critical levels appear to be the mean of normal values under normal growth conditions but like any mean value, they should be bounded by confidence limits. What is needed are balance indices of the type proposed by Kenworthy (1973). Interpretation of leaf analysis data still requires expert advice and cannot yet be mechanically applied.

6.2.8 Other interpretative approaches

As optimal nutrition is approached and in the absence of well defined deficiency conditions the concept of critical levels has been found to be imprecise and not sensitive enough for a decision on whether further responses are possible with upward changes in leaf nutrient level (Bar-Akiva, 1970).

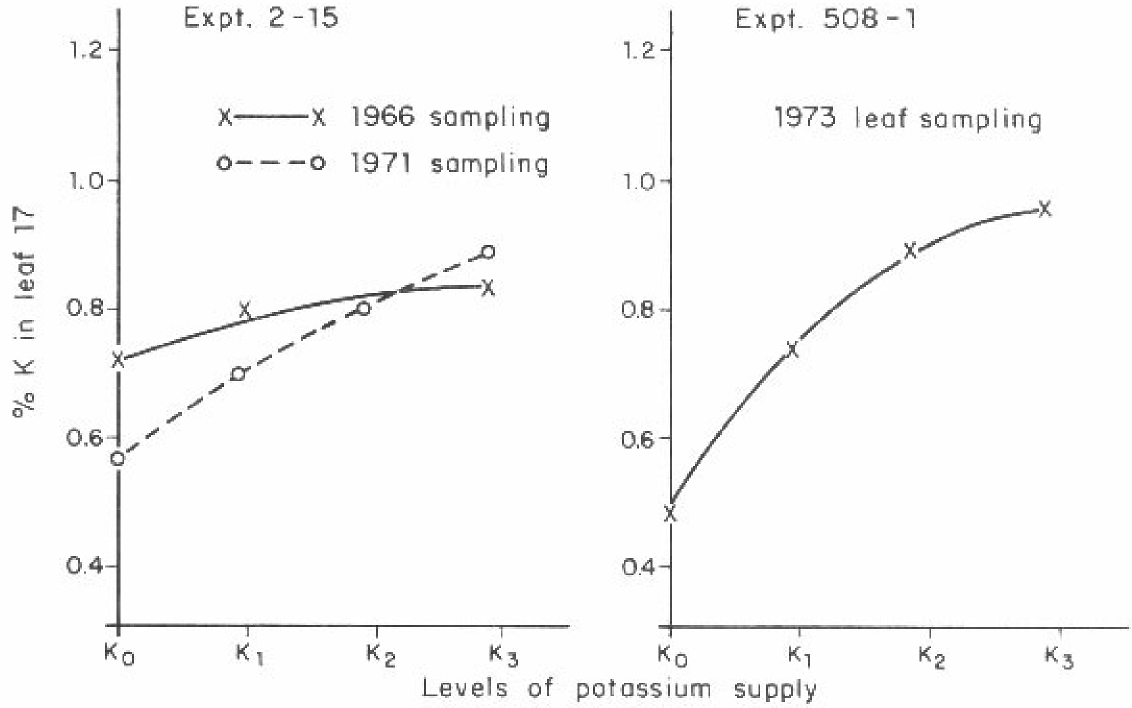


Fig. 2a Relationship between applied K and leaf K

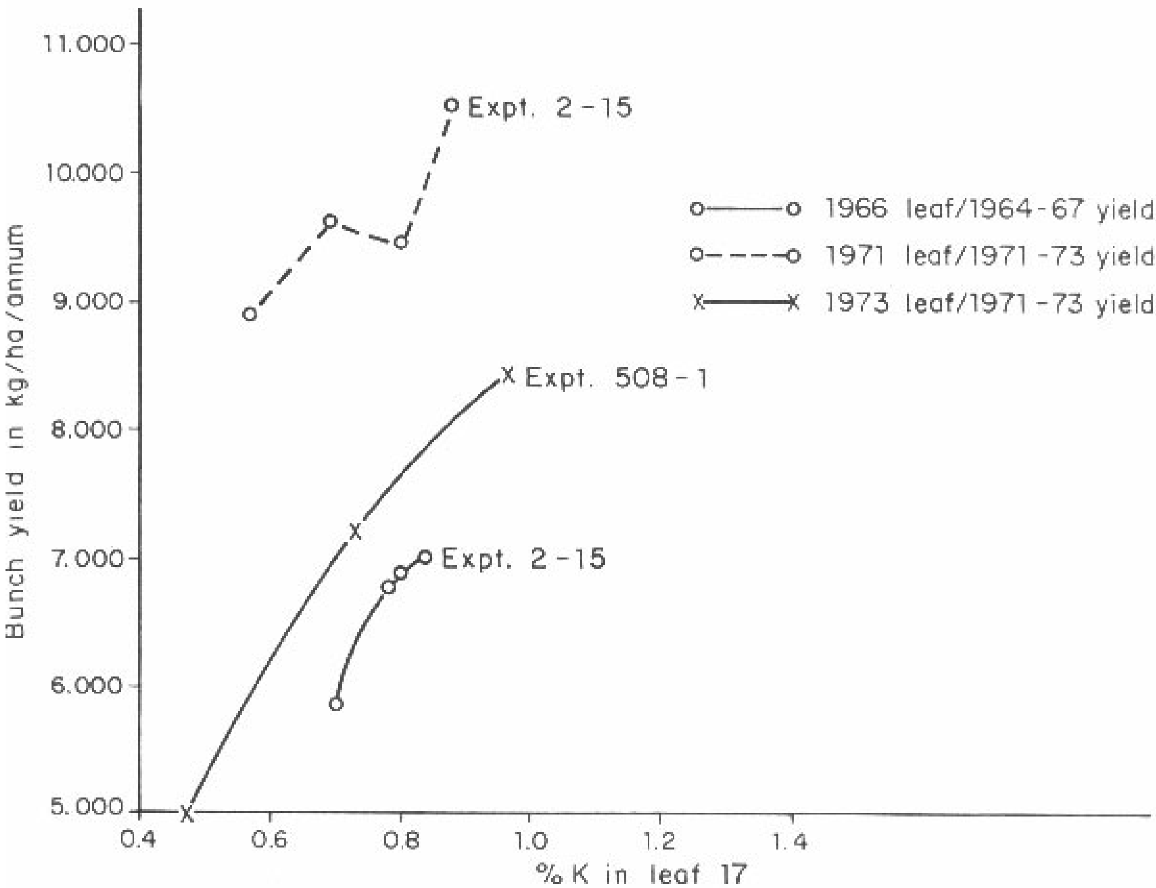


Fig. 2b Relationship between leaf potassium and yield

Alternative approaches to interpretation have been suggested such as the use of ratios and balance between leaf elements with optimal ratios or balance (Chapman and Gray, 1949; Prevot and Ollagnier, 1954; Broeshart, 1955; Ferwerda, 1961). Holland (1966) has reviewed these interpretative approaches and conceded that while the inclusion of as many elements as possible enhances interpretation, they are not without limitations. For example, in the use of binary ratios, the multiplicity of such ratios would constitute a problem unless some objective selection is possible. The bases for this objectivity - which are stability of these ratios to non-nutritional environmental factors causing variation in leaf nutrient levels, and then definite relationship with yield - are the subject of controversy (Ferwerda, 1961). The trivariate approach involving balance between three elements only, excludes any additional element that may be contributing to or affecting the balance. The use of a multi-variate analysis approach such as multiple regressions, principal component analysis and the crop logging system (Clements, 1961) have been proposed as offering hope for the future (Bolle-Jones, 1975), but the statistical computations involved are beyond the competence of an average diagnostician. Bolle-Jones (1975) has also proposed the assessment of fertilizer responses in terms of vegetative dry matter yield rather than bunch yield alone, as some elements are known to increase total dry matter yield without causing increases in leaf nutrient concentration.

Most of these alternative interpretative approaches have not been applied on a routine basis in diagnosing the fertilizer requirements of the oil palm by leaf analysis owing to their limitations as pointed out, problems in additional computations entailed, or no clear advantage over the conventional methods.

6.2.9 Future

There is no doubt that the main diagnostic problem in oil palm nutrition in the future is that of interpreting nutrient requirements in the region of optimal nutrition. As Green (1972) pointed out, the era of diagnosing primary deficiencies in oil palm nutrition is gone, especially under modern plantation management. The main nutritional problem will be maintenance of good productivity or, as in forestry (Leaf, 1973), improving a "good productive" site "to a very good productive" site by the use of fertilizers. Under this condition, the use of critical levels alone is inadequate to guide fertilizer policy because with good husbandry where fertilizers are supplied regularly, interactions and balances between nutrients become more important in both supply, uptake and final status within the plant than single nutrient levels.

While the use of computers may allow the examination of yield and nutrient relations through multiple regression and principal component statistical analysis, some more fundamental physiological aspects of ionic relations in plants will be needed to determine these relationships. Cation-anion relations and balance together with the diagnostic significance of some organic acids involved in the balance will have to be examined. The cation-anion concept appears to be an integrated value of several factors and has been used successfully in graminaceous plants to evaluate nutrient requirements (De Wit et al., 1963). Moreover, as variations in mineral contents of the different plant species and plant organs depend on physiological processes going on in the plant, more information is needed on the metabolic role of each element in the plant for correct diagnosis of requirement.

7. CONCLUSIONS

Leaf analysis will continue to be used generally for diagnosing the fertilizer requirements of the oil palm. For areas where little fertilizer is used and nutrient deficiencies are common, the conventional method of interpretation based on the concept of optimal ranges will be used to determine fertilizer policy. For areas with good husbandry and higher planes of nutrition, a radical change is required in the methods of interpretation as under this condition the classical concepts of critical levels, based on the law of minimum factors, barely apply; rather, nutrient balances become more important. Concepts based on ionic balances in leaf tissue and basic roles or functions of elements in the plant are likely to offer more sensitive diagnostic criteria.

The use of leaf and soil analyses to guide fertilizer policy in industrial plantations in Nigeria is expected to rise phenomenally in the very near future because of the current oil palm development programme. Very few industrial plantations have made use of these in the past. Information will be required on sampling procedures and interpretation of results. There is still much to be learned regarding sampling in large plantations. The current recommendation of 10% sampling intensity is uneconomic and tedious. In processing of samples, drying presents the greatest problem and to solve this, it will be necessary to have a number of processing stations in and around the big plantation areas or zones in the country. The analytical methodology in use is adequate as far as analytical errors are concerned but there is an urgent need to increase both the number of laboratories and the facilities in them to cope with the anticipated increase in samples. More personnel will have to be trained in analytical procedures and servicing of equipment. Factors affecting leaf nutrient level such as changes in climate, soil types, genetic make-up of plants have not been fully studied.

REFERENCES

BACHY, A. Diagnostic foliare du palmier à'huile - niveau critique chez les jeunes arbes.
1964 Oleagineux 19: 253-256.

BATES, T.E. Factors affecting nutrient concentrations in plants and their evaluation: a review. Soil Science 2: 116-130.

BOLLE-JONES, E.W. Limitations of foliar diagnosis with special reference to the oil palm.
1975 Trop. Agric. 52: 11-19.

BROESHART, H. The application of foliar analysis in oil palm cultivation. Thesis,
1955 Wageningen State University.

CHAPAS, L.C. and BULL, R.A. Effects of soil application of N, P, K and Ca on yield and
1956 deficiency symptoms of mature oil palms at Umudike. J.W. Afric. Inst. for Oil Palm Res. 2: 74-84.

CHAPMAN, G.W. and GRAY, H.N. Leaf analysis and nutrition of the oil palm. Ann. Bot.
1949 London 13: 415-433.

COULTER, J.K. Mineral nutrition of the oil palm in Malaya. Malay Agric. J. 41: 131-151.
1958

DE WIT, C.T., DIJKSHOORN, W. and NOGGLE, J.C. Ionic balance and growth of plants. Agric.
1963 Research Report Wageningen.

FERWERDA, J.D. Growth, production and leaf composition of the African oil palm as
1961 affected by nutritional deficiencies. In: Plant Analaysis and Fertilizer Problems. Am. Inst. Biol. Sci., Washington. pp 148-158.

FORDE, St. C.M., LEYRITZ, M. J-P. and SLY, J.M.A. The role of potassium in the nutrition
1968 of oil palm seedlings. J. Nig. Inst. for Oil Palm Res. 4: 334-369.

GREEN, A.H. Unilever Plantations Group Ann. Rev. Res. 1970. Unilever, London. 139 p.
1972

HALE, J.B. Mineral composition of leaflets in relation to chlorisis and bronzing of oil
1946 palms in West Africa. J. Agric. Sci. 37: 236-244.

HARTLEY, C.W.S. The Oil Palm (Elaeis guineensis Jacq.). Longmans Green, London.
1967

HOLLAND, D.A. The interpretation of leaf analysis. J. Hort. Sci. 41: 311.
1966

KENWORTHY, A.L. Leaf analysis as an aid in fertilizing orchards. In: Soil Testing and
1973 Plant Analysis. Soil Sci. Amer. Inc. Madison, Wisconsin. p 381.

KNECHT, J.C.Y., RAMACHANDRAN, R. and NARAYANAN, R. Some variational features of the leaf
1974 nutrient contents in oil palm leaf sampling. Oleagineux 29: 287-295.

LEAF, A. Plant analysis as an aid in fertilizing forests. In: Soil Testing and Plant
1973 Analysis. Soil Sci. Amer. Inc. Madison, Wisconsin. 427 p.

LEYRITZ, M. J-P. Leaf sampling studies: Diurnal variation in nutrient levels. NIFOR,
1967 3rd Annual Report, p. 92.

LUNDEGARDH, H. Leaf Analysis. Hilger and Watts, London.
1951

NG, S.K. The oil palm, its culture, manuring and utilisation. International Potash
1970 Institute, Berne.

NG, S.K. and THAMBOO, S. Nutrient content of the oil palm in Malaya. I. Nutrients
1967 required for reproduction: fruit bunches and male inflorescenses. Malay Agric. J.
46: 3-45.

NG, S.K., THAMBOO, S. and DE SOUZA, P. Nutrient content of oil palms in Malaya. II.
1968 Nutrients in vegetative tissues. Malay Agric. J. 46: 332-391.

NIFOR First Annual Report, 1965-66.
1965

NIFOR Fourth Annual Report, 1967-68, 79 p.
1967

NIFOR Fifth Annual Report, 1968-69, 84 p.
1968

OLLAGNIER et al. Manuring of the oil palm in the world. Fertilité 36: 3-61.
1970

PREVOT, P. and OLLAGNIER, M. Peanut and oil palm foliar diagnosis interrelations of
1954 N, P, K, Ca and Mg. Plant Physiol. 29: 26-34.

SCHEIDECKER, D. and PREVOT, P. Nutrition mineral du palmier à huile à Pobe. Oleagineux
1954 9: 13-19.

SMILDE, K.W. and CHAPAS, L.C. The determination of nutrient status by leaf sampling of
1963 oil palms. J. Nig. Inst. for Oil Palm Res. 4: 8-30.

SMILDE, K.W. and LEYRITZ, M. J-P. A further investigation on the errors involved in leaf
1965 sampling of oil palms. J. Nig. Inst. for Oil Palm Res. 4: 251-261.

TINKER, P.B.H. and SMILDE, K.W. Dry matter production and nutrient content of plantation
1963 oil palms in Nigeria. II Nutrient content. Plant and Soil 19: 350-363.

TURNER, P.D. and GILLBANKS, R.A. Oil Palm Cultivation and Management. Incorporated
1974 Society of Planters, Kuala Lumpur.

WARD, J.B. Sampling oil palms for foliar diagnosis. Oleagineux 21: 77.
1966

WERKHOVEN, J. The Manuring of the Oil Palm. Verlags Gesellschaft für ackerban mbH.
1965 Hanover.

Paper 17 SOME BASIC PRINCIPLES OF THE EVALUATION AND CALIBRATION OF SOIL TESTING METHODS

by

F. van der Paauw
Institute for Soil Fertility, Haren (Gr.), The Netherlands

1. INTRODUCTION

Some years ago the author read a paper at a symposium in Vatican City dealing, as here, with the use of fertilizers with special emphasis on developing countries. The title was "Adjusting fertilizer rates to soil fertility level on the basis of soil testing" and the underlying theme was whether other countries might take advantage of the progressive development of soil testing methods in the Netherlands.

The question was raised whether an equally intensive use of soil testing should be advocated elsewhere. Soil testing is especially relevant in cases where the level of a soil fertility factor (e.g. P) is very diverse, as in Holland. In contrast, little can be expected in those regions where all sites are equally fertile or equally poor. A warning referred to the very laborious task in establishing an effective system of fertilizer recommendation on this basis. Surely, the output will be disappointing if this is not fully understood.

It was concluded that soil testing is undoubtedly applicable wherever agricultural conditions are generally similar to those in Holland, though in each special case a renewed evaluation of the methods will be desirable. With regard to those countries where climatic and soil conditions are more widely different from the Dutch ones, it was said that methods developed in Holland would probably be of less use, though the basic principles underlying the methods, especially those related to the methods of evaluation of soil tests and the drawing up of fertilizer recommendation schemes, may still be of interest. It will be understood that this remark especially refers to developing countries where the agricultural conditions are so different from those in Holland.

In this lecture, the discussion will be restricted to the estimation of the phosphorus status of the soil. The reason is that perhaps the most promising development of the soil testing method has been obtained with this element.

2. SEPARATION OF SCIENTIFIC FROM ECONOMIC ASPECTS OF SOIL TEST EVALUATION

At present it is generally accepted that the evaluation of soil testing methods has to be done by means of field experiments. However, true as this may be, too much emphasis has unfortunately been laid on the economic aspect of the problem. It is not clearly understood that a purely scientific procedure has necessarily first to be followed, in which the relationship between the supply of soil phosphorus, as estimated by a special soil testing method, and the physiological response of the plant is established.

A scientific approach generalizes, aims at the establishment of valid relationships and general rules and excludes non-essential facts. On the other hand, the economic approach especially incorporates the actual conditions of practical farming.

The admixture of both principles has unfavourably affected the way of experimentation. Accordingly, the experimental design has been dominated by economic aspects especially relating to the yield.

This overestimation of the latter has led to the introduction of rather complicated designs of field trials. Special attention has been paid to the accurate assessment of yield increases and of yield curves over long periods. It has been overlooked that the purely scientific aspect of the evaluation of soil testing can be done in a much more simple and cheaper way. This possibility will be illustrated later. The question appears to be of special importance for work in developing countries, but first the more general aspects of the evaluation will be discussed.

3. EVALUATION PROCEDURE FOR A SOIL TESTING METHOD

Too little attention is paid to the point that special conditions need to be fulfilled before any exact statement can be made in a scientidic experiment.

The very first condition of an evaluation of soil testing methods for P is that there must be considerable differences in the P status of the soil at different sites. An evaluation will be impossible if this requirement is not met. If, however, such a situation does exist then a series of sites with different P status ranging from very low to very high P values in an even distribution can be selected for performing field trials. Therefore, the performance of soil tests in a number much exceeding that of the number of trials wanted, must precede the selection of sites.

The number of trials is based on estimations of type and size of possible errors in relation to the responses expected, also the number of treatments and replications may depend on this.

Design and treatment of all separate trials belonging to the same series must be similar. In many cases the design will be directed to the possibility of establishing complete yield curves. For this reason rates of fertilizing should range from none up to very heavy dressings in at least 5-7 rates. This will also enable the yields of control plots to be related to the maximum yields obtainable on the soils concerned, and likewise the economic interpretation of the results will be facilitated.

Special attention has to be paid to the choice of an appropriate test crop. The test plant must be particularly responsive to differences in P nutrition. Preferably the whole range of P status investigated in the series has to be covered by the reaction pattern of the plant. As to the economic aspect of the investigation, it is desirable that the test crop should be one that is commonly cultivated.

It seems strange that physiological responses are commonly expressed in terms of yield differences or, still worse, indicated by the amount of fertilizer which is just paying, however useful these values may be for the economic interpretation of the results. Experience has taught us that P contents of the aerial parts of plants or differences in plant growth in an early stage of development are more suited to this purpose than yield differences at the end, looked upon from a physiological point of view. Moreover, young plants normally respond more strongly to differences in P nutrition than plants at the end of the growth cycle.

A most effective P fertilizer, free from secondary effects, has to be used. This also applies to regions where other fertilizers (e.g. basic slag, rock phosphates) are commonly in use. If the effectiveness of these fertilizers has to be compared with that of the fertilizer applied in the test trial, separate trials have to be performed. The latter will be necessary for an economic interpretation of the results.

With regard to the variability of meteorological conditions long-term field trials are often advocated. This procedure would also enable soil testing methods to be evaluated with respect to other crops grown in the rotation. Apart from the time-consuming character of such experiments, there are reasons why the duration preferably has to be restricted to one season only. The fact is that differentiating the effects of freshly applied fertilizers from residual effects of earlier dressings is impossible in long-term experiments. Moreover, it is ineffective to devote time to crops which suit less well the special demands of the experimentation. Repeating a similar series of one year field trials is preferable.

It is sometimes argued that short-term experiments are less appropriate, as fertilizer recommendations based on soil tests are usually given for periods as long as 5-10 years. The objection does not hold, however, because P values of the soil remain almost constant provided no more than moderate dressings are applied.

The remark may still be made that the necessity to repeat experiments over a series of years will be less when the climate is less variable, which may contribute considerably to a reduction of work in some tropical countries.

4. COMPARISON BETWEEN SOIL TESTING METHODS

Although a large number of soil testing methods is known at present, much uncertainty still persists concerning their actual effectiveness. The chance of making an efficient choice between soil testing methods will be greatest when clearly different, or even conflicting indications concerning the P status of the soil are supplied by these methods. The demands made on the investigation will be the higher the closer the methods are mutually connected. A successful result of the investigation can be favoured by making a preselection of sites in such a way that the correlations between the data obtained by means of different soil testing methods, over a wide range of P status, will be as low as possible.

