INTERNATIONAL SOCIETY OF SOIL SCIENCE

JOINT MEETING OF COMMISSION II
(*Soil Chemistry*)
AND
COMMISSION IV
(*Soil Fertility and Plant Nutrition*)

DUBLIN, JULY, 1952

TRANSACTIONS

VOLUME II

ISRIC LIBRARY
PRO 2
52.01
Wageningen, The Netherlands

1082

PRINTED AT PARKGATE PRINTING WORKS
DUBLIN BY CAHILL & CO., LTD.

CONTENTS OF VOLUME II

Opening Session

	Page
Address by Mr. Thomas Walsh, Minister for Agriculture	11
Address by Dr. Michael Tierney, President, University College, Dublin	12
Address by President of Meeting	12
General Lecture for Meeting by Dr. E. M. Crowther	14

Section A

Session 1—Organic Matter and Nitrogen

	Page
Sessional Discussion	25
Scheffer, F. und Welte, E.—Über Ziele und Wege der modernen Huminstoffforschung	29
Hende, A. van den ; Cottenie, A. ; and Vlieghere, R. de—Preparation and Appreciation of Artificial Organic Manure	37
Barjac, H. de et Pochon, J.—Processus de Dénitrification dans ses Rapports avec la Microflore Totale	48
Coppier, O. et Pochon, J.—Recherches sur le Phénomène de nitrification en Rapport avec la Microflore	52
Jacob, A.—Die Wirkung der Düngung mit Mineralischen Stickstoff auf die biologischen Eigenschaften des Bodens	56
Lehr, J. J. and Veen, B.—Nitrogen Economy of the Soil in relation to Seasonal and Periodical Climatic Variations	61
Mattingly, G. E. G.—A Note on the Available Nitrogen of Composts from Waste Materials	68
Pochon, J. et Coppier, O.—Étude sur deux Cas Precis des Rapports entre la Microflore et la Fertilité d'un Sol	71
McDonnell, J. J. and Murphy, Miss C. M. B.—A Semimicro Kjeldahl Method for Nitrogen Determination Employing the Conway Microdiffusion Technique	74

Session 2—Phosphates

	Page
Barbier, G. et Tyskiewicz, Mlle. E.—Mobilité des Ions Phosphoriques " Fixés " dans le Sol, Étudiée au Moyen de P_{32}	79
Sessional Discussion	82
Williams, E. G. ; Reith, J. W. S. ; and Inkson, R. H. E.—Readily Soluble Phosphorus Values and Crop Responses for Different Soils	84
Bould, C. ; Nicholas, D. J. D. and Thomas, W. D. E.—Radiation Effects with $Phosphorus_{32}$ in Barley and Tomato Plants grown in Soil	92

Page

CARQUÉ, E.—The Adaptability of Rapid Test for Available Phosphorus in the Central Ebro Valley Soils 95
FERRARI, C.—A New Chemical Procedure for the Determination of the Soluble Phosphates of Soil 99
SANDRI, G.; CORADUCCI, P.; and LUGO, P.—The Determination of Soluble Phosphates in Acid and Sub-Acid Soil by the New FERRARI Procedure 103
HERNANDO, V. and JIMENO, L.—Studies on Phosphate in some Spanish Rice Soils 107

Session 3—Potash

MIDDELBURG, H. A.—Potassium and Calcium Interrelationships in Tropical Soils and in Tobacco Leaves 116
Sessional Discussion 121
GARAUDEAUX, J.; QUIDET, P.; et MALICORNET, H.—Essais en Pots et de Plein Champ sur l'Utilisation des Reserves Potassiques du Sol 126
FRANC DE FERRIERE, P. J. J.—Action des Engrais Potassiques sur la Pomme de Terre et Nature Minéralogique des Argiles . 132

Session 4—Calcium and Lime Requirement

Sessional Discussion 134
PLANT, W.—Field Aspects of Soil Acidity using Indicator Plants . 140

Session 5—Magnesium and Minor Elements

Sessional Discussion 143
JENSEN, H. L.—Biological Estimation of Magnesium in Soil . 153
NICHOLAS, D. J. D.—Some Aspects of the Use of Fungi as Test Organisms for Determining Mg and Trace Metals in Soils and Plants 158
JONES, L. H. P.—A Note on the Reduction of Manganese in Neutral to Alkaline Soils 164
WALSH, T. and GOLDEN, J. D.—The Boron Status of Irish Soils in relation to the occurrence of Boron Deficiency in Acid and Alkaline Soils 167
BOULD, C.; NICHOLAS, D. J. D.; and TOLHURST, J.—Copper and Zinc Deficiencies in Soil and Fruit Trees in Britain . . 172
PLANT, W.—The Molybdenum Content of some Brassicae and Lettuce Crops in Acid Soils 176
WALSH, T. and FLEMING, G. A.—Selenium Levels in Rocks, Soils and Herbage from a High Selenium Locality in Ireland 178

Session 6—Base Exchange, Nutrient Balance and Interactions

Sessional Discussion 184
BOLLE-JONES, E. W.—A Study of the Interrelationships of Iron and Potassium in the Potato Plant 186

SECTION B Page

Session 7—Field Experiments and Pot Culture Techniques

BOGUSLAWSKI, E. VON—Der Gefässversuch zur Bestimmung der Bodenfruchtbarkeit 195
Sessional Discussion 225
FERRARI, TH. J.—The Experimental Design with Single Plots and the Graphical Method of Statistical Analysis of Data . 231
HEWITT, E. J.—The Use of Sand Cultures for the Study of Mineral Disorders, especially Micronutrient Deficiencies . . . 240
JEWITT, T. N.—Seasonal Variations in Cotton Yields in the Sudan Gezira and Soil Fertility 243
ROSEAU, H. et BATS, J.—Observations sur la Solution du Sol Dite d'été en Cases Lysimetriques 248
RAYCHAUDHURI, S. P. and SUBBIAH, B. V.—Phosphate Manuring of Legumes and its Role in the Building of the Fertility of Indian Soils 253
ELGABALY, M. M.—Effect of Fertilizer Treatment on Yield and Composition of Sugarcane in Upper Egypt 259
ELGABALY, M. M.—Effect of Fertilizer Treatments on Yield of "Mounufi" Cotton in the Northern Part of the Delta . . 261
SCHUFFELEN, A. C.; LEHR, J. J.; and ROSANOW, M.—The Technique of Pot Experiments 263

Session 8—Plant Diagnostic Methods

Sessional Discussion 269
NICHOLAS, D. J. D.—Mineral Status of Cereals in Relation to Final Yields. 1. Potassium Status of Barley. 2. Manganese Status of Oat 278
NICHOLAS, D. J. D.—The Use of Macerators for Extracting Macro- and Micro-Nutrients from Fresh Plant Tissues . . 283
HOMES, M. V.—The Determination of Plant Nutrient Requirements 288
VANSTONE, F. H.—A Quantitative Flame Spectographic Method for Plant Material 292

SECTION C

Session 9—Survey Methods Evaluating Fertility Levels

Sessional Discussion 297

Session 10—Methods Used in Soils Advisory Services

Sessional Discussion 300
HENDE, A. VAN DEN and COTTENIE, A.—Soil Fertility in Belgium 304
HENDE, A. VAN DEN; COTTENIE, A.; and JONGHE, P. DE—The Value of some Methods for Chemical Soil Analysis applied to different Belgian Soil Types 307
TOVBORG JENSEN, S.—Laboratory Methods for Determining Soil Fertility 318

PAGE

WALSH, T.; RYAN, P. F.; and MCDONNELL, J. J.—Methods used in the Application of Soil Analysis to the Manurial Problems of Irish Soils 326
PASSERINI, G.—Soil Fertility Evaluation in Italy . . . 336
DAVIES, E. B.—The New Zealand Soil Advisory Service . . 340
LÅG, J.—Methods of Soil Fertility Evaluation used in Norway . 349
MCCONAGHY, S. and MCALLISTER, J. S. V.—The Evaluation of the Available Phosphate Status of Agricultural Soils in Northern Ireland 354
PIZER, N. H.—Evaluation of Soil Analysis for Advisory Purposes 364
SMITH, A. M. and SIMPSON, K.—The Assessment of Soil Fertility for Advisory Purposes by means of *Aspergillus Niger* . . 373
WHITTLES, C. L.—The Methods Employed in the Routine Examination of Soils at the West of Scotland Agricultural College 379

Session 11—*Correlation of Data*

Sessional Discussion 391

Closing Session

International Co-operation in Field Experiments on Soil Fertility 394
List of Delegates 400
Index of Authors 403

President :

F. STEENBJERG (Denmark).

Session Chairmen :

Session 1 : H. J. PAGE (Trinidad)

Session 2 : J. A. PRESCOTT (Australia)

Session 3 : T. WALLACE (United Kingdom)

Session 4 : P. BRUIN (The Netherlands)

Session 5 : S. HENIN (France)

Session 6 : R. K. SCHOFIELD (United Kingdom)

Session 7 : E. M. CROWTHER (United Kingdom)

Session 8 : F. STEENBJERG (Denmark)

Session 9 : H. KURON (Germany)

Session 10 : W. L. NELSON (United States of America)

Session 11 : P. H. GALLAGHER (Ireland)

OPENING SESSION

Monday, 21st July

PRESIDENT: Ladies and Gentlemen, it is with the greatest pleasure that I welcome you all to this International Soil Fertility Meeting here in Dublin. I would particularly like to say how pleased we are to have with us His Excellency The Minister for Agriculture who will now open our Conference officially.

Address by MR. THOMAS WALSH, *Minister for Agriculture*

It is with great pleasure that I welcome you to this Meeting of Commissions II and IV of the International Society of Soil Science. Your Society has since its foundation done very valuable work in furthering co-operation on an international basis in the field of soil science and this is one more and, I have no doubt, a very significant step in the advancement of that important work. Consequently this country was deeply honoured to be called on to provide facilities for this Meeting and we were most happy to give our consent.

Soil science to-day has developed several separate fields of study. Your meeting here will be concerned with the very important and closely related fields of soil chemistry, soil fertility and plant nutrition. These are subjects of crucial importance to all our countries because the soil itself and its yielding ability are the fundamental factors influencing production from the land. It is now obvious that in order to make the best use of our soils we must rely increasingly on scientific methods. We can all greatly assist one another by the fullest possible exchange of information on the results of our researches and on our experiences in the application of these results. I feel, however, that in order to secure the widest and most expeditious application of new developments we must strive for greater uniformity in our methods of both field and laboratory investigation. You as experts hold the key to attainment of this important objective and I have no doubt that it is a consideration which is foremost in your minds.

To-day the need to increase the world's food supply and to lower the cost of its production is a matter of great urgency. Large areas of the world are experiencing food shortages of varying degrees, amounting to famine or near famine conditions in certain cases. There is a growing awareness of the need for increasing international co-operative effort to relieve these conditions, and the fullest exploitation of our individual agricultural resources has become a problem of first rate importance and urgency.

I am aware that in many of your countries great progress has been made in soil research and in the application of the results of this research to farming problems. In Ireland we realise that in this sphere of work we have considerable leeway to make up as it is only in recent years that an organised soils advisory service has been established. As in every old country, however, there is in Ireland a considerable volume of traditional experience in the use of fertilisers and in soil fertility maintenance while a comprehensive system of field experiments which have yielded very valuable results has been in progress for the past half century. We have, therefore, a considerable background

for the scientific methods now being applied to the solution of our soil fertility problems and I am happy that the progress of this work has been relatively rapid. During your time in this country an opportunity will be provided for you to see some aspects of our activities in this field and we will welcome your advice and criticism. Indeed, many of you have already given invaluable assistance to our scientific officers in the development of their work and for that we are deeply grateful. I hope that you for your part will find in our methods and experiments something that is new as well as valuable inspiration. Finally, may I wish your deliberations every success and express the hope that your visit to Ireland will be both fruitful and pleasant.

PRESIDENT: DR. TIERNEY, President of University College, Dublin, who has facilitated this Meeting in every possible way will now welcome you here.

Address by DR. MICHAEL TIERNEY, *President, University College, Dublin*

DR. TIERNEY: I am very happy to welcome to University College, Dublin, the delegates to this Conference. We in the University are fully aware of the importance of research into the constituents of the soil and we hope that the deliberations of the Conference will throw light on the many and varied problems affecting the work of soil research. I wish the Conference every success.

Address by President of Meeting

PRESIDENT: We are indeed very grateful to the Minister for Agriculture and to DR. TIERNEY for honouring us with their presence here this morning. Our grateful acknowledgment is certainly due to the Irish Department of Agriculture and all their co-workers for organising this Conference and the excursion which follows through the important agricultural districts in Ireland.

At the final discussions of the Section on Soil Fertility in Amsterdam, in 1950, you remember that a proposal was made for a conference on Soil Fertility in Ireland in the Summer of 1952. There were two things in favour of such a conference. Firstly, the Congress in Amsterdam, in 1950, had so many sections that it was impossible to discuss the fertility questions arising with all the persons who were interested, and, secondly, the next Congress in the Belgian Congo, would be very expensive to attend and so many interested persons would have to wait at least nine years for a full meeting which would be particularly regrettable in view of the steadily more pressing food situation.

We are all aware, as has been pointed out by the Minister, that the potential food requirements are far in excess of the quantity of food man to-day is able to supply and distribute. Soil scientists are well aware of the contributions they can make to the solution of this world food problem when given the opportunity.

On behalf of the Commission of Soil Fertility and Plant Nutrition, DR. CROWTHER at Amsterdam recommended to the Council of the International Society of Soil Science that a conference should be held

in Ireland in 1952 or 1953. This Commission then invited the Commission of Soil Chemistry (Commission II) to hold a joint meeting in 1952 here in Dublin.

The main function of this Meeting should be to discuss as fully and as critically as possible the present techniques available for the evaluation of soil fertility in relation to improved crop production.

In Section A, which comprises six Sessions, the laboratory techniques for determining the nutrient status and the nutrient supply and potential of the soil will be discussed. Further plant and field techniques used in evaluation of soil fertility will be discussed in Section B, and in Section C all technical principles with respect to the correlation of the different laboratory tests with the growth and production of the crops in the field will be summarised and discussed. Verification of the tests is not the least important and interesting problem.

Ladies and Gentlemen, as you will understand, there is no doubt that we have a very busy week before us ; a week which will be paved with hard work and especially with discussions on all topics related to the assessment of soil fertility, with special consideration perhaps to the chemical aspect of this problem.

This Conference is your conference, the more so as you contribute to the discussions, which on our opinion, ought to form the most important contribution of this Conference to future investigations on diagnosis of soil fertility by laboratory tests of different kinds. We are, therefore, looking forward to you with respect to a critical and constructive discussion.

Ladies and Gentlemen, our Conference has been officially opened and we shall begin our programme. My first act during the Second Part of the Opening Session shall be to ask DR. CROWTHER to give the introductory lecture of this Session. DR. CROWTHER will speak on the Assessment of Soil Fertility.

THE EVALUATION OF SOIL FERTILITY

E. M. CROWTHER

Rothamsted Experimental Station, England

At the Fourth International Congress of Soil Science held in Amsterdam, 1950, it was urged that a special conference should be convened in 1952 " to discuss as fully and as critically as possible the present techniques available for the evaluation of soil fertility in relation to the improvement of crop yields." The time is certainly opportune. Within a dozen years or so we have passed from the frustration of so-called " over-production " to an urgent need for increasing agricultural output per acre and per man-hour. The world population grows more rapidly than the food supply. In many parts of the world, social and political unrest are aggravated by food shortage and low standard of living. In other parts, economic and political restrictions on international trade focus attention on producing more food and raw materials at home.

Many new things were learnt under the stress of war. In some countries fertilizer consumption rose rapidly. In a dozen years the consumption of NPK fertilizers trebled in the United States and the United Kingdom. In these countries, as in many others, it is realized that fertilizers must be used in steadily increasing quantities for many years to come, but they must also be used more efficiently. In the United Kingdom the area of tillage land was increased by a half within a few years, and good crops were grown on previously neglected fields or on what had been regarded as infertile soil. In the occupied countries there was less drive for food production and there was an acute shortage of raw materials but well-farmed land was found to maintain its productivity longer than had been expected. The residual values of phosphorus fertilizers had been underestimated. Perhaps the main lesson from wartime experience was that the study of soil fertility and the development of new techniques should be directed not merely to maintaining and cheapening production under current methods of farming but to changing these methods, sometimes quite drastically. The object should be to find new ways of cropping, cultivating and manuring which are better fitted, on the one hand, to local soils and climates and, on the other, to the prevailing economic and social conditions. The vast potentialities for improvement are so intimately interlocked with other factors that it is pointless to guess the likely rates of development.

In spite of the great progress made in recent years, there are still many obstacles to applying what is known and to obtaining new knowledge. Before we turn to details in our technical sessions, it may be worth while considering some of these more general aspects.

Except in a few countries such as Denmark, where the pattern and standard of farming are fairly uniform, soil fertility and agricultural output tend to vary widely over quite small distances. Good farmers commonly manure crops well or even extravagantly, whilst their neighbours allow fields to become weedy, acid and acutely deficient in nutrients. It is not difficult under these conditions to establish fair correlations between crop production and soil or plant analyses, but such correlations may be misleading. So many factors are involved

that, without critical experiments, it is often difficult to isolate the causal one apart from the skill of the farmer. Similarly, it is easy to show a high correlation between fertilizer consumption and the value of agricultural output among the countries in Europe or the individual States in the United States. The general level of fertilizer consumption is determined much more by the system of farming and the proximity to markets—or, in other words, by farm income—than by the inherent soil conditions. On a still wider scale, systems of farming are restricted to certain broad patterns by climatic conditions, mainly the seasonal distribution of rainfall and temperature, but these conditions also determine important soil characters. Chernozem soils are rich in organic matter and plant nutrients because cold winters and hot summers retard the decomposition of plant residues. These conditions also limit crop growth. Chernozem soils must, therefore, be farmed extensively at a low level of output. They may be regarded as having high capital and a slow rate of turnover. By contrast, the prolific vegetation of wet tropical forests is carried by soils with low reserves of plant nutrients which are, however, replenished by the rapid decomposition of dead leaves and branches. These soils have low capital and a high rate of turnover.

Climatic, soil, social and economic conditions vary so widely and interact so profoundly that theories and techniques on soil fertility questions may have only limited value outside the range of conditions for which they were established. A good deal of effort has been wasted in the past by overlooking this point.

A common difficulty in approaching soil fertility problems arises from the need for combining research, advisory and educational work. To avoid using technical jargon in talking to farmers and students some chemists express the results of their soil analyses in popular terms, such as "humus," "lime requirement" and "available phosphoric acid." In the course of years, as the students become farmers, advisory officers, industrialists, administrators or professors of agriculture, they not unnaturally come to treat these simple words as meaning something definite and scientific, and to believe that the hard work required for solving agricultural problems, especially in newly developed areas, can be avoided by calling in a soil chemist to do a few rapid tests.

Another general difficulty arises from the historical circumstances that the science of agricultural chemistry began in Western Europe just over a century ago at a time when farmers there were beginning to buy imported feeding stuffs for their animals and thus to produce more and better farmyard manure with which to improve their crops. The success of the new methods tended to support the old common-sense view that plants feed on soil organic matter and bulky manures in much the same way as animals feed on plants. As long-term experiments on the cumulative and residual effects of farmyard manure, crop residues and crop rotations are difficult to carry out, the old view died very slowly. The practical excellence of farming systems based on short-term leys (or "sown pastures") utilized by livestock is established in many countries under a wide range of conditions, but much still remains to be done in making detailed analyses of the mechanisms by which soil fertility is built up. Methods for maintaining soil organic matter also conserve plant nutrients, often in forms

which are slowly liberated throughout a growing season. The leys allow nitrogen fixation and tend to improve soil structure. The rotation of crops, especially of tillage crops and leys, reduces the risk of the serious damage by pests and diseases. The danger in condensing all these possible effects into glib phrases about "stored-up fertility," "maintaining the humus supply" or "using animal nitrogen" was well illustrated during the ploughing-up campaign in England and Wales in the early 1940's. Surveys showed that farmers quite generally gave less lime and phosphate to their newly ploughed pastures than to their old arable land because they assumed that the pastures had stored humus and fertility. Much of the old grassland was, however, woefully acid and deficient in readily soluble phosphate. Some of it was deficient in potassium because grazing and hay-making had led to continued loss of potassium down the drains from the dairy-barns.

A good deal may have been lost in the past by stating the aims and methods of soil fertility studies in too vague and general terms. Perhaps the main objective is to find better methods for classifying soils and cultural practices, so as to give more confidence in forecasting the likely results of modifying current practices. The difficulties increase with the scale of the changes contemplated. Often little more is needed in advisory work than giving guidance in the local application of practices already well established nearby, perhaps on adjoining farms. Much more difficult and general problems arise where the whole system of crop production needs to be modified to take advantage of new scientific and technical developments or to meet drastic changes in economic or social conditions. The problems become particularly acute in some of the under-developed areas of the tropics, where the traditional methods of cultivation are proving quite inadequate for modern needs.

The approach to soil fertility problems requires the integration of several lines of investigation, generally undertaken by separate groups of specialists. These might be listed as :

1. The study of chemical, physical and microbiological processes in soils and of the physiology and biochemistry of plants.
2. The characterisation of soil and climatic conditions.
3. The examination and improvement of farming systems.
4. The production and application of increasing quantities of better and cheaper fertilizers and liming materials.

The application of new ideas and techniques developed in the pure sciences is, of course, of fundamental importance. Analytical techniques derived from new concepts have often led to notable advances in soil fertility studies. One of the most outstanding steps forward was SORENSEN's treatment of reaction in terms of pH values measured colorimetrically or electrometrically. For many years advisory officers have been able to give sound advice on liming, but pH values classify soils usefully for many other purposes. In humid temperate countries a low pH value is one of the most certain indicators of the need for phosphorus fertilizers. The molybdenum-blue method for phosphate analysis, followed by the introduction of photoelectric colorimeters greatly stimulated investigations on soil phosphate. Flame photometers may do much the same for soil potassium. Foliar diagnosis

by visual symptoms, injection, whole-plant or tissue analysis and sensitive microbiological assays for several trace elements have greatly extended the range of techniques for studying nutrient deficiencies. Radioactive isotopes provide an entirely new attack because it is now possible to distinguish between nutrients taken from the soil and from added fertilizers. Quite recently the possibility of using synthetic polyelectrolytes to stabilise soil crumbs has indicated a new experimental approach to the old problem of distinguishing the physical from the chemical and microbiological effects of crop residues and bulky organic manures.

Looking back over the history of several of the more novel methods of investigation it is possible to recognize a fairly uniform pattern. In the early stages the new technique reveals contrasts between extreme sites. It is then used over a wider range of conditions, until sooner or later its value ceases to be obvious. Thus, in the early 1920's simple pH tests on soils gave good guidance on the need for lime on the drier eastern parts of Britain, but in North Wales—a wetter area—the late Professor G. W. ROBINSON found pH values of little use in his advisory work on liming. He much preferred to use the exchangeable calcium or some related quantity. The method of analysis has to be selected for the prevailing climatic and soil conditions.

There is a vast variety of methods for estimating readily soluble phosphorus in soils, especially by extraction with dilute acids. Many of these methods have given serviceable information to chemists experienced in the technique and in the behaviour of local crops and soils, but have failed when used elsewhere. Alternative methods may give highly discordant results when applied to the same group of soils. It is partly for this reason that the use of the word " available phosphoric acid " is to be deprecated in expressing analytical results. The function of analytical methods is to characterize and classify soils and not to determine how plants feed. Uniform methods of analysis would be convenient for classifying soils over wide areas, especially in surveys of farm practice, but it is doubtful whether the time is yet ripe for formal standardisation. The most important immediate steps seem to be, first, to secure closer checking and calibration against results from series of field trials and, secondly, to define more precisely the range of general soil conditions in which each method proves serviceable. As a first step it may be sufficient to specify the useful range in terms of pH values or calcium carbonate contents. Thus, we have found the citric acid test serviceable on slightly acid or calcareous soils but of little or no value for very acid soils ; by contrast, leaching with acetic acid gave good results on acid soils and bad ones on calcareous soils.

The newest method for estimating the effective phosphate supply of a soil by isotope dilution is based on the assumption that the plant reacts in the same way to P_{32} and P_{31}. With suitable precautions this condition may be satisfied as far as the fertilizer phosphorus is concerned, and the plant phosphorus may then be divided into fractions derived from soil and fertilizer respectively. But a much more serious difficulty remains when attempts are made to use fertiliser containing P_{32} to estimate the supply of the effective phosphate from the soil. In soils capable of furnishing little phosphate to plants added fertilizer may greatly alter the way in which the

plant develops, especially by allowing the roots to explore the soil mass more quickly and thoroughly. In some unpublished results of recent Beltsville pot experiments, which I have been privileged to see, increasing additions of fertilizer often increased the amount of phosphorus taken up from the soil. The effective soil phosphorus increased as more fertilizer phosphorus was added. This example illustrates a common difficulty in soil fertility work. The plant's response to alterations in a single factor depends on the joint action of this and numerous other factors, many of which are necessarily ill-defined. It is often more efficient to experiment with moderate accuracy over a range of environmental and seasonal conditions, varying several factors experimentally and studying their interactions, than to strive for high accuracy under a single set of conditions. A somewhat similar difficulty arises in attempts to diagnose nutrient status and manurial requirements from plant analyses. In some of his earliest investigations Sir JOHN LAWES showed that the nutrient contents of various crops afforded little guidance to their relative responses to fertilizers. In work in which our President has played a leading part, it has often been found that, where the supply of one nutrient is inadequate, the final crop may have a fairly high concentration of this element. Adding moderate amounts of the element to the soil may markedly reduce its concentration in the final crop. It may, therefore, be difficult to diagnose deficiencies by plant or leaf analysis, unless several other factors are taken into account. The critical test is to show that yields can be increased by adding the element in question.

The problem of defining the background in soil fertility investigations is, of course, vastly simplified where the soils have already been classified and mapped in a soil survey and where the farming techniques are both well developed and fairly uniform over a region. Detailed soil maps designed for farm planning may have an embarrassing variety of soil series, types and phases, and some broader groupings must often be made before they can be used in soil fertility work.

The attack on soil fertility problems is particularly difficult in under-developed areas or where new crops or systems of cultivation are contemplated. It may often be more profitable to concentrate the early work on learning how to use alternative methods of cultivation and manuring and then comparing them than to rely on applying methods of soil analysis developed for quite different environments. For example, where, as in parts of Central Africa, composts and farm manures show marked residual effects, it might often prove more enlightening to initiate experiment on P and K fertilizers than to concentrate on means of building up the organic matter content of the soils. The added organic matter must disappear rapidly but the mineral nutrients associated with it may have marked residual effects on soils of low nutrient status. We have had similar experience in Southern England during the last few years in investigating the manuring of conifer seedlings and transplants on very poor and very acid soils, known to be capable of producing good plants if heavily treated with composts. We have obtained at least as good plants by inorganic NPK and Mg fertilizers but it took several years before we found how to use the fertilizers effectively and how to

plan long-term rotation experiments to test the cumulative effects of manuring with and without additions of organic materials.

In countries with temperate climates and well developed farming systems, a large part of soil fertility investigations is devoted to advisory work on manuring. There have been too few precise field experiments to settle with any confidence the general form of the equations or curves relating crop yields to amounts of added nutrients. Provided there are sufficient experiments for each of the principal crops with nutrients at three or more rates (e.g., 0, 1, 2) to obtain the approximate form of the curve, several simple equations will serve well enough to reduce to a common basis results from series of single-rate experiments in which the actual rates varied between experiments. When the standard responses to unit fertilizer dressings are established from a sufficient number of experiments, it is possible to calculate for given economic conditions the most profitable dressings for the average conditions covered by the experiments and then to make adjustments for any other information which can be used with confidence. Thus, for British conditions the most profitable dressings of phosphorus and potassium fertilizers, but not of nitrogen fertilizer, should be reduced where farmyard manure is given or where appreciable reserves of phosphorus and potassium are expected from recent manurial treatments or from soil analyses. It can be shown that fertilizers are used most efficiently where the dressings for each field on the farm fall by a constant amount below the most profitable dressings for the crop and soil concerned. Thus, in Britain, on fields where root crops need only moderate dressings of phosphorus or potassium fertilizer, cereals will need none. If the cereals really need phosphate, then the root crops will need quite heavy dressings. These principles were used successfully in rationing phosphorus and potassium fertilizers between farms in England and Wales from 1942 to 1947. For each farm basal allocations were made for each of the more responsive and valuable crops, with additional allowances where the soils were believed to be particularly deficient in either phosphorus or potassium.

Where a sufficiently large series of field experiments has been carried out and the soils tested by alternative methods of analysis, it is possible to see from the experimental results how far adjusting the manuring in accordance with the analytical results would have increased the over-all returns beyond what would have been obtained by manuring all fields the same way. The groupings or regressions would not, of course, be limited to single factors. pH values and other qualities easily assessed would be brought in. Since results by alternative methods are generally correlated, their relative merits might be assessed by seeing whether one method gives additional information on data already classified by another method.

Until we have much more extensive series of field experiments it is an interesting question to consider what kind of crop could most usefully be employed for testing the relative value of alternative analytical methods. At first sight a highly responsive crop such as potatoes might be thought suitable, but this crop appears to make particularly effective use of suitably placed fertilizers. It is thus a rather poor indicator of the status of the soil. In any event, all potato crops in Britain should receive some NPK fertilizer whatever

the soil analysis. Similarly, all swedes on acid soils should receive phosphate. Cereals in Britain respond well to phosphorus fertilizers only on phosphorus-deficient soils and there is much more opportunity with these crops for economy on the richer soils and for ensuring good responses on the poorer ones. There have, unfortunately, been relatively few fertilizer experiments on cereals in Britain on account of the trouble in harvesting and threshing experimental plots over a number of commercial farms. This defect may be overcome when small combines are used more generally.

As fertilizer distributors with controlled placement come into more general use it may prove economic to use small dressings of soluble phosphorus fertilizers as " starter-doses " to assist rapid establishment, even on soils already well supplied with reserves.

In spite of the large amount of attention given in soil laboratories to phosphate fixation there are singularly few field experiments showing how long phosphorus fertilizers continue to act on different classes of soil. There are a number of indications that the benefits may last for many years, though the gain in any one year may be small by comparison with that in the year of application. Quite apart from any reactions between soil and fertilizer, the residues from earlier applications lack the advantage of proper placement and may be said to suffer " positional unavailability." But repeated heavy applications will slowly overcome this defect and may build up large and useful reserves. A Rothamsted experiment still shows each year striking residual benefits from either superphosphate or farmyard manure given in heavy repeated dressings over fifty years ago, with none since. It is easy to detect the residues by rapid soil tests.

It is noteworthy, too, that countries such as the Netherlands which have used fertilizers heavily for many years are now increasing their consumption of nitrogen and potassium more rapidly than that of phosphorus and, also, that experimenters in many countries seem to encounter increasing difficulty in finding a set of highly responsive sites for testing methods of using phosphate fertilizers.

With restricted supplies of sulphur and sulphuric acid and a steadily increasing demand for fertilizers, increasing attention must be given to learning how to use alternative forms of phosphate fertilizers and then to evaluate them against superphosphate. Too often in the past materials have been compared only in pots or in field trials using a single heavy rate. It seems essential that at least one of the materials should be tested at two rates, e.g. single and double, to indicate how far the experimental conditions were sensitive to changing supplies and to determine what rates of the various materials would have given equal yields over the sensitive range. The experiments must, of course, be made at several centres and spread over several seasons to obtain fair averages.

In newer areas and for new crops, it will generally prove better to use factorial experiments testing two or three nutrients supplied in standard forms than to begin with materials which may be available locally at more attractive prices. The risk of losing valuable information by concentrating on the more immediately practical treatments may be illustrated by experience in improving poor hill grazing in Britain. The value of basic slag for manuring poor grassland has been known for fifty years and the use of heavy dressings before reseeding

such land with improved strains has been strongly advocated for the last twenty years. As basic slag supplies both calcium and phosphorus it was not known how much each element contributed and how much depended on their joint action. The ratio of calcium to phosphorus was left for the steel manufacturer to decide and little attention was given in the early experiments to limestone and superphosphate. More recently it has been realized that heavier dressings of limestone improved the sward and helped to maintain the sown species and that superphosphate or related materials could be used equally well to supply the phosphorus, provided limestone was given.

Some of the most difficult problems in soil fertility arise in analysing the long-term effects involved in rotational systems, especially in the tropics where in traditional native methods productivity falls rapidly after opening up land previously rested for many years, under bush. Before more intensive methods can be introduced with confidence it is necessary to know how far the improvement in fertility by resting the land from cultivation depends on organic matter, crumb structure, or the accumulation in the surface soil of nutrients brought up by deeply rooting plants. Very difficult problems arise too in interpreting the violent seasonal fluctuations in yield of annual crops often obtained in the tropics, even with irrigated crops. Long continued experiments with contrasted treatments provide one of the essential steps in trying to disentangle the effects of nutritional and disease factors.

In temperate countries practical men often describe soils as " worn-out " or " exhausted " by over-cropping, when the same kind of crop has been taken frequently. They often assume that the defect lies in the loss of organic matter, but detailed examination may disclose damage by diseases and pests or the deficiency of some nutrient. Where the traditional use of farmyard or stable manure has been replaced by heavy dressings of inorganic fertilizers and the level of production increased thereby, it must often happen that in time magnesium or some other element may become deficient relative to other nutrients and the level of production desired. There are still many unsolved borderline problems in intensive cropping in which pathological and nutritional factors appear to be jointly involved. Thus, so-called " partial sterilisation " by steam, formalin and many other materials in tomato-houses or seedbeds for tobacco and conifers checks pathogenic fungi, eelworms and nitrifying organisms. Similar benefits have been obtained for tobacco seedbeds in North Carolina by very heavy autumn dressings of urea and calcium cyanamide and for conifer seedbeds in England by acidifying the soils or by giving repeated top-dressings of ammonium sulphate. The ways in which these apparently unrelated treatments act are not yet known, but the responses on so-called " worn-out " soils are often most dramatic and it has often happened in soil fertility work that systematic experimentation or the critical investigation of an unusual observation has revealed an effective treatment before its mechanism was fully understood.

PRESIDENT: I am sure we are all grateful to DR. CROWTHER for this lecture on the evaluation of soil fertility. DR. CROWTHER has a very wide experience in all the aspects of this important problem and I take the opportunity to thank him for this excellent and comprehensive introduction to the work of the following days.

The Opening Session is now closed.

Section A

SESSIONS 1 TO 6

SESSION 1

ORGANIC MATTER AND NITROGEN

21st July. Chairman: H. J. PAGE (Trinidad)

H. LEES. Carbon and Nitrogen in Soils (Volume I, page 9)
G. DROUINEAU, G. LEFEVRE, et MME. BLANC-AICARD. Estimation de la Richesse des Sols en Azote et Aspects particuliers de ce Problème dans la Région Méditerranéenne (Volume I, page 13)
J. TINSLEY. Methods for Assessing the Organic Matter Status of Soils (Volume I, page 22)

SESSIONAL DISCUSSION

F. C. GERRETSEN: Referring to the paper of DR. DROUINEAU it may be pointed out that as the nitrogen in the soil is constantly transformed from soluble into insoluble inorganic compounds microbes, lignin–protein complexes, etc. and vice versa, it is very difficult to estimate which part of the total nitrogen will become available to the plant. In order to get at least some idea of the availability of the nitrogen in the soil we determine at daily intervals during two to three weeks the amount of CO_2 developed by the soil microbes in 0.5 kilogram of soil at 25°C.:

A. without any added nitrogen
B. with 5·0 and 20·0 mg. N as ammonium nitrate
C. with 2·5 gr. cellulose
D. with 2·5 gr. cellulose + treatment B.

From the curves obtained valuable conclusions may be drawn in a number of cases, i.e. when the addition of nitrogen results in a pronounced increased CO_2 production it is evident that the nitrogen present in the soil is insufficient for the mineralisation of the organic matter in the soil and that it is possible that when this soil is dressed with nitrogenous fertilizer part of the nitrogen will be used by microbes for mineralisation of the organic matter. When following the addition of cellulose without nitrogen there is a large increase in CO_2 evolution the soil contains a certain amount of directly available nitrogen. When, moreover, following the addition of cellulose + nitrogen the velocity of decomposition is the same as with cellulose alone, it is indicated that the soil contains plenty of nitrogen which is readily available for the cellulose decomposing micro-organisms so enabling them to act at maximum speed and probably also contains sufficient nitrogen for adequate plant growth. This method has, of course, its limitations one of which is that when there is a rapid turnover of microbial nitrogen into inorganic nitrogen and vice versa the increased CO_2 production might indicate a rather high availability of the nitrogen whereas it is questionable if the plants would be able to use this nitrogen. The investigations are still in progress at the Microbiological Department of the Agricultural Experiments Station at Groningen and the results of the above-mentioned experiments are compared with the yields of pot experiments and of field experiments in order to investgate to what extent dependable correlation exists between the different values.

A. JACOB: From the standpoint of the practical farmer one of the chief aims of the determination of the nitrogen and carbon content of the soil is to find a means to indicate the biological condition of the soil. From the papers read by DRS. LEES and DROUINEAU it is evident that this is rather difficult. My own experiments, the results of which are summarised in a paper in Volume II of the Transactions of this Meeting, confirm this difficulty. Consequently I would like to draw your attention to a more direct method of determining the biological condition of soils, namely the determination of their enzymatic activity. This method has been proposed by E. HOFMANN of Munich and has recently been highly recommended by Russian workers as an excellent means for characterising the biological conditions of soils. The principle of this method is as follows. All micro-organisms in the soil contain enzymes which may transform, for instance, saccharose into reducing sugars. The activity of these enzymes has an optimum at a certain pH which for saccharose is 5·5. In order to determine the enzymatic activity of a soil a sample of the soil is sterilized with tuluol and introduced into a buffer solution of pH 5·5. A solution of cane sugar is added and the mixture is kept at a temperature of 37°C for 23 hours. Reducing sugars are determined after the method of FEHLING.

HOFMANN was in a position to demonstrate by his method the influence of manuring on the biological conditions of the soil from different plots of fertilizer experiment fields. In my own investigations it was shown that biological activity decreased with increasing depth of the layers of soil. I think it would be interesting if this method were also tried by other institutes.

C. L. WHITTLES: Agricultural advisory officers apply a small dressing of a nitrogenous fertilizer to the crop when a deficiency of nitrogen is suspected. The yellow colour of the foliage may have been caused by a number of factors but if nitrogen deficiency is responsible it will be shown by a rapid change in colour. This procedure avoids the difficulties inherent in detecting nitrogen deficiency in the laboratory.

W. KUCZAROW: La remarque avait pour objet de préciser l'importance du choix de la méthode de dosage de la matrice organique dans les sols tropicaux.

Par suite de la fréquente présence dans ces sols du charbon de bois, l'emploi de toute technique pouvant le faire intervenir dans les résultats peut conduire à des erreurs.

La méthode de WALKLEY et BLACK appliquée au laboratoire de l'INIAC à Yongambi a donné satisfaction.

Il a été toutefois prouvé que dans les conditions d'oxydation décrites par WALKLEY et BLACK une partie de charbon de bois à l'état très fin peut être oxydée. Cet inconvenient peut être sensible dans les sols de sarane étant donné la finesse du charbon d'herbes laissé par les feux de brousse.

Des conclusions intéressantes concernant l'évolution du charbon organique dans les sols tropicaux sous végétation diverses (forêt, graminées diverses) ont peut être releveés par l'application de la méthode.

Un parallelisme étroit entre les résultats obtenus par la méthode de WALKLEY et BLACK et ceux obtenus par dosage de matrices humiques

précipitable par acidification de l'extrait au flourine de sodium a été observé dans de nombreux cas.

J. J. LEHR : In our laboratory an investigation was carried out by one of our research workers, who followed CAROLAN's method. This method was compared with the methods of ISCHTSCHEREKOV and of MCCREADY and HASSIM, the latter giving absolute results. In CAROLAN's method a slight alteration was made in so far as our test curve for the colorimetric determination was checked on oxalic acid ; known amounts of oxalic acid were oxidised and the readings were put into a graph. When applying this method to Dutch soils the carbon recovery was generally good and about 100% as checked against the method of MCCREADY and HASSIM. This indicates that it is possible to avoid the use of conversion factors for incomplete oxidation by applying an empirical method. At the same time we find some evidence that incomplete recovery of carbon does not exclusively depend on the presence of fractions that are difficult to oxidize (such as coal particles) but may be caused largely by incomplete oxidation of normal organic compounds such as oxalic or humic acid.

A. COTTENIE : In order to calculate the ratios $\frac{C}{N}$ and $\frac{N}{\text{total organic matter}}$ in artificial and natural organic manure carbon was determined by wet combustion with $KMnO_4$ and by dry combustion (ashing). In both cases the critical values for $\frac{C}{N} = 20$ and for $\frac{N}{\text{total organic matter}} = 0{\cdot}019$ were reached at nearly the same time during the decomposition. The limits between the $\frac{C}{N}$ ratios evaluated in artificial and natural organic manures are very different. In artificial manures the $\frac{C}{N}$ ratio lies between 50 and 10 and in natural organic matter between 15 and 10. Which methods of carbon determination should be suggested for the accurate determination of the $\frac{C}{N}$ and $\frac{N}{\text{total organic matter}}$ ratios in both organic manure and soil ?

R. CHAMINADE : Trois séries d'expériences ont été realisées pour préciser l'un des aspects des relations entre l'humus des sols et la nutrition minérale des végétaux.