5. SIMPLIFICATION OF EXPERIMENTAL PROCEDURE

It has been mentioned already that separation of the scientific aspects of soil test evaluation from the economic aspects may be giving rise to a considerable simplification of the experimental approach. By leaving out the painstaking determination of yield differences and replacing this reference value by a standard of merely physiological interest, such as the P content of certain plant tissues or yield difference in an early stage of growth, the approach can be drastically simplified. The extent of this simplification may be elucidated by the following example.

5.1 'Spot' Trials

In 1943, during the German occupation of Holland, there was a lack of P fertilizers for practical farming, also conducting of field trials in considerable numbers was impossible. Nevertheless, as the intention was to compare the soil testing methods then in use (a warm water and a 1% citric acid extraction) agricultural advisers were requested to send soil samples taken from an area of 0.25 m^2 together with samples of the young crop grown on the same spot. More than 1000 pairs of samples were sent by express post. About half of this number originated from permanent grassland. P values of soils according to both methods and P contents of aerial parts of the crops were assessed and correlated. A possible confounding of the effects of soil and fertilizer phosphorus was absent as P fertilizers were totally lacking.

Remarkable results were obtained with grass especially. As opposed to the water extraction method, the citric acid extraction proved to be rather highly correlated with the P concentration in the grass. As an example, the results obtained with 106 samples from peaty soil are compared with those from regular field trials laid down in 1947 on the same type of soil (Figure 1).

The correlation between the P extracted by citric acid and the P concentration in grass (1947) was higher than that with yield differences. Similar high correlations showing only few aberrant data, were obtained in the simplified experiment (1943). Almost no correlation with warm water was found.

Similar approaches might be tried tentatively in developing countries.

5.2 Pot Trials

Another simplification can be obtained by using pot experiments instead of field trials. Pots standing outdoors represent an intermediate stage of field and laboratory experimentation. Certain disturbing factors are eliminated, for instance fluctuations in water supply, adverse effects of soil structure and possible effects arising from the subsoil. The experiment can be interrupted at an arbitrary growth stage at which the response of the plant to the soil factor under investigation is strongest. When potatoes are grown the sensitivity can be increased by making use of young shoots detached from sprouting seed potatoes. These shoots are more responsive to P than plants grown from a seed potato.

In this way a successful comparison was made between the P-AL method according to Egnér, Riehm and Domingo (1960; a weakly acid extractant), in use at the time (1958), and an alternative improved water extraction method (Pw method according to Van der Paauw and Sissingh, see below). 1/ The soils used were obtained from a concurrent series of field trials. Sites were selected in such a way that the correlation between the data obtained with both methods was very low.

The plant responses were found to be exclusively related to the soil data obtained by water extraction (Figure 2). On the other hand, no correlation whatever was found with P-AL values.

Where the correlation between Pw and P-AL values was higher, the latter were also correlated with the plant's response. The impression is that a contribution to this correlation from the non-water-soluble component of the AL extract which has been dissolved by the chemical action of this extractant is normally lacking. This inactive portion varies considerably from soil to soil. It follows that important systematic errors can be made when the AL method, or similar methods, are applied. Probably this is the most serious limitation of most soil testing methods.

6. COMPARISON BETWEEN POT AND FIELD TRIALS

The question may arise whether conclusions drawn from pot trials are applicable to conditions in the field. Therefore, the results of pot trials will be compared with those of contemporary field trials performed with identical soils.

In the early stages of growth a remarkable agreement was found between the results obtained in pots and in the field (Figure 3). Correlations between Pw value and plant data are high in both cases, the scattering of dots being only slightly higher in the field. Likewise, relative yields (yields without P as a percentage of maximum yield) are quite highly correlated with the Pw value. Clearly, no essential differences with the results of the pot experiment were found. Also practically no correlation was found with P-AL.

1/ Pw = P water

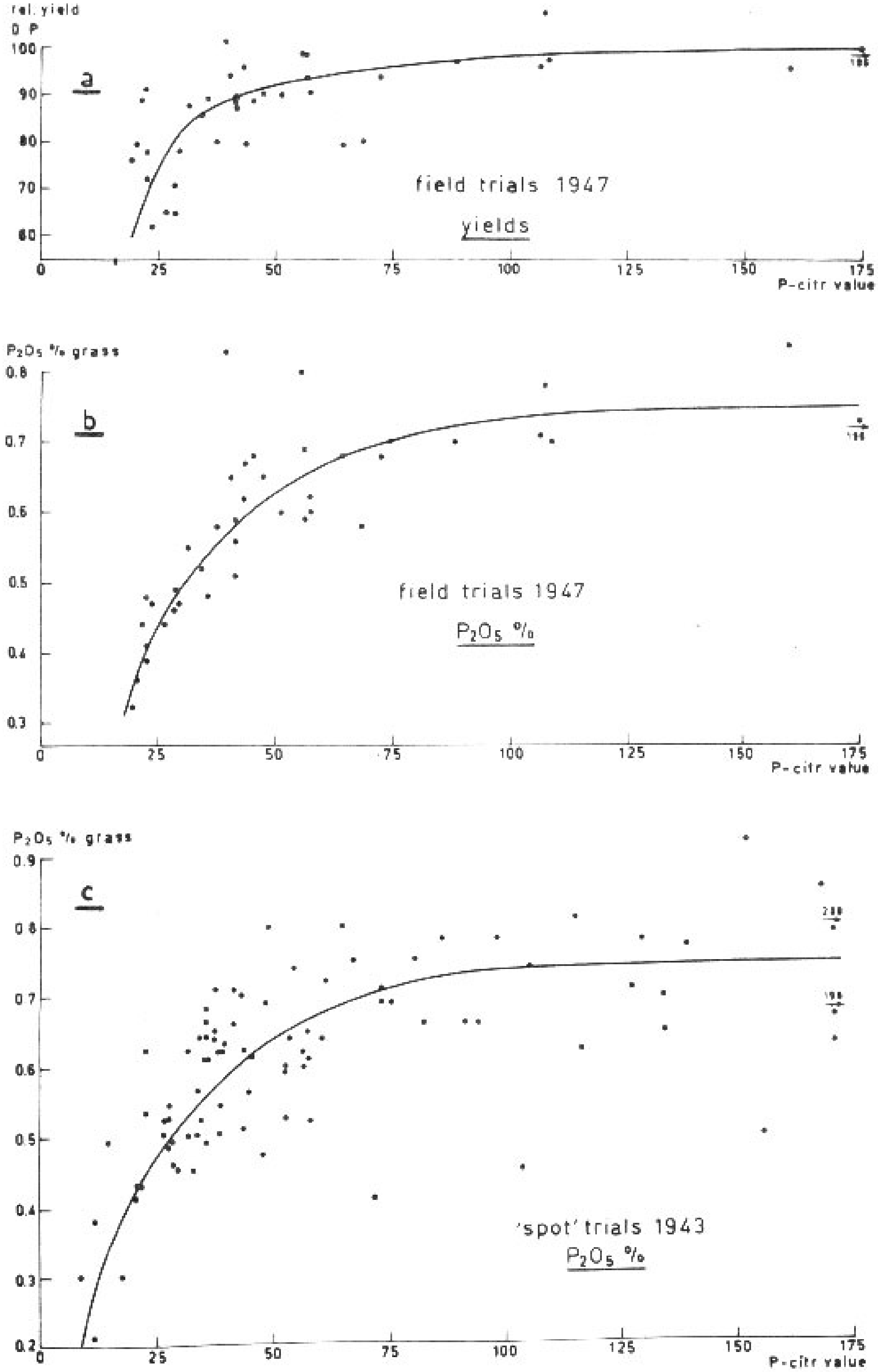


Fig. 1 Results of simplified 'spot' trials in 1943 (c) compared with results of a normal series of field trials in 1947, both on grassland on peaty soils (a and b). Relationship between soil P (citric acid) and grass P (P_2O_5 % on dry matter; b and c respectively; P_2O_5 % corrected to N = 1.8%) and relationship (a) with relative yield (yield of control as % of maximum)

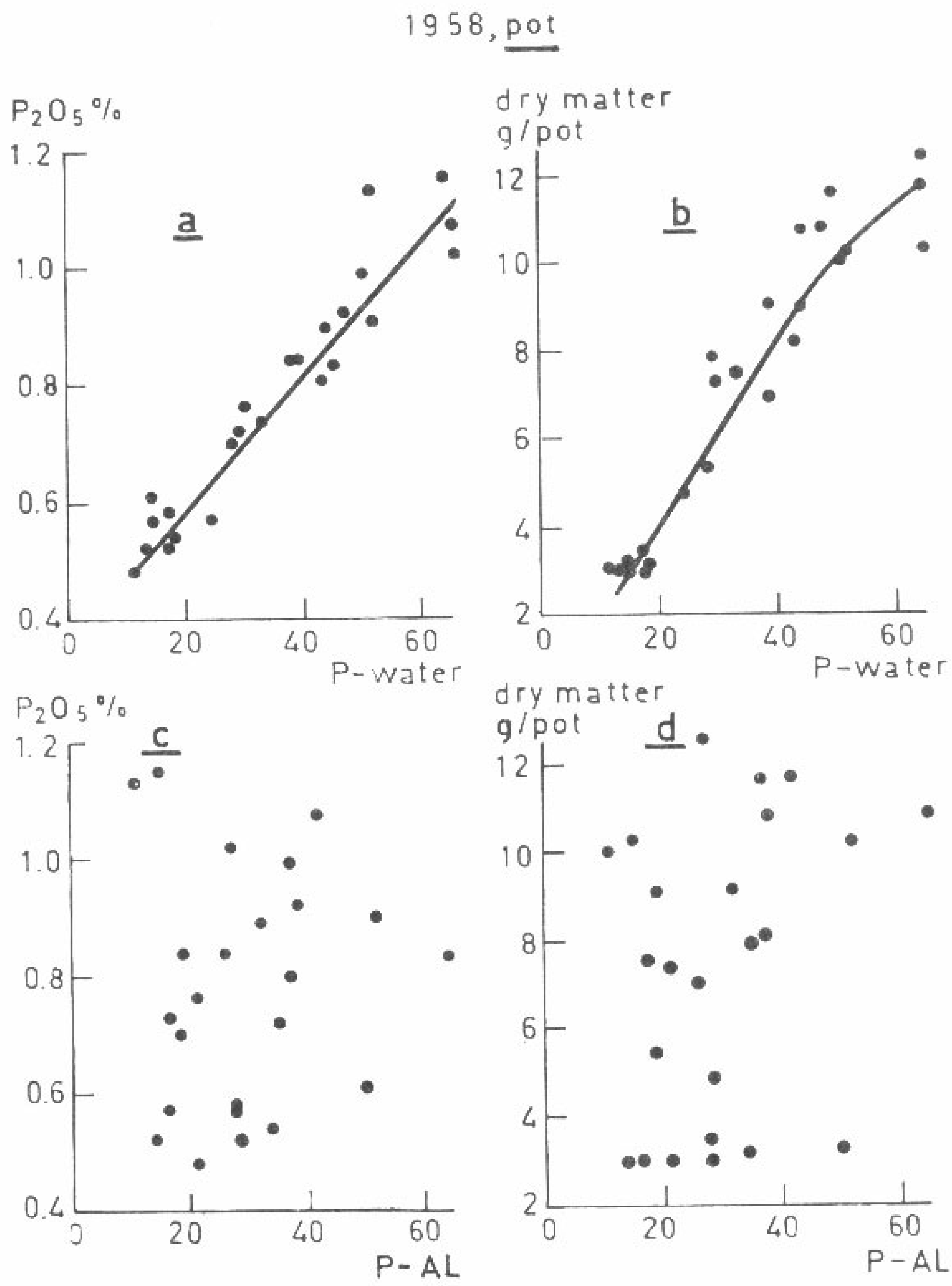


Fig. 2 Efficiency of P-water as compared with P-AL extraction in a pot trial with potato shoots on sandy soils (1958). Top: Relationship between Pw value and crop response (a. P_2O_5 % of dry matter, b. dry matter yield of rather young plants). Lower: same for P-AL value (c and d)

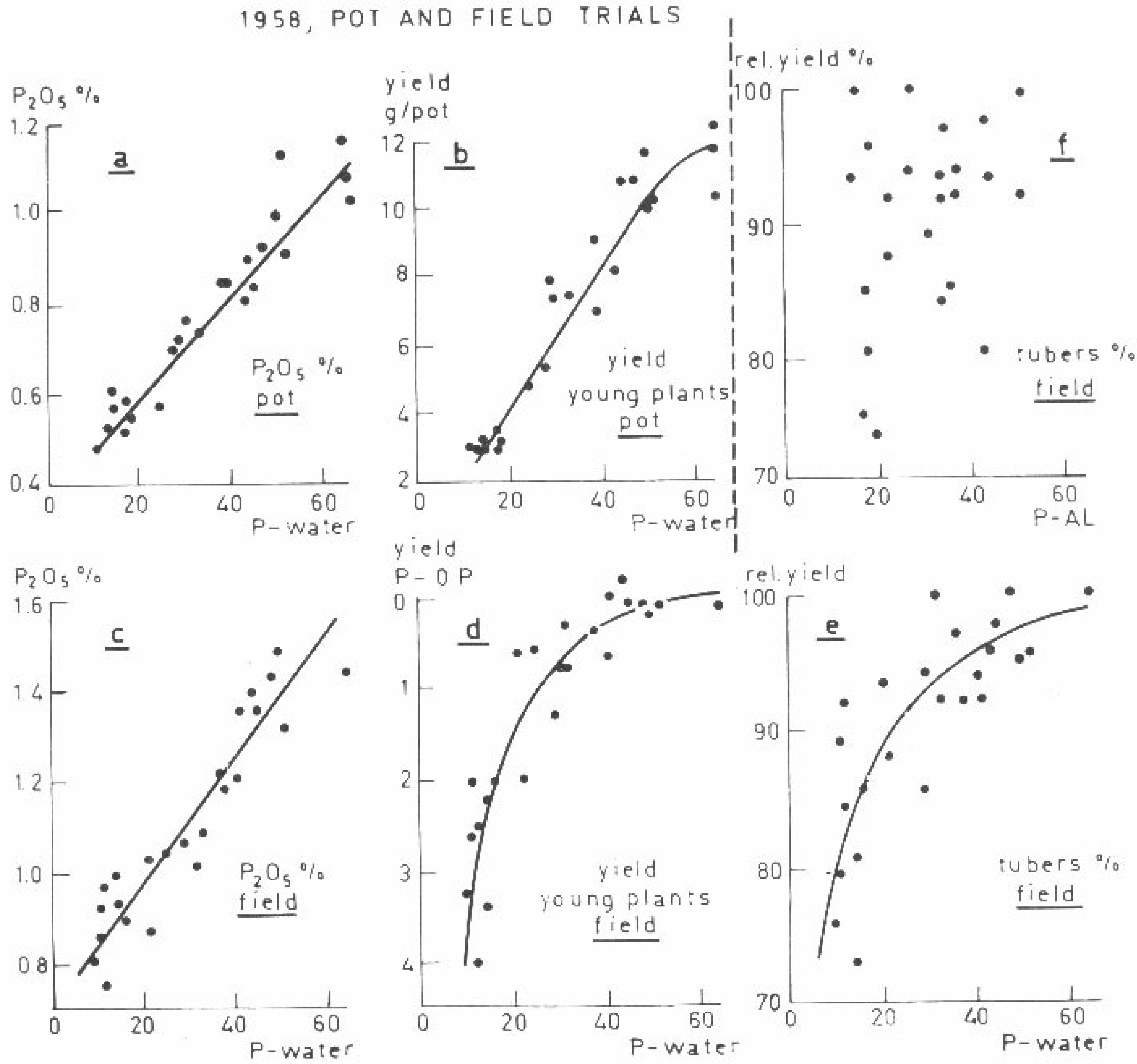


Fig. 3 1) Efficiency of Pw for extraction in pot trials as compared with field trials (1958): relationship with crop response (top: a. and b. in pots), bottom: c, d. and e. in the field; a. and c. P_2O_5 % of shoots, b. and d. yield response of young crop (b. weights, d. visual rating of yield differences relative to control plants; e. relative yield of potatoes (control in percentage of maximum).
2) Relationship between P water value (e) or P-AL value (f) and relative yield of potatoes in field trials.

In 1958 weather conditions were normal. In contrast, in 1960 when a similar comparison was made (including other soils), the weather was extreme in two respects. It was very dry till the end of June and very wet afterwards. This difference was reflected in the standard deviations of the yields per plot, amounting to 3.7% in 1958 as against 6.2% in 1960.

At an early stage of growth there was close agreement between the results obtained in pots and in the field as in the first year, correlations being only slightly lower. However, the correlation between Pw value and relative yields was considerably lower than in 1958. Again no correlation was found with P-AL (Figure 4). Apparently the efficiency of the Pw method in regard to the yield, and consequently the difference between both methods, was appreciably smaller than in the first year. What matters is that the Pw method still proved to be the better one, despite the inadequate conditions of the experiment.

7. CORRELATION WITH Pw METHOD IN POT TRIALS

It is of great interest that the correlation between the Pw method and the plant response in the pot trials was so high that it approximated to the ideal. Apparently the considerable differences existing between the soils had little or no effect on the relationship.

The question arose whether similar results would be obtained when soils differing more than those of merely Dutch origin are used. For this reason a pot experiment was started with wheat grown on 75 soils of different origin, comprising Western Europe, the USA and Australia. Similar results were obtained as before (Figure 5).

It will be clear that the relationship between Pw value and crop response under the conditions of a pot trial is not seriously affected by the kind of soil and all soil factors related to this difference (such as pH, $CaCO_3$, humus and clay content). Clearly a statement of general validity has been made.

Probably the inconstancy of weather is especially responsible for the larger variability of plant responses in the field. A closer relationship between soil test values and crop yields is plausible wherever the climate is less variable than in western Europe.

The very high correlation between the Pw value and crop response in pots may suggest that the rate of a real growth controlling factor is approximately determined by the Pw method. This factor may correspond to part of the fraction of mobile phosphate which is actually available. In this connection Dr. Sissingh emphasizes that water extraction is a simple physical procedure, leaving the soil phosphate in its original mobility status and not affecting the chemical constitution of the soil in any appreciable way, as soil <u>in situ</u> is already in equilibrium with water. Contrarily, chemical treatments cause the dissolution of soil components which may strongly affect the mobility of soil P.

8. POSSIBLE APPLICATION OF Pw METHOD ELSEWHERE

The main interest in the Pw method for use elsewhere lies in that it might be looked upon as a usable standard for testing the properties of other methods.

It is more dubious whether a direct use in tropical countries can be advocated. An indication for this was given by experience in Brazil, which is

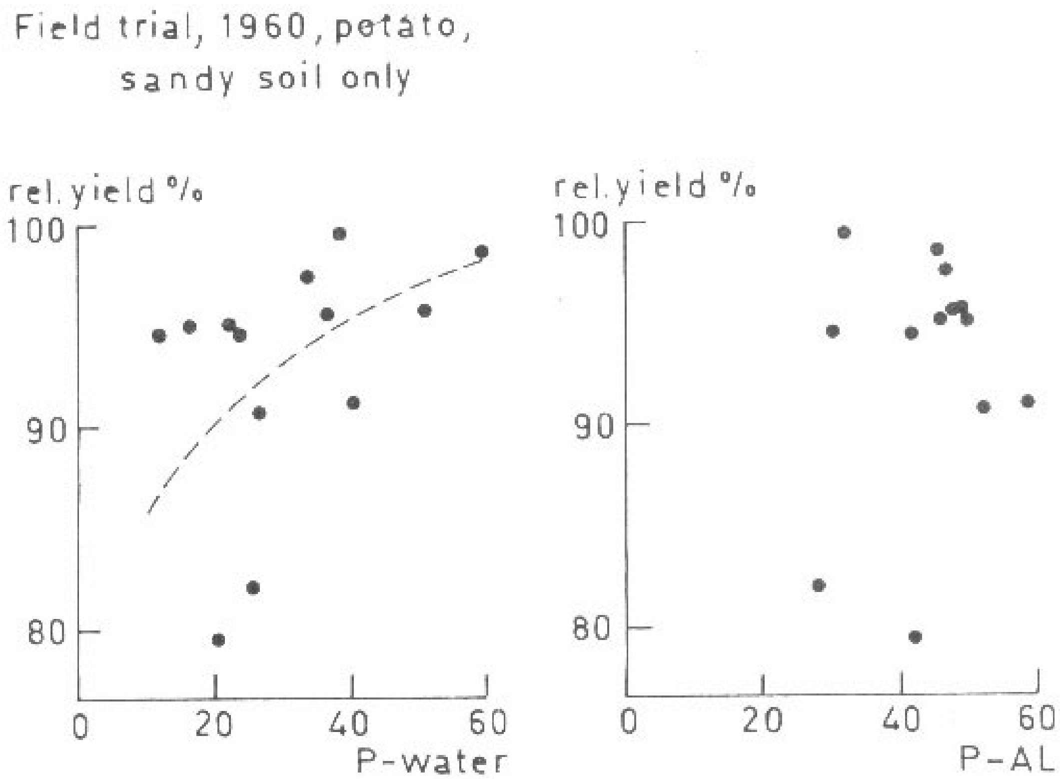


Fig. 4 Pw value as compared with P-AL value in field trials with potatoes in a year of extreme meteorological conditions (1960). Correlations with P water value are lower than in the normal year 1958 (figure 3 e and f)

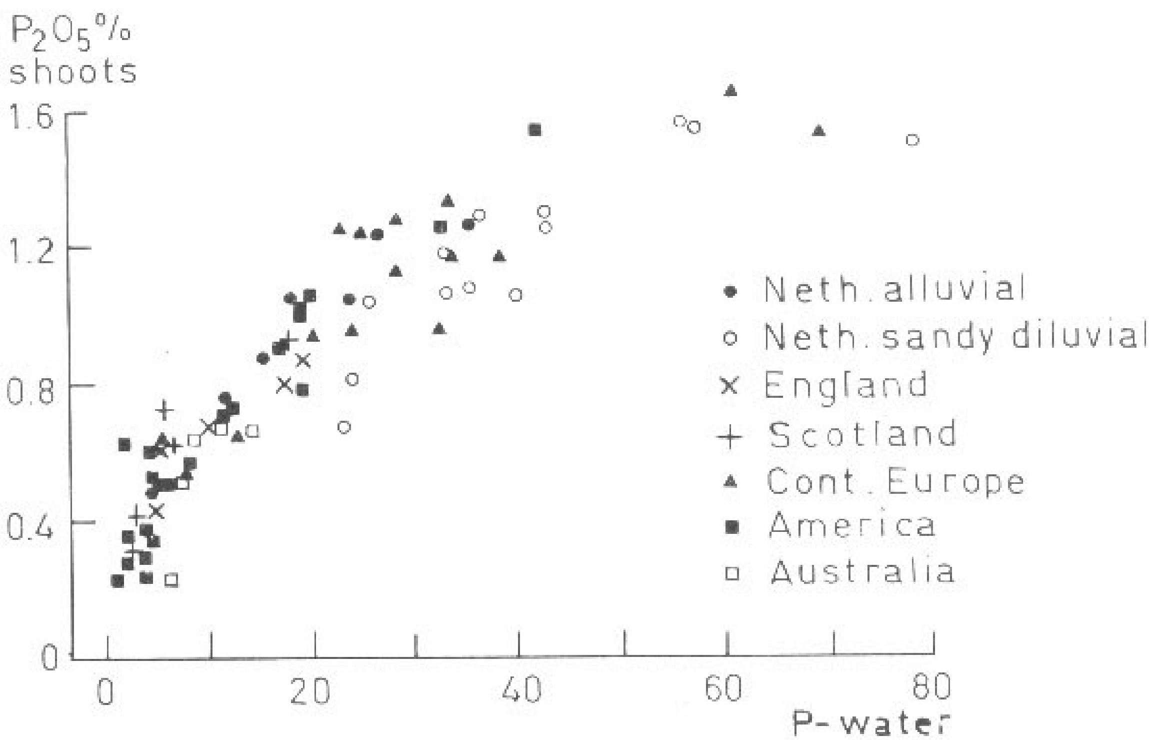


Fig. 5 Relationship between Pw value of soils collected from different parts of the world and percentage P_2O_5 in wheat foliage grown in a pot trial in Holland

illustrated in Figure 6. The high correlation found between Pw value of five rather different oxisols and P content of barley grown in pots looks promising. A difficulty encountered in tropical soils is that Pw values often appear to be low which may hinder an accurate estimation. An adaptation of the method by raising the temperature of the extraction (20°) to a more adequate constant temperature for the region in question might be considered.