1° *Essais en solutions nutritives* : Une dose d'humate calcique de l'ordre de 2 à 5 mg./litre provoque un accroissement de l'exportation d'éléments mineraux par les végétaux

2° *Essais de* NEUBAUER : Les quantités d'éléments minéraux exportées par les peaux de seigle dans les conditions des essais de NEUBAUER se trouvent accrues par l'addition au sol de 0,2% d'humate calcique

3° *Essais en vases de végétation* : Des essais en vases de végétation ont montré que des fumiers minérals apportant les 3 éléments N, P, K, ont eu sur le développement des végétaux et sur le rendement une action plus marquée après addition de 0,2 d'humate calcique pour 100 de sol.

S. TOVBORG JENSEN: The determination of "available nitrogen" or of "nitrogen deficiency" by soil analysis will hardly be possible because ammonia and nitrates are produced and consumed simultaneously. The actual content of these compounds at a given moment tells nothing about the rate of production or about uptake. Normally, all soils which have been under cultivation for a number of years will show nitrogen deficiency and respond to the application of nitrogenous fertilizer even if liberal amounts of farmyard manure are applied.

H. LEES: I agree entirely with PROFESSOR JENSEN. My own views on the matter are reflected in the stress I have laid on kinetic rather than static methods of determination.

W. FLAIG: Bei der Bedeutung der Bestimmung des Stickstoffs im Boden nach KJELDAHL wurde auf die alte Erfahrung aufmerksam gemacht, dass nach dieser Methode oft nur ein Teil des Stickstoffs als Ammoniale gefasst werden kann, während der Rest elementar entweicht. F. ZINNEKE (*Angewandte Chemie*, **64**, 220 (1952)) umgeht diese Schwierigkeit, indem er in einer geschlossenen Apparatur unter Zusatz von kolloidatem Palladium aufschliesst. Dabei entsteht nur elementarer Stickstoff, der sich volumetrisch bestimmen lässt.

H. L. RICHARDSON: In work done at Rothamsted many years ago mineralisable nitrogen (ammonium + nitrate produced on incubation under standard conditions) was determined on a number of soils from field experimental sites. It was found that

1. The production of ammonium nitrogen was sometimes appreciable and occasionally larger than that of nitrate nitrogen; thus it is not sufficient to determine nitrate production alone.

2. The relationship (inverse) between mineralisable nitrogen and the response to nitrogenous fertilisers was moderately good—as good as that found for phosphate and potash when the usual methods for available nutrients are compared with the fertiliser responses.

G. DROUINEAU: Ainsi que vient de l'indiquer le DR. JACOB les menues d'activité enzymatique présentent un grand intérêt. Malheureusement comme elles doivent être effectués à un pH déterminé elles sont généralement impossibles dans les sols calcaires.

H. LEES: I should like to make one concluding point on carbon and nitrogen determinations. When a method is being checked for its adequacy in giving absolute values for carbon nitrogen it is essential that the checking should be done on compounds that are difficult to break down. Soil organic matter is notoriously difficult to disintegrate and a carbon method that deals adequately with, for instance, sucrose may well fail when applied to soil organic matter. I suggest that all carbon methods should be tested against some polycylic such as cholesterol and all nitrogen methods against heterocylic compounds such as the quinolines. If the methods deal adequately with compounds of this type they are probably satisfactory for all compounds.

UBER ZIELE UND WEGE DER MODERNEN HUMINSTOFFFORSCHUNG

F. SCHEFFER UND E. WELTE

Agrikulturchemisches und bodenkundliches Institut der Universität Göttingen, Deutschland

Die Umwandlung der postmortalen organischen Substanz ist neben der Tonbildung der bedeutendste Vorgang der Bodenbildung. Durch chemische und biologische Eingriffe werden aus den pflanzlichen und tierischen Ausgangsstoffen bodeneigene Aufbaustoffe neu geschaffen, die mit besonderen Sorptionseigenschaften für Nährstoffe und einem grossen Vermögen, Wärme und Wasser nutzbar zu speichern, ausgestattet sind. Wir bezeichnen diesen Vorgang allgemein als Huminifizierung und die neu entstandenen mehr oder weniger braun gefärbten Substanzen als Huminstoffe.

Nun ist es nicht so, dass diese Huminstoffe als chemisch einheitlich anzusehen sind. Vielmehr stellen sie ein Gemisch von höher bis hochmolekularen Verbindungen dar, die in ihrem konstitutionellen Aufbau je nach Herkunft und Bildungsweise voneinander verschieden sind. Allen gemeinsam ist jedoch die dunkle Farbe, die physikalische Homogenität und eine gewisse biologische und chemische Resistenz insbesondere gegen Sauerstoff, weshalb F. SCHEFFER für diese Gruppe den Begriff "Dauerhumus" eingeführt hat. Ihnen gegenüber stehen die Stoffe der postmortalen organischen Substanz, die leicht zersetzbar sind und für die Mikroorganismen daher eine wertvolle Nahrungsquelle darstellen. Dieser sog. Nährhumus unterliegt einer weitgehenden Mineralisierung, soweit er nicht unmittelbar für den Baustoffwechsel der Bodenorganismen benötigt wird. Mit den schwer angreifbaren, nicht oder nur wenig huminifizierten Ausgangsstoffen (Wachse, Sterine, Harze u.a.) bildet der Nährhumus die Gruppe der Nichthuminstoffe, die zusammen mit den Huminstoffen den Humus, d.i. die gesamte organische Masse des Bodens, ausmachen.

Diese Begriffsbildung über Humus ist nicht in allen Ländern gebräuchlich. Dann wird unter Humus nur der dunkel gefärbte Anteil der bereits umgeformten organischen Ausgangsstoffe verstanden, ist also identisch mit unserem Begriff "Huminstoffe."

Als Folge einer solchen Einengung des Humusbegriffs wird allzu oft die Bedeutung der Nichthuminstoffe für die Bodenentwicklung und für die Erhaltung und Mehrung der Dauerhumuskomponente unterschätzt. Gerade der Nährhumus ist aber für die biologische Aktivität, Verwitterungsintensität und Krümelbildung, für die Produktion organischer Wirkstoffe (Antibiotika, Wuchshormone) sowie den ungestörten Spurenelementkreislauf und nicht zuletzt für die Steigerung der Assimilation (bodenbürtige CO_2) von allergrösster Wichtigkeit. Seine stoffliche Zusammensetzung und sein biologischer Wert sind ausserdem auf Menge und Qualität der Huminstoffe von stärkstem Einfluss.

Jedoch soll an dieser Stelle auf die umfassende Bedeutung der Nichthuminstoffe für die bodenbildenden Vorgänge nicht näher eingegangen werden, da die in den letzten Jahren gewonnenen Erkenntnisse auf diesem Spezialgebiet der Humusforschung (22) eine eingehendere Darstellung erforderlich machen.

Erwähnt sei noch, dass sich die Unterscheidung in Dauer-und Nährhumus in der Praxis bewährt hat, da der Landwirt bei der Handhabung der Humusdüngung etwas mit diesen Begriffen anzufangen versteht. Die Einteilung in Huminstoffe und Nichthuminstoffe besitzt in erster Linie wissenschaftlichen Wert. Sie bietet einen fruchtbaren Ansatzpunkt, die Aufgabe und Wirkung der organischen Substanz bei der Bodenentwicklung klarer zu erfassen und die Parallelität von Tonbildung und Huminifizierung im Boden deutlich erkennbar zu machen.

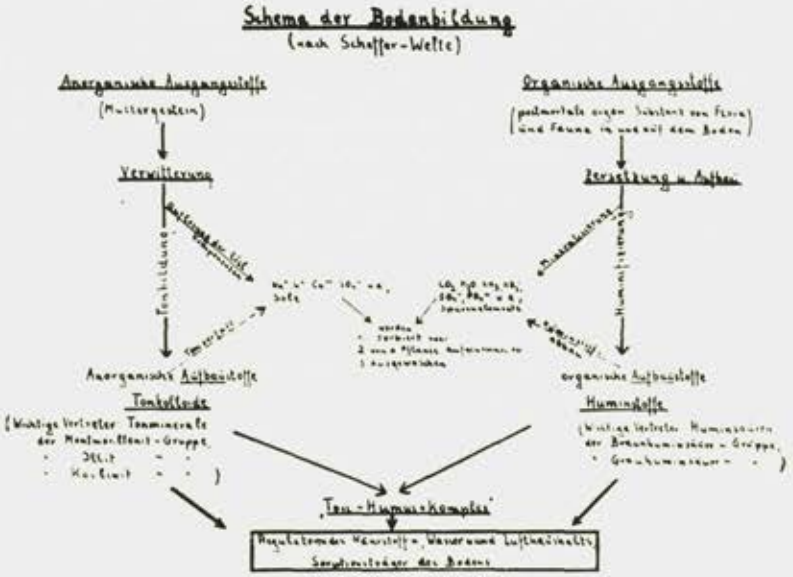


Abbildung 1

Man ersieht aus diesem stark vereinfachten Schema der genetischen Folge der Bodenentwicklung, wie die einzelnen Begriffe in der Reihe der anorganischen und organischen Komponente miteinander korrespondieren.

Unsere Kenntnis über die Entstehung der Huminstoffe ist in den letzten Jahren durch umfangreiche experimentelle Arbeiten erweitert worden. Die frühere Auffassung, dass in erster Linie das Lignin für die Huminstoffbildung in Frage kommt, wird heute in diesem Umfang nicht mehr vertreten. Vielmehr hat sich zeigen lassen, dass eine ganze Reihe von labilen Zwischenprodukten beim Abbau der organischen Ausgangsstoffe für die natürliche Huminstoffsynthese Bedeutung besitzen. Hinzu kommt eine Reihe von Endprodukten des Stoffwechsels der Bodenorganismen, die mengenmässig erheblich ins Gewicht fallen kann. W. KUBIENA und FRANZ (1,2) haben in ihren Studien über die Rendzinabildung dargelegt, dass die koprogenen Bestandteile in den frühen Entwicklungsstudien der Bodenentwicklung die organische Phase im Boden weitgehend bestimmen. Wir wissen auch heute, dass die Theorie S.A. WAKSMAN's (3) über den Aufbau der Humusstoffe aus Lignin-und Proteinkomplexen oder die von

F. FISCHER und H. SCHRADER vertretene Ansicht der Huminstoffbildung aus Lignin oder die von J. MARKUSSON betonte Auffassung ihrer Entstehung aus Kohlenhydraten einseitige Markierungen einiger möglicher Wege der Huminstoffbildung darstellen, dass darüber hinaus aber noch weitere natürliche Synthesen unter Verwendung der verschiedenartigsten Bausteine im Boden möglich sind.

Das Wesentliche dieses Reaktionsgeschehens liegt in der Verknüpfung geeigneter reaktionsfähiger Stoffe durch Polymerisation oder Polykondensation zu höhermolekularen Verbindungen von kugelförmiger Gestalt. Ähnlich den Wofatiten (synthetic resins) enthalten diese Neubildungen freie phenolische Oxygruppen bzw. Karboxylgruppen, die den Säurecharakter bestimmen und für die Salzbildung, das Quellungsvermögen und den Basenaustausch verantwortlich sind. Wir fassen diese Gruppe von Huminstoffen mit Säurecharakter unter den Begriff " Huminsäuren " zusammen. Mit zunehmender Alterung, insbes. bei der Inkohlung findet eine allmählich fortschreitende Abspaltung der Seitenketten statt, wobei die Säureeigenschaften mehr und mehr schwinden, bis schliesslich " Humine " entstehen. Damit einhergehend nimmt die Löslichkeit in Alkalien entsprechend ab.

Die Huminsäuren sind für den Bodenkundler als das Primärprodukt des natürlichen Huminstoffbildungsvorganges von grösstem Interesse. Aus ihrer Zusammensetzung lassen sich in vielen Fällen genetische Beziehungen zum jeweiligen Bodentyp ableiten und über den Basensättigungszustand für die Fruchtbarkeit eines Bodens wertvolle Anhaltspunkte gewinnen. Charakteristische Eigenschaften sind u.a. der Farbtyp (Farbquotient), der Stabilitätsfaktor, die Elektrolytempfindlichkeit und der Stickstoffgehalt. Bei der Isolierung der Huminsäuren aus dem Boden bedient man sich im allgemeinen stark verdünnter Natronlauge oder auch Alkalisalzlösungen kalkfällender Säuren (1%iges NaF oder 1%iges Na-Oxalat). Die Extrakte sind mit organischen und mineralischen Begleitstoffen noch weitgehend verunreinigt. Während sich durch Äther-bzw. Benzolextraktion und durch wiederholte Fällung mit verdünnten Mineralsäuren die organischen Verunreinigungen einschliesslich der sog. Huminsäurevorstufen entfernen lassen, liegt die mineralische Komponente gewöhnlich in sehr fester Bindung mit den Huminsäuren vor. Durch Kochen mit verdünnter Salzsäure lässt sich diese Bindung zwar lösen, es werden aber auch die Huminsäuren selbst weitgehend irreversibel verändert. Diese Schwierigkeiten der Reindarstellung von natürlichen Huminsäuren treffen wir vorwiegend auf den Tschernosemen, Rendzinen und Niederungsmoorböden an, die durch das Vorkommen von Grauhuminsäuren ausgezeichnet sind. Die hohe Elektrolytempfindlichkeit der meist stickstoffreichen Grauhuminsäure hat eine sehr feste sorptive Bindung an Tonmineralien und polyvalenten Kationen zur Folge. Der Mineralgehalt von aus Schwarzerden isolierten Huminsäuren betrug nach Entfernung der organischen Nebenbestandteile bis zu 30%. Leichter und in verhältnismässig hoher Reinheit lassen sich die weniger elektrolytempfindlichen und daher labilen Braunhuminsäuren, die überwiegend in den Podsolböden auftreten, isolieren. Trotzdem ist auch hier eine vollständige Entfernung des mineralischen Anteils ohne Veränderung der Huminsäuren nicht zu erzielen.

Das Ergebnis dieser Feststellungen zeigt, dass die Konstitutionelle

Aufklärung der natürlichen Huminsäuren mit den üblichen chemischen Methoden nicht ohne weiteres möglich ist, da stoffliche Umwandlungen durch den chemischen Eingriff nicht verhindert werden können. Hinzu tritt noch ein anderer die Untersuchungsverhältnisse sehr erschwerender Umstand.

Wie bereits erwähnt, stellen die aus dem Boden extrahierten und weitgehend gereinigten Huminsäuren keine einheitliche Stoffgruppe dar. Vielmehr handelt es sich in jedem Fall um Mischpolymerisate bzw. Mischkondensate aus den verschiedensten Bausteinen, deren Zahl und Konstitution von der Beschaffenheit der organischen Ausgangsstoffe, dem durch mikrobielle Umsetzung bestimmten Reaktionsverlauf und von den jeweils vorliegenden Bodenverhältnissen abhängig ist. Derartige polymerisations-bzw. kondensationsfreudige Bausteine können z.B. aus dem Kohlehydratabbau stammen. Dann handelt es sich zumeist um Verbindungen furanoider Kernstruktur wie z.B. Furfurol, Oxymethylfurfurol, also um reaktionsfähige autoxydable Stoffe, die sich leicht aus Fructose zu bilden vermögen —oder aber um C_3-Körper vom Charakter des Methylglyoxals, das nach Untersuchungen von C. ENDERS (4) als wichtiger Baustein der Huminsäurebildung angesehen werden darf. Weiterhin kommen in Frage reaktionsfähige Zwischenprodukte des Ligninabbaus. Diese entstehen, sobald die Abspaltung der reaktionsblockierenden Methoxylgruppen vor sich geht. Wie sich eine derartige Reaktion in vitro durchführen lässt, hat A. RUSSEL (5) unter Anwendung der FRIES'schen Verschiebung bei einer künstlichen Ligninsynthese aus Vanillinazetat zeigen können. An solchen Synthesepräparaten durchgeführte eigene Untersuchungen über die UV-Absorption haben ergeben, dass es sich beim Poly-8-methoxydihydrobenzopyron um eine Übergangsbildung zu den Huminsäuren vom Charakter der Ligno-Huminsäuren handelt. Auch Flavan-Derivate und Gerbstoffe von Katechincharakter liefern geeignete Bausteine für die natürliche Huminsäuresynthese. So sind z.B. die Aromastoffe des Tees von huminsäureähnlicher Beschaffenheit und nach den Untersuchungen von R. W. MONCRIEFF (6) Polykondensationsprodukte von Gallokatechin und Epikatechin. Ebenso fallen im Eiweissstoffwechsel reaktionslabile Zwischenprodukte an, aus denen Huminsäuren gebildet werden, so z.B. das Tyrosin, das sich unter geeigneten Bedingungen nach dem von H. S. RAPER (7) aufgestellten Reaktionsschema über orthochinoide Zwischenstufen unter Einwirkung des Luftsauerstoffs zum braunschwarzen Melanin polykondensieren lässt. Darüber hinaus haben sich die chinoiden Stoffwechselprodukte der Mikroorganismen, insbes. der Actinomyceten und Pilze als wichtige Huminstoffbildner erwiesen (8, 9). Durch besondere Reaktionsfähigkeit zeichnen sich dabei die Polyoxyphenole aus. Schon W. ELLER (10) hat in überzeugender Weise experimentell darlegen können, dass die aus Hydrochinon, Brenzkatechin, Chinon und Pyrogallol durch Autoxydation bei alkalischer Reaktion entstandenen Huminsäuren in ihrem chemischen Verhalten eine auffallende Ähnlichkeit mit gewissen natürlichen Vorkommen besitzen.

In gleicher Weise ist die Beteiligung von Pyrrol-Bausteinen des Chlorophyll—bzw. Häminstoffwechsels gegeben. Nach Untersuchungen von W. SIEDEL und Mitarbeitern (11) bestehen z.B. die braunen Farbstoffe der menschlichen Fäzes aus Polymerisationsprodukten

des Mesobilifuscins. Dass die im Kot der landwirtschaftlichen Nutztiere vorhandenen dunklen Farbstoffe zum Teil Huminsäurecharakter besitzen, konnte von F. SCHEFFER und E. WELTE (12) nachgewiesen werden.

Die angeführte Auswahl einiger an der natürlichen Huminsäuresynthese fast immer gleichzeitig beteiligten Bausteine möge erkennen lassen, dass eine Konstitutionsforschung an natürlichen Huminsäuren im Sinne der hochmolekularen Chemie nicht ohne weiteres möglich ist, da eine exakte Lokalisierung der einzelnen Bausteine in dem Mischpolymerisat bzw. Mischkondensat ausgeschlossen ist, zumal auch Zahl und Menge der Bausteine von Boden zu Boden verschieden sein können. Diese Erkenntnis hat dazu geführt, dass heute die Konstitutionsforschung ausschliesslich an Synthesehuminsäuren vorgenommen wird. Im Vordergrund steht dabei die Kardinalfrage nach dem Verknüpfungsmechanismus der Bausteine miteinander und ihr chemischer Aufbau. Da in vitro die Möglichkeit besteht, nur jeweils einen einzigen und dazu bekannten Baustein für den Aufbau natürlicher Huminsäuren zu verwenden, gelangt man im Gegensatz zu den Naturprodukten zu polymereinheitlichen Stoffen, deren Bearbeitung mit den Methoden der makromolekularen Chemie bisher bereits mit Erfolg betrieben worden ist.

Ohne im einzelnen auf die aufschlussreichen Arbeiten einzugehen, sei mit Rücksicht auf den Umfang des Referates darauf verwiesen, dass zur Aufklärung der Konstitution derartiger polymereinheitlicher Synthese-Huminsäuren Untersuchungen über die Reaktionsbedingungen, die Sauerstoffaufnahme sowie Messungen über die Teilchenform, -grösse und -gewicht und über den Grad der Polydispersität gemacht worden sind (13, 14, 15, 16, 17, 18, 19, 20). Es hat sich dabei gezeigt, dass mit dem primären Vorgang der Polymerisation bzw.-kondensation in Abhängigkeit vom pH-Wert ein reversibler sekundärer Vorgang der Aggregation verbunden ist, der sich im alkalischen Bereich ausschalten lässt. Ähnlich wie bei der Kieselsäure wird diese Sekundärreaktion durch Wasserstoffionen und polyvalente Kationen ausgelöst. Ein wichtiges Hilfsmittel zur Charakterisierung der künstlichen Huminsäuren ist die Ultraviolettabsorption (17). Dabei liess sich feststellen, dass der Aufbau von Huminsäuren aus Hydrochinon in ammoniakalischer Lösung zu einer Rotverschiebung des Spektrums führt, dessen Ausmass vom Stickstoffgehalt der Huminsäuren abhängt.