Another point of interest is whether results of pot and field experiments performed in the tropics will show a similar agreement as in a moderate climate. In this respect, experience obtained with soil testing methods on grassland may be very instructive. The behaviour of grass species grown in pots is similar to that of arable crops: both show the same preference for the Pw method in predicting P responses. As mentioned before, quite different results with grass were obtained in field trials. Grass responded much more closely to methods with weakly acid extractions. Possibly this difference is due to a much more intensive P absorption from grass densely rooting in a thin superficial soil layer. This experience implies a warning that <u>a priori</u> judgements are dangerous in these problems.

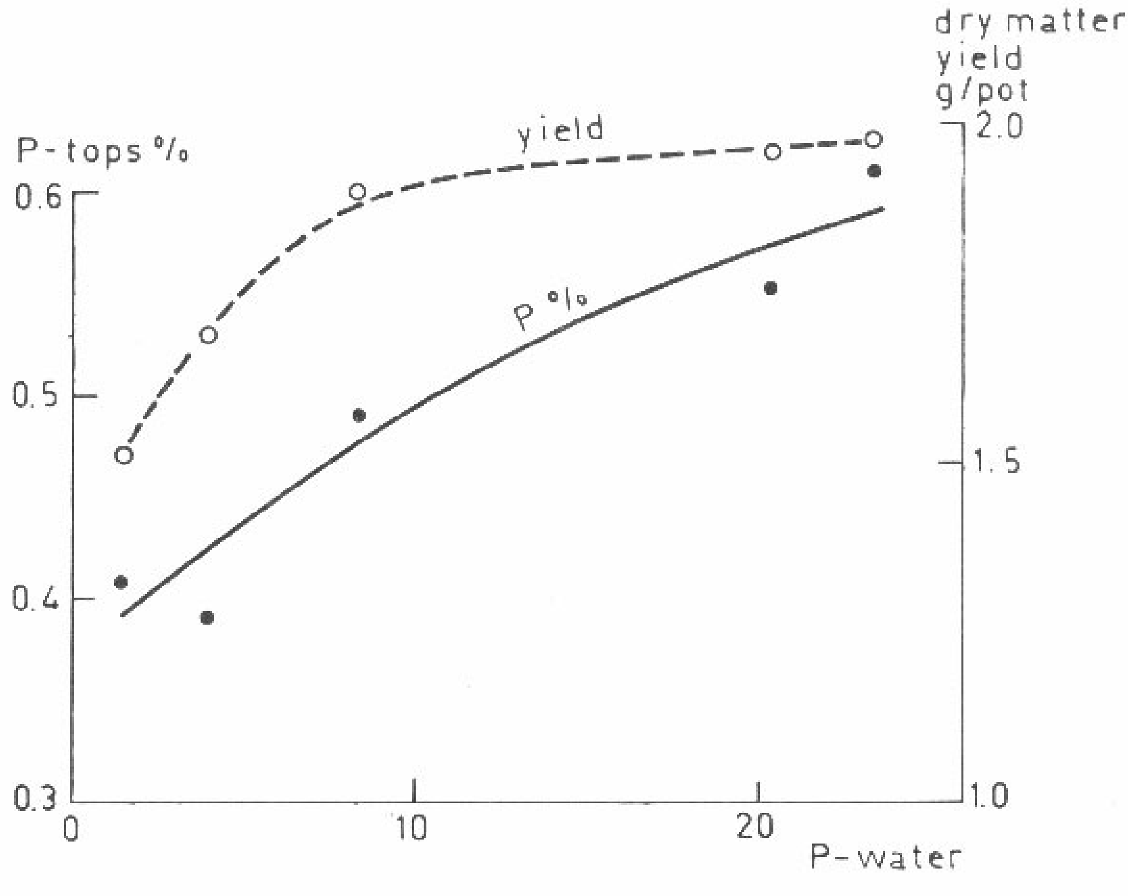


Fig. 6 Relationship between Pw value of some soils from Rio Grande do Sul, Brazil and percentage P_2O_5 in barley foliage and dry matter yield in a pot trial performed in Santa Maria R.S

9. DESIGNING OF NEW SOIL TESTING METHODS

Perhaps the most intriguing result of our investigations has been the designing of a soil testing method which proved to be highly adequate to characterize the availability of soil phosphorus. As the need for similar highly qualified methods may also arise in the tropics, it is of interest to know how this result was achieved. In this procedure an important place was reserved for the method of soil test evaluation.

Apart from weakly acid solvents, warm water was also used in Holland some years ago. In some cases reliable results were obtained. A main objection to the water extraction, however, was that most data obtained with different soils were not comparable. As it was found that these differences could be changed by modifying the method, it became desirable to look for a procedure fully devoid of this drawback. The preference for water was further strongly stimulated by a study of Sissingh on soil phosphate availability. From a comparison of isotopically exchangeable soil phosphate as determined in pot experiments (L value) and in acqueous soil suspension (E value) it was concluded that extraction with water does not affect the mobility of the soil phosphate in humid soil.

The method of water extraction was systematically varied in respect to water/soil ratio, duration of extraction, temperature etc; also, the effect of premoistening of the dried soil samples was systematically tried. An intensive evaluation of all variants of the water extraction method guided the procedure. For this purpose a pot trial was performed with 88 different soils, also widely differing in P status. Soil test data obtained with the different variants of the extraction methods were successively tested against the P contents of young potato shoots grown in the pots. In this way the method was improved step by step. It appeared to be possible to eliminate all possible influences of different soil type and soil features. The most fitting variant was then tested independently by means of pot and field trials.

10. CALIBRATION OF SOIL TEST METHODS IN TERMS OF FERTILIZER RATES

A last step to be made is the calibration of a soil test method and the drawing up of a fertilizing scheme. For this purpose complete field trials carried out in sufficient numbers in series are needed. They have to be performed under the conditions of practical farming at sites widely differing in P status of the soil.

The ratio between cost of fertilizer applied and estimated profits at different rates of fertilizer is decisive for the estimation of the rate that is still profitable.

Some examples of the procedure and schemes used for fertilizer recommendation in Holland, classified in groups of crops of different requirement, were given in a lecture in Vatican City. Figures were derived from a certain ratio between cost of fertilizer and value of yield increase expressed in terms of money. Such an assumption is permissible if more or less stable price ratios can be assumed. However, much more attention has to be paid to the price ratio in framing fertilizer recommendations in developing countries.

In Holland 172 short term field trials with potatoes carried out in six different years and on different soils have given the basis for the recommendation scheme. The average relationship between fertilizer rate and yield increase found may elucidate the significance of the price ratio (Figure 7). The relation between P dressing and yield increase, presented as averages from six different groups of Pw values, is given.

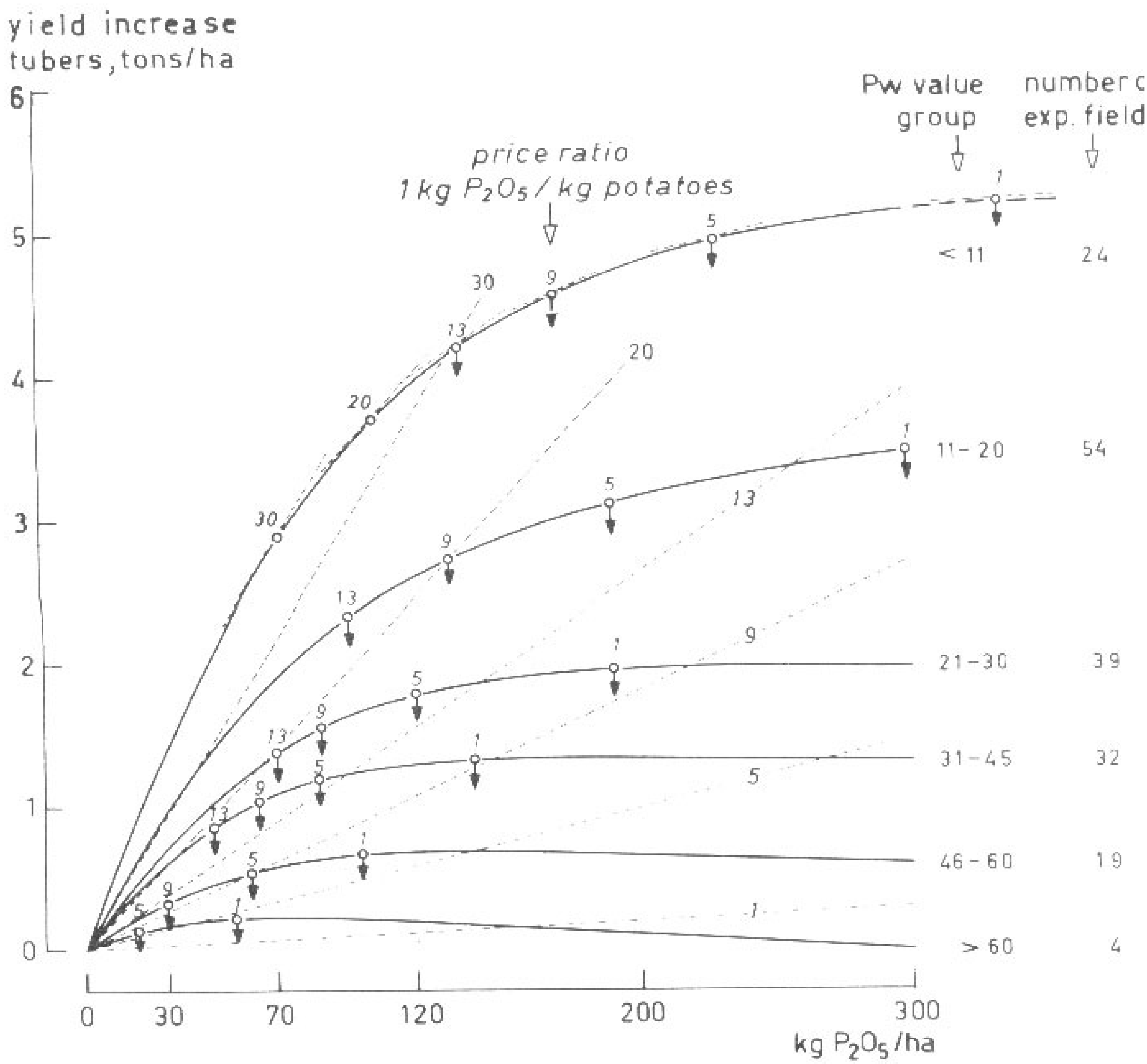


Fig. 7 Relationship between P dressing and yield increase of potatoes as represented by the average of 6 different Pw value groups (solid curves). Different price ratios (1 kg P_2O_5/1 kg potatoes) ranging from 1:1 to 30:1 are indicated by 7 dotted lines. Points of tangency of each curve with straight lines indicate optimum amount of P fertilizer at different price ratios (arrows)

The yield curves have been obtained by averaging the purely empirical curves found in the field trials belonging to each group. The curves are characterized by a quite regular shape and are also normally in harmony with the P status of the groups.

The increase in the cost of fertilization, at different prices of fertilizer (P_2O_5 per kg) (1, 5, 9, 13, 20 and 30 times the price of 1 kg of potatoes respectively) is represented by straight dotted lines. The tangent points of each curve with these lines representing the direction (angle of intersection with abscissa) of the various fertilizer cost lines, indicate the economically optimum amount of P fertilizer (see arrows with numbers indicating the ratio). It appears that the higher the price ratio, that is to say the more expensive the fertilizer relative to crop, the lower the rate of profitable P dressing. A relatively high price ratio might frequently be a characteristic in developing countries.

A result having such a high standard might hardly be attainable under the more difficult conditions of field experimentation in developing countries. Although a lower degree of perfection is permissible, a certain insight into these relations must necessarily be pursued. Its realization must be left to the inventive ability of agronomists and advisory workers in this field.

11. CONCLUSIONS

1. The applicability of soil testing is dubious in those regions where the fertility level of the large majority of sites in respect to the factor concerned (in this instance P) is uniformly low (or high). In such a case a soil test evaluation cannot be realized.

2. The introduction of a soil testing system is very laborious. However, simplifications of the work may be possible.

3. The applicability and evaluation of soil testing methods are favoured by more stable climatic conditions.

4. Economic and purely scientific aspects of soil test evaluation have to be separated. This view may allow for a more simplified scientific appraoch.

5. The fulfillment of special experimental conditions in field trials is a necessary condition for a successful evaluation of soil testing methods:

   a. sites have to be preselected in such a way that a wide range of P values, regularly distributed over the whole range, is realized;

   b. use of a highly sensitive test crop responding to differences in P nutrition as measured by physiological standards;

   c. use of an effective P fertilizer free from secondary effects;

   d. when methods are to be compared, the correlations between the P values estimated by means of these methods should be as low as possible (by means of a preselection of sites).

6. Trials of one year duration repeated in a similar way in following years are to be preferred to long-term trials. The need of repeating the trials will be less if the climatic conditions are more stable.

7. The introduction of 'spot' and pot trials simplifies soil test evaluation.

8. Conclusions drawn from pot experiments have to be verified in the field.

9. The P water extraction method (according to Van der Paauw - Sissingh) has a scientific foundation.

10. The preference for water extraction in comparison to weakly acid extractions (in a moderate climate) appears to be restricted to arable crops.

11. The very high correlation between P water values and crop response, after some disturbing factors have been eliminated (in pot trials), appears to indicate that an essential rate controlling factor is assessed by the Pw method.

12. A possible applicability of the P water method under tropical conditions should be considered. Adaptations of the original method for use in the tropics might be desirable.

13. The designing of the P water method was characterized in part by using the method of soil testing evaluation. A similar procedure might be followed when other new methods have to be developed.

14. Complete field trials including different rates of P dressing are wanted for the economic interpretation of results. The ratio costs of 1 kg P_2O_5/estimated price of 1 kg product (yield increase due to P fertilization) is of special interest for the recommendation of fertilizer rates.

15. A shortcoming of probably most soil test methods is that very often systematical errors are introduced.

Paper 18 ECOLOGICAL AND AGRONOMIC INFORMATION REQUIRED IN SOIL TESTING INTERPRETATION

by

K. Shaw
Agricultural Development and Advisory Service
Newcastle upon Tyne, England

1. INTRODUCTION

It is not possible to operate a soil analysis advisory service in isolation. Agronomic and in some areas ecological factors are so important that they must always be taken into consideration before fertilizer recommendations are made from soil analysis results. In a country such as the United Kingdom (UK) where agriculture is well developed over most of the land, the ecological implication of soil analysis interpretation is of minor importance. For instance in hill and afforested areas soil analysis will identify soil nutrient deficiencies, but it is unlikely that these will be of much significance or value under the established ecological environment of those areas. It is only when land improvement is intended which changes the ecology completely that soil analysis becomes of value. However, agronomic factors affect nearly every fertilizer recommendation which is made from soil analytical results. This paper presents some of the more important information which we consider necessary for effective interpretation of soil analysis in the UK.

2. ORGANIZATION OF THE SOIL ANALYTICAL ADVISORY SERVICE

England and Wales have one unified Government-sponsored and financed "Agricultural Development and Advisory Service" (ADAS) serving the agricultural and horticultural community. Scotland and Northern Ireland also have such a service but theirs differs considerably from ADAS in organization and administration. This paper refers only to the agricultural advisory service of England and Wales.

ADAS provides advice to the farming community on all aspects of agriculture. The Soil Science Section is specifically concerned with advisory and research work in the broad field of the subject in agriculture and horticulture. By the use of soil and plant analysis it advises on all aspects of nutrition of the crops grown in the UK. The soil scientists also deal with many problems in soil physics such as soil structure and its relation to cultivations and drainage, in addition to pollution in and by agriculture, and land use potential assessment. One of the major sections of the Soil Science Department is field experimental work which is designed to determine the response of crops to major and minor nutrients, and is conducted extensively over a wide range of soil types and climate. From the results of this work it is possible to assess the optimum amounts of fertilizer to be used depending on the nutrient status of the soil as determined by chemical soil analysis.

The Soil Science Department is responsible for the daily organization of the soil advisory service: the Analytical Chemistry Department conducts the analytical work on all samples on behalf of the Soil Science Department. Usually soil samples are taken by the ADAS advisers in general agriculture or horticulture or by the farmer himself after professional instruction and submitted to the Soil Science Department together with a soil record card providing relevant agronomic and fertilizer use information. After analysis, which for most soils covers determination of pH, available phosphorus, potassium and magnesium, the results are classified into indices, and returned to the farmer with a small explanatory booklet. The local ADAS adviser also receives a copy of the soil report and if appropriate may discuss the analytical results and their implications with the farmer. Nutrient recommendations are tabulated in relation to the soil nutrient status (as indicated by soil P, K or Mg index) in the Ministry of Agriculture, Fisheries and Food (MAFF) Bulletin 209 "Fertilizer Recommendations", which is available throughout the UK. It will be noticed in the recommendation tables in this bulletin that the higher the soil nutrient status as indicated by higher P and K indices, the lower the fertilizer requirement. This bulletin is used by all ADAS advisers and many non-government organizations as a guide to fertilizer recommendations. The available nitrogen status of a soil cannot yet be determined satisfactorily by soil analysis in the UK. The most important factor affecting nitrogen requirement is the residual nitrogen from previous crops and the soil nitrogen status classified into an index system based on previous cropping and manuring, which is used throughout ADAS and is shown in Annex I to this paper.

Many problems in plant nutrition are examined in the Soil Science Department which necessitates the analysis of plant materials in conjunction with soil analysis. In many instances plant analysis is more informative than soil analysis in the diagnosis of crop or animal disorders, but wherever possible both plant and soil are tested in elucidating such problems.

3. AGRONOMIC FACTORS INFLUENCING SOIL ANALYSIS INTERPRETATION

The most obvious and important agronomic factor influencing soil analysis interpretation is the crop to be grown. All nutrient recommendations made by ADAS in England and Wales are dependent upon the crop and its management and adjustments in recommendations are based on these two agronomic factors. This is well exemplified in many of the tables in Bulletin 209 "Fertilizer Recommendations" where the system of management of a crop has altered its nutrient requirements. Another major modification is made according to the soil type on which the crop is to be grown and a further minor modification for a few crops due to climatic variations.

As already stated, the optimum amount of each plant nutrient required to produce the maximum economic yield is determined by field experiment with each crop on soils of different nutrient status. It is important to emphasize that it is essential to establish this relationship of crop response to nutrients in the environment in which the crop is normally grown before embarking on an extensive soil and fertilizer advisory service based on soil analysis. Over the last forty years there have been large numbers of such experiments conducted on all the main crops in the UK. Potatoes, sugar beet, forage crops, cereals, grassland for grazing and conservation, vegetables and fruit have all been extensively investigated and their responses to nutrients determined under as many different circumstances as possible. Although the extrapolation of field experimental results for the same crop growing in a contrasting environment of another area may seem an attractive short cut, the variations in climate, soil and management are often so great that the experimental results are not applicable elsewhere.

In ADAS three main differentiations are made for crop type, namely grassland, arable and horticultural crops. Each group is subdivided into individual crops and in many cases further divided by systems of management. This is particularly well exemplified in grassland where for instance grazing or conservation of herbage necessitates very different fertilizer applications.

4. SOME AGRONOMIC CONSIDERATIONS IN SOIL ANALYSIS INTERPRETATION

4.1 Grassland

As the soil under grass is disturbed only during reseeding or on transition to an arable cropping rotation the nutrients applied to the surface only move into the soil by the percolation of rain. Because phosphorus, potassium and magnesium move only slowly in soil the depth of soil sampling for grassland is obviously important in assessing its nutrient status. Experiments have shown that even a few years after application of these nutrients most of those applied are retained in the surface few centimetres. At present, in ADAS, soil samples are taken in grassland to a depth of 7.5 cm but there is some recent evidence to suggest that even this may be too deep.