Röntgenographische Untersuchungen und Elektronenbeugungsaufnahmen haben die bisherige von den meisten Humusforschern vertretene Auffassung bestätigt, dass die Huminsäuren keine mit diesen Methoden nachweisbare Gitterstruktur aufweisen, also sphärische Körper darstellen, in denen die einzelnen Bausteine ungeordnet miteinander verknüpft sind. Es ist allerdings denkbar, dass mit zunehmendem Alter, insbes. unter dem Einfluss der Diagenese, wie er bei der Inkohlung gegeben ist, eine Einordnung der Sechser-Ringe durch fortlaufende Abspaltung der sterisch hindernden Seitenketten in Verbindung mit der fortschreitenden Ausbildung der C–C–Bindung in der Ebene erfolgt, wodurch zuletzt die Struktur des Graphits als letzte Inkohlungsstufe erreicht wird. Ein solcher Vorgang ist vor allem von H. L. RILEY (21) anschaulich dargelegt worden. (Abb. 2). Das hohe Quellungsvermögen der Huminstoffe deutet darauf hin, dass die einzelnen Bausteine nich starr miteinander verknüpft sind,

sondern in einem durch die Bindungsart begrenzten Ausmass dehnbar sind und daher Wasser durch die hydrophilen Seitenketten innermolekular und reversibel einzulagern vermögen. Bei den Hydrochinonhuminsäuren ist auf Grund der bisherigen Untersuchung ziemlich sicher eine Verknüpfung durch Sauerstoffbrücken, die über die Oxychinonstufe eingeleitet wird, anzunehmen. (Abb. 3).

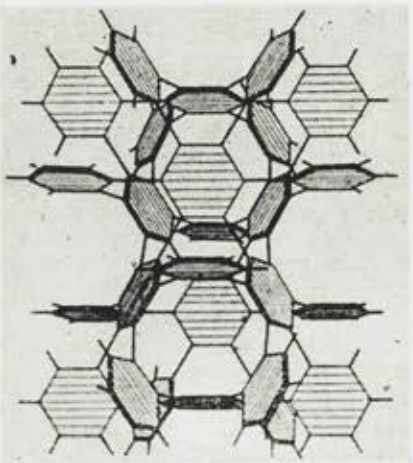


Abbildung 2

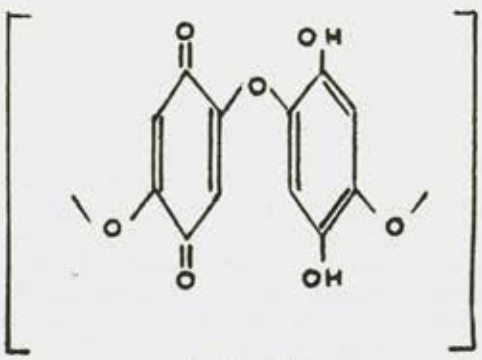


Abbildung 3

Mit diesen kurzen Ausführungen über Ziele und Wege der modernen Humusforschung war die Absicht verbunden, besonders darauf hinzuweisen, dass die Konstitutionsforschungen an natürlichen Huminsäuren, die in jedem Falle als Mischpolymerisate bzw. Mischkondensate von stets wechselnder Zusammensetzung der Bausteine vorkommen, von vornherein zum Misserfolg verurteilt sind, zumal auch die Abtrennung der mineralischen Komponente ohne chemische Veränderung der Huminstoffe nicht möglich ist. In der Erforschung

der von den verschiedensten Bausteinen ausgehenden, jeweils jedoch polymereinheitlich aufgebauten Synthese-Huminsäuren sehen wir dagegen einen wertvollen Weg, der uns einen Einblick in die natürlichen Bildungsverhältnisse verschaffen und eine Möglichkeit bieten kann, bei Kenntnis der chemischen Reaktionsbedingungen die im Boden ablaufende Huminstoffbildung planmässig zu steuern und zu fördern.

SUMMARY

The following terminology is generally adopted in Germany :

" Humus " means the whole of the organic material of a soil.

" Huminstoffe " are the dark coloured substances formed during the process of " Huminifizierung." These dark and comparatively resistant substances are also called " Dauerhumus."

" Nichthuminstoffe " means all substances which are readily decomposed by micro-organism (so-called " Nährhumus ") or those, which, however, are resistant enough that " Huminifizierung " cannot take place (e.g., waxes, sterols).

The differentiation between " Dauerhumus " and " Nährhumus " is very useful for the farmer and they are terms which are generally accepted.

Fig 1 shows in a simplified way how, during the formation of soil, the changes of organic and inorganic substances bear corresponding similarity.

Examples are given for substances which may be sources for the building up of " Huminstoffe " and the mechanism of their linkage and the characteristics of " Huminsäuren " are discussed. The review is then concerned with the following points : the importance of the " Huminsäuren " for soil genesis ; methods for their extraction and purification together with the difficulties involved with especial reference to the removal of the inorganic constituents.

Further, doubt is expressed as to the success in the research on the constitution of the " Huminsäuren " as long as natural products are used because (1) extraction changes the original substances,
and (2) " Huminsäuren " extracted from the soil are always heterogeneous, i.e., mixed polymers with reactants of different structures.

From research carried out on the other hand with synthetic *homogeneous* " Huminsäuren," meaning condensation polymers from only one species of monomers, information has been obtained, on the conditions of forming different types of " Huminsäuren," the uptake of oxygen, particle size, shape and weight, U.V.-absorption, x-ray diffraction and electron microscopy.

The authors understand under " Huminifizierung " a condensation or addition polymerization from monomers which usually are at least trifunctional. Due to the great irregularity of the three dimensional network structures the " Huminsäuren " are not crystalline.

SCHRIFTTUM

(1) KUBIENA, W. Entwicklungslehre des Bodens (Berlin, 1948).
(2) FRANZ, H. Bodenzoologie als Grundlage der Bodenpflege. Mit besonderer Berücksichtigung der Bodenfauna in den Ostalpen und im Donaubecken, (Berlin, 1950).

(3) WAKSMAN, S. A. Humus, 2. Aufl. (London, 1938.)
(4) ENDERS, C. Über den Chemismus der Huminsäurebildung unter physiologischen Bedingungen. *Biochem. Ztschr.*, **312**, 339 (1942); **313**, 174 u. 352 (1942); **315**, 259 (1943).
(5) RUSSEL, A. Interpretation of lignin. *J. Amer. Chem. Soc.*, **70**, 1060 (1948).
(6) MONCRIEFF, R. W. Die Aromastoffe im Tee. *Food* **18**, 228 (1949).
(7) RAPER, H. S. Die Entwicklung von Tyrosinase auf Tyrosin. *Fermentforschung*, **9**, 206 (1927).
(8) LAATSCH, W. Untersuchungen über die Bildung und Anreicherung von Humusstoffen. *Beiträge zur Agrarwissenschaft*, **III**, 3 (1948).
(9) SCHEFFER, F., VON PLOTHO, H. C. und WELTE, E. Untersuchungen über die Bildung von Humusstoffen durch Actinomyceten. *Landw. Forschung*, **1**, 86 (1950).
(10) ELLER, W. Studien über Huminsäuren. *Liebigs Ann.*, **431**, 133 (1923) **442**, 160 (1925).
(11) SIEDEL, W., VON PÖLNITZ, W. und EISENREICH, F. Bilifuscin und Mesobilifuscin als natürliche Abbauprodukte des Blutfarbstoffs. *Naturw.* **34**, 314 (1947).
(12) WELTE, E. Über die Entstehung von Huminsäuren und Wege ihrer Reindarstellung. *Pflanzenern., Düng. u. Bodenkunde*, **56**, 105-139 (1952).
(13) FLAIG, W. Zur chemischen Konstitution der Huminsäuren. *Pflanzenern., Düng. u. Bodenkunde*, **51**, 193-212 (1950).
(14) FLAIG, W. und BEUTELSPACHER, H. Elektronenmikroskopische Untersuchungen an natürlichen und synthetischen Huminsäuren. *Pflanzenern., Düng. u. Bodenkunde*, **52**, 1-21 (1951).
(15) BEUTELSPACHER, H. *Physikalisch-chemische Beiträge zur Humusforschung*, **57**, 57-65 (1952).
(16) SCHEFFER, F. und WELTE, E. Über absorptionsspektrographische Untersuchungen an natürlichen Huminsäuren. *Landw. Forschung*, **1**, 81 (1950).
(17) SCHEFFER, F. und WELTE, E. Die Anwendung der Absorptionsspektrographie in der Humusforschung. *Pflanzenern., Düng. u. Bodenkunde*, **48**, 250 (1950).
(18) WELTE, E. Über einen neuen Weg der Molekulargewichtsbestimmung und über die Elektrolytempfindlichkeit von Chinon-Huminsäuren. *Pflanzenern., Düng. u. Bodenkunde*, **57**, 142-151 (1952).
(19) SCHEFFER, F. und WELTE, E. Die UV-Absorption von Huminsäuren aus Hochmoortorf, Braun- und Steinkohlen. *Landw. Forschung*, **3**, 1-6 (1951).
(20) JODL, R. Über die Beziehungen zwischen Hymatomelansäure und Huminsäure. *Brennstoff-Chem.*, **22**, 259 (1942).
(21) RILEY, H. L. An *X*-ray diffraction study of humification. *J. Soil Sci.*, **1**, 104-111 (1949).
(22) ROEMER-SCHEFFER. Lehrbuch des Ackerbaues, 4. Aufl., 1951.

PREPARATION AND APPRECIATION OF ARTIFICIAL ORGANIC MANURE

A. VAN DEN HENDE, A. COTTENIE AND R. DE VLIEGHERE
Agricultural State University, Ghent, Belgium.

During the last years, the omission of regular periodical introduction of organic matter into the soil has held the attention of soil and agricultural scientists.

Consequently, with the orientation given to modern farm exploitation, one fears, with reason, a progressive decrease of the humus content and of the physical conditions assured by it in the subsoil.

G. BARBIER and G. GUENNELON (1) have tried to find out at which ratio this decrease is to be expected, therefore they used analyses executed with an interval of seven years (1943–1950). They concluded that the quantity of organic matter to introduce into the soil in order to keep the humus-content upon the same level, which is not necessarily the optimum one, should be about four tons per year and per Ha., taking also into consideration the important quantity of remaining crop residues.

On account of the progressive specialisation of farm production, an acute shortage of the needed quantities of farm manure is often experienced, and not seldom a considerable quantity of straw remains unused. In some periods, and considering the quality of this straw, it can be sold at a reasonable price to the industry, but in other periods it seems to be unsalable. So we saw in 1950 in Belgium, great quantities of straw being burnt on the fields. A rational use of the available straw is imposed, as well by economical as by technical agricultural considerations.

Therefore, there are two possibilities: the production of artificial manure and the direct introduction of straw into the soil. The direct introduction of straw into the soil has only very recently received special attention in Belgium and is related to the mechanical possibilities which will be obtainable (combine with straw-hopper, etc.).

We had the opportunity to study more thoroughly the transformation of straw into artificial manure. The transformation of vegetal residues, rich in cellulose, hemi-cellulose and lignine into a useful compost, coloured dark brownish and biologically very resisting, is based upon chemical and micro-biological processes. These transformations having partly the properties of a fermentation are coupled with a certain mineralisation of the composts, while another part is transformed by the synthetic action of micro-organisms into more resistant components.

The influence of the surroundings (temperature, air and moisture conditions) is very important: in favourable conditions the destruction of carbohydrates and the subsequent building up of stable ligno-protein complexes, called humus, can take place relatively quickly.

DEMOLON (2) estimates that the fermentation is possible in the following conditions:

(1) sufficient moisture content, that means more or less the moisture content of the green tissue. Straw containing ± 76% of moisture is completely saturated.
(2) moderate aeration.
(3) a source of nitrogen useful to the micro-organisms: there-

fore he recommends an addition of 2·5% nitrogen to the straw.

In a series of experimental preparations aimed at the working out of methods for artificial manure preparations, we tried to follow the progressive decomposition and to characterise the value of the final products by some objective standard. Therefore, the knowledge of norms or tests is a prime necessity.

A first criterion used by F. C. GERRETSEN, A. MANTEN and F. M. MULLER (3) and others was the evolution of the *temperature*.

M. NIKLEWSKI (4) has, however, stated that the temperature of the heaps is coupled with an increase of the intensity of decomposition and a decrease of the influence of the added nitrogen. The nitrogen, in fact, is necessary for the micro-organisms attacking the carbohydrates, but at higher temperature the activity of micro-organisms is less pronounced. Thus, at lower temperature, the decomposition should be dominated by biological and at higher temperature by chemical processes.

Our colleague, J. VAN HOLDER, making a microbiological study of the problem*, stated that above the temperature of 60°C, a very large number of bacteria continued to develop as well as one fungus, *Chætomium elatum*, attacking the cellulose.

In our preparations a temperature remaining high always corresponded with an active decomposition and gave a product ready for use after a relatively short period (see Table 3).

It is also possible to study the *chemical composition* of the heaps in order to compare them with those of natural stable manure. The important point is either to determine the optimate time at which the manure should be used, if its quality evolves as an optimate function, or, if not, to determine the moment from which the product has reached a sufficient decomposition to be used.

Therefore we should be able to determine, by chemical analysis, the most favourable decomposition stage; and—what is important for practical purposes—find an easily perceptible characteristic eventually correlating with this stage. The chemical and physico-chemical indices which we have determined during our preparations were:

(1) The total organic material, determined by ashing at 450°C.
(2) The humic acids, extractable with 1% NaOH, after treatment with 5% HCl.
(3) The crude cellulose.
(4) The oxidisable organic carbon, determined as per ISCHTSCHEREKOFF.
(5) The nitrogen content.
(6) The pentosans content.
(7) The mineral composition.

With these results were calculated the following ratios, which we have tried to test as possible criteria for the appreciation of the artificial manure:

the relation C/N (above determinations 5 : 6);
the relation N : total organic matter (6 : 2);
the relation humic acids : total organic matter (3 : 2).

*J. VAN HOLDER. Not yet published communication.

TABLE 1.—*Scheme of preparations*

Preparation	Methods	Straw used	Days	Remarks
A (Adinkerke)	1. with CaNCN addition 2. with fermentation liquid 3. with water only 4. with stale	BARLEY 200 K°/m² (7 cwt./sq. yard) 140 K°/m² (5 cwt./sq. yard) 200 K°/m² (7 cwt./sq. yard) 200 K°/m² (7 cwt./sq. yard)	from 11.10.50 till 26.1.51 (110 days).	In this preparation the percolation-liquid was recovered and re-utilised. This working procedure seems to have accelerated the decomposition by re-adding the leached mineral elements.
B (Melle)	1. with CaNCN and phosphate slacks addition 2. with fermentation liquid	BARLEY 250 K°/m² (8,5 cwt./sq. yard)	from 21.9.51 till 12.3.52 (174 days)	On the heap with fermentation liquid the aeration was fairly deficient because the density of straw per square yard showed to be too high.
C (Hamme-Mille)	1. with CaNCN addition 2. with fermentation liquid 3. with water only	WHEAT + OATS 130 K°/m² (6,5 cwt./sq. yard)	from 24.10.50 till 11.9.51 (321 days).	Different factors combined to delay the decomposition of the straw: the very low temperature of that Winter, and the fact that the straw had previously been exposed to a certain leaching.

TABLE 2.—*Analytical determinations on artificial manure*

	Adopted norms	Preparation A					Preparation B			Preparation C			
		days	1 CaNCN	2 Ferment. liquid	3 water	4 stale	days	1 CaNCN	2 Ferment. liquid	days	1 CaNCN	2 Ferment. liquid	3 water
1. Total organic matter (ashing at 450°C.) %		7	90,92	91,00	—	—							
		22	89,06	88,43	92,14	86,70				25	87,35	90,84	90,21
		50	87,05	87,19	92,85	80,73	46	83,97	86,98	36	84,79	92,01	93,59
		64	79,78	92,52	89,43	85,42	78	66,96	82,66	87	85,70	91,62	83,62
		114	77,48	88,55	86,65	74,35	108	78,49	80,38	123	81,88	89,79	84,72
							152	72,93	82,48	322	54,54	80,09	76,62
2. Humic acids ... %							46	15,86	16,10				
							78	15,24	13,58				
							108	13,76	14,88				
							152	16,31	13,29				
3. Crude cellulose ... %		7	48,78	41,65	—	40,38							
		22	43,29	42,70	45,51	47,85							
		50					46						
							78	30,22	37,83				
							108	38,43	31,68				
							152	23,74	33,61	322	16,27	25,91	17,81
4. Oxydable organic carbon (ISCHTSCHEREKOFF) %		7	26,44	27,46	28,18	27,36							
		22	29,16	28,70	29,32	28,79				25	28,45	30,15	29,16
		50	28,18	28,28	29,17	30,13	46	26,90	29,02	36	28,91	29,74	29,76
		64	28,86	28,10	28,79	28,88	78	27,22	30,55	87	29,00	27,42	28,38
		114	26,95	26,08	28,18	27,95	108	27,56	28,46	123	28,98	27,98	28,45
							152	29,15	31,39	322	26,33	31,15	31,72

5. Nitrogen		7	0,70	0,63	0,52	0.74							
		22	0,96	0,79	0,59	1,42				25	0,62	0,58	0,72
		50	1,08	0,57	0,57	1,65	46	1,20	1,06	36	1,13	0,86	0,82
%		64	1,57	0,55	0,77	1,63	78	2,03	1,57	87	1,17	0,72	1,21
		114	1,76	0,92	1,11	2,26	108	1,69	1,70	123	1,73	1,17	1,22
							152	2,42	1,88	322	2,24	1,77	2,00
6. Pentosans ...		64	13,60	24,30	22,10					322	4,70	10,12	11,41
		114	12,20	18,60	17,60								
7. Relation	maximum	7	37,60	43,40	54,50	36,80							
C/N	20	22	30,50	39,90	49,50	20,30				25	46,10	51,70	40,50
		50	26,10	51,20	51,20	18,20	46	22,42	27,38	36	25,50	34,50	36,30
		64	18,40	51,10	37,30	17,70	78	13,41	19,46	87	24,80	37,80	23,45
		114	15,30	28,40	25,20	12,40	108	16,31	16,74	123	17,30	23,80	23,38
							152	12,04	16,70	322	11,75	19,40	16,01
8. Relation	minimum	7	0,008	0,007	0,006	0,008							
N/Total org.	0,019	22	0,011	0,008	0,006	0,016				25	0,007	0,006	0,008
matter		50	0,012	0,006	0,006	0,020	46	0,014	0,016	36	0,013	0,009	0,009
		64	0,020	0,005	0,009	0,019	78	0,030	0,018	87	0,014	0,008	0,014
		114	0,023	0,010	0,013	0,030	108	0,021	0,021	123	0,021	0,013	0,014
							152	0,033	0,022	322	0,039	0,021	0,023
9. Relation	minimum												
humic acids/total org.	0,10						46	0,179	0,173				
matter							78	0,204	0,151				
							108	0,158	0,171				
							152	0,210	0,150				

There are two main methods in use for the preparation of artificial manure :

(1) A method using addition of mineral salts or CaNCN*.
(2) A method, recently appeared in Belgium, using a fermentation liquid, to be mixed with water used to moisten the straw.

We have compared those two methods with a preparation using water only, in the same quantity as in the above-mentioned preparations, and also with a method using stale instead of water.

The preparations were repeated three times, as shown in Table 1, and took place on different farms. They were carried out in the following way. After the soil was made sufficiently level, a first layer of pressed straw-packs was spread out and slightly loosened. The complete saturation was then effected with the aid of an automatic sprayer. After the application of the first part of the respective additional products a second layer of straw was stacked upon the first and the same operation continued until the heaps were completely mounted and saturated with water. A period of six days separated the application of each layer. During the following days water was still sprayed upon the heaps as much as this proved to be necessary to preserve complete saturation in the heating mass. The most favourable quantity of straw per square yard proved to be about 300 pounds ($\pm$ 150 K°/m²).

The advance of the decomposition was followed by measuring regularly the temperature and by periodical chemical analysis.

It is to be mentioned that the difficulties of sampling such material as well as the conventional character of the analytical methods for the determination of C, humic acids, etc., make it impossible to realise more than a relative analysis. The results of this analysis are brought together in Table 2. They brought us to the following considerations.

1. *The ratio C : N*

The evolution of the C : N ratio, depends mostly upon the progressive mounting of the relative N content, the C content as determined by the wet oxydation of ISCHTSCHEREKOFF, being much more constant.

Many scientists have emphasized the importance of the C : N ratio as a criterion for judging the artificial manure.

DEMOLON (2) holds that the organic products introduced into the soil accomplish a biochemical function as long as its C : N ratio is higher than 10 and a more physical function after having reached a value $<$ 10. G. BARBIER (5) holds that the value of artificial

*1. *Preparation with the aid of CaNCN*
Calcium cyanamide was added to the straw at the rate of 3·5%. Considering that 1 ton of straw gives 2·7 tons of finished artificial manure, 1 ton of manure contains about 1/2 pound of supplementary, pure nitrogen (0·260 K°). It was spread out between the different layers of straw packs, partly before and partly after the water application. In our preparation B (see Table I), 1% of phosphate slacks was added.

2. *Preparation with the aid of fermentation liquid*
This product at the rate of 400 cc. per ton of straw diluted with some water, was also sprayed upon each layer of straw-packs.

TABLE 3

		Preparation A				Preparation B		Preparation C		
		1 with CaNCN	2 with fermentation liquid	3 with water	4 with stale	1 with CaNCN	2 with fermentation liquid	1 with CaNCN	2 with fermentation liquid	3 with water
Temperature	Top reached	75	72	68	71	71	69	70	65	60
	after days	14	13	9	17	11	11	32	28	36
	days above 60° C.	44	27	14	61	45	29	15	3	1
	days above 40° C.	86	29	87	92	100	85	65	30	25
C : N=20	after days	62	—	—	28	55	76	110	190	235
N : org. matter =0,019.	after days	63	—	—	45	51	78	113	277	222
N : org. matter	at C : N=20	0,0185	—	—		0,023	0,018	0,0185	0,0135	0,0175

manure is the same as that of natural farm manure having the same C : N ratio.

It is generally accepted that the product can be considered as ready for use as soon as this ratio has reached the value 20. However, in our preparation A the value 20 has only been reached with the CaNCN and the stale preparation.

In preparation B and C the C : N value 20 was reached after very different periods (see Table 3).

In a general way we could conclude that the visual appreciation of artificial manures fairly corresponded with the thesis that the value C : N=20 indicates a product enough decomposed to be used. However, the same criterion was not suitable in the case of the stale preparation A where C : N reached the value 20 after 28 days, the decomposition of straw not already being enough advanced.

We therefore analysed also some natural farm manure obtained in different ways, the results of which are given in Table 4.

As we see, the natural farm manure, even not yet decomposed, starts with a C : N ratio, which is much lower than the one found in the artificial preparation. This is due to the presence of the excrements in the former. This means that the absolute value of the C : N figures are not the same in the case of an artificial and a natural manure. The decomposition of the straw corresponds in both cases with decreasing C : N ratios, but the limits between which this happens are very different : in natural farm manure, the C : N ratio moved between 15 and 10, in artificial manure between 50 and 12.

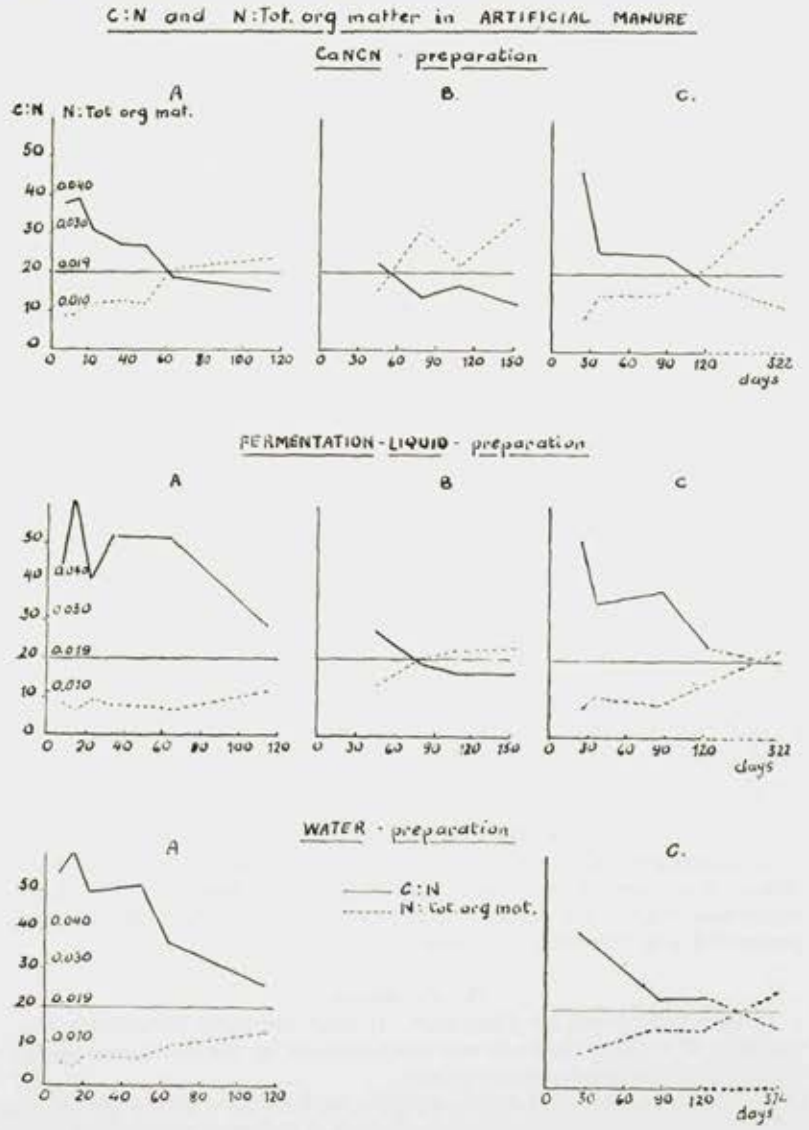
TABLE 4.—*Analysis of natural farm manure*

		sampled after days	C : N	visual appreciation
1. farm manure prepared with long straw	prep. 1	73	10,79	very well decomposed
	prep. 2	49	12,47	less decomposed than former
2. farm manure prepared with pressed long straw	prep. 1	53	13,33	decomposition only well started
	prep. 2	49	11,96	as much decomposed as second
3. farm manure prepared with cut straw	prep. 1	73	10,39	very well decomposed
	prep. 2	49	11,75	less decomposed than former
	prep. 3	80	12,47	very well decomposed
4. farm manure obtained with cut straw		14	14,91	decomposition only started

II. *Ratio N : total organic matter*

This value, being nearly 0,005 (straw) at the start, increased continuously during the preparations. The norm to be obtained, admitted by the French Ministry of Agriculture, being 0,019 has generally been reached and even greatly surpassed when composting was continued after having reached this value.

In Figure 1 we brought together the ratios N : organic matter and C : N reaching their respective critical values of 0,019 and 20 after nearly an equal number of days. The curves of C : N and N : total organic matter in function of the time show a remarkable symmetry. It is to be mentioned that the oxidisable C and total organic matter, occurring in these ratios, are not analogous and result from a completely different analytical determination (+).



We remark that the CaNCN method gave a product in which the critical ratios were reached earlier than in the other methods, although

at the beginning of the preparation the C : N ratios found in the CaNCN heaps were from the same order as in the other heaps.

Another point affirming the reliability of the two ratios as criteria is their remarkable correlation with the visual appreciation of the products, although the factors which constitute these ratios separately were not in relation with this appreciation. A good idea of this fact is given in Table 5, which indicates some analytical data of samples taken at different places in two heaps.

TABLE 5

Method	sample	days	% N	% C	% total organic matter	C : N	N : org. matter	visual appreciation
CaNCN ...	ordinary mean sample	174	2,05	20,22	60,29	9,86	0,031	very well
	sample taken in a layer where CaNCN has been applied	174	1,97	16,24	41,50	8,24	0,043	completely decomposed
	sample taken between two layers where CaNCN has been applied (middle part of the heap)	174	3,45	33,60	70,50	9,74	0,042	very well
	sample taken in the lowest layer of the heap	174	1,90	29,85	84,32	15,71	0,020	fairly well
fermentation product	not enough aerated	174	1,93	30,39	90,72	15,75	0,021	fairly well
	well aerated ...	174	2,50	29,90	86,77	11,96	0,028	very well

Table 5 shows also that equally well decomposed manures, prepared by the two different methods, are both characterised by nearly the same analytical figures, in spite of the nitrogen addition to the CaNCN heaps.

III. *Ratio humic acids : total organic matter*

In agreement with the French Ministry of Agriculture this ratio should tend towards 0,10 in a fully decomposed manure. The determinations which we made concerning the preparation B have not permitted any conclusion (Table 2).

IV. *Pentosans*

It has been noted by DEMOLON (2) that the most favourable preparation of artificial manure was characterised by the most pronounced decrease of the pentosanes-content.

In our preparations, A and C, starting with a straw with respectively 26,94% and 23,74% pentosanes, we saw a decrease continuing even after more than one year (C) and correlating fairly with the visual rate of decomposition (see Table 2).

V. *Mineral elements*

In a general way the relative contents of mineral elements in the heaps went continuously increasing. This is due to the relative decrease of total organic matter by combustion.

We found that the manure prepared with additional Ca and P, was in fact higher in CaO and P_2O_5 content, but lower in K_2O, Na_2O, MgO and Cl than the one prepared with fermentation liquid. Table 6 shows the mineral composition of some artificial organic manures in comparison with that of natural stable manure.

TABLE 6—*Mineral composition of organic manures*

		% N	% P_2O_5	% MgO	% K_2O	% CaO	% Na_2O	% Cl
Preparation A (after 64 days).	with CaNCN ...	1,078	0,174	0,075	—	3,173	0,419	0,573
	with stale ...	1,654	0,214	0,093	1,272	0,656	0,639	0,880
	with ferm. liquid ...	0,572	0,144	0,057	0,266	0,400	0,178	0,186
Preparation B (after 78 days).	with CaNCN and phosphate slacks ...	2,030	0,457	0,157	1,006	6,976	0,187	0,342
	with ferm. liquid ...	1,570	0,362	0,332	1,677	2,393	0,282	0,643
Natural stable manure		2,580	1,212	0,651	3,763	2,120	0,467	1,015

LITERATURE

(1) BARBIER, G. and GUENNELON, G. Sur la loi de variation quantitative de l'humus dans le sol au cours des années. IIe Congrès Mondial des Engrais Chimiques (Rome, 1951).

(2) DEMOLON, A. La Dynamique du Sol. (Dunod, Paris, 1948).

(3) GERRETSEN, F. C., MANTEN, A. and MULLER, F. M. Investigations concerning the preparation and application of substitutes for the present practice of using stable manure and cereal straw in the biological heating of hot-beds. *Plant and Soil*, 240 (1949).

(4) NIKLEWSKI, M. The decomposition of organic matter in soil. *Stornik Chesholov. Akad. Zemedelske*, **22**, 188-94 (1949). (Publ. 1950.)

(5) BARBIER, G. Essai de mise au point de la question de l'humus. *B.T.I.*, **41**, 1949.

PROCESSUS DE DÉNITRIFICATION DANS SES RAPPORTS AVEC LA MICROFLORE TOTALE

H. DE BARJAC ET J. POCHON
Laboratoire de Microbiologie du Sol, Institut Pasteur, France

Les divers chainons du cycle de l'azote sont actuellement bien connus. L'évaluation de l'intensité de leur processus dans un sol donné se fait couramment en ce qui concerne la fixation de l'azote, l'ammonification, la nitrification. Nos connaissances sur la dénitrification, prise au sens large de réduction des nitrates, sont par contre fort limitées. Les plantes étant capables d'assimiler les nitrates, on leur a facilement cédé toute la place dans l'attaque de l'azote nitrique, en reléguant à un plan secondaire les actions microbiennes. Ainsi le pouvoir dénitrifiant d'une terre est-il considéré comme pathologique, sous l'aspect négatif d'une perte d'azote moléculaire. Il est un aspect positif sur lequel nous voudrions appeler l'attention. Le pouvoir de réduction des nitrates rentre dans l'activité globale de la microflore tellurique, au même titre que son pouvoir de formation de ces mêmes nitrates. Il traduit la puissance de transformation de la microflore vis-à-vis de l'azote nitrique, dont on sait l'importance dans la constitution des tissus végétaux d'une part, et dans celle du sol même d'autre part. Si les plantes assimilent les nitrates, est-ce une raison pour refuser cette possibilité aux microorganismes du sol ? Pourquoi la réduction des nitrates serait-elle plus pathologique que celle des sulfates ? Les travaux de BAUMANN, rapportés par V. DENK (1), tendent d'ailleurs à prouver que les réducteurs de sulfates sont aussi capables de réduire les nitrates, et que ce dernier processus peut prendre, au moins partiellement, la place de celui de réduction des sulfates dans les phénomènes d'oxydo-réduction. L'imprécision reste encore sur les rapports concernant la vitesse de réduction des nitrates et leur assimilation ou au contraire leur perte pour le sol, donc pour les végétaux cultivés. Une fois levé ce doute, le pouvoir dénitrifiant d'un sol peut devenir l'un des critères de la fertilité.

Envisageant la dénitrification sous cet angle plus général, nous avons cherché à l'évaluer dans le sol. En effet, les travaux antérieurs d'auteurs tels que WAKSMAN (2) et VERONA (3) se bornent à une classification des germes réducteurs des nitrates isolés du sol et en culture pure, en fonction des produits de réduction (NO_2, NH_3, N_2, N_2O) et de leur utilisation métabolique. Nous proposons ici, moins une technique de mesure de la " dénitrification effective " se produisant dans une terre, qu'une " appréciation qualitative et quantitative de la puissance dénitrifiante " de la microflore. L'efficacité de cette puissance reste, dans le sol, sous la domination des conditions écologiques. La méthode utilisée est la suivante :

1. *Principes*

Ensemencement d'un milieu liquide salin stérile (NO_3 : 2 gr. glucose : 10 gr. CO_3Ca : 5 gr. milieu salin de WINOGRADSKY à 1/20 q.s.p. 1000 cm³, à raison de 1cm³ par tube à hémolyse) avec 0 cm³, 5 de dilutions croissantes de terre stérile (de 10^{-1} à 10^{-8}) 6 tubes par dilution ; étuve à 28°.

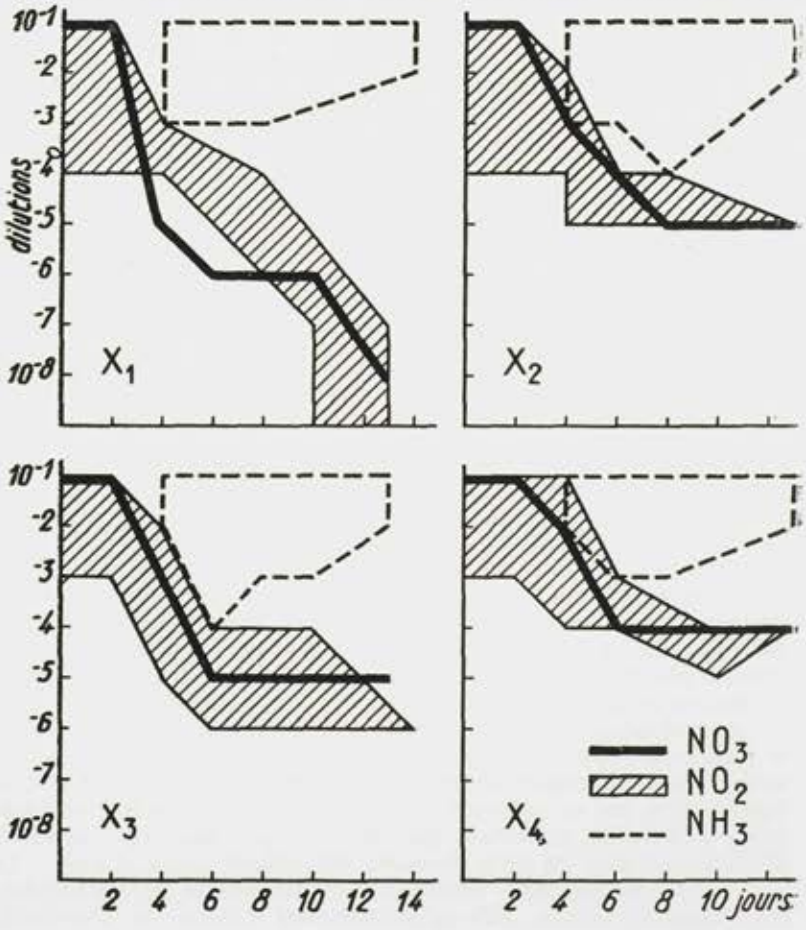
On recherche systématiquement (lecture d'une gamme de dilutions les 2e, 4e, 6e, 8e, 11e et 14e jours) les zones correspondant aux phases du phénomène étudié, à savoir :

—présence des nitrates : par la diphénylamine sulfurique, après élimination des nitrites par l'urée
—présence de nitrites : par le réactif de GRIESZ.
—présence d'ammoniaque : par la formation d'iodure d'azote sous l'action d'iodure de potassium à 10% + extrait du javel. (La présence du glucose rend inutilisable le réactif de NESSLER.)

Ces 3 tests nous ont paru les plus adéquats pour cerner une étude pratique de la dénitrification, la mesure du dégagement de N_2 ne pouvant, pour des raisons techniques, faire maintenant l'objet d'une méthode standard. Au moins, peut-on suivre, grâce à ces tests, l'évolution simultanée et respective des nitrates, des nitrites et de l'ammoniaque.

2. *Resultats*

Nos essais effectués sur une vingtaine de terres, choisies volontairement très diverses, ont révélé de nettes divergences entre ces terres et entre des échantillons d'une même terre ayant subi divers



traitement. Nous n'en donnons pour exemple, en représentation graphique, que les réponses de prélèvements sur sol latéritique du Foumban (Cameroun), avant et après feu de brousse. Il est manifeste que le feu, par destruction des germes, a fortement diminué la puissance dénitrifiante (voir x2, x3 et x4 = échantillons prélevés respectivement le lendemain, 15 jours et 2 mois après le feu). Il apparait ainsi une relation directe entre la puissance dénitrifiante et l'activité microbienne totale du sol. Les graphiques traduisent une vitesse de disparition des nitrates très ralentie par rapport à celle du prélèvement d'avant le feu (x1), qui est elle—même moindre que celle des terres fertiles témoins simultanément étudiées. Les réponses de x2,x3 et x4 sont proches de celles obtenues avec des tourbes de Rambouillet où la vitesse d'attaque des nitrates est aussi plus faible, tout en donnant lieu à un dégagement d'ammoniaque plus important.

Un même schéma général se dégage des graphiques obtenus avec l'ensemble des terres. En effet, si de telles différences apparaissent suivant les échantillons, quant à la vitesse d'apparition, la durée, l'extension et le chevauchement des phénomènes, il n'en reste pas moins que :

(*a*) la formation des nitrites accompagne parallèlement l'attaque des nitrates ; elle est fugace, et sa disparition coincide souvent avec celle des nitrates,

(*b*) la formation de l'ammoniaque suit celle des nitrites et est relativement plus faible dans les sols fertiles témoins. Ceci doit être en rapport avec une réutilisation de l'ammoniaque comparable à celle se produisant à la fin du processus d'ammonification. On peut rapprocher ces résultats de ceux obtenus, avec une toute autre méthode, sur le contenu de panse de mouton par LEWIS (4) qui démontre la formation de NO_2 et de NH_3, ainsi que la fugacité des nitrites.

Conclusions

Au point de vue qualitatif, les divers sols étudiés nous conduisent à considérer la dénitrification comme une phénomène complexe où s'enchainent et s'interpénètrent, en cours d'expérience, les phases de disparition des nitrates, d'apparition et de disparition des nitrites et de l'ammoniaque. Au point de vue quantitatif, ces phases se déroulent dans des limites bien définies de concentration en terre, donc de concentration en germes dénitrificateurs. Ces limites circonscrivent graphiquement de véritables " zones de réactions " nettement différentes selon les terres.

Une technique simplifiée pourrait être appliquée à l'évaluation de la puissance dénitrifiante, en réalisant une gamme de dilutions et en recherchant sur celle-ci, après 4 jours d'incubation à 28°, le dernier tube où l'on est en présence de nitrates. Les expériences réalisées jusqu'ici ne nous permettent pas de nous prononcer sur toutes les déductions à tirer de cette puissance dénitrifiante ainsi évaluée. La question d'un couplage nitrification-dénitrification, en particulier, est d'un grand intérêt. Elle est actuellement à l'étude au laboratoire,

et nous espérons que ces expériences, jointes à d'autres, permettront à la " puissance dénitrifiante " de prendre place parmi les caractères distinctifs de l'analyse pédologique.

BIBLIOGRAPHIE

(1) DENK, V. Zur Frage der Ammonentstehung im Stoffkreislauf der Natur. *Arch. f. Mikro.*, **15**, 308 (1950).
(2) WAKSMAN, S. Principles of soil microbiology (Williams et Wilkins ed. 1927).
(3) VERONA, O. Elementi di microbiologica pedologica. (Maori ed. 1947).
(4) LEWIS. *Biochem. J.*, **49**, 149 (1951).

RECHERCHES SUR LE PHÉNOMÈNE DE NITRIFICATION EN RAPPORT AVEC LA MICROFLORE

O COPPIER ET J. POCHON

Institut Pasteur, France

Le phénomène de nitrification a été l'objet de nombreuses recherches, envisagées sous les angles les plus divers. Nous nous sommes ici volontairement bornés à une étude du groupement physiologique pris dans son ensemble, en cherchant à évaluer la richesse du sol en microorganismes capables de produire ce phénomène : germes nitreux pour la première phase ($NH_4 \rightarrow NO_2$), germes nitriques pour la deuxième ($NO_2 \rightarrow NO_3$).