Under modern intensive grassland farming systems, the question arises as to how often soil samples should be taken for analysis in order for the farmer to be certain that he is not depleting his soil of nutrients. Under extensive grassland farming the time between sampling is not critical, but under intensive systems where high levels of nutrients are applied and removed in the herbage it is recommended to monitor soil nutrient status every three years.

One of the major problems of interpretation of soil analysis for grassland manuring is that of "luxury" uptake of potassium by herbage. It is well known that grass will absorb far more potassium than is necessary for maximum dry matter production provided there is ample available potassium in the soil. Such a situation may be caused by natural weathering of soil minerals especially in heavy soils, accumulation of fertilizer residues or too much fertilizer in one application. Soil analysis can well predict the first two conditions and thus prevent aggravation of the situation by applying further potassium fertilizer. However, as grass so readily absorbs potassium the soil may soon become depleted under intensive conservation management. Again soil analysis is a good guide as to when a soil is approaching deficiency level and fertilizer applications can then be made to correct it. Excessive levels of potassium in herbage, as determined by plant analysis, should be avoided as magnesium uptake is depressed when a high soil K/Mg ratio is reached and stock consuming the herbage may suffer from "grass tetany" or hypomagnesaemia. Plant analysis can in some circumstances also be used for prediction of potassium requirements. For instance if herbage contains below 2.0% K, potassium fertilizer application is necessary before full production can be achieved. However, although tested, this prediction method has not yet been adopted nationally in ADAS.

Under extensive grazing systems only small amounts of potassium are removed from the soil and soil analysis usually demonstrates that little if any need be applied for several years.

The demands of grass for phosphorus are much less than for potassium and unless soil analysis shows a serious phosphorus deficiency (soil P index 0; Annex II to this paper) only small amounts of phosphorus fertilizer annually are necessary as a maintenance dressing. A convenient practice is to apply one large dressing of a phosphorus fertilizer which will be sufficient for three to four years under any system of grassland management. Unfortunately there are many insoluble phosphorus fertilizers throughout the world offered as long-term sources of phosphorus which are ineffective under soil conditions of high pH (above 6.0) or after recent lime applications.

In the UK small areas of certain soil types have the capacity to 'fix' phosphorus applied as fertilizers, which therefore precludes the use of a large single dressing. In these circumstances phosphorus fertilizer should be applied annually or for each crop. Such phosphorus 'fixing' soils are readily identified by analysis over a period of years when it is noticed that the available soil phosphorus remains low in spite of adequate regular applications of fertilizers.

The nitrogen status of a soil is rarely considered in nitrogen recommendations for grassland, although it is the major nutrient for increasing grassland production. In the UK, the yield of grass is directly proportional to the amount of nitrogen applied up to about 350–400 kg N/ha provided that other soil conditions are optimal.

In view of this relationship grass production can be controlled at any level within this range of nitrogen use, but as already stated it is essential to check by soil analysis periodically that other nutrients are not depleted in the soil under a high nitrogen, intensively stocked regime.

Several stock disorders are due to trace element deficiencies in the herbage consumed. Unfortunately soil analysis is not a good predictor of such troubles except for cobalt deficiency in sheep. In most trace element stock troubles, herbage analysis is a much more reliable guide, although this is not infallible.

4.2 Arable Crops

Soil analysis for both major and minor nutrients is probably of more direct value in arable crops than in grassland. Many field experiments have been conducted to determine the response to nutrients of a very wide range of arable crops. In the UK, potatoes, cereals and sugar beet have been investigated in such experiments for many years and correlations between crop response and nutrient application at different levels of phosphorus, potassium and magnesium in the soil have enabled soil analysis to become a very useful guide in the fertilizing of these crops. Many results could be quoted from these investigations, but the following table gives a typical example of the response in yield of sugar in sugar beet to applied phosphorus and potassium at different soil nutrient status levels.

Table 1 RESPONSE IN SUGAR YIELD OF SUGAR BEET TO P AND K AT DIFFERENT NUTRIENT STATUS LEVELS

Soil analysis	Response in sugar yield (kg/ha)	Optimum application of P_2O_5 or K_2O (kg/ha)
Soil phosphorus		for phosphorus
P Index 0	400	113
" " 1	252	70
" " 2	138	10
" " 3	63	Nil
Soil potassium		for potassium
K Index 0	526	314
" " 1	476	293
" " 2	276	187
" " 3	101	75

Source: Cooke (1960)

The response of beet to phosphorus and potassium applications decreased as the soil nutrient status rose. Thus the optimum dressing of both nutrients varied with the soil analysis value. The results quoted in this table are typical of many others obtained for different crops and form the basis of the tables of recommendations in Bulletin 209. For the large majority of soils, analysis provides a useful estimate of the 'available' reserves of phosphorus and potassium, although it is not completely reliable in all circumstances. This is particularly so when predicting crop response to fertilizers at high soil nutrient status levels. As responsive crops grown on soils rich in 'available' phosphorus and potassium sometimes give economic field increases with fertilizer, recommendations in ADAS include 'insurance' dressings of these nutrients for high value crops. For example, it is always recommended to apply some phosphorus and potassium fertilizers to potatoes no matter how high the soil phosphorus and potassium status.

It is well known that phosphorus and potassium do not readily move in soil so that for their most efficient use they should be placed as near as possible to the root system of plants. Often the most effective use is made of plant nutrients by placing the fertilizer in a band close to, but not in contact with, the seed when the crop is planted, i.e. fertilizer 'placement'. By this technique it is possible to use less fertilizer at any soil nutrient level which is a considerable financial saving. This technique is particularly applicable to potatoes and cereals. The following table shows the advantage of using fertilizer placement for potatoes.

Table 2 FERTILIZER PLACEMENT FOR POTATOES

Treatment	Yield of potato tubers (t/ha)
No fertilizer	16.0
Broadcast fertilizer*	
940 kg/ha	21.7
1880 kg/ha	25.8
'Placed' fertilizer	
940 kg/ha	24.2
1880 kg/ha	27.8

Source: Cooke (1960)

* Fertilizer analysis N:P:K, 7:3:8
($N:P_2O_5:K_2O$, 7:7:10.5)

This 'placement' technique is particularly effective at low soil nutrient status levels but is less so where the soil is very fertile.

One particularly important agronomic factor which has been well established by experiment and yet not accepted by many farmers is that the amount of nitrogen required for optimum sugar yield from beet is critical. Beyond this level the yield of sugar per hectare slowly decreases, although the beet plant itself increases in size. In the UK, on soils of low nitrogen status (soil N index 0), 100 kg N/ha is adequate for maximum sugar yield but unfortunately the average nitrogen use on beet is well above this at 156 kg N/ha, not all of which is applied on soils of low nitrogen status.

Cereals provide several examples of soil and agronomic interest. Experiments have shown that unless a soil is particularly deficient in phosphorous or potassium (soil P and K index 0) cereals show very little, if any, response to these elements applied as fertilizer. Therefore except in very deficient soils phosphorus and potassium fertilizers are applied only as maintenance dressings to prevent their depletion in the soil. Thus for long rotations of cereals all the phosphorus and potassium requirement for up to three or four years can be given in one single heavy dressing provided the soil is not deficient in these elements or that it does not have a high phosphorus 'fixing' capacity. If the soil is very high in phosphorus and potassium no fertilizer need be applied until soil analysis shows that the phosphorus and potassium status has fallen to normal levels.

Owing to the large effect of nitrogen on the growth of cereal crops it is particularly important to be able to estimate the correct amount to be applied under all circumstances of type of crop, variety, soil type, nitrogen residues, leaching and winter rainfall etc. Although soil scientists in ADAS have examined many chemical and biological laboratory methods for the determination of the nitrogen status of a soil in order to be able to predict a crop's nitrogen requirement, no satisfactory technique has yet been found. Because of this the soil nitrogen index system (see Appendix I) of assessment has to be used. After the nitrogen fertilizer recommendation has been determined from the tables in Bulletin 209, further modifications have to be made to allow for differences in cereal variety, soil type and winter rainfall.

Experiments have suggested that normal winter (October to March inclusive) rainfall over the UK, except in a few eastern counties, is sufficient to leach all residual mineral nitrogen to below the rooting zone of cereal crops and therefore no extra nitrogen fertilizer need be applied after a very wet winter. On the other hand, after a particularly dry winter more residual mineral nitrogen than usual will remain in the soil following crops such as potatoes and vegetables which have received large nitrogenous fertilizer dressings. Under such conditions it is recommended that nitrogen applications, especially to cereals, should be reduced. A very dry winter in the UK is defined as one in which the excess winter rainfall is less than 100 mm.

Much of the agriculture of the UK is devoted to stock and grassland farming and hence forage crops are important. Much field experimental work has been carried out on the fertilizer requirements of these crops on soils of varying nutrient status and soil analysis has proved to be a good guide to the use of fertilizers. Swedes are widely grown and respond well to large applications of phosphorus. These dressings can be reduced by as much as two thirds where soil analysis indicates an adequate soil phosphorus status. This type of reduction can also be made in phosphorus and potassium fertilizer dressings for kale, mangolds and fodder beet.

4.3 Horticultural Crops

Most of the vegetables consumed in the UK are home produced. In the past they were mainly grown in very fertile intensive systems with nutrients supplied by bulky organic manures with little inorganic fertilizer. Changes in method of production have taken place in recent years and nowadays many vegetables are grown extensively as farm crops on soils of lower nutrient status and receive virtually no organic manures but rely entirely on fertilizers for their nutrient supplies. Therefore, because the soils are of lower initial fertility, soil analysis is valuable in determining the soil nutrient status and subsequent fertilizer recommendations. Since many vegetables have a greater demand for nitrogen, phosphorus and potassium than most arable crops, it is even more important to determine by field experiments the optimum amounts of each element on soils of different nutrient status. Thus soil analysis can be a very useful guide in determining the precise amount of fertilizer to be used with consequent savings on soils with higher nutrient status. The principle of fertilizing soil to raise and maintain its nutrient status at a 'threshold' value is often propounded as the best way of ensuring consistently good yields of high value crops such as vegetables. Although this is attractive in theory, in practice there is considerable uncertainty about the levels at which to aim and they also depend on other unpredictable factors such as weather and rainfall. If the threshold values were very high, fertilizer may be wasted and nutrient residues may be leached, fixed or immobilized in the soil. Clearly the phosphorus and potassium should be maintained well above deficiency level but no higher than is required to ensure only a moderate response in the crop to further application of fertilizers.

A new approach to vegetable manuring has been proposed by Greenwood et al., (1974) for predicting the nutrient requirements on soils of different nutrient status. In their work, the responses of vegetable crops to nitrogen, phosphorus and potassium were defined and mathematical models developed to predict these responses. His predictions for phosphorus and potassium responses were in approximate agreement with the results from many other independent fertilizer experiments in the UK. This type of prediction is in its infancy and may eventually be wholly successful for a wide range of both horticultural and agricultural crops. Until then fertilizer predictions based on soil analysis will still need to be used.

4.4. Fruit Trees

Soil analysis of the top and subsoil in a mature orchard is a guide to the phosphorus, potassium and magnesium requirements of the trees. An even more accurate assessment of the availability of the nutrients to the trees is made by analysis of the concentrations of nutrients in the leaves. The latter improvement may be due mainly to the effect of the agronomic factor of the soil management system on the nutrient availability in the soil and also on the soil moisture status throughout the tree root range. For example the crop growing on the soil surface has a large effect on the nutrient availability to the trees; the type of cover crop or grass sward or the degree of soil disturbance by cultivations under fallow all have profound effects on the fertilizer requirements of the tree. In view of this situation very careful leaf sampling and analysis have now become standard practice in determining the nutrient requirements of fruit trees. Leaf analysis surveys in the UK have shown that average rates of fertilizer application in orchards could be reduced with potential advantages in fruit quality as well as economy.

4.5 Soil Analysis and Rotational Manuring

When soil analysis results indicate a satisfactory nutrient status it is possible with some crops to apply a large amount of fertilizer in the rotation once every three to four years without any detriment to crop yield. As already mentioned this rotational manuring is successfully practised with cereals in the UK where maintenance dressings of phosphorus and potassium are applied to soils at three times the recommended annual rate on soils with a satisfactory nutrient status (soil P or K index 1 or higher).

Similarly rotational applications of phosphorus fertilizers can be made to grassland where either grazing or conservation is practised. The normal dressing of about 88 kg P/ha (200 kg P_2O_5 per hectare) as insoluble phosphate in the form of basic slag has been a traditional means of building up and retaining a satisfactory soil phosphorus status over much of the grassland in the UK for about 100 years.

The principle of rotational manuring is not possible with all crops, especially those with high nutrient demands such as potatoes, sugar beet and vegetables. Nor is it possible to apply this idea to the use of nitrogen since there are practically no residues left from one year to the next even from large applications of nitrogenous fertilizer after a normal winter's rainfall over most of the UK.

4.6 Soil Nitrogen Residues

Much mineral nitrogen, mostly as nitrate, remains in the soil in autumn after harvesting of well manured crops such as potatoes and vegetables. Soil analysis shows that as much as 100 ppm of nitrate nitrogen may be present in the top soil in October after potatoes. This residue is not only from fertilizer nitrogen but also from the soil itself and from any organic manure which may have been used. Further analysis of the soil profile to 100 cm depth during the following winter suggests most of this nitrate is leached through the profile by rainfall. Calculations show that once the soil has reached field capacity only a further 100 mm of rain is necessary to remove nearly all the nitrate from the soil profile to the drains or subsurface water. Thus over an extensive water catchment area a very large amount of nitrate can be removed and analysis of drainage waters from such areas has shown increases in the nitrate content during mid and late winter. These findings are supported by the more accurate assessment of leaching in lysimeters by many workers throughout Europe. Not only is this leaching a serious loss of nitrogen from the soil and hence a financial loss to the farmer but it is also a possible source of nitrate contamination of drinking waters. At present we are very much aware of this situation in the UK, but so far have insufficient evidence to differentiate between the contribution from nitrogenous fertilizers and that from the soil itself in the contamination of drainage waters. Indications from early work suggest that the soil itself may be a major contributor.

5. OTHER AGRONOMIC ASPECTS OF SOIL ANALYSIS INTERPRETATION

5.1 Soil pH and Lime Requirement

Perhaps the oldest and most traditional analysis of soils is the pH determination and subsequent measurement of lime requirement. Although this is still the aspect of soil analysis in most demand by farmers, problems of underliming and overliming are continually brought to our notice as soil scientists in ADAS. There are few crops which can tolerate either too low or too high a soil pH and for some crops on certain soil types the pH range for optimum growth is very narrow. It is essential to determine the best soil pH value at which each crop grows and to aim at this level in making the lime recommendations. For instance in the UK, the modern varieties of barley grown on light sandy soils suffer from the effects of acidity at less than about pH 5.6 (water) and exhibit trace element deficiency symptoms above pH 6.6. Thus soil analysis is valuable in determining soil pH, especially for acid sensitive crops such as barley, sugar beet and some horticultural crops. Similarly some trace element deficiencies can be predicted, nearly with certainty, by knowledge of the soil type and soil pH.

In ADAS each soil analysis report contains a statement of soil pH (water) and if below pH 6.5 the lime requirement determination by a laboratory chemical method (modified Woodruff) is also given in tonnes per hectare of ground limestone.

5.2 Organic Manures

The farmer's attitude to the use of farm waste products and manures has changed completely since the days when agriculture relied upon them nearly entirely to provide the plant nutrients for all the farm's crops. The major problem now seems to be one of disposal rather than use. However, since the recent large increases in the cost of fertilizers in the UK more interest has been shown in using such manures as a substitute for the nutrients supplied by fertilizers. In ADAS from the chemical analysis of the manures in conjunction with results from field experiments to determine the availability of the nutrients, we make recommendations on the adjustments in fertilizer use which can be made when such manures are used. However, many farmers still seem reluctant to utilize this information and in practice rarely reduce their fertilizer applications when manures are also used. In some cases this is positively detrimental to crop yield and quality, as some crops, especially grassland used for conservation, receive nutrient applications greatly in excess of those recommended from soil analysis data.

5.3 Toxic Elements in Soil

Most soils contain insufficient amounts of phytotoxic elements to hinder plant growth. However, a few small areas of soil in the UK are contaminated by naturally occurring deposits of toxic heavy metals such as copper, zinc and lead which cause stunted growth of crops, grass and sometimes stock. Other soils have been polluted by man with industrial wastes or sewage sludge and as a result contain excessive amounts of heavy metals and other toxic compounds. It is essential to use soil analysis to determine the extent and intensity of such pollution before recommendations are made on which crops (if any) can be grown on these soils. Chemical analysis of sewage sludge before application is the obvious means of preventing future soil contamination and in the UK soil scientists are constantly emphasizing the importance of such analysis before using sewage on land. Once soils are contaminated, either naturally or artificially, the effects last for many years, during which time crops either fail completely or become uneconomic to grow.

5.4 Soil Organic Matter

Under continuous arable cropping systems soil organic matter slowly decomposes and unless action is taken to maintain or increase soil organic matter its level may be reduced so much as to allow serious soil structure deterioration. Once this stage is reached at which soil management becomes very restricted or crop growth seriously affected, it is both difficult and expensive to restore the organic matter to a satisfactory level. Very heavy application of bulky organic manures for many years is rarely possible and a complete change of farming system to grassland may not be suitable or even agronomically possible. Soil analysis is an excellent guide to the soil organic matter content and should be used in conjunction with various physical soil determinations where soil structure problems occur.

6. SUMMARY

The successful interpretation of soil analytical results depends on very many factors which the soil scientist takes into consideration before making fertilizer recommendations to the farmer.

The obvious essential agronomic information required is that of the crop for which recommendations are to be made. It is important that all the agronomic characteristics of each crop are known and it is essential that its nutrient demands are determined from scientifically conducted field experiments. For any new or unknown crop this is the first necessity before effective use of analysis for soil nutrient status can be made. If this information is not available insufficient or excessive fertilizer application may well occur.

In addition to the determination of soil nutrient content for the prediction of fertilizer applications to crops, soil analysis is a valuable tool in assessing other factors which affect crop growth. Soil pH and lime requirement, evaluation of organic manures, determination of soil organic matter and soil physical measurements, and assessment of levels of toxic elements in soils and soil amendments are amongst many examples where soil analysis provides vital information in giving the best advice to farmers.

REFERENCES

COOKE, G.W. Fertilizers and Profitable Farming. Crosby Lockwood.
1960

GREENWOOD, D.J., CLEAVER, T.J. and TURNER, M.K. Fertilizer requirements of vegetable
1974 crops. Proceedings No. 145, The Fertilizer Society.

ANNEX I - SOIL NITROGEN INDEX

1. Soil Nitrogen Index assessment is based on past cropping and manuring.

2. In a large number of cases it is only necessary to consider the last crop grown to determine the Nitrogen Index. However after crops of lucerne, long leys and good quality permanent pasture, which leave long lasting residues, it is necessary to consider cropping histories greater than one year.

3. The values in the following tables are calculated for average conditions and do not attempt to cover all situations.

Use of the tables

a. If lucerne, long leys (3 or more years) or permanent pasture have NOT featured in the last 5 years cropping, use Table A only.

b. If the last crop was lucerne, a long ley or permanent pasture use Table B only.

c. If one of the crops in item b. has been grown in the last 5 years, but was not the last crop, look up the values from both Tables A and B. The higher of the two values is the Nitrogen Index.

Table A — NITROGEN INDEX BASED ON LAST CROP GROWN

Last Crop	Nitrogen Index
All crops receiving FYM 1/ or slurry	1
All crops receiving large frequent dressing of FYM or slurry	2
Beans	1
Cereals	0
Forage crops removed	0
Forage crops grazed	1
Leys (1 - 2 year) conserved	0
Leys (1 - 2 year) grazed, low N 2/	0
Leys (1 - 2 year) grazed, high N 3/	1
Maize	0
Oil seed rape	1
Peas	1
Potatoes	1
Sugar beet, tops ploughed in	1
Sugar beet, tops removed	0
Vegetables, recieving less than 200 kg N/ha	0
Vegetables, receiving more than 200 kg N/ha	1

1/ FYM Farm Yard Manure
2/ Low N = less than 250 kg N/ha per year or low clover content
3/ High N = more than 250 kg N/ha per year or high clover content

Table B

NITROGEN INDEX
BASED ON PAST CROPPING WITH LUCERNE, LONG LEYS AND PERMANENT PASTURE

Crop	Years since "ploughing out" 0	1	2	3	4	5
	Nitrogen Index					
Lucerne	2	2	1	0	0	0
Long leys, receiving low N 1/	1	1	0	0	0	0
Long leys, receiving high N 2/	2	2	1	0	0	0
Permanent pasture, poor quality, matted	0	0	0	0	0	0
Permanent pasture, average quality	2	2	1	1	0	0
Permanent pasture, high N 2/	2	2	2	1	1	0

1/ Low N = less than 250 kg N/ha per year or low clover content
2/ High N = more than 250 kg N/ha per year or high clover content

Example of use

A long ley with a high clover content ploughed out one year ago was followed by peas, i.e. the last crop was peas. The value from Table A is Index 1 but from Table B is Index 2. The higher of the two values is 2 and is therefore the Nitrogen Index of that soil.