Les méthodes, très nombreuses, publiées jusqu'ici, évaluent cette richesse, les unes directement dans la terre, en additionnant celle-ci de sels ammoniacaux et en dosant les nitrates formés après un délai variable ; les autres dans un milieu artificiel, soit liquide ensemencé avec un poids connu de terre et dosage final des nitrates ; soit solides (silicogel) ou liquides, ensemencés avec des " grains de terre ", et détermination statistique du nombre de grains donnant une culture ; celle-ci étant elle-même testée chimiquement. Cette méthode des grains nous a semblé peu satisfaisante :

—difficulté et imprécision des lectures.

—aléa des chiffres trouvés.

En effet, sur plaque de silicogel (méthode de WINOGRADSKY) seuls les germes localisés à la portion de surface du grain au contact du milieu vont se développer ; surface éminemment variable avec le volume, la forme et la structure du grain, qui s'imbibera plus ou moins de liquide nitritif.

Sur les plaques où la source d'azote est un sel d'ammonium, les grains s'entourent d'une auréole translucide par dissolution de l'émaillage calcaire, mais ces auréoles sont presque toujours de taille très inégale, et leur diamètre varie facilement, entre les grains positifs d'une même plaque du simple au décuple.

Cela doit-il être attribué à un nombre plus ou moins grand de germes nitreux au départ dans le grain ?

La lecture est encore plus délicate sur plaque au nitrite ; les colonies de bactéries nitriques forment une petite tache jaunâtre qu'il est presque impossible de différencier des taches colorées dues à la diffusion autour des grains des substances humiques de la terre.

Il faudrait tester séparément chaque grain, ce qui est impossible par voie chimique (NO_2, NO_3 formés diffusant rapidement à toute la plaque de silicogel) et fort délicat par examen microscopique ; ce dernier est souvent pauvre en germes, qui sont très difficiles à identifier morphologiquement.

Ce test individuel de chaque grain a été réalisé par KAUFMANN et BOCQUEL, en les ensemençant séparément en milieu liquide dans des tubes à hémolyse. Les résultats sont encore ici exprimés par un pourcentage de grains positifs. Mais cette notion de pourcentage nous semble aléatoire.

Ces méthodes donnent pour chaque grain de terre, une réponse " tout ou rien." En dénombrant les grains fertiles, on ne préjuge

aucunement sur leur richesse en microorganismes nitrificateurs : qu'ils contiennent une ou plusieurs colonies, importantes ou minuscules, la réponse sera uniformément positive, pourvu qu'un seuil de croissance soit atteint. Pour évaluer la richesse d'un sol en germes responsables d'une réaction, il faudrait connaître le nombre de microbes nécessairement présents dans le milieu pour que la réaction se produise. Or, il ne semble pas que jusqu'à présent, la biologie des germes de la nitrification ait été éclaircie sur ce point. Ceci nous a donc amené à poser arbitrairement la notion d'unité réactive, de " seuil " de croissance : quantité x de germes nécessairement présents dans le milieu pour qu'une culture ait lieu et que l'on puisse caractériser les produits de son métabolisme (seuil qui peut être égal à l'unité pour les germes capables de proliférer à partir d'une cellule unique). (Nous ne ferons dans le cas des nitrificateurs aucune hypothèse sur la valeur quantitative du seuil.) Dans la technique du " grain," la grosseur de celui-ci, qui dépend essentiellement de l'expérimentateur et de la structure physique de la terre, influencera d'une manière très importante les résultats. Pour une terre, d'une richesse donnée en microorganismes nitrificateurs, plus le grain prélevé sera gros, plus la probabilité qu'il contienne la quantité x de germes sera grande.

Nous avons donc cherché à remplacer le " grain " par des prélèvements de terre *qualitativement* semblables (par une répartition plus égale des germes fixés sur les particules de terre, par trituration au mortier et émulsion dans l'eau), et *quantitativement* égaux (ensemencement des milieux sélectifs par des poids connus de terre, obtenus par des dilutions successives dans l'eau Seine).*

Une gamme de dilutions successives jusqu'à 10^{-7} s'avère suffisante pour les divers échantillons de terre sur lesquels nous avons expérimenté. Mais il peut être nécessaire de pousser les dilutions jusqu'à 10^{-10} et même au delà, dans le cas de terres particulièrement riches, de boues activées, etc.

Nous employons un milieu électif dont la formule est la suivante :

—Pour les germes nitreux

Milieu salin de WINOGRADSKY, dilué au 1/20ème	1000 cm³
CO_3 Ca	1g.
SO_4 $(NH_4)^2$	0,95

—Pour les germes nitriques

Milieu salin de WINOGRADSKY, dilué au 1/20ème	1000 cm³
CO_3 Ca	1g.
NO_2 NA	1g.

milieux qui correspondent chacun à la même concentration en azote, soit 0,20%.

Ces milieux sont répartis à raison de 1cm² par tubes (bouchage au coton—stériliser 20' à 112°). Nous avons employé des tubes de différents diamètres de manière à faire varier le rapport $\frac{S}{V}$

*Nous employons pour toutes les manipulations (émulsions, dilutions, préparations des milieux) l'eau de Seine stérilisée ; l'eau de conduite fournie à Paris contenant des antiseptiques susceptibles d'entraver les cultures, et l'eau distillée des traces non négligeables de Cuivre.

Série I $\frac{S}{V}=3{\cdot}2$

Série II $\frac{S}{V}=0{\cdot}8$

Série III $\frac{S}{V}=0{\cdot}5$

Il ressort de nos expériences que la vitesse d'apparition des NO_2 et NO_3 augmente avec ce rapport. On a donc intérêt à employer des tubes à large ouverture, mais il faudra tenir compte alors de l'évaporation du milieu liquide (il faut disposer les séries de tubes dans une conserve en milieu humide, ou complèter au volume initial avec de l'eau de Seine stérile tous les 4 ou 5 jours). Les ensemencements sont effectués avec 1 cm^3 de chaque dilution—séjour de 1 mois à l'étuve à 29°, avec agitation tous les 4 ou 5 jours pour permettre une meilleure neutralisation du milieu par le CO_3Ca.

Notre test sera basé sur la quantité minima de terre correspondant au "seuil," c'est-à-dire la quantité minima de terre donnant encore lieu :

pour la nitritation, à une transformation de NH_4 du milieu en NO_2 (mis en évidence des nitrites (ou des nitrates le stade nitrite étant transitoire) par le réactif à la diphénylamine sulfurique→ coloration bleue)

pour la nitratation, à une transformation de NO_2 du milieu en NO_3 (caractérisation des nitrates par le même réactif, après avoir pris la précaution d'éliminer les nitrites qui peuvent n'avoir été que partiellement transformés dans le milieu (décomposition par l'urée ou l'azide de sodium en présence d'acide sulfurique)).

Il nous a paru commode d'adopter, pour rendre compte des résultats, une échelle analogue à celle utilisée par SÖRENSEN pour les pH.

Nous définirons ici un "indice de nitrification" qui sera le cologarithme n du poids de terre minimum (c'est-à-dire 1 g. x 10^{-n}) qui donne encore lieu au développement d'une culture. Les résultats seront ainsi exprimés par un simple chiffre et l'on déterminera pour l'analyse biologique d'une terre, un indice de nitritation, et un indice de nitratation.

Soit par exemple une terre P, pour laquelle nous avons encore obtenu une réaction de nitritation positive par ensemencement de 1 g. de dilution à 10^{-5}. L'indice de nitritation de la terre P sera égal à 5—même définition d'un indice de nitratation.

Lors la mise au point de cette méthode, les ensemencements de chaque dilution furent fait en quadruple. Il arrive fréquemment que la zone limite soit indécise, la dernière dilution à envisager comportant à la fois des tubes positifs, des tubes négatifs et des tubes dans lesquels on ne peut révéler que des traces de produit transformé. On donnera alors à l'indice une valeur intermédiaire, compte tenu du pourcentage de tubes positifs dans la dilution envisagée, ceci sans

vouloir attribuer au deuxième chiffre significatif une valeur, une rigueur qu'il n'a pas.

La *concordance* de la méthode a été vérifiée en ensemençant 10 tubes par dilution (expérience réalisée sur plusieurs terres). Tous les tubes d'une même dilution se comportent, aux erreurs d'expériences près, de la même manière, sauf pour la zone limite, dans laquelle l'ensemencement est de l'ordre de grandeur du seuil $\pm$ ce qui explique les irrégularités signalées plus haut.

Pour étudier la *fidélité* de notre méthode, nous avons cherché quel pourrait être l'écart entre les résultats obtenus à partir de prises d'essai différentes prélevées sur une même terre. Ces écarts sont toujours très faibles.

Voici quelques résultats obtenus au laboratoire :

	Ii	Ia
Terre de prairie ombragée (Juin 51)	5	5
Terre de jardin (Septembre 1951)	6	6
Terre de Bauce (Septembre 1951)		
—No. 1 champs donnant des récoltes moyennes	3,75	2,5
—No. 2 champs donnant de très belles récoltes	5	4,5
Tourbière de Cerizet (fôret de Rambouillet) (Novembre 1951)	1,5	0,75

Ainsi l'emploi des indices de nitritation et de nitratation, s'il ne permet pas une détermination exacte du nombre de germes nitrificateurs d'une terre, en donne cependant une évaluation fidèle en fonction d'une " seuil de croissance," notion liée à la biologie de ces germes, que nous espérons pouvoir préciser ultérieurement.

L'emploi de ces indices nous a déjà permis de comparer des terres entre elles au point de vue de leur richesse en germes nitrificateurs et de tenter un rapprochement entre cette richesse en microorganisme et leur fertilité. Notre technique n'a donc pas la prétention d'être rigoureuse, mais elle nous a semblé intéressante dans son principe, et pratique dans ses résultats.

DIE WIRKUNG DER DÜNGUNG MIT MINERALISCHEM STICKSTOFF AUF DIE BIOLOGISCHEN EIGENSCHAFTEN DES BODENS

A. JACOB

Agrikulturchem. Laboratorium der Gewerkschaft Victor, Castrop-Rauxel, Deutschland

Die Düngung mit Stickstoff äussert zwar ihre Wirkung in erster Linie auf den Pflanzenertrag, sie ist aber auch auf den Boden nicht ohne Einfluss. Infolge der starken Dynamik des Stickstoffs ist allerdings der Einfluss der Stickstoffdüngung auf den Stickstoffhaushalt des Bodens nur sehr schwierig zu erfassen. Die Umsetzungen, welche der durch die Düngung zugeführte Stickstoff im Boden erfährt, sowie die Wirkungen, die er auf den Boden ausübt, sind daher bisher noch verhältnismässig wenig untersucht worden, sodass es angebracht schien, einmal dieser Frage nachzugehen. Insbesondere wurde dabei auch die Wirkung des Stickstoffs auf die biologischen Verhältnisse des Bodens ins Auge gefasst.

Die Unterlagen lieferte ein Düngungsversuch auf einem Versuchsfeld des Klosters/Gerleve Westf. Der Boden des Versuchsfeldes war ein diluvialer, lehmiger Geschiebesand, er war durch ständige Stallmistdüngung in gutem Düngungszustand; pH in Krume und Untergrund lag bei 7,0. Als Stickstoffdünger wurde Ammoniakstickstoff in einer Gabe von 200 kg. N je ha verabfolgt. Die Niederschläge während der Versuchszeit (15·5.—19·11.) waren bei 298 mm. Die Versuchsfrucht war Kohlrabi.

Wie Tabelle 1 zeigt, hatte die Stickstoffdüngung eine sehr starke ertragssteigernde Wirkung.

TABELLE 1

	Ohne Stickstoff	Mit Stickstoff 200 kg./ha.	Mehr-Ertrag durch N
Knollen	131,7 dz./ha.	316,2 dz./ha.	184,5 dz./ha.
Laub	112,8 ,,	196,8 ,,	84,0 ,,
Wurzeln	4·4 ,,	7,8 ,,	3·4 ,,

Zur Untersuchung der Umwandlungen, die der mineralische Stickstoff im Boden erfährt, wurden vor Anlage des Versuches, während der Wachstumsperiode unmittelbar nach der Ernte, sowie einige Wochen nach der Ernte mit einem besonders konstruierten Bodenbohrer Bodensäulen bis zu 40 cm. Tiefe ausgestochen, aus denen Mischproben der Schichten aus 0–13, 13–26 und 26–40 cm. Tiefe zusammengestellt wurden. In diesen Proben wurde der Gehalt an Gesamt N, NH_4–N und NO_3–N bestimmt. Die Ergebnisse dieser Untersuchungen sind in den Tabellen 2–4 wiedergegeben:

TABELLE 2.—*Gesamtstickstoff im Boden*

	Ohne Stickstoff	Mit Stickstoff
0-13 *cm. Tiefe*		
1. Probe 15.5.1951	135,6 mg./100 g.	135,6 mg./100 g.
2. ,, 20.6.	135,4	133,8
3. ,, 19.7.	127,9	125,1
4. ,, 24.8.	130,9	124,9
5. ,, 9.11.	135,4	128,6
13-26 *cm. Tiefe*		
1. Probe	119,5	117,0
2. ,,	113,3	111,0
3. ,,	110,6	113,9
4. ,,	107,8	105,2
5. ,,	105,2	112,4
26-40 *cm. Tiefe*		
1. Probe	85,0	78,4
2. ,,	86,7	86,7
3. ,,	84,7	85,6
4. ,,	85,3	84,4
5. ,,	85,2	86,6

TABELLE 3.—*Ammoniakstickstoff im Boden*

0-13 *cm. Tiefe*		
1. Probe	6,46 mg./100 g.	6,19 mg./100 g.
2. ,,	5,99	6,50
3. ,,	5,98	5,75
4. ,,	6,08	5,51
5. ,,	5,96	5,62
13-26 *cm. Tiefe*		
1. Probe	6,58	5,74
2. ,,	5,29	4,72
3. ,,	4,88	4,63
4. ,,	4,91	4,41
5. ,,	4,74	4,71
26-40 *cm. Tiefe*		
1. Probe	3,83	3,81
2. ,,	3,34	3,85
3. ,,	3,52	3,42
4. ,,	3,60	3,13
5. ,,	3,67	3,76

TABELLE 4.—*Nitratstickstoff im Boden*

0-13 *cm. Tiefe*		
1. Probe	0,89 mg./100 g.	0,86 mg./100 g.
2. ,,	0,82	3,78
3. ,,	1,00	3,99
4. ,,	0,78	0,90
5. ,,	0,31	0,35
13-26 *cm. Tiefe*		
1. Probe	0,75	0,61
2. ,,	0,72	1,08
3. ,,	1,04	3,52
4. ,,	0,70	1,85
5. ,,	0,39	0,72
26-40 *cm. Tiefe*		
1. Probe	0,68	0,61
2. ,,	0,64	0,89
3. ,,	0,68	1,45
4. ,,	0,76	1,28
5. ,,	0,42	0,67

Wie die Untersuchung der vor der Düngung entnommenen Proben zeigt, war das Feld von einer befriedigenden Gleichmässigkeit. Immerhin waren aber die Schwankungen so gross, dass die durch die Düngung zu bewirkenden Veränderungen des Gehalts an Gesamt-N nicht zu erkennen waren. Ein deutlicheres Bild ergaben dagegen die Bestimmungen der Gehalte an NH_4-N und NO_3-N.

Der durch die Düngung zugeführte NH_4-N war bereits 5 Wochen nach der Düngung durch die Bodenbakterien vollständig zu NO_3-N umgesetzt worden. Der durch die Düngung mit NH_4-N zugeführte Stickstoff wurde also von den Pflanzen nicht in dieser Form aufgenommen, sondern erst durch die Bodenbakterien zu NO_3-N verarbeitet.

Die Umwandlung des NH_4-N in die Nitratform ist zunächst von Bedeutung für die Stickstoffauswaschung. Solange der Stickstoff als NH_4-N vorliegt, wird die Auswaschung dadurch verhütet, dass NH_4 durch Austauschadsorption von den Bodenkolloiden festgelegt wird. Wie Tabelle 3 zeigt, hat eine Abwanderung von NH_4-N in die tieferen Schichten nicht stattgefunden.

Für den NO_3-N, der nicht durch Adsorption festgelegt wird, besteht kein Schutz gegen Auswaschung. Wie Tabelle 4 zeigt, ist der NO_3-N 5 Wochen nach dem Ausstreuen etwas über 13 cm. tief in den Boden eingedrungen. Die Vegetation stand zu dieser Zeit noch im Anfang und ihr Wasserverbrauch war nur gering. Bei der nächsten Probe ist in der Schicht von 13–26 cm. bereits eine Erhöhung des Nitratgehalts infolge Auswaschung aus der oberen Schicht eingetreten. Wenn trotzdem noch in der obersten Schicht etwa die gleiche Nitratmenge festgestellt wurde, wie bei der vorhergehenden Untersuchung, so lag das offenbar daran, dass in dieser, für die Bakterientätigkeit günstigen Jahreszeit ein Teil des organischen N in die Nitratform übergeführt wurde. Durch den starken Stickstoffentzug der Pflanzen ändert sich aber dann das Bild; der Gehalt an Nitratstickstoff geht in sämtlichen Schichten, die durchwurzelt sind, infolge des Entzuges durch die Pflanzen wieder zurück. Solange das Feld mit Pflanzen bestanden ist, ist eine Auswaschung von Nitratstickstoff in den Untergrund offenbar nicht eingetreten. Anders ist dies aber bei den Proben, die 6 Wochen nach der Ernte gezogen waren. In der obersten Schicht der gedüngten Parzellen ist nunmehr der Nitratgehalt nicht mehr höher als in den ungedüngten Parzellen.

Der starke Einfluss der Stickstoffaufnahme der angebauten Pflanzen auf den Stickstoffhaushalt des Bodens ist aus der in Tabelle 5 wiedergegebenen Stickstoffbilanz ersichtlich, die insbesondere auch wieder zu dem Schluss führt, dass eine Auswaschung von Stickstoff während der Vegetationszeit nicht stattgefunden hat.

TABELLE 5

	Ohne Stickstoff N-Entzug kg./ha.	Mit Stickstoff N-Entzug kg./ha.
Knollen	50,0	208,7
Laub	33,8	86,6
Wurzeln	1,5	9,3
Gesamtentzug	85,8	304,6

Da von Kreisen, die gegen die Mineraldüngung eingestellt sind, behauptet wird, dass durch die Anwendung von Mineraldünger das biologische Verhalten des Bodens geschädigt wurde, wurden auch Untersuchungen nach dieser Richtung hin angestellt. Dass diese Ansicht nicht zutreffend ist, zeigte schon die starke Nitrifikation, die in den ersten Wochen nach dem Ausstreuen der Dünger eintrat.

Es wurde zunächst die Behauptung geprüft, ob durch die mineralische Düngung der Humusgehalt des Bodens vermindert würde. Bei den Parzellen ohne Stickstoff ergab sich ein Humusgehalt von 1,62%, bei den Parzellen mit Stickstoff von 1,66% organ. Substanz. Eine Verminderung des Humusgehaltes ist also nicht eingetreten. Es war dies auch schon deshalb nicht zu erwarten, weil durch die Stickstoffdüngung die Wurzelmasse von 4,4 dz./ha. auf 7,8 dz./ha. vermehrt worden war, sodass dadurch eine Zunahme an organischer Substanz im Boden bewirkt wurde. Auf die Bodenmenge von 100 g. umgerechnet, ist die Zunahme aber so geringfügig, dass sie sich analytisch nicht nachweisen lässt.

Ein weiterer Weg, der eingeschlagen wurde, um die biologische Tätigkeit des Bodens zu kennzeichnen, war die Bestimmung der von den Bodenbakterien gebildeten Fermente (nach E. HOFMANN). Hierbei ergaben sich die folgenden Gehalte an Saccharase in 100 g. Boden :

TABELLE 6

	Ohne Stickstoff	Mit Stickstoff
Oberste Schicht	5,08	5,10
Mittlere ,, ...	3,84	3,85
Untere ,, ...	2,62	2,94

Deutlich zeigt sich hier die Abnahme der Aktivität nach den tieferen Bodenschichten hin. Eine Veränderung der Aktivität als Folge der Düngung lässt sich nicht feststellen, jedenfalls trat keine Verschlechterung durch die Salzzufuhr ein.

Zur Kennzeichnung der biologischen Tätigkeit des Bodens wurde dann weiter die Entwicklung von CO_2 bestimmt. In 22 Tagen wurde je 100 g. Boden folgende Entwicklung von CO_2 festgestellt :

Ohne Stickstoff : 37,5 mg. *Mit Stickstoff :* 44,1 mg.

Die CO_2–Entwicklung des gedüngten Bodens war also deutlich höher als die des ungedüngten Bodens.

Von den Gegnern der mineralischen Düngung wird nun die Behauptung aufgestellt, dass die chemischen Methoden nicht fein genug seien, um die geringen Veränderungen zu erfassen, die sich bereits biologisch schädlich auswirken können. Wir haben daher die Wirkung der Stickstoffdüngung auf die biologischen Verhältnisse des Bodens auch direkt dadurch verfolgt, dass wir die Anzahl der Regenwürmer bestimmten, die auf den verschieden behandelten Parzellen auftraten. Die Regenwürmer haben die Möglichkeit, auf ungünstige Verhältnisse ohne weiteres damit zu reagieren, dass sie abwandern, sodass auf diese Weise derartige Veränderungen nachweisbar sein müssten. Zur Bestimmung der Zahl der Regenwürmer wurde in der Mitte

jeder Parzelle mit einer Schablone ein Quadrat von 50 cm. Seitenlänge bis zu einer Tiefe von 20 cm. ausgestochen und die darin enthaltenen Regenwürmer ausgezählt. Regelmässig zeigte sich, dass bei den ungedüngten Parzellen die Zahl der Regenwürmer stets erheblich niedriger war, als auf den abwechselnd angeordneten gedüngten Parzellen und zwar ergaben sich im Durchschnitt je m^2:

Ohne Stickstoff: 128 Regenwürmer.
Mit Stickstoff: 176 Regenwürmer.

Die Regenwürmer bevorzugten mithin gerade die mit Stickstoff gedüngten Parzellen. Dies steht natürlich nicht im Zusammenhang mit der Anreicherung des Bodens an mineralischem Stickstoff, wohl aber damit, dass auf den mit Stickstoff gedüngten Parzellen infolge des besseren Pflanzenwachstums der Boden stärkere beschattet war und auch in Form von Blattabfällen und abgestorbenen Wurzeln den Regenwürmern mehr Nahrung bot.

NITROGEN ECONOMY OF THE SOIL IN RELATION TO SEASONAL AND PERIODICAL CLIMATIC VARIATIONS

J. J. LEHR AND B. VEEN
Plant Nutrition Research Laboratory and Institute of Forestry (Agricultural University), Wageningen, Netherlands

The characterisation of the nitrogen status from the point of view of soil fertility provides considerably more difficulties than that of the K–, P– or Ca–status. At best one can state a content for the total amount of nitrogen, present in the soil organic matter, and try to express its availability on the basis of the C : N ratio. The determination of carbon contents is, however, uncertain in the analytical methods concerned (except for the elementary analysis) and the usability of an average C : N ratio for a mixture of different organic compounds is so doubtful that it is difficult to base reliable conclusions hereon.

It is not possible either to characterize the nitrogen status of the soil on the mobile N–forms (nitrate and ammonium), as their contents are liable to very heavy fluctuations. These fluctuations arise largely from weather conditions. Beside short-term fluctuations there are seasonal variations in rainfall, temperature and sunshine, which are of great influence on microbiological processes, together ruling the soil's N–economy ; excessive rainfall also causes leaching of nutrients. Apart from seasonal variations long-term climatic variations occur, also provoking changes in the N–status of the soil, which therefore shows a continuously varying picture. To enable a fruitful discussion on the nitrogen-status of the soil, a closer insight into this climatic influence is of primary importance.

Some observations which can serve this purpose have been made on a field experiment on light humic sandy soil, which was laid out in 1949 and has been sampled at intervals to determine the pH, nitrate–N, ammonia–N and moisture content (mainly from March until October). The years 1949, 1950 and 1951 offered rather extreme weather types and it was observed that, following the wet winters of 1950 and 1951, contents of nitrate–N and ammonium–N were considerably lower than after the dry winter of 1949 (uncropped soil).

TABLE 1

Average NO_3-N and NH_4-N contents of a humic sandy soil in successive dry and wet years

Year	Precipitation† 1st Dec.-30th Nov.	Uncropped control		Cropped control	Uncropped plots with NH_4NO_3-dressings		
		NO_3-N*	NH_4-N*	N-withdrawal by crop	N-dressing	NO_3-N*	NH_4-N*
		p.p.m.	p.p.m.	kg./ha.	kg./ha.	p.p.m.	p.p.m.
1949	606	6·2	3·5	53 (oats)	66	17·8	9·5
1950	890	3·9	2·1	33 (s. rye)	60	6·8	3·3
1951	845	2·3	4·4	22 (w. rye)	75	6·4	6·5

†Normal yearly precipitation 723 mm.
*Average content of the topsoil during growing season.

The N-withdrawal by the crop for the three years is not strictly comparable (crops: oats, summer rye and winter rye respectively). Nevertheless the figures for 1950 and 1951 also indicate a reduced availability of soil nitrogen. Besides, fertilizer nitrogen showed a considerable leaching in the latter years; this is illustrated by Table 2, with the figures of NO_3–N and NH_4–N contents in the upper layer of the uncropped soil (15 cm.) following a dressing with NH_4NO_3. The figures represent an average of 3 plots and have been reduced by the N-content of the uncropped soil at that time.

TABLE 2

NO_3-N and NH_4-N contents of a humic sandy soil in relation to rainfall after dressing NH_4NO_3

	NO_3-N	NH_4-N	Sum	Rainfall during preceding interval
1950	p.p.m.	p.p.m.	p.p.m. N	mm.
28/3	13*	13*	27*	—
3/4	12	11	23	6
12/4	9	5	14	33
24/4	8	(13)	21	15
3/5	9	3	12	45
15/5	0	3	3	21
1951				
14/3	6*	6*	13*	—
20/3	3	6	9	24
27/3	0	0	0	13

*Theoretical figures, computed from an even distribution of the N-fertilization over a soil layer of 15 cm., 60 and 30 kg. N per ha. respectively.

The applied dressings, ammonium as well as nitrate, can disappear from the cultivation layer in a few weeks, even in April or the beginning of May.

A better understanding of the movement of soilwater under Dutch climatic conditions is acquired from Figure 1, which was designed by one of the authors from average data for rainfall and temperature. The drawn line represents the yearly trend of the precipitation, the interrupted line indicates the evaporation of a cropped loamy soil, with a waterholding capacity of 22%, computed according to THORNTHWAITE (8).

In winter the precipitation exceeds the evaporation; then the soil is saturated with water which results in leaching. In summer the evaporation is beyond rainfall owing to which the water reserve gradually diminishes until it is wholly exhausted at about the end of July. Under its influence the soil water rises in summer and a part of the nutrients, that were leached in winter and remained suspended in the subsoil, again become available for plant growth.

The transition from winter to summer and from summer to winter is marked by two equivalence points (E.P.), between rainfall and evaporation. Averagely, these points occur in the first half of April and in the middle of September.

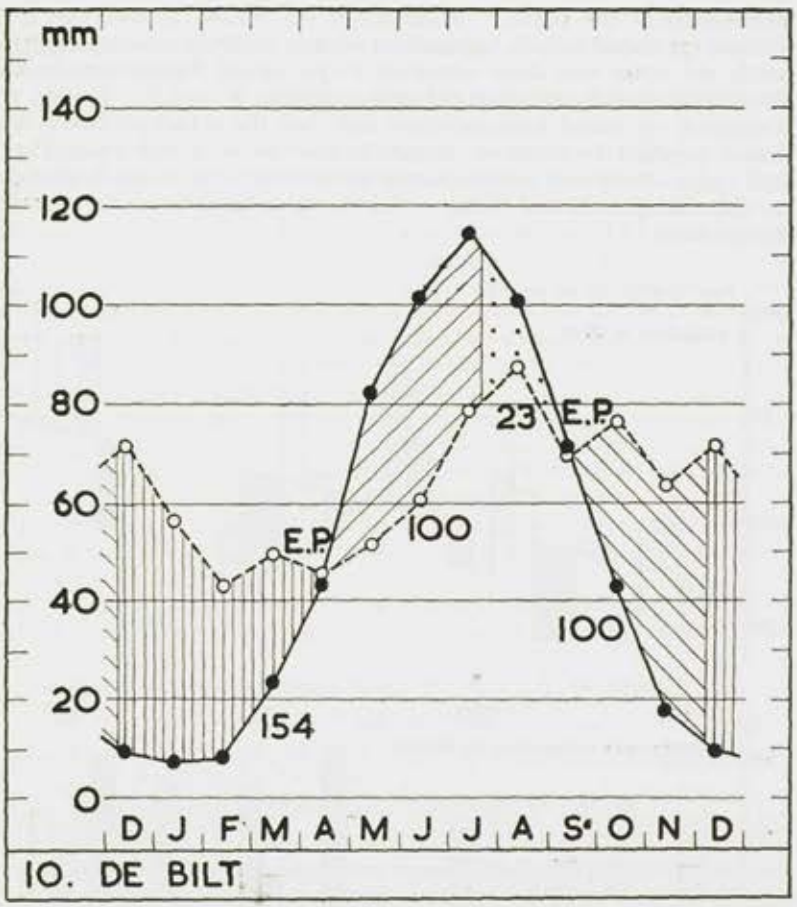


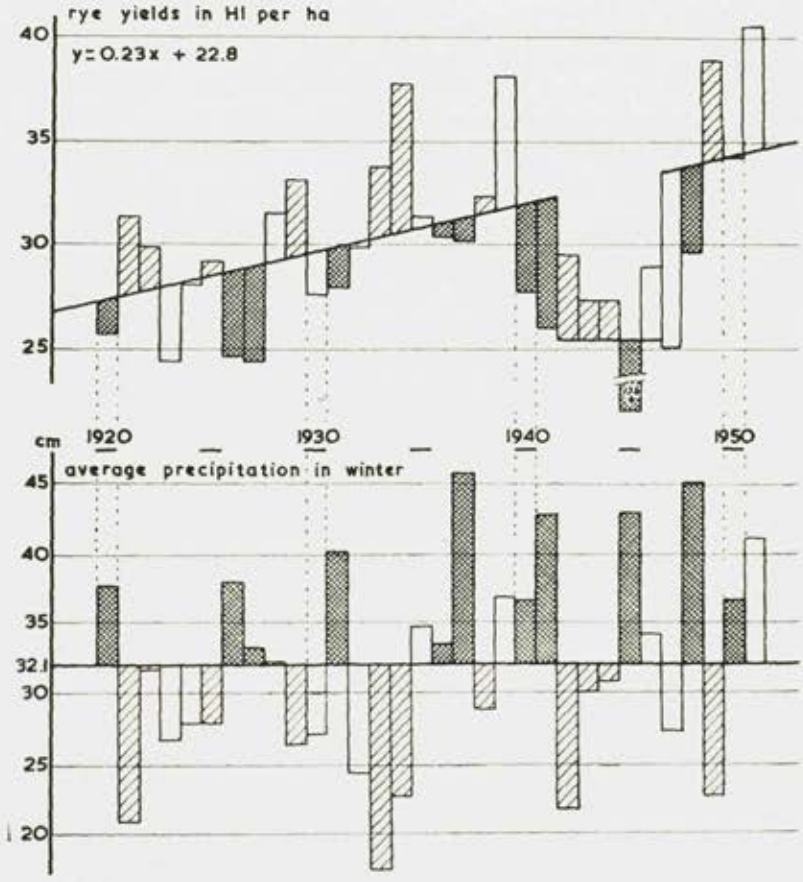
Figure 1

Normal trend of precipitation and evaporation for De Bilt (Netherlands) computed according to THORNTHWAITE.

It follows from this that there is no more danger of leaching after the beginning of April and before the second half of September. As, however, a deficit of water still occurs in the soil at that time, saturation of the soil with water will only be reached later, i.e. in the beginning of December. Under the influence of climatic variations important deviations from this picture can present themselves from one year to the other. Independently from this shifting of the equivalence points, changes of the amount of drainwater in winter can result. In wet autumn periods the saturation point may shift towards November and the equivalence point in spring towards the end of April or even the beginning of May. Therefore for Holland the precipitation in the period from November until April is decisive for leaching.

Different efforts have been made to find a relationship between climatic factors and crop yields. FEEKES (3), WOUDENBERG (9) and VAN DOBBEN (2) searched for the factors, composing "the ideal wheat-climate," basing themselves more or less on the physiological

disposition of the plant. KAMERLING (5), BEAN (1) and VAN DER PAAUW (7) stated certain regularities of crop yields in successive years while the latter also drew attention to periodical fluctuations in soil fertility, especially relating pH and available P and K. FRANC DE FERRIERE (4) stated for a sabulous soil that the return of the K fertilizer (applied to potatoes) lagged behind in very wet years (1937 and 1940). No special investigations are known to us in which changes in the nitrogen status of the soil have been correlated to climatic fluctuations.



Yield below normal when precipitation beyond normal.

Yield beyond normal when precipitation below normal.

Figure 2

Relation between average rye yields in the Netherlands and the average precipitation in winter.

To indicate a closer relationship between climate and soil fertility, especially in connection with the N–status, Figure 2 relates the average rye yields in the Netherlands and the precipitation in the winter

months (November up to April inclusive). The following remarks have to be made hereon :

1. In Holland, rye (mostly winter rye) is cultivated chiefly on sandy soils, which are most liable to leaching,

2. Since 1880 rye yields are moving in an ever ascending line and have meantime been doubled approximately. To account for this increase with the yearly fluctuations a trend has been computed for the last 30 years ($y = 0{\cdot}23\,x \pm 22{\cdot}8$ in which y = yield and x = year 1900),

3. During the wars 1914–18 and 1940–45 yields lagged very much behind owing to shortage of fertilizers. For this reason the period before 1920 has been left out of consideration. As in the years 1940 and 1941 a sufficient amount of fertilizers was available these have been classed under the normal trend, while the yields from 1942 to 1946 are only compared with their own average.

Though precipitation during the winter season is not the only deciding factor, a rather good and statistically highly significant negative correlation ($r = -0{\cdot}419$) is found between these two factors. It also appears from Figure 3 and the following data :

A. Of 6 years with a surplus of precipitation in winter of 25% or more, five gave bad rye-yields, three of which were markedly lower than the average,

B. 5 years with extremely dry winters (precipitation more than 25% below the average) gave all yields substantially exceeding the yearly average.

The linear regression equation is : $y = \bar{m}.x + \bar{q}$, in which :

y = yield difference from the average (hl) ;

x = total amount of precipitation during November up to April inclusive (cm.) ;

$\bar{m}$ = regression coefficient = $-0{\cdot}215 \pm 0{\cdot}038$ (Hl/cm.)

$\bar{q} = +6{\cdot}9 \pm 1{\cdot}3$ (Hl)

No effort has been made for a more detailed analysis of the relationship between weather conditions and yield. In 1947 a long-continued period of drought caused the yield to remain far below expectation. Very probably the rainfall in the third decade of June and the first and second decades of July plays an important role with the ripening of the grain ; unfavourable results in the years 1927, 1930, 1936 may be explained from heavy rainfall in this period. For a more detailed yield analysis it would be necessary also to have straw yields at disposal.

The following conditions may be deemed of influence on the leaching of nutrients from the soil :

1. Heaviness of the soil. As a rule, heavy soils have a greater water-holding capacity than lighter soils and drain less rapidly, so that there is less danger of leaching.

2. Depth of the profile. With soils of a sufficiently deep profile (for example, loamy soils on a loamy subsoil or old cultivation soils with a cultivation layer up to 1 metre or more thickness as occur in Holland) there will be a better chance for washed out nutrients to remain suspended in the lower soil layers, even in wet winters. With shallow profiles (for example, a thin layer of clay on a subsoil of sand or a humic sandy soil on a layer of gravel) the leaching chances are considerably greater.

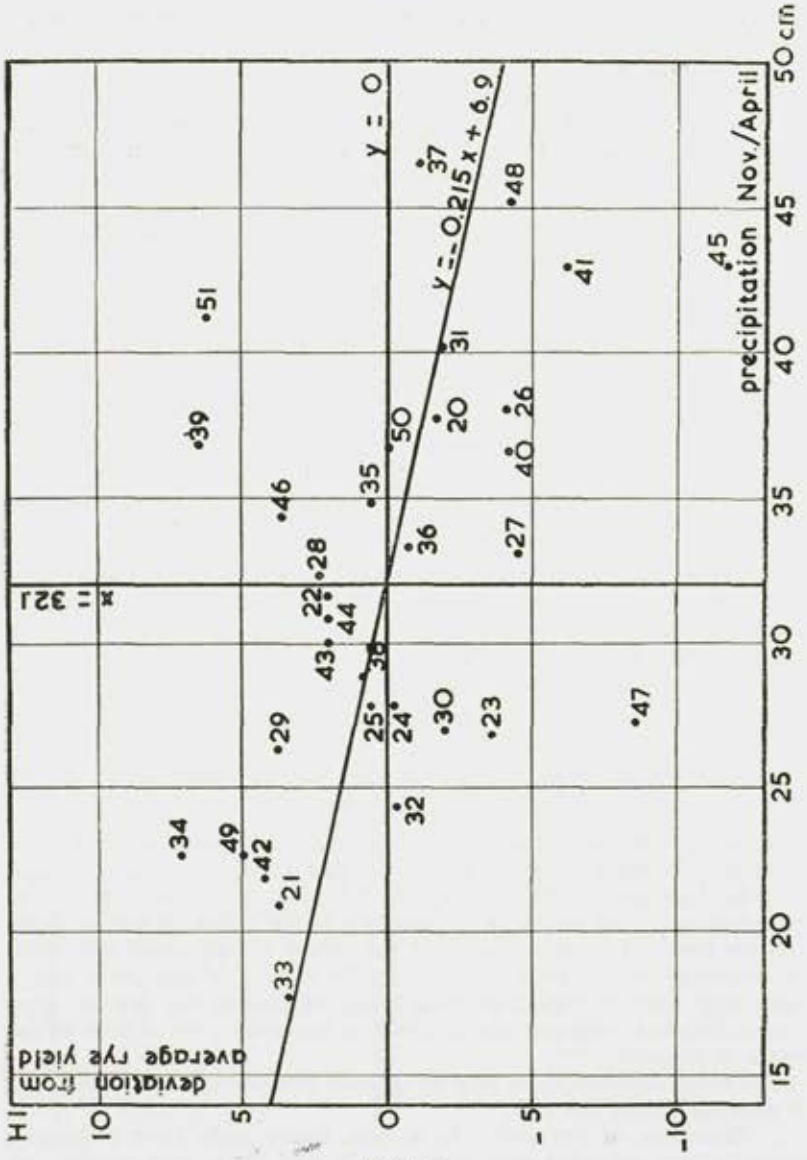


Figure 3
Regression graph referring to Fig. 2.

3. Level of the soil water and depth of drains.

4. Vegetation. On a cropped soil there will be less leaching as the plants are more developed and there is a better rooting of the soil. The plants not only absorb nitrogen from the soil solution but by their evaporation also reduce the amount of drainage water.

5. Climate during the summer months. Dry and warm weather during May, June and July stimulates the rising of the soil water,

so that nutrients, that have remained in the subsoil, are brought again within the reach of the roots.

6. On acid soils all cations, and in consequence ammonium too, are more subject to leaching.

It is the aim of the present communication to attract more attention to the relation between climate and soil fertility, especially as regards nitrogen economy, and to recommend a closer study of the fluctuations connected herewith. This study may be largely bound by local conditions of climate but may still yield aspects which are of general use.

A better insight into the N-status of the soil would also enable certain recommendations regarding the time of application and dosage of fertilizers to be made.

With winter cereals two factors are to be considered which have an opposite tendency. On the one hand, it is desirable to apply an early nitrogen dressing in order to start growing as soon as possible. The favourable effect of early N dressing on winter rye, established by VAN DOBBEN (2), is very probably based on improved tillering. On the other hand, there is an undiminished danger of leaching in extreme wet winters (to be expected at least once in four years) and it would seem wise, in order to diminish this risk, to subdivide the nitrogen gift and to apply the greater part of it towards the time of the equivalence point. In extreme wet winters the nitrogen doses will also have to be enlarged on account of the losses of soil nitrogen.

With summer crops that are sown early, the habit of fertilizing at the time of sowing includes considerable risks of leaching as well and it seems to be a better policy to the good of yield security to apply nitrogen as a top dressing. Allowance can always be made for the rainfall of the preceding winter.

LITERATURE

(1) BEAN, L. H. Misc. Publ. 471, Dept. of Agriculture and Dept. of Commerce (Febr., 1942).
(2) DOBBEN, W. H. VAN. *Maandbl. Landbouwvoorlichtingsdienst*, **4**, 64-67 (1947).
(3) FEEKES, W. Verslagen Techn. Tarwecommissie, **17** (1941).
(4) FRANC DE FERRIERE, P. J. J. Deux champs centraux d'essais d'engrais potassiques aux Pays-Bas, Soc. Commerciale des potasses d'Alsace (1951).
(5) KAMERLING, Z. Periodische klimaatswijzigingen en tropische landbouw (Haarlem, 1916).
(6) PAAUW, F. VAN DER. *Landbouwk. Tijdschr.*, **60**, 83-92 (1948).
(7) PAAUW, F. VAN DER. Fourth Intern. Congress of Soil Science (Amsterdam, 1950). Trans. **2**, 151-155.
(8) THORNTHWAITE, C. W. *The Geographical Review*, **38**, 55-94 (1948).
(9) WOUDENBERG, P. J. M. Meded. en Verh. van het K.N.M.I. nr 50 (1946).