ANNEX II

Table C

NATIONAL SOIL ANALYSIS CLASSIFICATION
PHOSPHORUS, POTASSIUM, MAGNESIUM, CONDUCTIVITY AND NITRATE INDICES

INDEX	PHOSPHORUS (mg/l in soil)	POTASSIUM (mg/l in soil)	MAGNESIUM (mg/l in soil)	CONDUCTIVITY (micromhos)	NITRATE-N (mg/l in soil)	INDEX
0	0–9	0–60	0–25	1900–2200	0–25	0
1	10–15	61–120	26–50	2210–2400	26–50	1
2	16–25	121–240	51–100	2410–2600	51–100	2
3	26–45	245–400	101–175	2610–2800	101–150	3
4	46–70	405–600	176–250	2810–3000	151–250	4
5	71–100	605–900	255–350	3010–3300	over 250	5
6	101–140	905–1500	355–600	3310–3500		6
7	141–200	1510–2400	610–1000	3510–3700		7
8	205–280	2410–3600	1010–1500	3710–4000		8
9	over 280	over 3600	over 1500	4010 and over		9
Extract-ant	Sodium bicarbonate (Olsen's, pH 8.5)	M-Ammonium nitrate	M-Ammonium nitrate	Sat'd $CaSO_4$	Sat'd $CaSO_4$	

Sources: Soil Science Department. Ministry of Agriculture, Fisheries and Food
Agricultural Development and Advisory Service for England and Wales

Paper 19 POSSIBLE USE OF A COMPUTER FOR RECORDING AND PROCESSING SOIL ANALYSIS DATA

by

J.C. Remy
Station Agronomique de Laon, Rue Farnand Christ 02011 Laon, France.

1. INTRODUCTION

The agronomist is confronted by complex problems often involving a large quantity of data with which he must deal to make a judgement or a diagnosis. It is well known that man can only manipulate simultaneously five or six concepts to formulate an opinion, and it is therefore, necessary to have recourse to a machine to carry out rigorously and tirelessly a repetitive and uninteresting task. As in agronomy, the computer can help the doctor in his management of medical records, in his diagnosis and in building up and using data banks (Figure 1). This similarity is found in the collection of information, in methodology and in results, and also in the material and psychological difficulties encountered in application.

An attempt will be made in this paper to demonstrate the possibilities of using a computer in the field of agronomy. The paper discusses the different applications in soil analysis by showing the results obtained and the difficulties to be overcome.

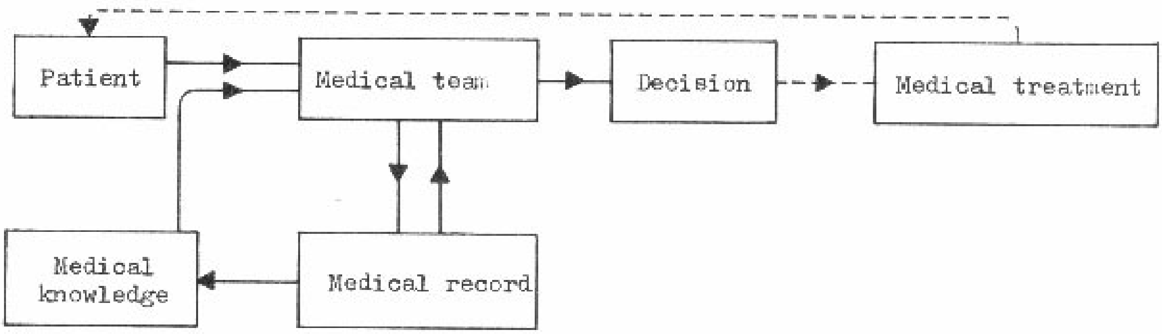


Fig. 1 Circulation of medical information (according to F.G. Remy, 1976).

2. USE OF THE COMPUTER IN THE LABORATORY

To improve productivity and to lower the cost of analysis, the computer can be a valuable help in the following tasks:

i. management of information; preparation of the plan of work generally, weekly checking, sorting and listing of results;

ii. collection of data from the different analyses. Each analogue output has to be converted into digital form, identified and stored;

iii. control of automatic analytical systems, whether sequential or continuous flow.

The different elements necessary for the elaboration of an integrated laboratory can be combined ad infinitum. Clearly, only part of the operations can be carried out by the computer. Moreover, the user has the choice between:

a. the on-line system with continuous supervision of the system and built in safeguards in case of power failures. This system has the drawback of allowing but little manual intervention. Formerly it was little used because of the high cost since it permanently immobilized a computer. The advent of micro-processing has allowed for diversification of the central computer, reducing supervision to a strict minimum : micro-processor - clock - keyboard with visual display - floppy disc facilities - entries/ exits -

b. the off-line system frees the computer for other tasks, the information being stored in a support bank using punched cards, perforated tape, mini-cassettes, magnetic tapes or floppy discs. Processing is then carried out later when all the necessary information is available. The speed of reading varies between 10 characters per second (teletype) to 30 000 characters per second (floppy disc).

The collection of data supposes that each analysis leads to analogical output. All analyses ending in a molecular or atomic spectroscopy provide a current. On the other hand, the determination of the lime content or of the size of soil particles, for example by the Bouyoucous method, necessitates manual intervention. Some information can however be taken into account by a keyboard.

The cost of such a system, exclusive of the analysers, can be from \$10 000 to 30 000. The main drawback to processing in the laboratory is the vulnerability of the equipment. As the correct functioning of a unit requires each component to be faultless, the standard of maintenance is an essential factor in the use of systems with a high level of integration. It is difficult to envisage their installation without qualified individuals being at hand.

3. ASSISTANCE IN AGRONOMIC DATA PROCESSING

The establishment of sources of regional information necessitates the use of results obtained in the field.

3.1 Data from Classic Experiments

These experiments may be monofactorial or multifactorial, but in general it is convenient to limit them to three or four factors at one or more localities. To explain the mechanism, a single closely-supervised experiment is used. On the other hand, to obtain generalized information on one technique it is necessary to have recourse to a series of experiments (from 3 to more than 100). To obtain a good estimate of the residual variance it is necessary to be able to collect about 30 points of observation. The replications can sometimes be taken into consideration.

3.2 Data from Farm Surveys

If the experimentation allows the prior definition of a control area, the enquiry must be preceded by the choice of a sampling method and selection of the procedure for interpretation of the results.

Consequently it remains closer to agricultural practice and provides an excellent means of understanding the system being studied. On the other hand, it rarely provides the estimated values or descriptions of mechanisms. In certain cases, however, one can separate the predicted material from the actual findings.

3.3 Data Processing

The main processes of present day data processing are:

i. variance analysis which presupposes the choice of a model which can be tested along classic statistical lines. The interpretation of the results is in general precise and quite easy, but conditions affecting the validity of the test must be observed.

ii. the adjustment proceeds in the same manner although a certain flexibility can be allowed thanks to :

a. a progressive adjustment : step by step, by elimination, by arbitrary choice or by a combination of procedures. The results have often been discussed (Cady and Fuller, 1970; Cady and Allen, 1970; Laird and Cady, 1969). All generally agree that it is necessary to proceed along two lines : free choice first of all, then reasoned choice according to the existing agricultural knowledge of the subject. In general the equations obtained have an explanatory power almost identical to the free choice procedure, but, above all, they are often more comprehensible to the expert.

b. the utilization of quadratic terms and of interactions; e.g. :

$$\hat{Y} = b_o + b_1N + b_2N^2 + b_3P + b_4P^2 + b_5K + b_6K^2 + B_7NP + b_8NK + b_9PK$$

The models are in general limited to interactions of the first order. Wherever possible, if the interactions carry no supplementary explanation in relation to the quadratic model, it is better to retain the latter as being easier to interpret particularly when seeking the optimum.

c. changing the variables. It permits curve fitting by means of linear combination of functions chosen :

$$\hat{Y} = b_o + b_1f_1(X_1) + b_2f_2(X_2) + \ldots\ldots$$

The main inconvenience is to carry the variable weight of the different observations according to the value of X_1 or X_2. A correction can be applied by the use of a different weight with each observation. The most typical case is that of exponentials.

d. non-linear adjustments. Nowadays algorithms permit an adjustment of the least square by successive iterations. The chosen equation is such that only the parameters are selected by the procedure. If the initial parameters are totally unknown there is a high risk of finding a false solution with a minimum relationship to the sum of the squared deviations.

A classic use of these methods of regression is the optimization of the response curves obtained by experimentation, an example of which will be given later.

Multi-variate data analysis consists of describing the structure of a numerical table. When it concerns measurements one would generally turn to principal component analysis. In frequency tables the analysis of "correspondences" can be applied. This last method has the advantage of treating in a symmetrical manner the data matrix, and of allowing without difficulty a mixture of qualitative and quantitative variables after dividing the frequencies into classes.

These techniques are very interesting when it comes to studying little known populations, or when the number of observations is very large. On the other hand, they are often misleading in well-studied scientific areas where the mechanisms are partly known. In association with the study these methods are of great help in developing countries, as much in the psychological sphere as in that of the results.

In summary, the computer is a great help in registering and handling the treatment of information. It allows the systematic collection of information and an improvement in its quality, because it insists upon a greater accuracy in the level of codification. It also enables the key variables to be determined while allowing the simultaneous retention of variables strongly correlated to the preceding ones but which add little supplementary information or which are difficult to measure.

4. SOME PRELIMINARIES TO PROGRAMMING

The old laws of fertilization (law of diminishing returns law of the minimum and law of restitutions) can be expressed today by optimization of the application of nutrients and respect of the balance in a steady state.

The optimization of nutrient application supposes knowledge of the response curves which can be established by following the procedures described above. To take an example we will draw conclusions from an experiment quoted by BOSC (1977) by a linear adjustment according to Mitscherlich :

$$L_n = (1 - \frac{Y}{Y_o}) = a + bR + cP$$

where Y = yield

Y_o = maximum yield (56 q/ha)

R = fertility of the soil (ppm P_2O_5 Joret-Hébert)

P = amount of phosphate fertilizer.

whether it is :

$$Y = 56[1 - 0.484 \exp(-0.00885\ (1.08\ R + P))]$$

and : $$\frac{dY}{dP} = 0.24 \exp\ (-0.00885\ (1.08\ R + P))$$

If S is the relationship between the cost per kilogramme of phosphoric acid and the price of 100 kg of wheat the optimum is obtained by :

$$P = 113\ L_n\ (0.24\ /\ S) - 1.08\ R$$

With the chosen model, the optima according to the soil fertility are found on a horizontal line for the same value of S. Figure 2 shows the straight lines (a), (b) and (c) corresponding to the relationships 0.020, 0.030 and 0.040 respectively, representing costs of 24, 36 and 48 cents per kilogramme for P_2O_5 and a wheat price of $12 per 100 kg.

The maintenance fertilization rate corresponds to the amount of applied nutrient which is necessary to maintain the available reserves at a constant level. Clearly, it differs according to the level of maintenance as well as to the level of fertility or productivity. For example, Figure 2 represents (curve E) the quantity of P_2O_5 necessary to provide for the different levels of maintenance:

$$E = \underbrace{Y}_{\text{yield}} \cdot \underbrace{(0.015\,Y + 0.175)}_{P_2O_5\ \text{content}} \cdot \underbrace{1.2}_{\text{coefficient of increase}}$$

It may perhaps be necessary to increase the applications to take into account specific losses (leaching or irreversible fixation). The correct level of maintenance corresponds to the intersection of the lines (a), (b) or (c) and the curve E. The response curve passing through this point is that corresponding to the "satisfactory" fertility level. For example, if one takes $b \cap E$ one obtains $R = 161$ ppm. Other relationships are shown in Table 1.

Table 1 OPTIMUM YIELDS AND NUTRIENT RATES AS A FUNCTION OF FERTILIZER/PRODUCT PRICE RATIO

Price ratio S	Optimum yield Y (q/ha)	Optimum fertilizer P (kg P_2O_5/ha)	Optimum available P_2O_5 R (ppm)
0.020	53.7	63.5	201
0.030	52.6	61.1	161
0.040	51.5	58.8	133

The optimum level can vary between broad limits according to the economic conditions. The response curves can also vary according to the type of soil and crop. It is therefore not surprising that references to optimum fertility levels should tend to differ.

The correction fertilization rate can be defined as the difference between the optimum fertilization and the maintenance fertilization. It will be positive if the optimum is to the right of curve E or negative if it is to the left as in the case of "over-fertile" soils. In general, the supplement will tend to enrich the soil and to diminish the level of maintenance (Figure 3). The ideal would be to reduce the corrective fertilization by half every 3 years.

5. DIAGNOSIS

For diagnosis it is enough to compare the criteria to one reference system. The criteria can be a qualitative estimation, a measurement, an index, or a combination of criteria.

The number of classes chosen can vary from 3 to 10. Seven are generally used and are defined as follows:

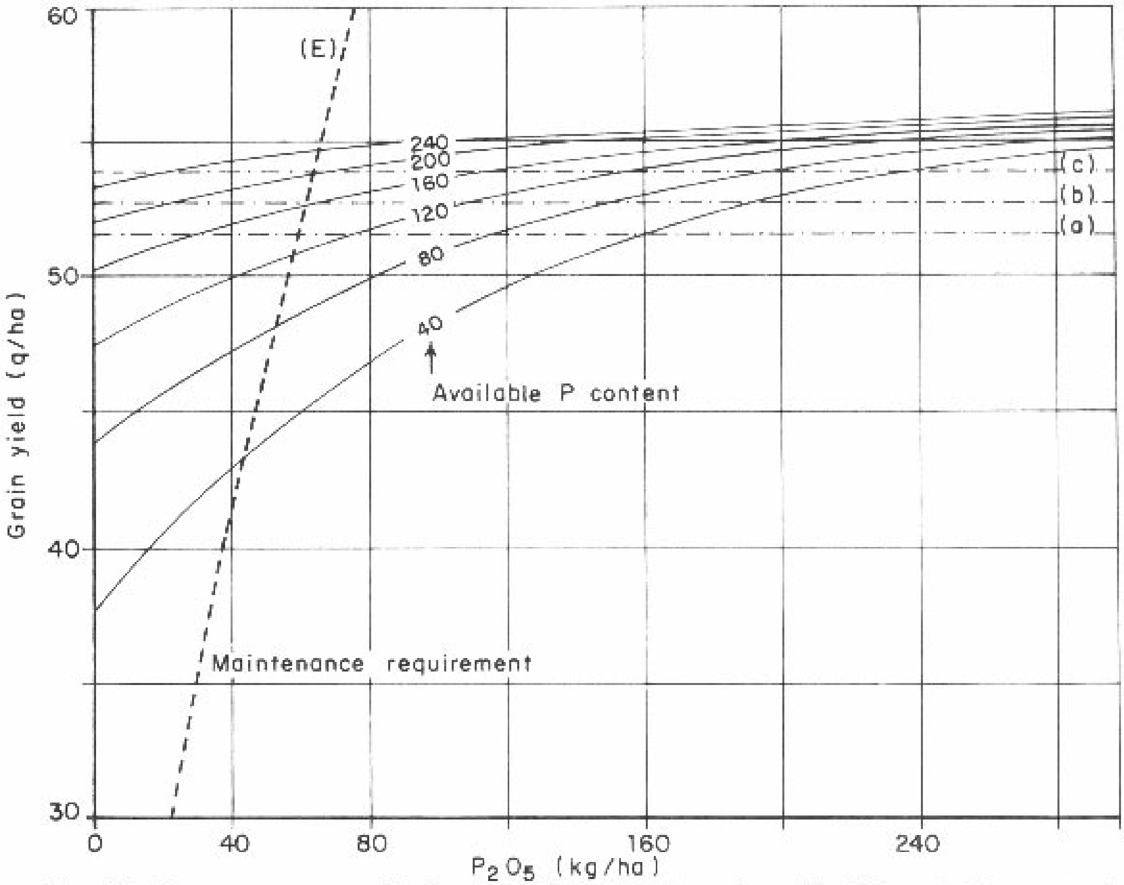


Fig. 2 Response curves of wheat to P applied to soils with different P contents (according to BOSC 1977)

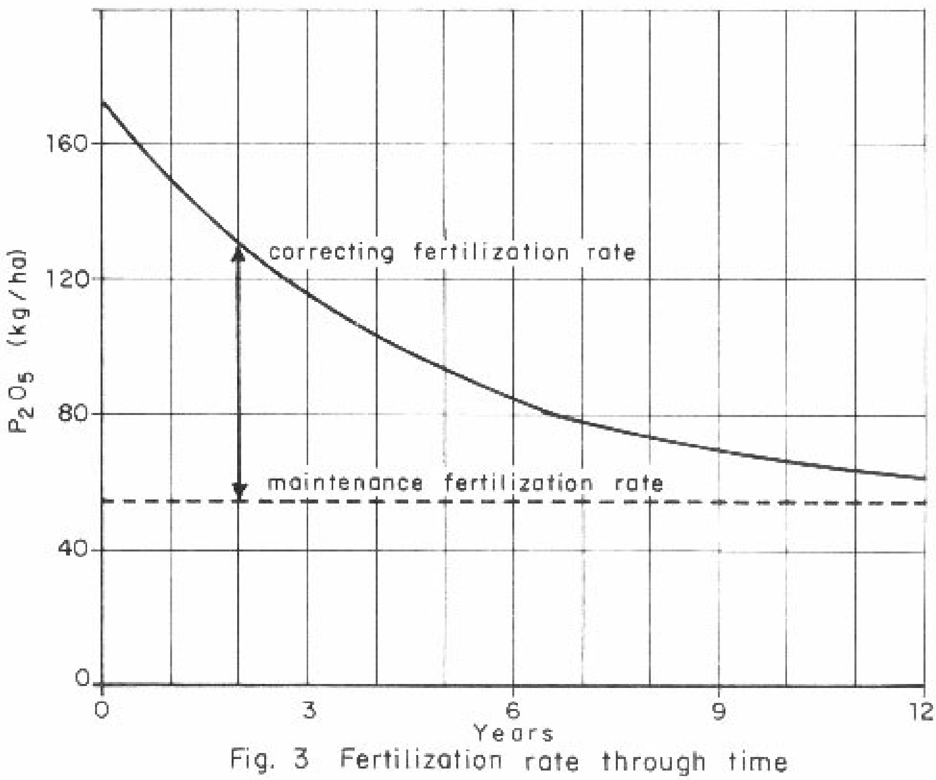


Fig. 3 Fertilization rate through time

Very low:	systematic presence of symptoms of deficiency
Low:	possible presence of the same symptoms
Slightly low:	no symptom of deficiency but yields slightly affected
Satisfactory:	the level of maintenance is just reached
Slightly high:	slight reserves
High:	large reserves - rate of fertilizer can be reduced
Very high:	very large reserves - fertilizer can sometimes be dispensed with.

Sufficiently numerous classes allow the avoidance of large qualitative jumps when reaching the threshold of the limits.

Single classification poses no problem. To take account of many simultaneous criteria various systems could be used, of which three are described below.

i. Establishment of an index

The possibilities are numerous. The most common are the ratios between constituents and antagonistic properties. For example, the susceptibility of soil to crusting can be characterized by the ratio of unstable elements, that is to say, the quantity of loam (L) to the stabilizing elements such as clay and organic matter (OM).

$$IB = \frac{L}{A + 10\ OM} - 0.2\ (pH\ 7) \quad \text{(correction of one class for pH} \rightarrow 7)$$

The scale of classification is fixed:

> 2.0	very liable to crusting
1.8 - 2.0	crusting
1.6 - 1.8	quite liable to crusting
1.4 - 1.6	little liability to crusting
1.2 - 1.4	very little likelihood of crusting
< 1.2	crusting improbable.

ii. Use of variable scales of classfication

For example, the level of fertility for potassium varies according to the nature of the cation on the complex.

$$P_{K_2O} = \frac{[K]}{\sqrt{[Ca] + [Mg]}} \# k \frac{[K]}{\sqrt{(A + 5\ OM)}}$$

K = exchangeable potassium
Ca = exchangeable calcium
Mg = exchangeable magnesium
CE = exchange capacity
A = clay content
OM = organic matter content

Consequently, the dimension of the class can be proportional to the value:

$$\sqrt{A + 5\ OM}$$

One can likewise take into account many other criteria such as the nature of the plant (ability to extract potassium) and the depth of soil (importance of potassium reserves).

iii. Combination of qualitative criteria for classfication purposes

An example will illustrate this possibility:

X - make an application of magnesian limestone

A - deficiency of lime (class <2)

B - deficiency of magnesia (class <2)

C - ratio $K_2O/MgO > 2$

D - presence of maize in crop rotation

E - presence of sugar beet in rotation

$$X = \underbrace{A \cdot B \cdot C}_{\text{and}} \; (\underbrace{D + E}_{\text{or inclusive}}) \qquad \text{Boolean equation}$$

The application of magnesian limestone would only be recommended if lime and magnesia were both deficient, if the ratio of K_2O/MgO exceeded 2 and in the presence of maize or sugar beet in the rotation.

It is thus possible to set up a series of Boolean expressions for the different possible recommendations. The programming is facilitated by the direct use of Boolean operators in the language of the computer.

CALCULATION OF BALANCE SHEETS

As one of the most important laws in agronomy is the law of restitution, it is easy when the information is stored in the memory to make a very large number of calculations, if possible looking to the future, to be able to advise the farmers.

These relatively simple calculations however, demand much information at the input:

i. data resulting from a cropping system. It is essential to know:

- the frequency and even the sequence of the crops,
- the rate of return of crop residues,
- details of mineral and organic corrections applied.

ii. data resulting from soil analysis allowing especially the calculation of the corrective fertilizer rate. This calculation must take into account:

- the desired rate of growth,
- the quantity of arable land (stoniness, depth of ploughing),
- risk of losses by leaching or by irreversible fixation,
- fertilizer correction rate (see Figure 3).

iii. general necessary data, available in the form of tables:

- details of crops removed from the land,
- coefficients necessary for the establishment of scales for diagnosis.

The methods of estimation can be more or less sophisticated. In most systems, there are tabulated data recorded on discs relating to soils and fertilizer use which can be modified by criteria such as the level of intensification or the fertility of the soil (Bulgarian system, 1975).

A more analytical system has been chosen here where each component is estimated:

Maintenance fertilization

+	crop requirements	(1)
+	leaching	(2)
±	irreversible fixation (or release)	(3)
-	rate of return of crop residues	(4)
-	addition of organic matter	(5)

Corrective fertilization

±	variation in available nutrients	(6)
±	irreversible fixation (or release)	(7)

If convenient values are allotted to (1) and (4) and data are obtained by lysimetry for (2), (3) and (7) lack solid reference points. For number (5) in general the composition is known but information is lacking on the speed of release of the nutritive elements contained therein. Nowadays, the annual effect on the first crop after application is considered, the balance being divided between all the crops in the rotation.

To establish such balance sheets, it is necessary to consider a stabilized crop system. The operation therefore presents a forecast which corresponds well to the technical criteria which the manager seeks to help him in his decisions.

7. USE OF SIMULATION

Development of this technique has recently been made possible by certain programming languages such as CSMP (Continuous System Modelling Programme), particularly in the numerical solution of differential equations.

The given models fall into two categories:

i. mechanical models where the methods of working are well known and where the classic laws of physics or biology can be applied. These models concern relatively simple systems.

ii. empirical models. These are generally the more widely used. They concern broader or less known systems. One can therefore use relatively simple equations of prediction, sometimes obtained by regression methods.

The modelling of a system requires initially an unambiguous description of the compartments composing the system, the flows between compartments and the flow between the system and the external environment.

The variables taken into consideration can be flows of material or energy, or the conditions which, in general, modify the intensity of the flows.

The choice of system, and above all, its degree of complexity, will depend on the time base taken for the development of the system.

Without going into detail, two examples used by the author can be quoted; first, the long-term development of humus, and second, the forecasting of nitrogenous fertilization.

7.1 Humus Management

The development of organic matter assumes the choice of a model. Henin and Dupuis have used the following:

$$\frac{dM}{dt} = \frac{R_i\ K_{1_i}}{n} - MK_2$$

R_i = residues in dry matter of crop i

K_{1_i} = coefficient of transformation to humus

M = amount of humus in the soil

K_2 = annual coefficient of destruction.

Advice about humus restitution can be obtained from the following calculation:

$$A = \frac{15 \cdot E \cdot K_2\ (T_s - T_a)}{1 - e^{-K_2 \theta}}$$

E = depth of soil (in cm)

T_s = ideal humus content

T_a = actual humus content

θ = delay in attaining T_s

BH = actual humus balance

A = advised change in addition of organic matter.

If this exponential model is valid for soils near equilibrium, it has been shown that it is invalid, for example, for soils after clearing, where there is a high proportion of free organic matter, not bound to the mineral fraction.

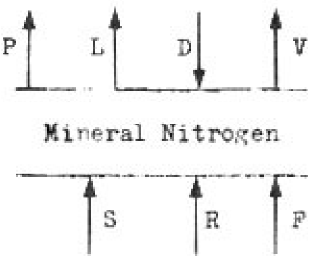
In spite of the imperfections of the models and the relative uncertainty concerning the coefficients K_1 and K_2, they are nevertheless good indicators which enable large errors in humus management to be avoided.

7.2 Forecasting Nitrogen Requirements of Winter Wheat

The requirements of wheat throughout its growth imply that at each stage there is a need to respect the balance of mineral nitrogen.

In the first stage, limits have been set to the evolution of the system between two dates, i.e. the beginning of spring, 15 February, and harvest time, that is to say, 15 August.

The compartment studied is limited to the mineral nitrogen in the soil. The diagram below shows the inputs and the outputs across the period studied.



P = needs of the plant 3 kg N/q

L = leaching

D = nitrogenous fertilizer

S = secondary mineralization of soil humus

R = primary mineralization of crop residues

$$N = N_a - N_f = E + S + R - (L + P) \quad *$$

* On first approximation, it is assumed that the fixation (F) of atmospheric nitrogen is compensated by the denitrification (V) and the difference between these two processes lies within experimental error, i.e. $(F - V \# \varepsilon)$.

Such a calculation has been in use for ten years and the validity of the expression has been successfully tested for two years in the north of France.

The next stage consists of continuously integrating the data during the cropping season. This simulation takes into account changes in the turnover of soil nitrogen, movements of water and nitrate in the soil profile, and the development of root functions. Some investigations were made at the Institute of Soil Fertility, Groningen (Beek and Frissel, 1972), concerning the first two of these, but to our knowledge there has been little work done on the integration of the plant into the system.

A climatic model should be such as to enable the effect of an average, a dry or a wet year to be forecast and so minimize the risks accompanying an intervention.

8. ADVANTAGES AND DISADVANTAGES OF USING A COMPUTER

Great attention must be paid to the quality of the information collected. In spite of the performance of programmes to test the probability of information, erroneous information, whether imprecise or incomplete, will lead to an error in the results. The establishment of such systems is often characterized by a high rate of rejection at the beginning but which will quickly correct itself. A testing period of 3 to 6 months is necessary.

A computer allows the storage of information in an easily accessible form. The co-ordinated reference points allow the retrieval of localized information and changes in the thematic maps, for example soil fertility.

Research models, whether deterministic, stochastic or empirical lead to a synthesis which often sheds light on the gaps in our knowledge of the subject. This step therefore contributes to the orientation of research.

The precision of the computer response can sometimes be striking. Far from weakening the personal links between the agricultural advisers and the farmers themselves, the contacts are, on the contrary, strengthened.

One of the most serious disadvantages is the lack of flexibility and the delicacy of the computer system. It is enough, in fact, for one single component to fail for the whole system to be inoperative. In the developing countries, maintenance problems must be foreseen, risks of breakdown being very high. Working at great distances is possible but there are uncertainties in postal communications. Without doubt the future will justify small and medium decentralized units.

REFERENCES

BEEK, J. and FRISSEL, M.J. Simulation of nitrogen behaviour in soils. Centre for
1973 Agricultural Publishing and Documentation, Wageningen, Netherlands.

BOSC. Quelques aspects sur la fertilization phosphatée. C.R. Acad. Agric. France (in
1977 press).

CADY, F.B. and ALLEN, D.M. Combining experiments to predict future yield data. Agron.
1970 J. 63(2): 211-214.

CADY, F.B. and FULLER, W.A. The statistics computer interface in agronomic research.
1970 Agron. J. 62(5): 599-604.

LAIRD, R.J. and CADY, F.B. Combined analysis of yield data from fertilizer experiments.
1969 Agron. J. 61(6): 829-834.

Paper 20 EXTENSION OF SOIL TESTING RESULTS AND FERTILIZER RECOMMENDATIONS TO THE FARMERS

by

B. van Raij
Instituto Agronômico of the State of São Paulo Campinas, Brazil

1. INTRODUCTION

Few activities in agriculture present so many aspects of common interest for so many people as soil testing. Soil testing is relatively cheap, it is an effective working tool for the soil scientist, the agronomist in advisory work and the fertilizer salesman and, more importantly, it leads to an increase in profits for the farmer through the more efficient use of fertilizers and higher productivity.

The use of soil testing as an aid for fertilizer recommendations to farmers has been increasing in developing countries, but the total number of soil samples that are analysed falls short of what would be desirable. Many farmers still do not use fertilizers and most of those who do are unlikely to have their soils tested.

The existing systems of soil testing present weaknesses and need improvement. There are many problems of the following general nature that hinder development:

a) weakness in organizational structure of soil testing systems;

b) lack of understanding or of confidence in soil testing by both farmers and agronomists;

c) dispersion and lack of orientation of research activities that could or should contribute to the improvement of soil testing.

This paper deals with several problems that arise in the practical use of soil testing for the recommendation of fertilizers to farmers. The ideas largely reflect the experience of the author in the southeastern region of Brazil.

2. ORGANIZATION OF SOIL TESTING SERVICES

The first requirement to enable soil testing organizations to perform efficiently is the existence of laboratories capable of analysing large numbers of samples in short periods. Such laboratories exist or are being constructed in many developing countries.

Soil testing in its infancy usually starts in research organizations. Later, other types of soil testing services might develop to serve different purposes. The example given in Table 1 illustrates a situation in which privately owned laboratories are analysing a growing proportion of the soils tested in a developing region.

The existence of soil testing services within research organizations presents advantages in keeping research activities in touch with the practical aspects of soil analysis and fertilizer recommendations, and also by making it much easier to introduce in practice innovations produced by research. On the other hand, if the activities associated with soil testing and fertilizer recommendations become too extensive, they will conflict with research activities for resources and for time of the often precious specialized staff.

Private organizations might relieve state organizations of the burden of excessive growth of soil testing services by organizing their own services. Their

Table 1 SOIL SAMPLES ANALYSED FROM 1965 TO 1975 BY THE MAJOR SOIL TESTING LABORATORIES OF THE SOUTHEASTERN REGION OF BRAZIL

Organization		Laboratories and thousands of samples analysed yearly										
		1965	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975
Research institutes	Laboratories	2	3	4	4	4	4	4	4	4	4	4
	Samples x 1000	9.7	18.2	27.3	55.2	48.7	35.2	34.3	39.3	42.7	41.1	44.0
University	Laboratories	1	1	1	1	1	1	1	1	1	1	1
	Samples x 1000	1.2	1.2	2.1	4.8	5.4	5.8	5.6	8.5	7.5	6.0	16.6
Fertilizer companies	Laboratories	–	–	–	–	2	2	2	2	3	3	3
	Samples x 1000	–	–	–	–	9.1	43.6	46.3	50.7	46.7	19.9	44.5
Independent laboratories	Laboratories	–	–	–	–	1	2	3	3	3	3	3
	Samples x 1000	–	–	–	–	3.7	18.6	23.3	33.9	42.8	28.2	51.2
Sugar and tobacco	Laboratories	–	–	–	–	–	1	1	1	1	2	2
organizations	Samples x 1000	–	–	–	–	–	5.2	4.7	7.1	8.2	14.8	21.3
Total numbers of laboratories		3	3	5	5	8	10	11	11	12	13	13
Total numbers of samples analysed x 1000		10.9	19.4	29.4	60.0	66.9	108.4	114.2	139.5	147.9	110.0	177.6

performance will usually be characterized by an higher degree of administrative flexibility. Their involvement with soil testing will be based on interests that differ from those of state organizations and relationships with farmers will also be different.

The existence of many organizations involved with soil testing and fertilizer recommendations will become a source of confusion and distrust for farmers if the results of soil analysis and recommendations are not uniform and comparable.

The internal and external organization of soil testing services also might vary between laboratories and this will certainly affect their overall performance.

3. PROBLEMS AT THE FARMER LEVEL

First of all the farmer has to know that soil testing can be done and he must be willing to have his soil analysed. Usually farmers have first to be convinced of the benefit of using fertilizers.

The tasks of collecting and identifying soil samples, filling in questionnaires and sending soil samples and payment (if required) to the laboratory, are often difficult to carry out by those farmers who did not have the benefits of a better education. Thus the intervention of the extension agent or the fertilizer salesman is then necessary, at least for the first sample sent by an individual farmer.

Sampling is probably the weakest point in the whole process of soil testing, the most common error consisting in taking too few samples to make up a composite sample.

For many farmers one major source of discouragement is the long interval between sending the soil samples and receiving the results of soil analysis and the fertilizer recommendations. Others are the lack of uniformity between results of supposedly the same soil samples sent to the same or different laboratories and disparities of fertilizer recommendations issued by different organizations.

Other problems can arise through farmers not using the given recommendations for reasons such as the following: the recommendations arrive too late, the farmer finds it economically impossible to buy fertilizers or the recommended fertilizers are not locally available. The existence of a large number of compound formulas often leads to the use of fertilizers that differ in nutrient contents from the recommended amounts.

4. BACKGROUND RESEARCH

In many regions soil testing services are organized without many results of local research. This is probably the best way to act in developing countries, since the existence of laboratories will open opportunities and stimulate research.

To be efficient, a soil testing system needs to be backed by a very large amount of research. It supports itself by the consistency that is a feature of fertilizer recommendations based on soil analysis. Research must necessarily be conducted locally, in the laboratory, the greenhouse and the field.

Soil testing requires inputs from several sectors that undertake research with soils and plants. Difficulties are found in the fact that in many organizations research is fragmented and directed into very specific lines of work. Research in subjects that could or should affect the whole system of soil testing is often conducted in isolated units that hardly communicate with each other. Soil testing as a practice and even fertilizer recommendations, which should be specific activities towards which research outputs should be directed, are often forgotten aspects in research strategy. In consequence, progress in soil testing has been somewhat slow in many places despite the great advances made in analytical chemistry, data processing and other supporting activities.

5. SPECIFIC ASPECTS OF SOIL TESTING AND SUGGESTIONS FOR IMPROVEMENT

All aspects involved in building up and operating a soil testing service should be carefully considered if it is to be efficient. Some of the more important of these are discussed in the following sections.

5.1 Arrangements at the Farmer Level

Every effort should be made to ensure that as many farmers as possible become acquainted with the soil testing services. They should be given simple but correct information about what soil tests can provide. One effective way of ensuring that farmers make use of the soil testing services is to require evidence of soil analysis before financing the supply of fertilizers.

Special attention should be given to the soil sampling which should be fully explained in publications and leaflets and its importance constantly emphasized. All sampling equipment needed, such as containers and questionnaire forms, should be at the disposal of the farmers. Instructions for taking a representative sample, filling in questionnaires, and sending samples and payment, should be made as clear and simple as possible. The local manufacture of inexpensive tools which permit only small samples to be taken could be of great help in ensuring better sampling.

Farmers should be persuaded to send samples as early in the season as possible, so avoiding the peak periods. For most purposes, samples can even be taken with crops still in the field, if sampling in the bands where fertilizer was applied can be avoided.

The utilization of fertilizer recommendations by the farmers should be verified and the reasons for any divergence from them examined. The help of agronomists is often necessary to ensure correct implementation of the recommendations.

5.2 Laboratories

In any given region the soil testing facilities should be evaluated and laboratories organized if necessary. This can be done at a reasonable cost.

If there are already several laboratories, efforts could probably be better directed towards obtaining uniformity. It would be most appropriate for laboratories of a given region to use similar analytical methods as well as printed matter comparable in its essential content. Differences in methods and units of expressing results and recommendations are a source of annoyance for farmers and agronomists.

Programmes to keep the laboratories in constant contact can be organized by the laboratory linked to the research organization. Such programmes can direct efforts to the comparison of results of soil samples analysed by all laboratories throughout the year, and so make possible the evaluation of the consistency of the results from each laboratory and between laboratories. A programme of this type serves also as a stimulus to the spread of information, including new methods, and is fundamental in obtaining uniformity. In the long run it will signify to the farmer that several soil testing laboratories perform similarly, so that he can choose the one that is more conveniently located.

5.3 Adequacy of Fertilizer Recommendations

There is often a distance separating what might be considered to be a technically and economically correct fertilizer recommendation based on soil analysis and that which the farmer will finally use. This is a well pronounced problem in developing regions where often a whole spectrum can be found between primitive and very advanced farmers.

Certainly the most important problem is lack of money or credit or the willingness to assume the financial risk that the use of fertilizers requires. The farmer might reduce the amounts recommended, but in so doing would cause little harm. Often, however, he might decide to omit some component of the recommended dressing, e.g. lime or nitrogen, with possibly disastrous consequences for himself and for the credibility of fertilizer use.

Another common occurrence is the use by the farmer of recommendations that in the past have proved to be efficient. Thus he might, for instance, continue to use lime, even if it is no longer recommended.

In some specific cases, recommendations might reflect the different levels of management of farmers, as indicated by yield goals or past yields.

The cases mentioned illustrate the fact that supposedly good fertilizer recommendations in the hands of the farmer, do not constitute the end of the process. Continuous intervention of agronomists is necessary to ensure proper implementation of the recommendations.

Recommendations should be kept up to date with available products, which tend to change from single fertilizers to the increasingly concentrated compound fertilizers. Regional efforts should be made to reduce to a minimum the number of available compound fertilizers. This can probably be done if the most frequent recommendations are known, with the definition of some minimum ratios of nutrients that are necessary, and by grouping crops of similar requirements.

As in the case of laboratories, some permanent type of contact between organizations affected by fertilizer recommendations is desirable.

5.4 Background Research

Research that could lead to progress in soil testing and fertilizer recommendations is often so dispersed as to make it a difficult task to gather the necessary information. Trained people that are able to integrate different aspects of research are not always available.

Perhaps a useful approach to attaining higher efficiency in research is for soil and crop scientists to discuss the principles of soil testing to show the need for part of their research to be directed towards practical aspects of soil testing and fertilizer recommendations. From this they should gain a general knowledge of the whole organization of soil testing and learn where specific research efforts are needed.

Besides the many specific aspects of soil testing related to methods of soil analysis and fertilization of crops, there are some subjects that certainly deserve closer attention. To mention a few: the terms correlation and calibration need better understanding; economics of fertilizer use should consider soil analysis and the need of maintaining and increasing soil fertility; alternative working philosophies of soil testing should be compared; more organized efforts should be made in defining the fertilizer requirements of different varieties of plants, especially comparing native cultivars with improved cultivars, and nutrient budgets should be determined for different methods of management of major crops.

5.5 Follow-up on Soil Testing

The impact of soil testing and fertilizer recommendations should be constantly evaluated at the farmer level.

Thus it would be useful to know how many farmers in a given region use fertilizers and have their soils analysed and among these, what are the effects on productivity, profits and soil fertility. Deviations from the expected behaviour should be evaluated and corrections applied if needed.

The constant evaluation of soil testing and fertilizer recommendations at the farmer level will also provide very important feedback information for the extension and research services, since specific problems that need educational or research efforts will certainly be identified.

Results of soil analysis also constitute a valuable source of information about specific regional soil fertility problems. Thus, general patterns of soil fertility can be mapped and followed on a time basis.

Surveys of the most frequent recommendations serve as orientation for the fertilizer industry.

6. CONCLUSIONS

Soil testing is an effective aid in the preparation of fertilizer recommendations for crops. To promote progress in this activity the following aspects should be considered:

i. efforts at the farmer level to ensure proper and easy sampling, mailing of soil samples and correct implementation of fertilizer recommendations;

ii. organization of laboratories, to ensure soil analysis capabilities, and of programmes to ensure the greatest possible uniformity between laboratories;

iii. provision of up-to-date fertilizer recommendations with built-in flexibility to accommodate specific cases;

iv. coordination of research into soil testing and fertilizer recommendations;

v. constant following up of the use and consequences of soil testing and fertilizer recommendations by farmers.

EQUIPMENT FOR SOIL SAMPLING AND ROUTINE SOIL ANALYSIS

by

G.M. Jonas
Bureau of Soils, Manila, Philippines

1. HISTORY OF SOIL ANALYSIS IN THE PHILIPPINES' BUREAU OF SOILS

Soil analysis had its beginning in the Philippines in 1939. It started as one of the activities of a Division of Soil Survey and Conservation, the forerunner of the present Bureau of Soils of the Department of Agriculture. The analysis was concerned with the determination of the total amounts of nitrogen, phosphorus and potassium present in the soil rather than the available forms of these elements now used as the basis of fertilizer recommendations.

Soil analysis as a rapid soil test was initiated by the above Division in 1947. In 1951, this Division was transformed into a larger organization, the Bureau of Soil Survey and Conservation (renamed later as the Bureau of Soils). From then on, soil testing activity was decentralized from Manila, with the creation of two field soil testing laboratories. In the subsequent years, the number of soil laboratories gradually increased. Today there are 29 laboratories under the Bureau, of which 16 are in Luzon, 6 in Visayas and 7 in Mindanao.

Luzon, Visayas and Mindanao are the three main divisions or groups into which the Philippines is subdivided. The whole country is composed of 7 107 islands, presently comprised of 72 provinces, and sub-divided into 12 soils regions to which the various functions of the Bureau are decentralized.

Each soils region has a central laboratory called the regional soils laboratory; other laboratories in a region, if any, are known as district laboratories. It has been suggested that only one laboratory, the regional laboratory, should be maintained if only to be assured of better equipped laboratories, but owing mainly to difficulties of communication and transportation, the laboratories have proliferated to the present number.

Today, soil analysis is a country-wide activity and support to the food production programmes of the national government especially those for rice, maize and feed grains. Other programmes to which soil testing is linked are those concerned with the production of coconut, tobacco and other crops, pasture development and non-agricultural uses such as soil engineering and urban development.

2. SOIL SAMPLING AND EQUIPMENT USED

Relatively cheap tools and equipment used in soil sampling are available locally and present little difficulty.

The spade, which is readily available on almost every farm, is the tool most widely used in soil sampling for soil testing. It is used in the following manner. After opening a V-shaped hole in the ground 15 cm deep, a slice 2cm thick is taken *from one side. The central portion (5 cm wide) of this slice constitutes a sub-*sample. A sample representative of the area is a composite of at least 10 such sub-samples, each as uniform as possible in dimensions, collected from points evenly distributed over the area.

District or provincial offices of the Bureau are making increased use of the tube soil sampler, 20 or more core sub-samples from which constitute the representative sample. The use of such samplers ensures the collection of uniform cores to form the composite sample. The larger number of sub-samples drawn by this method should more accurately represent the whole area sampled, and is therefore the more appropriate method to use, especially when collecting samples for research purposes.

3. ROUTINE SOIL ANALYSIS AND EQUIPMENT USED

3.1 Soil Analysis from 1947 to 1967

With the introduction of routine soil analysis as the basis of fertilizer recommendations in 1947, the following routine soil tests or determinations were made by the methods specified until 1967. Nitrates and ammonia, colorimetric by the Spurway method (by spot plate and colour chart); pH, by nitrazine paper indicators and later by glass electrode; available P, colorimetric by the modified Truog method (by photometer); available K, Ca, Mg, Fe and Mn, colorimetric by the Peech and English method (by photometer).

3.2 Bureau of Soils and UNSF/FAO Assistance Projects

From 1963 to the present, development projects on soil analysis and other activities such as soil classification and land use studies have been undertaken with UNSF and UNDP/FAO assistance in cooperation with the Bureau of Soils.

These projects specifically were:

Research and Soil Fertility Project, 1963-68;
Soil Survey and Classification, 1969-73;
Soil and Land Resources Appraisal and Training Project, 1974 to the present.

The assistance provided for UNDP/FAO experts and equipment in the various projects. Thus in 1965, the ten regional soil laboratories then existing were recipients of essential laboratory equipment from the UNSF to augment and modernize existing laboratory equipment. Other equipment so supplied to the soil testing programme was a number of UN vehicles which were used in the gathering of soil samples.

Studies to correlate soil test values with the yield response of crops to fertilizers were also conducted under this Project.

In 1967, with the object of reducing the time involved in soil tests facilitating rapid soil tests and establishing a more valid basis for fertilizer recommendations, the Bureau adopted the following soil tests and methods; soil texture determination by the feel method; pH determination by glass electrode; organic matter by chromic acid digestion and visual colour comparison using a series of colour standards prepared from dextrose solutions; lime requirement by $CaCO_3$ direct treatment method; available P by the Olsen and modified Truog methods with the use of a colorimetric photometer; exchangeable K by the hot sulphur acid extraction method and flamephotometric determination, and by the cold sulphuric acid extraction as a substitute method.

In 1976, the Bureau was again a recipient of equipment for soil characterization analysis at three laboratory centres, one each in Luzon, Visayas and Mindanao.

4. THE PRESENT STATUS OF LABORATORY EQUIPMENT

The regional soil laboratories each of which is located at the Regional Office Headquarters in every soils region, are generally better equipped than the district laboratories.

The regional soils laboratories undertake soil analysis as the basis of fertilizer recommendations besides other special laboratory activities such as fertilizer assay, tests of soil salinity and alkalinity, suitability tests for irrigation waters, and soil inoculant production. Apart from the laboratory equipment supplied through UNSF/FAO projects, each regional laboratory is also equipped with a Varian-Techtron atomic absorption spectrophotometer, donated by the Australian government.

Most of the district soil laboratories are equipped by the national government, a few by the local governments and some by joint provincial-USAID funds.

Items of equipment in regional soil laboratories include atomic absorption spectrophotometer, flame photometer, photometric colorimeter, pH meter, distilling apparatus, electric hot plate, shaking machine, drying oven, analytical apparatus and muffle furnace. A district laboratory would have: photoelectric colorimeter, pH meter, distilling apparatus, electric hot plate, shaking machine, analytical balance and drying oven.

Of the twelve regional laboratories, three are equipped with facilities for soil inoculant production and another three have facilities for physical and chemical characterization of soils.

4.1 Brief Description of Some Equipment

i. Atomic absorption spectrophotometer - Varian Techtron Model 1200, with digital read-out.

ii. Flame photometer - Dr. Lange, Model M6a. In the central laboratory in Manila, the unit is of the city gas type, while in the regional laboratories the source of fuel is acetylene. A good feature of the apparatus is its non-clogging type of atomizer.

iii. Photoelectric colorimeter - most of them are Leitz Model M, provided with a rotating filter disc. A few of the laboratories have a Japanese type, remnants of the UNSF/FAO donation.

iv. pH meter - various makes of pH meter are used: Beckman, Metrohm, Corning EEL and the Japanese TOA DEMPA. A few of the Beckman and Corning EEL instruments are battery operated.

v. Distilling apparatus - some laboratories are equipped with a Japanese-made distilling apparatus and the rest are equipped with a Barnstead model.

vi. Hotplate - almost all the laboratories use Lindberg models but a few still have Japanese-made apparatus.

vii. Shaking machine - two kinds of shaking machine are used. One is the Fisher-Khan type and the other is a Japanese type.

viii. Drying oven - there are several kinds of drying oven: Japanese makes, Sargent, Precision Scientific and B & T Unitemp.

ix. Analytical balance - many of the balances are of the swinging beam type. There are only five units of the electrically operated Mettler monospan type.

The diverse makes of equipment in use by the various laboratories present a problem, especially concerning the acquisition of spare parts and maintenance. In the district laboratories, the equipment for the determination of potassium is the photo-electric colorimeter, while in the regional laboratories, the flame photometer is being used. The shaking machines are of various kinds and the rates of operation vary somewhat, but this does not affect significantly the amounts of the elements extracted.

Much of the existing laboratory equipment is ageing and is due for replacement. Apart from up-dating this equipment, we have recommended and are trying to attain uniformity of equipment among laboratories and a full complement of all items necessary.

Paper 22 TRAINING NEEDS OF DEVELOPING COUNTRIES IN SOIL TESTING

by

E.J. Thompson
Faculty of Agriculture, University of Ghana, Legon, Ghana

1. TYPE OF PERSONNEL NEEDED IN SOIL TESTING

To plan and supervise the careful execution of field and laboratory tests a well trained soil scientist is needed. Furthermore the reliability of the fertilizer recommendations depends upon the validity or otherwise of the interpretation put on it. In other words, this depends on the interpreter himself.

In interpreting the results of the various tests it is important that the operator recognizes not only that soils vary greatly in composition and behaviour, but the crops also differ greatly in their plant food requirements. It follows therefore that a fund of basic knowledge is required of the person to whom the interpretation of soil test results is entrusted. Basic knowledge of the soil is acquired by studying the soil in the field, its cropping history and past treatment together with a chemical analysis to determine readily available plant food. This pre-supposes a good grounding in soil science as well as plant physiology.

The accuracy and value of the soil test results will be determined also by the appreciation of the fundamentals involved in the sampling as well as the analytical phases of the work.

Any person involved in the drawing of samples from the field should be able to differentiate between soil types and must learn to avoid areas in the field that are not representative of the field as a whole. It is of importance also that the sampler should have some conception of what the analyst in the laboratory does with the soil after he receives it.

Most soil samples are collected by or under the instructions of some agricultural agency such as a county agent, soil conservationist, agricultural teacher or a fertilizer concern. In the developing countries, where such institutions are not well developed, the choice of persons is rather restricted. Sampling is usually done by field assistants from experiment stations or research institutes. Whatever the case, these persons need to be trained to appreciate the importance of the work they are doing. The training of such persons will clearly be at a lower level.

In the last few decades significant advances have been made in the techniques of laboratory and field experimentation and more reliable results are being obtained in the developing countries. Laboratory technicians or assistants are being better trained to carry out routine analyses of soil samples. It requires that these operatives understand the purpose for which the analyses are being carried out.

The soil tests and recommendations used should be followed up to determine whether the farmer carried out the recommendation and what yields were obtained. Because detailed farm records are not kept in developing countries, staff of either the research institutes and experiment stations or occasionally agricultural extension officers carry out the necessary investigations. Members of the extension services need training in large numbers to enable them to undertake these important duties.

2. TRAINING NEEDS OF PERSONNEL FOR SOIL TESTING

Experience has shown that a well planned organization is needed if soil testing programmes are to produce results of value. Such work cannot be carried out by individual specialists working alone and almost independently, however well trained and experienced they may be. They need the support of assistants of many categories including field men, laboratory assistants of all grades, technicians to look after instruments and equipment etc. These need to be supervised by formally trained persons who would not normally be considered scientific specialists.

Three general categories of personnel are therefore required: (a) scientific administrators and soil specialists; (b) officers whose duties would consist mainly of executive work and technical supervision and (c) field and laboratory assistants.

The first category of personnel would need formal university training at degree level, the second category would receive a sub-degree level of training but at a higher diploma level, while the third group would require the local primary, secondary or technical training at various levels. Considerable importance should be attached to officers of the second category. These represent the so-called middle level manpower who are so essential to the success of most programmes. Schemes for development often appear to emphasize unduly the need for research. There must be officers to put the results of this investigational work to economic use. The successful application of the results of scientific investigation is as deserving of respect as is research itself. This is particularly important in the developing countries and men recruited for technical application of the results of investigations should be well trained and well paid.

2.1 Training of Field and Laboratory Assistants

In the developing countries trained manpower is scarce and persons with a scientific or technical background are even more scarce. The young person with good science subjects at the Ordinary Level School Certificate level sooner or later is likely to proceed to the Advanced School Certificate level and eventually to one of the institutions of higher learning. Experience in Ghana is that those who seek permanent employment in soil testing or other laboratories are those with the least chance of proceeding beyond the Ordinary Level School Certificate. Our normal requirement is the West African School Certificate or the General Certificate of Examination (G.C.E.) with a pass in a science subject, failing which a pass in a science subject or such relevant experience as may be judged by the Appointments Committee to be equivalent. In certain cases the system admits to an apprentice grade a person with Middle or Primary School Leaving Certificate. Such a person must pass a Preliminary Examination for entering into the normal stream within two years. The Universities in Ghana operate a Unified Scheme of Service for its junior staff to which other research institutions generally conform. The range of categories within this group is as follows:

i. Technical Apprentice

Qualifications: Middle School Leaving Certificate. Must pass Preliminary Examination within 2 years.

Duties: General laboratory practice under the supervision of a more highly qualified assistant, e.g. routine cleaning and care of simple reagents and equipment, a knowledge of safety precautions and simple laboratory manipulations.

ii. Technical Assistant Grade III

Qualifications: Either the West African School Certificate or G.C.E. with a pass in a science subject or unsuccessful candidates with a pass in a science subject or such relevant experience or may be judged by the Appointments Committee to be equivalent.

Duties: General laboratory practice without direct supervision; and duties requiring preliminary knowledge of special laboratory techniques relevant to the Department concerned.

iii. Technical Assistant Grade II

Qualifications: As for grade III plus a pass in Special Technique Examinations I and II and recommendation from the Head of Department.

Duties: Similar to those of Technical Assistant Grade III, the difference between their grades being a matter of experience, skill and responsibility.

iv. Technical Assistant Grade I

As for Grade II plus a pass in the Special Technique Examinations I, II and III and recommendation from the Head of Department concerned.

v. Assistant Technician

Qualifications: Either the Certificate of the Association of Science Technologists or the Intermediate Certificate of the City and Guilds of London Institute (Science Laboratory Technician Certificate) or such relevant experience.

Duties: Duties involve highly specialized skills in one or two advanced laboratory techniques; or supervisory and administrative responsibility in the laboratory plus some specialized skills.

Training under the scheme is organized within the Universities and is carried out while on the job. Staff members are released one day a week to attend the lectures and practicals which span three years. Candidates spend an average of 240 hours a year in lectures and practical work, the latter absorbing a minimum of 50% of the time.

The syllabus is similar to that of the Intermediate Certificate of the City and Guilds of London Institute and covers general laboratory techniques which include procedure, general safety, laboratory workshop practices, and techniques of physics, chemistry and biology. In addition there is a special syllabus for technical staff of the Soil Science Department dealing with relevant aspects of soils work on which a special paper is set in the examinations.

The training scheme attempts to correct the weak scientific background of staff members and successful candidates have often advanced to further academic work. The product of the scheme is a highly satisfactory one.

2.2 Training of Executive and Technical Supervisory Staff

In this category under the Unified Scheme of the Universities are three grades namely, Chief Technician, Senior Technician and Technician. The duties attached to the posts are similar but the difference between the grades is a matter of experience, skill and responsibility.

Training programmes are generally arranged with overseas institutions under technical aid schemes. Staff members go on attachment. The training is one of two kinds:

i. a course of training leading to the Science Laboratory Technicians, Advanced Certificate of the City and Guilds of London Institute in conjunction with the Institute of Science and Technology or some other appropriate qualification. It consists both of training in one or more university departments and of instruction taken part-time in the trainees' free time at a technical college;

ii. a course of training in specialized techniques in a university department or research institution. Formal instruction at a technical college may also be required.

Present thinking is that the training at this level should also be carried out at University institutions at home. It is at this level and in such a scheme that FAO and sponsoring agencies could be of help. Such training programmes could be arranged regionally for periods of up to one year. Such programmes already exist and can be further expanded. An example is the International Institute of Tropical Agriculture (IITA) Training Course for Research and Extension Supervisors; one has been held for grain legume production in Tropical Africa and another in integrated pest management. Similar schemes could be developed to suit people working on soils and soil testing in particular.

Some of the University institutions in developing countries hold a training programme in agriculture for the middle level grade of technician. At the University of Ghana there is a National Diploma course primarily designed for the middle level extension staff of the Ministry of Agriculture and recently patronized by staff of the Ministry of Education. The course spans two years and in the second and final year it can be modified to suit the interests of individual students.

Similar courses could be started in other countries with the help of interested sponsoring agencies. Alternatively students could be sent to institutions in countries where such courses exist for training.

2.3 Training of Scientific Administrators and Specialists

This aspect of the training scheme presents the least difficulty because trainees are few and can be accommodated in existing institutions. Generally, for the first degree at least, training facilities exist in local university institutions in the developing countries. What is lacking is adequate post graduate training facilities. However, first degree personnel can be given on the job training for a number of years after graduation before going abroad to acquire more experience. Alternatively, experienced scientific and technical staff from abroad may be attached to university or research institutions in the various countries where they can help train potential administrative and specialist staff. Another choice is that of regional training programmes similar to the IITA training in integrated pest management. This course included a graduate training programme.

3. CONCLUDING REMARKS

The Ghanaian example has been used not because there is anything unique or exemplary about it, but simply that it is reasonably representative of the situation in the rest of the developing world.

The need for trained manpower at all levels of the scale is obvious. The preconditions exist in a number of cases for the training of personnel-manpower, budding institutions and men of goodwill. It is to be hoped that external agencies with the know how will continue to help in the development of manpower and resources of these developing countries.

Paper 23 INSTITUTIONAL AND ORGANIZATIONAL PROBLEMS IN DEVELOPING COUNTRIES IN THE ORGANIZATION OF SOIL TESTING SERVICES

by

G.W. Arnott, FAO Soil Analyst 1/

1. INTRODUCTION

It appears unnecessary to try to make a distinction between "developed" and "developing" countries and the term "Less Developed Countries" (LDC) used by the Organization for Economic Cooperation and Development (OECD, 1975) is preferable, particularly when there is good reason to emphasize the similarity of many problems of development in most parts of the world. The foundation and organization of soil testing services is a case in point; problems are similar in most countries.

Before considering the problems mentioned in the title of this paper, the first question to be answered is,"should soil testing services be developed?" or if they already exist, "should they be expanded?". As Chang (1976) observed, it is common to find that although large volumes of analytical data (on soil and other samples) have been accumulated, these data have seldom been evaluated and used to interpret the results of field experiments. The very bulk of the data generated is the main difficulty. It is relatively indigestible without treatment and the only really efficient way is by computer processing.

Soil testing services in an LDC usually are part of a combined effort aimed at improving the productivity of the small farmer and his socio-economic standards. They also may be established to satisfy the needs of field experimenters in agricultural research and extension. There may be a need and a place for soil testing services and their worth will be proved when the demand leads to the establishment of commercial laboratories, as in many of the more developed countries. In an LDC it may take many years before this situation is reached and the demand makes such laboratories viable.

Whether an LDC decides to fend for itself or whether it seeks outside help in the development of soil testing services might not affect some long term problems or the solutions required in their establishment and organization. The United Nations Development Programme, USAID, and Bilateral Aid from various Governments can be mentioned as having successful records in this field. The external aid may be given either as a loan or as a gift and, when coupled with foreign advisers, usually leads to the rapid establishment of the services. The loan or gift may, however, only serve to postpone or even accentuate later problems such as the upkeep and replacement of equipment, budgeting for operating costs , and staff training and development.

2. ESTABLISHMENT OF SOIL TESTING SERVICES

Welch and Weise (1973) considered that soil testing programmes can be divided into four distinct parts: (i) educational; (ii) analytical and laboratory operation; (iii) research to provide correlation or calibration data; (iv) interpretation and recommendations. In an LDC the soil testing service will usually be established within the Government Department of Agriculture and there will be an existing infrastructure which can support, to a greater or lesser extent, these four aspects.

1/ Present address: Soil and Land Resources Appraisal and Training Project, c/o UNDP, P.O. Box 1864, Manila, Philippines.

The general aim of such a department is the production of more food (or industrial or export crops) per unit area, a main input for which is fertilizer (or manures in general). Prior to the establishment of soil testing services it is useful to assess the present use of fertilizers and the potential increases in demand and supply within the country. As Ismunadji and Uexkull (1976) noted, it is not so long ago that chemical fertilizer meant ammonium sulphate to the majority of paddy farmers in Asia. In Indonesia the paddy farmer is limited to a choice of about four main materials but in Japan more than 3 000 products are marketed. The choice of the correct fertilizer is thus becoming increasingly difficult, especially for the small farmer who may prefer to buy the fertilizer with which he is most familiar (often regardless of cost and effectiveness) or the fertilizer which appears cheapest per bag, or the one which he believes (or is made to believe) is of the best quality. Farmers sometimes paid premium prices for certain brands, or fertilizers dyed red (preferred solely because red was considered a lucky colour).

These points serve to highlight the useful role which soil testing services can play but also emphasize the problems. The services might include water and plant sample analysis and must be linked to, or backed by, laboratories for fertilizer quality control (in turn supported by effective fertilizer legislation). They also rely heavily for their success on the Advisory or Extension Service with agronomists linking the laboratories and their results directly to the farmer, preferably by personal contact.

The similarity of problems in establishing soil testing services means that much time and effort can be saved, and mistakes avoided, by cooperation and the transfer of technology and expertise between countries. Foreign aid usually has a good impact and effectiveness, but it should not be too short in duration at this critical stage of establishment. Apart from the material support, foreign staff either on loan from a university or from an international organization need time to gain an appreciation and understanding of local problems and to attain their maximum effectiveness. They should have continuity of contact although this need not be continuous in time and may be spread over several years.

It might be better to adopt a not too optimistic programme of expansion or proliferation of soil testing services. The possibilities of future problems in the four aspects mentioned above (educational, analytical, correlation, interpretation and recommendations) should be assessed when the aid programme is planned, and assistance should be phased accordingly. A more gradual withdrawal of aid than is customary for a developing or strengthening programme may be advisable.

3. ORGANIZATION

The development of soil testing services within an established department may involve founding a new Division or Section. A problem common and perhaps inherent to the government system is the lack of cooperation across divisional boundaries. Budgeting is by division and it may be especially difficult for a new division to establish the necessary cooperative links when financing is a factor. The success of soil testing services depends so much on these cooperative efforts with soil fertility specialists, laboratories for fertilizer quality control and for research, and extension officers. These problems could be minimized in the new organization by adopting the "team" approach whereby a team leader organizes, integrates and controls the work of the laboratories, field experimental officers, extension officers, economists and agronomists.

Although government departments are usually non-profit making, it is desirable to instil some of the "commercial attitude" during the training programmes and in the day-to-day work of staff concerned with soil testing services. Efficiency of operations should be high whether or not fees are charged. There are pros and cons, especially when the main "customers" are small farmers, but a service is often appreciated the more when the user has to pay. Each soil testing service should decide for itself, however, whether or not a charge should be made for the analysis and/or advisory work.

Another main problem of organization for the laboratories as well as field staff is the uneven flow of samples (and thus demand for results) throughout the year. If a fee is charged then quick service is expected and to provide this, at peak periods, sets organizational problems concerning staff, equipment, methods selected and techniques of analysis. Either the capacity has to be flexible or a certain percentage of the results has to be delayed. The latter may be feasible if a service is provided for samples from fertilizer trials, but any delays in supplying results must be programmed and explained to users.

4. BUILDINGS AND SERVICES

4.1 Design

Laboratories are seldom designed well in any country and it is especially difficult in an LDC to find architects with experience in such designs. As with other buildings to meet special internal functions, laboratories should be designed specifically to suit the particular equipment and space required. Yet it is often the case that a building (even a new one) is provided and the soil testing service is expected to fit into the shell, complete with rooms.

Limitations of government budgets and procedures often lead to the acceptance of the lowest tender, or to construction in stages but this can be false economy in the long run, or even not so long, particularly with laboratories. The finish and fittings need not be lavish (money should not be wasted); they should be functional but not spartanly so. The comfort of the staff must be considered as well as the efficiency of the working system, and one of the aims should be to provide pleasant working conditions. This may be one of the main factors related to retaining good staff.

4.2 Planning

Following on from the principle of planning laboratories for specific requirements, it is essential to have a clear idea of what is to be done and the equipment and staff needed to do it. Guidance can be obtained from an experienced architect backed by knowledgeable scientists. If an architect experienced in laboratory design is not available, the advice to be found in books should be followed. For example, Ferguson (1973) in his book "Practical Laboratory Planning" presents admirably comprehensive information based on many years of practical experience.

If central and regional laboratories are envisaged, an overall plan should be made. Considerable savings are possible by standardizing units for furniture and fittings (laboratory modules) and for architects plans and building materials (modular construction).

4.3 Location

The choice of location is important for several reasons. If the soil testing service is to serve mainly farmers, there must be easy access for the farmers or their samples to the laboratory. Space may be needed for planned expansion in the future. The physical relation to other sectors, such as experiment or research stations, is important (a station might provide the best location) in that the laboratories should not be isolated from complementary disciplines.

The convenience of the location for laboratory staff should be considered in matters such as proximity to public transport, access to schools, shops and recreation centres. In some places it may be necessary or desirable to provide houses and/or transport facilities and so on for staff.

4.4 Facilities

Following from the above, seldom is sufficient consideration given to factors such as the comfort of staff and training/recreational facilities for them. Castenson (1973) suggested the provision of an employee's lounge and building plans should include such a lounge and/or canteen-cum-lounge (note that it is usually recommended that food should not be consumed in a laboratory). In addition there should be provision for a conference/training room, perhaps doubling as a recreation room; an attractive, comfortable, sound-proofed library; and adequate toilets and shower room.

Storage space is often inadequate and preparation rooms are usually too small, both being considered of minor importance in bad planning. The latter rooms should have dust extractors and Castenson (1973) noted that a soil sterilizer, traps and screens are needed to guard against the escape of infestations such as soybean cyst nematodes.

4.5 Maintenance and Services

The adequacy or otherwise of electricity and water supplies must be estimated. If power is inadequate, or irregular, battery-operated instruments may be preferred and if water is of poor quality, rain-water storage tanks could be installed (if the climate is suitable) or bulk-treatment plants considered.

The most functional or best suited laboratory fitments may not be readily available in an LDC and, if need be, plans should include allowance for the importation of items such as fume-cupboards and fans, laboratory taps, large sinks, waste disposal channels and effluent traps. Whenever possible, use should nevertheless be encouraged of good quality materials available locally.

Although not readily available commercially as yet, solar heating is an obvious choice for most LDC in non-tropical zones. In tropical countries, solar heating could be used for hot water supply and perhaps as part of the energy needed for water baths and distilled water preparation. In the process it might also be used for cooling purposes if a suitable heat-exchange system were developed.

The external services should include sufficiently large effluent traps in which laboratory wastes could be treated before discharge to the public drainage system.

Maintenance of the buildings and services is often a problem, there being insufficient annual budget allowance (if any) made for this. Deterioration can take place very rapidly and it will affect the efficiency of operations as well as the morale of the staff.

5. STAFF

It might be thought that an LDC would have a main problem in obtaining suitably trained staff for the operation of soil testing services; but this is not always the case. If outside aid is given, fellowships are usually included for the overseas training of senior staff. In addition, there may be foreign "experts" who assist in the establishment of the soil testing service and help with on-the-job training. What may be much more of a problem in an LDC is keeping good senior and junior staff. If the job does not pay well enough (or satisfy in other ways) there are many opportunities for well trained staff to obtain higher paid jobs in the private sector, or to transfer to more senior positions in other government departments.

Another main staff problem, not confined to LDC, is the lack of experienced instrument technicians. Such positions usually fall into the lower grades within a government wage structure, but it might be said that they are worth their weight in "the equivalent of local currency." Foreign aid schemes occasionally are far-sighted enough and well planned to include this grade of staff in their training programmes and/or expert assistance. It should be remembered that good technicians are especially liable to be tempted away from government service to the commercial sector in an LDC.

The balance between centralization and decentralization is sometimes swung to the latter for reasons other than technical. Decentralization, or the proliferation of laboratories and associated activities, may be encouraged for the less admirable reasons of simple "empire building" or a combination of this and the perhaps justifiable desire to provide job-opportunities. It might be argued that labour-intensive systems should be developed to satisfy the demands of an increasing flow of graduates from universities and diplomates from technical colleges. This problem has an influence on the choice of equipment and is elaborated below.

6. EQUIPMENT

The choice of systems of analysis may pose problems for an LDC. It might appear most attractive to import a "package" automated system or automated instruments from the more developed countries. These may be advocated because of (proven) efficiency, less liability to human error and, possibly, greater flexibility of throughput. In fact the LDC might have such a system thrust upon them by the donor country, and it may be accepted for no other reason than it would appear ungrateful not to do so. For example, direct-reading emission spectrographs allow the simultaneous determination of several elements in a sample and may be linked directly to computer facilities. They are expensive instruments but can handle large numbers of samples with minimum labour and time. But the labour-intensive methods may be preferred in an LDC where the same number of samples can be handled with more staff. Even in the absence of sophisticated instruments, it is possible to develop systems which allow a large output with manual methods, perhaps aided by "automation" to the extent of automatic dispensers and diluters which are operated by hand.

As mentioned above, the available water and electricity supplies may determine the choice of equipment. If there is any doubt about the reliability of power, battery-operated instruments should be installed wherever possible; most of the instruments required in basic soil testing services can be operated by 12-volt batteries.

A reasonable degree of standardization of equipment is both sensible and desirable, especially where many laboratories are to be established. There are obvious advantages in avoiding too many different makes and models, but the choice of equipment suitable for the soil testing service (in a particular LDC) calls for expertise on the part of the planners. They must have a sound knowledge of the methods and techniques to be used and of their ruggedness. One particular method or technique may be more sensitive than another but, for the purposes of soil testing services, the more rugged method (Youden and Steiner, 1975) may be preferred. This may involve an instrument which is cheaper than another although less sensitive. An additional consideration is that the more sensitive (and usually more expensive) instrument may be affected by humidity, and air-conditioning/dehumidification may be essential to its satisfactory operation.

A survey should be made of local suppliers, companies and agents to find which have repair services (it is not sufficient to have company technical experts who visit occasionally). Donor governments or agencies should bear this in mind when providing equipment under a package deal. Whatever the choice of equipment may be, the soil testing service should have a well-equipped central store from which replacements can be obtained. For example, if twenty laboratories have to be equipped with pH meters, the store should carry two or three spare units.

Taking the above pessimistic but practical attitude a step further, a "dual system" of analytical procedures might be considered for an LDC, so that the auxiliary system could be brought into operation when the first fails (because of instrument breakdown and so on).

7. MISCELLANEOUS PROBLEMS

7.1 Soil Sampling

The importance of soil sampling is often stressed but it is difficult for a small farmer to collect "proper" samples, even though he is given detailed instructions. It is better if the agronomist or extension officer has assistants to take the samples. Considering the labour involved, a composite of 10 sub-samples is often accepted as sufficient, but this seldom provides a representative sample. A minimum of 20 sub-samples should be recommended. Sub-surface sampling will be of increasing importance after a few years of fertilizer application when residual effects become more important. These requirements emphasize the need for well-designed equipment which will allow quick and accurate sampling of surface and sub-surface layers. Stainless steel tube-type samplers (with a slit down the side to facilitate sample removal) are best for topsoils. Screw augers, although not ideal for taking samples, allow reasonably rapid sampling of sub-surface layers.

Again considering the amount of labour involved in collecting a composite sample of soil (or plant material) the importance cannot be overstressed of proper packing, labelling and transportation.

7.2 Glasshouse Investigations

It is a moot point whether or not glasshouse pot-testing should be included as part of the soil testing service development, but as long as the limitations are borne in mind (and too definitive extrapolations avoided) the technique is convenient, especially for comparative purposes. Bulk soil samples can be taken from widely distant areas, gathered together under the same roof, and subjected to the same, uniform treatments, allowing a rapid and well-controlled comparison and establishment of main differentials. If it is decided that glasshouses should be established, their design, the work to be done, and the equipment needed require careful consideration.

When properly conducted, glasshouse investigations can provide a useful link between the laboratory soil tests and field experiments.

7.3 Field Experiments

Although the glasshouse stage might be omitted, the field experimental stage cannot. Without the results of field experiments the recommendations of soil testing services will contain a very large element of guesswork. Cooperation with soil fertility specialists is required to plan a network of field experiments. Designs and techniques were described in FAO Soils Bulletin No.11 (1970). More complex but more powerful designs were described by Colwell (1975) but these may be better used on Experiment Stations because they require more plots than the normal "Trials on Farmers' Fields" and a consequently greater degree of control and supervision. Whether the experiments are done on farmers' fields, or on Experiment Stations, or as a combination of the two, does not lessen the need for repetition on the same site, preferably for at least three or four years. This requirement is often overlooked and it can raise special problems in budgeting and planning. It does emphasize, however, the dangers of starting with too many experiments (with the accompanying problems of logistics). It is better to have a modest programme of say 50 well-supervised trials with an average coefficient of variation of 20 percent than 500 trials with an average CV of 50 percent.

Unless there is a reliable commercial source of chemical fertilizers, the supplies for field experiments should be analysed by the Fertilizer Quality Control Laboratory to check the composition and ensure uniformity of materials to be used in the field experiments.

Further support to the soil testing service and fertilizer experiment programme should be provided by plant and water-quality analysis laboratories and the input/output of these should be an integral consideration of the service.

7.4 Control of Laboratories

If there are Central and Regional Laboratories in the soil testing service, the system of control of accuracy and precision is of paramount importance. It might be thought that in a field such as human medicine the accuracy and precision of medical laboratories would be above question, but this is apparently not so; it has been reported that accuracy and precision may be poor and gross errors common. The soil tester may feel the safer, in that the doctor or the patient cannot sue for damages, and it is true that the plant (low-yielding or even dead) cannot answer back; but the farmer can, if only in losing faith in the service and advice provided. This must be avoided and results and recommendations must be carefully examined before being given.

7.5 Extension/Advisory Services

The important place of the Extension/Advisory Service cannot be overemphasized. It should form the direct link to the individual farmer or to farmers' organizations. The advisory officers must avoid the mistaken assumption (vide: Ulbricht, 1976) of the illiterate, ignorant peasant farmer. The small farmer has an intimate knowledge of his land and usually appreciates and accepts advice on how to increase his yields, but has to be convinced that he should accept this advice. The field experiment may need to be carried a stage further, to the demonstration plot, before this advice is readily accepted.

Prior to deciding the fertilizer recommendation, a technical officer should collect information about cropping history and previous treatments, soil analyses, crops to be grown and rotations with other crops.

7.6 Research

If the "team" approach is not established in soil testing services, there is the danger that the service becomes isolated from research activities. They should be complementary. Cases of insufficient or non-response to recommendations should be discussed with research officers. Special problem soils may be identified in this way. On the other hand, although soil testing services concern themselves mainly with the more commonly used fertilizers (or with those most readily available), they should pay attention to the use and effects of "fertilizers and fertilizer systems of the future" which may be part of the research programme. Examples are: the possible use of sulphur-coated urea; other sulphur-coated or encapsulated straights or compounds; slowly available forms of nitrogen (and phosphorus and potassium); minor element "fritted" complexes; and the possible development of N-fixing (though non-leguminous) varieties.

Research aimed at reducing the dependence of an LDC on imported (oil based manufacture) fertilizer materials is of long-term importance to soil testing services. Admittedly the main concern at present is with NPK requirements, the most important of which is nitrogen. Research and soil testing services should combine in the study of manuring systems tailored to suit local conditions, and aimed at lessening dependence on imported materials.

8. SOIL TESTING SERVICES IN THE PHILIPPINES

Soil testing services in the Philippines were started in 1947. During the period 1963-69 a United Nations Special Fund Project assisted with the strengthening and expansion of these services and related aspects. It is interesting to review the present situation to see how successfully problems were solved and which have recurred or developed and still require solution.

The project was successful in improving methods and services in eleven laboratories, in establishing a wide network of field experiments and in integrating the findings of field and laboratory work to the stage of advisory services. The soil chemist of the Project, Dr. S.C. Chang, made several recommendations in his report (Chang, 1967) and some of these are noted below with comments about the present situation.

i. increase in number of laboratories was not encouraged, it being recommended to integrate all the field laboratories into eight main centres. Owing to the demands from districts to have their own service, the number of laboratories has increased from 17 in 1967 to 29 in 1977 (including four founded by Provincial Development Assistance Programmes). This expansion has aggravated problems of equipment, supplies, operational funds, supervision and control of work and staff training, and of cooperation with research and extension officers.

ii. the training programme should be strengthened, with emphasis on the training of research leaders. Good progress has been made with training courses for laboratory staff although the sheer weight of numbers has posed financial problems and too great a demand on the time and efforts of the limited number of senior staff. Potential research leaders have been trained by fellowships abroad, but many or most of them have subsequently been attracted away from the Bureau of Soils by offers of better salaries and/or better opportunities. The Soil Fertility and Research Divisions were particularly hard hit in this way.

iii. strong recommendations were made for close links with research and for joint work with research and soil fertility divisions. The Philippine Council for Agricultural Research was established and this has done much to rationalise agricultural research effort. Within the Bureau there is still room for improvement in cooperative work among divisions. A main constraint is the lack of funds which has affected all aspects. Nevertheless, the situation is improving and, if the "Team Leader plus Team" approach were established to cross divisional boundaries, even better progress could be made.

Some other aspects which reflect the institutional and organizational problems of soil testing services in the Philippines are outlined in the next sections.

8.1 Buildings

Limited funds for building led to the use of the cheapest materials in many cases and maintenance has been a problem. Rehabilitation is required and is being implemented.

Plans for new Central Laboratories reflect the lack of the architects' experience in laboratory design and the restrictions imposed by having to fit laboratories into a pre-conceived exterior design.

Locations are usually good in that the laboratories are attached to the Bureau of Soils Offices where the staff have contact with officers from other divisions, but the laboratories are seldom linked to experimental stations, urban locations being preferred because of water and electricity supplies and other facilities.

Despite their urban location, many laboratories have poor water and electricity supplies and this has interfered seriously with instruments and work output.

8.2 Equipment

In general the equipment has lasted well but many instruments are reaching the stage of almost being beyond repair (spare parts being unavailable) and replacements are needed although unobtainable for lack of funds. On the other hand, the Provincial Development Assistance Programme funds have often been spent on ill-suited items, the Bureau of Soils not having been consulted on details of makes and models. This has led to an undesirable complexity of different types of instruments.

A good development has been that of a Maintenance Section although their efforts are often frustrated by lack of spares, tools, instrument kits for repairs and many miscellaneous items required in a well-equipped workshop.

8.3 Staff

The loss of well-trained qualified staff has been mentioned above. Once again, this can be ascribed to budget limitations which, in fact, affect all levels of staff. There are insufficient "permanent" staff positions and many are employed on a temporary basis. This is not good for staff morale or continuity of reliable output and leads to resignations and many inter-sectional transfers.

9. CONCLUSIONS

There have been development and organizational problems in the soil testing services of the Philippines but the services are well established and have gained very good acceptance by farmers.

The problems are recognized and the solutions to most of them are known. Financial limitations are a main restraint postponing their solution, but these financial problems of the Bureau reflect the abnormally difficult few years through which the country as a whole has been passing. The Philippines are not alone in this respect, however, and all countries look forward to the resurgence of world economy which will allow expansion of their development programmes in such important fields as soil testing services.

REFERENCES

CASTENSON, R.F. Operation and management of a commercial soil testing and plant analysis
1973 laboratory. Chapter 27 in Soil Testing and Plant Analysis. Soil Sci. Soc. Amer. Madison, Wisconsin. 491 p.

CHANG, S.C. Report of the Soil Chemist. UNSF/FAO Project Soil Fertility Survey and
1967 Research in the Philippines. FAO, Rome.

CHANG, S.C. Some reseach needs of fertilizer management of rice in Southeast Asia.
1976 Extension Bulletin No. 71. ASPAC, Food and Fertilizer Technology Centre, Taipai.

COLWELL, J.D. Computations for studies of soil fertility and fertilizer requirements.
1975 AGL/MISC/75/1, FAO, Rome.

FAO A standard guide to soil fertility investigations on farmers' fields. Soils
1970 Bulletin No. 11, FAO, Rome.

FERGUSON, W.R. Practical laboratory planning. Applied Science Publishers Ltd., Barking
1973 Essex, England. 147 p.

ISMUNADJI, M. and VON UEXKULL, H.R. Comparative values of chemical fertilizers for
1976 paddy rice. In "The fertility of paddy soils and fertilizer application for rice." ASPAC, Taipei.

OECD. Toward new forms of cooperation in development. Development Centre, Organization
1975 for Economic Cooperation and Development. Liaison Bulletin No.1: 49-56.

ULBRICHT, T.L.V. Priorities in agricultural research. Food Policy, 313-319.
1976

WELCH, C.D. and WEISE, R.A. Opportunities to improve soil testing programmes. Chapter
1973 1 in Soil Testing and Plant Analysis. Soil Sci. Soc. Amer. Madison, Wisconsin. 491 p.

YOUDEN, W.J. and STEINER, E.H. Statistical manual of the AOAC. Association of Official
1975 Analytical Chemists, P.O. Box 540, Benjamin Franklin Station, Washington. 88 p.

AGENDA

Monday, 13 June 1977

10.00 – 12.00		Opening
		Introduction
	1.	Review of the present status of soil testing for fertilizer recommendations and improvements of soil fertility. F.G. Viets (USA)
14.00 – 17.00	2.	Review of the present status of plant testing. A. Cottenie (Belgium)
		The operation of soil and plant testing services in some countries
	3.	Operation of soil and plant testing services in the USA. A. Mehlich (USA)
	4.	Operations of soil and plant testing services in Japan. S. Motomura (Japan)

Tuesday, 14 June 1977

09.00 – 12.00	5.	Operation of soil and plant testing services in Bulgaria. I. Garbouchev (Bulgaria)
	6.	Operation of soil and plant testing services in Kenya. G. Hinga (Kenya)
	7.	Operation of soil and plant testing services in India. V.K. Mutatkar (India)
14.00 – 17.00	8.	Operation of soil and plant testing services in the Dominican Republic. G. Tirado (Dominican Republic)
	9.	Problems in setting up soil testing laboratories in developing countries. R.G. Menon (Tanzania)
		General review of the methodology
	10.	Problems connected in soil testing for phosphorus and potassium. H.W. Fassbender (Federal Republic of Germany)
	11.	Soil diagnosis and plant diagnosis in K nutrition and fertilization. A. Loué and J. Quémener (France)
	12.	Scope and possibilities of soil testing for nitrogen. C.M. Smith (USA)

13. Soil testing for soluble nitrogen as an aid for calculating nitrogen fertilizer recommendations.
J. Dressel (Federal Republic of Germany)

Wednesday, 15 June 1977

09.00 - 12.00

14. Methodology in the determination of micronutrients.
M. Sillanpää (Finland)

15. Principles and practices in plant analysis.
B. Evenhuis (The Netherlands)

16. Plant analysis as an aid in some tropical crops' fertilization.
H.C. Okoye (Nigeria)

14.00 - 17.00

17. Calibration of methods and correlation of analytical data and field fertilizer results.
F. van der Paauw (The Netherlands)

Interpretation and transfer of soil and plant testing results

18. Ecological and agronomical information required in soil testing interpretation.
K. Shaw (United Kingdom)

19. Use of computers for data processing and interpretation of soil testing results.
J.C. Remy (France)

Thursday, 16 June 1977

09.00 - 12.30

20. Extension of soil testing results and fertilizer recommendations to the farmers.
B. van Raij (The Netherlands)

Instrumentation

21. Equipment for soil sampling and routine laboratory analyses.
G.M. Jonas (Philippines)

22. Training needs of developing countries in soil testing.
E.J. Thompson (Ghana)

23. Institutional and organization problems in developing countries in the organization of soil testing services.
G. Arnott (Philippines)

14.00 - 17.00 Afternoon discussions of Working Groups

Friday, 17 June 1977

09.30 - 12.30 Discussions and recommendations

Closing

LIST OF PARTICIPANTS

BELGIUM	Prof. Dr. A. Cottenie State Agricultural University Coupure Links 533 9000 Ghent
BULGARIA	Prof. Dr. I. Garbouchev N. Poushkarov Institute of Soil Science Shosse Bankja Street, 5 Sofia
DOMINICAN REPUBLIC	Mr. Gustavo Tirado Director del Departamento de Suelos CNIECA - Casilla de Correo 24 San Cristóbal
FINLAND	Prof. Dr. M. Sillanpää Institute of Soil Science Maantutkimuslaitos 01301 Vantaa 30
FRANCE	Dr. J.C. Remy Station agronomique de Laon Rue F. Christ 02011 Laon
	Mr. Roche Institut Mondial du Phosphate 8, rue de Penthièvre 75008 Paris
	Mr. A. Loué Service Agronomique Société Commerciale des Potasses et de l'Azote 2, Place Général de Gaulle Cédex BP 239 68053 Mulhouse
GERMANY, FEDERAL REPUBLIC OF	Prof. H.W. Fassbender Forstlichen Facultät Georg-August Universität Göttingen
	Dr. J. Dressel Landwirtschaftliche Versuchsstation BASF 6703 Limburgerhof
GHANA	Dr. E.J. Thompson University of Ghana Faculty of Agriculture Legon

INDIA	Mr. C.K. Mutatkar Chief, Planning and Development Division Fertilizer Corporation of India Ltd. Sindri Bihar
JAPAN	Dr. Satoru Motomura Head, Soil Laboratory Chemistry Department National Institute of Agricultural Science Nishigahara Kita-Ku Tokyo
KENYA	Mr. G. Hinga Senior Soil Chemist Ministry of Agriculture National Agricultural Laboratory P.O. Box 30028 Nairobi
NETHERLANDS	Mr. F. van der Paauw Bodemkundig Institute Haren Groningen
	Mr. B. Evenhuis Head, Chemical Laboratory Royal Tropical Institute Amsterdam-Oost
	Mr. B. Van Raij Laboratory of Soils and Fertilizers De Drayan 3 Wageningen
	Ir. A. Muller Head, Tropical Soil Division Department of Agricultural Research Royal Tropical Institute 63 Mauritskade Amsterdam-Oost
NIGERIA	Mr. H.C. Okoye Nigerian Institute for Oil Palm Research P.M.B. 1030 Benin City
PHILIPPINES	Mr. G.M. Jonas Bureau of Soils Sunvesco Bldg. Taft Ave. cor. T.M. Kalaw St. Manila
TANZANIA, UNITED REPUBLIC OF	Mr. R.G. Menon Project DP/URT/73/006 National Soil Service P.O. Box 1385 Tanga

UNITED KINGDOM	Dr. K. Shaw Regional Soil Scientist Agricultural Development and Advisory Service Ministry of Agriculture, Fisheries and Food Northern Region Government Buildings Kenton Bar Newcastle upon Tyne, NE1 2YA
	Mr. H. Ashby 7 Lenton Road Oxford
UNITED STATES OF AMERICA	Mr. A. Mehlich North Carolina Department of Agriculture Agronomic Division Blue Ridge Road Center Raleigh North Carolina 27611
	Mr. F.G. Viets 102 Yale Way Fort Collins Colorado 80521
	Mr. C.M. Smith North Dakota State University Fargo North Dakota 58102

FAO Staff

Dr. R. Dudal - Director, Land and Water Development Division, AGL

Dr. P. Arens - Technical Officer (Soil Survey), AGLS

Mr. H. Braun - Technical Officer (Soil Fertility), AGLS

Mr. T.L. Chan - Technical Officer (Soil Fertility), AGL

Dr. F.W. Hauck - Chief, Soil Resources, Development and Conservation Service, AGLS

Dr. F.I. Massoud - Technical Officer (Soil Reclamation), AGLS

Mr. M. Mathieu - Manager, Fertilizer Programme, AGL

Dr. H. Matsuo - Technical Officer (Soil Fertility, Research and Training), AGLS

Dr. C.S. Ofori - Technical Officer (Soil Fertility), AGLS

Dr. J. de la Vega - Technical Officer (Fertilizer Programme Operations), AGL

Mr. D. Westcot - Technical Officer (Agricultural Water Quality), AGLW

Mrs. P. Bottega - Secretary

Miss H. Tonkin - Editorial and Meetings Assistant, AGL