A NOTE ON THE AVAILABLE NITROGEN OF COMPOSTS FROM WASTE MATERIALS

G. E. G. MATTINGLY
Rothamsted Experimental Station, England

Despite much published work on methods of preparation of composts, relatively few attempts have been made to evaluate the availability of the nutrients in them. While the nitrogen content of farmyard manure is certainly variable, that of composts appears to vary over a wider range. JENKINS (1935) gives the mean nitrogen content of the dry matter of Adco composts from wheat straw, grass cuttings and veld grass as 2·9, 4·9 and 2·2% N respectively and farmyard manure as 2·2% N.

The availability of nitrogen in F.Y.M. has been estimated by a number of workers (see JENKINS, p. 11 et seq.); the estimates show wide differences and vary, among other things, with the length of time after application, the crop grown, the soil and the mean temperature during the growing period. Most estimates suggest that only 10–20% of the total nitrogen is taken up by crops in one growing season. BOULD (1945; 1948) obtained the same range for composts from town refuse and sewage sludge and from straw and sewage sludge.

Table 1 summarizes some of the results obtained with a wide variety of composts prepared at Reading University between 1947–1951. Most composts utilized sewage sludge as a source of nitrogen, but a few other materials were also used. They have been grouped into four classes depending on their initial N content; the table gives the mean % N in dry matter and organic matter after 1 year and estimates of the available nitrogen. All composts included in this table except two, were prepared under comparable conditions of moisture [70±5%] and aeration [16±2 weeks] and varied only in the initial level of nitrogen and the type of materials used. No attempt was made, as some workers have done (ASHWORTH, 1942) to make the levels of other nutrients, e.g. P_2O_5, K_2O constant because there are indications that they do not seriously limit decomposition (BOULD, 1945; GERRETSEN, MANTEN and MULLER, 1950).

The estimate of available N in the final compost is based on the nitrogen extracted in 24 hours by cold 0·1 N HCl; this "soluble nitrogen," which includes ammonia, nitrate and some organic N, is closely correlated with nitrate accumulation in soil (HOYLE and MATTINGLY, 1952).

TABLE 1

Mean total and "soluble" N contents of composts prepared with different initial levels of nitrogen

Initial N (%d.m.)	% N in dry matter	after 10-12 months		
		% N in organic matter	"soluble" N as % of total N	"soluble" N as % of dry matter
up to 1.2	1.4	3.9	10.6	0.11
1.2 to 1.7	2.3	3.7	17.3	0.37
1.7 to 2.2	2.7	4.8	12.4	0.35
over 2.2	3.9	5.0	6.4*	0.21*

*Mean of only 2 composts.

Table 2 relates the initial soluble N in 7 composts to the "soluble" N after 1 year.

TABLE 2

Initial and final soluble N in 7 composts

		mgms. per 100 gms. dry matter						
Sol. N at start ...	...	108	136	138	398	486	728	1160
Sol. N after 1 year ...	...	280	60	176	292	284	410	826

Table 3 gives a more detailed analysis of the four composts which had the highest percentage of nitrifiable nitrogen recorded in these experiments.

TABLE 3

Analysis of 4 composts with high available N

Compost	Initial N % dry matter	Age (months)	% N in dry matter	% N in organic matter	% Total N nitrified in 3 months	Nitrifiable N as % dry matter
Balsa sawdust —sludge ...	2·23	11	3·22	4·6	17·8	0·57
Wheat straw —sludge ...	2·44	16	3·22	6·3	18·9	0·61
Wheat straw —sludge ...	1·97	22	3·15	6·0	20·4	0·64
Wheat straw —ammonium sulphate ...	1·55	8	2·11	3·0	30·5	0·64

The results above (Table 1) illustrate how much the "soluble" and total nitrogen in the final composts vary with the initial nitrogen contents. It is possible, despite the wide range of values within groups, to indicate certain general trends in these results. The final nitrogen content in the dry matter increases nearly threefold as the level of the initial nitrogen increases from the lowest to highest range but the increase in nitrogen in the organic matter is much smaller.

The "soluble" nitrogen, when expressed as a percentage of the total N, increases only slightly with increasing initial N content but the higher level composts supply over three times as much soluble nitrogen per unit dry weight as composts from the low N group. The composts with less than 1·2% N initially included refuse-sludge, straw-refuse-sludge, garden waste + soil composts and a straw-sludge compost with a high ratio (3 : 1) of straw to sludge. Most of these composts contained high percentages (50–60%) of ash. The composts with over 1·7% N initially included two straw sludge composts with lower ratios (1 : 1 and 1 : 2) of straw to sludge, a compost from balsa sawdust (0·83% N) and sludge, and a straw-ammonium sulphate compost; these gave the highest figures for "soluble" and nitrifiable N determined in this work (Table 3). One compost from sludge and coffee waste (initial N—2·63%) behaved quite anomalously; after one year less than 2% of the nitrogen was "soluble" and less than 1% of the

total nitrogen nitrified in soil in a further three months although the percentage N in the organic matter exceeded 5%, which further illustrates the difficulty or impossibility of predicting the availability of nitrogen in composts from analysis alone.

ACHARYA, PARTHASARTHY and SABNIS (1946) emphasised that for rapid liberation of nitrogen from composts it was essential to use starting materials rich in soluble or easily decomposable nitrogenous materials; the limited data in Table 2 support this conclusion but also indicate that there is considerably less soluble nitrogen in some composts a year old than in the starting materials, particularly as the total dry matter decreases by nearly 50% during composting.

It is possible to generalize about the composition and properties of composts prepared under different conditions from the same materials, for example, straw and sludge (HOYLE and MATTINGLY, in the press), but this summary emphasizes that for composts of different materials, even when prepared under controlled conditions the composts are variable and it is difficult to predict the level of available nitrogen by analysis for total nitrogen.

Summary

1. The relation between "soluble" and total nitrogen in composts is discussed briefly with particular reference to composts prepared from sewage sludge as a source of nitrogen.

2. Total nitrogen in the dry matter of composts after 1 year increases nearly threefold as the initial percentage N increases from about 1·2 to 2·2% N; the increase in N in the organic matter is considerably smaller.

3. The amount of "soluble" N in the dry matter of composts increases from about 0·1% for composts with less than 1·2% N initially to about 0·35% for composts with 1·2 to 2·2% N initially. Several well matured composts contained about 0·6% nitrifiable N which represented 18–30% of the total N.

4. The final level of soluble N in composts is approximately proportional to and usually less than the initial soluble N.

5. The data summarized emphasize the difficulty of estimating available N in composts from analysis for total N.

The work summarized here formed part of a research programme carried out in the Department of Horticulture at Reading University with the aid of a special grant from the Agricultural Research Council to which grateful acknowledgement is made.

The author wishes also to thank Professor R. H. STOUGHTON and MRS. D. A. HOYLE for permission to use data not yet published.

REFERENCES

ACHARYA, C. N., PARTHASARTHY, C. and SABNIS, C. V. *Indian J. Agric. Sci.*, **16**, 90 (1946).

ASHWORTH, M. R. F. *J. Agric. Sci.*, **32**, 360 (1942).

BOULD, C. *J. Inst. Sewage Purif.*, 79 (1945).

BOULD, C. *Emp. J. Exp. Agric.* **16**, 103 (1948).

GERRETSEN, F. C., MANTEN, A. and MULLER, F. M. *Plant and Soil*, **1**, 240 (1949).

HOYLE, D. A. and MATTINGLY, G. E. G. *Nature*, **169**, 116 (1952).

HOYLE, D. A. and MATTINGLY, G. E. G. *In the press.*

JENKINS, S. H. Organic Manures. Commonw. Bur. Soil Sci., Tech. Comm. No. 33 (1935).

ETUDE, SUR DEUX CAS PRECIS, DES RAPPORTS ENTRE LA MICROFLORE ET LA FERTILITE D'UN SOL

J. POCHON ET O. COPPIER
Institut Pasteur, France

Les rapports entre la fertilité d'un sol, d'une part, et, d'autre part, la composition chimique minérale et organique, la structure physique de ce sol ou du sous-sol, les engrais apportés, les façons culturales, ont fait l'objet de nombreux travaux. Par contre, sur les interférences entre la fertilité et la microflore, nos connaissances sont extrêmement réduites.

Ont été étudiés, en effet, les rapports étroits entre le développement d'une plante donnée et la microflore, au contact ou à faible distance des racines, dans cette zone très spéciale appelée rhizosphère. Etudiés également les rapports entre la microflore *Rhizobium* d'un sol et la croissance des légumineuses. On connait enfin les interactions très générales entre microflore et végétaux, en particulier l'augmentation globale des microorganismes dans un sol cultivé ; pour employer la terminologie de WINOGRADSKY, la microflore zymogène est beaucoup plus abondante et variée que la microflore autochtone d'un sol en jachère noire, au repos.

De toutes ces études, la notion de fertilité est presque complètement absente.

Cette carence de nos connaissances est certainement liée pour une large part, au fait que l'expérimentation, pour qu'elle soit valable ou tout au moins interprétable, ne peut être réalisée que dans des conditions très précises.

Pour pouvoir comparer bactériologiquement d'une manière valable un sol fertile à un sol infertile il est nécessaire que ces deux sols, aussi peu différents que possible quant à leur composition chimique et leur structure physique, soient également soumis aux mêmes conditions climatiques. C'est seulement dans ce cas que des différences de fertilité peuvent être rapportées à des différences éventuelles de la microflore.

Cependant, même dans ces circonstances favorables, les corrélations entre microflore et fertilité ne sont pas faciles à établir. Elles peuvent, à priori, être de trois types :

1°—Un même facteur, ou une série de facteurs, peuvent déterminer à la fois la déficience de culture et les modifications anormales de la microflore.

2°—La microflore anormale peut entraîner l'infertilité.

3°—Enfin, cette infertilité (en rapport avec des facteurs propres) peut retentir secondairement sur l'équilibre de la microflore.

Il nous a été possible d'observer deux cas où les conditions étaient suffisamment précises pour que l'on puisse mettre en évidence certains faits, sinon les interpréter.

Dans le premier cas, il s'agit de terrains d'alluvions (Marais de Redon, Loire-Inférieure), que l'on tente actuellement de rendre à la culture, soit en betterave sucière, soit en pomme de terre. Or, dans certaines parcelles (A) les rendements en ces deux végétaux sont satisfaisants ; dans d'autres parcelles (B) au contraire, ils sont presque nuls. La végétation spontanée est importante dans la première ;

il n'y en a pratiquement pas dans la seconde. Nous avons donc ici un cas très favorable : deux terres voisines, soumises aux mêmes conditions climatiques, aux mêmes façons culturales ; l'une apparaît normale au point de vue végétation ; l'autre est nettement pathologique, infertile.

Or, ces deux terres diffèrent peu par leur composition chimique, ainsi que le montre le tableau suivant :

	Parcelle A	*Parcelle B*
pH	7	6,5
Sable p. cent	22,40	21,15
Limon p. cent	24,20	21,40
Argile p. cent	47,20	48,15
Calcaire p. cent	1,85	1,74
Matières humides p. cent	4,35	7,46
N total p. mille	2,40	4,00
Acide phosphorique assimilable p. mille ..	0,53	0,22
Potasse assimilable p. mille	0,49	0,66
Chlorures p. mille	Traces	1,54

La seule différence défavorable à la parcelle B, infertile, est une teneur plus élevée en chlorures (1,5 p. mille) ; mais, par contre, cette parcelle B est plus riche en humus et en azote total ; ainsi qu'en carbone organique (34 p. 1000 contre 16 p. 1000).

Dans le deuxième cas, il s'agit de terrains situés en Brie (S. & M.).* Les rendements (blé-betterave) sont satisfaisants, sauf dans certaines zones, limitées à quelques ares, disséminées irrégulièrement dans une région de grande culture homogène et sans qu'aucune particularité pédologique ou climatique puisse être évoquée pour les expliquer. Leur moindre fertilité s'est d'ailleurs révélée constante et stable depuis de nombreuses années.

Il nous a donc semblé intéressant de rechercher, dans ces deux cas, si les parcelles fertiles et infertiles différaient par leur microflore.

Dans ce but, nous avons pratiqué une évaluation de la microflore totale d'une part, et, d'autre part, apprécié l'activité des divers groupements bactériens des principaux chaînons des cycles du carbone et de l'azote.

Pour le cycle de l'azote : les fixateurs aérobies (*Azotobacter*) et anaérobies (*Clostridium*) ; la flore ammonifiante les nitrificateurs, la microflore dénitrifiante.

Pour le cycle du carbone : les cellulolytiques aérobies et anaérobies.

En ce qui concerne les Marais de Redon, les numérations de la microflore totale montrent que la parcelle A, fertile, est plus riche en microorganismes (environ trois fois plus) que la parcelle B, infertile.

La microflore fixatrice nous a donné les résultats les plus intéressants. Les plaques de terre moulée de la parcelle B ne présentent aucune prolifération d'*Azotobacter*, en opposition à la très grande richesse de la parcelle A. De même, les plaques de silicogel " B " sont restées stériles, alors que, avec cette technique, la parcelle A s'est révélée avoir une teneur normale en *Azotobacter*. En ce qui concerne les *Clostridium* fixateurs, on en trouve de petites quantités en A, aucun en B. La différence entre ces deux parcelles est donc d'une netteté absolue.

*Département français situé dans le bassin parisien.

Les microflores nitrificatrice et ammonifiante sont par contre sensiblement identiques pour les deux parcelles, de même que la microflore dénitrificatrice.

La microflore cellulolytique aérobie est un peu plus abondante dans la parcelle B que dans la parcelle A. *En ancérobiose* les résultats sont du même ordre.

Il apparaît donc que ces deux parcelles A et B, si semblables par la constitution de leurs terres et si dissemblables par leur fertilité, diffèrent également par leur microflore.

Les deux faits importants mis en évidence portent sur la microflore totale, trois fois plus abondante dans la parcelle fertile, et sur la microflore fixatrice, normale dans cette même parcelle et absente dans la parcelle infertile. On peut accessoirement signaler, par contre, que les cellulolytiques sont plus abondants dans cette parcelle infertile, observation d'interprétation difficile, car nous ne savons pas dans quelle mesure on n'a pas essayé de fertiliser cette parcelle B par des apports organiques (engrais ou fumiers).

Avec la technique de la terre moulée, une déficience en P, K, Ca, assimilables pourrait être invoquée pour expliquer le caractère négatif des cultures d'*Azotobacter* ; mais les résultats identiques obtenus sur silicogel doivent faire éliminer cette hypothèse puisque le liquide d'imprégnation des plaques contient ces éléments en quantités normales et équilibrées (WINOGRADSKY).

Les analyses des terres de Brie ont été faites avec les mêmes techniques et les résultats obtenus sont comparables.

La différence la plus caractéristique entre terrains fertiles et inferiles porte, ici encore, sur la flore fixatrice aérobie. En effet, les *Azotobacter* sont en proportion normale dans les premiers. Ils sont complètement absents des seconds. De plus, la flore nitrificatrice est plus abondante dans les terrains fertiles.

Les résultats sont donc assez concordants on ce qui concerne les deux cas étudiés et l'on peut, chaque fois, rapprocher la fertilité de ces terres et leur microflore fixatrice.

Mais comment interpréter les faits observés *in situ* et au laboratoire ?

Il ne semble pas que l'on puisse attribuer l'infertilité à la seule absence d'*Azotobacter*, puisque les parcelles infertiles ont une teneur normale en azote total et même supérieure à celle des parcelles fertiles (bien que nous sachions qu'azote total ne veuille pas dire azote assimilable). Encore que dans l'importance écologique des *Azotobacter* d'autres modes d'action que la fixation puissent être invoqués et, en particulier, l'élaboration de facteurs de croissance.

Il ne semble pas non plus, inversement, que ce soit l'absence de végétation qui puisse expliquer la carence en fixateurs ; on admet bien un effet rhizosphère positif sur cette espèce (tout au moins avec certains végétaux), mais on concevrait mal une disparition aussi élective, puisque la microflore totale n'est que partiellement diminuée.

L'hypothèse d'un même facteur (ou d'une série de facteurs) agissant à la fois sur la microflore, en particulier les fixateurs, et sur la fertilité, paraît donc la plus plausible des facteurs qui restent à préciser.

Il est bien évident que ce n'est pas l'étude de deux cas qui permettront de résoudre le problème des rapports de la microflore et de la fertilité, mais il nous a semblé utile de la présenter comme contribution à un ensemble plus vaste.

A SEMIMICRO KJELDAHL METHOD FOR NITROGEN DETERMINATION EMPLOYING THE CONWAY MICRODIFFUSION TECHNIQUE

J. J. McDONNELL AND C. M. B. MURPHY

Department of Agriculture, Ireland

Many modifications of the original KJELDAHL method for total nitrogen determinations have been suggested since its publication. The conventional method, as applied to plant and soil analysis, involves digestion with sulphuric acid—catalyst—salt mixture, distillation of the ammonia thus formed, absorption in standard acid and titration with standard alkali. This method is slow and tedious and without elaborate equipment it cannot be applied to routine work requiring, perhaps, 50 to 100 analyses per day. The chief disadvantage of such methods lies in the slowness of the distillation procedure.

Ammonia may, in certain cases, be determined colorimetrically on the digest by the Nesslerisation procedure, but the method is subject to interference from turbidity and other factors which require careful attention (13).

One of the most promising methods for ammonia determination has been the application by CONWAY (4) of the microdiffusion principle in the analysis of small samples of material. This concise technique has been found extremely suitable for total nitrogen determination of plant and soil in this laboratory and its adoption in a method intended for large scale routine analysis is reported here.

This method aims primarily at reducing the time and space required for routine analysis. Digestion is conducted on a semimicro scale using selenium as catalyst, and ammonia is determined by the CONWAY microdiffusion technique. Only a small fraction of the digest is required for ammonia determination and, since the use of salt in digestion is dispensed with, the remainder of the digest may be used for inorganic analysis.

The method

Reagents required

Sulphuric acid (conc.), nitrogen free.

Selenium powder.

1% Boric acid solution : 1 g. pure boric acid plus 20 ml. alcohol plus 1 ml. mixed indicator made up to 100 ml. with distilled water.

Mixed indicator : 0·033 g. bromocresol green plus 0·066 g. methyl red dissolved in 100 ml. alcohol.

40% Sodium hydroxide.

N/50 Hydrochloric acid.

Preparation of sample

Plant material is oven dried, finely ground and sieved (0·8 mm. screen). Soil is air-dried, sieved (2 mm. screen) and finely ground in a porcelain mortar.

Digestion

0·28 g. plant material (or 1 g. soil) is taken in a 50 ml. KJELDAHL flask. Preliminary treatment for nitrate, using salicylic acid and thiosulphate (A.O.A.C.—GUNNING method, (1)), may be carried out

if required. To the sample are added 0·04 g. Se and 2 ml. H_2SO_4, together with a glass bead to prevent bumping. The mixture is heated gently for 10 minutes, removed, and a further 2 ml. H_2SO_4 added. The temperature is increased until the mixture is boiling vigorously. The solution clears after about 20 to 40 minutes and digestion is continued for one hour after this stage. To maintain a fairly constant level of acid while heating, further additions of H_2SO_4 are made when necessary. After digestion the flasks are allowed to cool, and the digest mixture diluted to contain about 100 μg. N per ml., (a dilution to 50 ml. will usually suffice). In the case of soils, the solid residue is first removed by filtering or decanting.

The digestion procedure is carried out on the laboratory bench, flasks being handled in groups of ten. They are heated on racks constructed of asbestos sheeting and carrying a series of gas jets. Fumes are disposed of by suction to a water pump.

Ammonia determination

An aliquot of exactly 1 ml. of the diluted digest is transferred to the outer chamber of a No. 1 CONWAY Unit. To the central chamber is added approximately 1 ml. boric acid solution. Finally, with the lid in readiness, approximately 1 ml. 40% NaOH solution is added to the outer chamber, the unit is sealed and the solutions in the outer chamber are mixed by 'rotation.' After standing for a minimum of 90 minutes the contents of the central chamber are titrated with N/50 HCl using a CONWAY burette, each large division on the burette being equivalent to 2·8 μg. nitrogen.

Analyses of the digest are made in duplicate or triplicate. With each batch of analyses, 'standard' and 'blank,' units are prepared in which standard ammonium sulphate and distilled water, respectively, is substituted for the unknown.

Results and discussion

Digestion

Numerous modifications have been introduced in the KJELDAHL procedure to increase rate and recovery in the digestion process. The literature has been summarised by KIRK (8) and GERRITZ and ST. JOHN (6). Among the factors investigated in connection with the elaboration of the present method were: addition of salts to raise the boiling point of the digest mixture (11); the use of perchloric acid (12); the nature and quantity of catalyst used (2, 8, 10), and the intensity and length of heating (3, 7). The working materials for these investigations were a sample of casein and samples of plant tissue and soil.

In a preliminary investigation perchloric acid treatment and the addition of potassium sulphate were not found to be of definite advantage in increasing digestion rate or recovery. Best results were obtained using 0·04 g. selenium as catalyst. The time of digestion allotted in the procedure described was found satisfactory for plant and soil samples. Heating should be sufficiently strong to maintain the digest mixture at a vigorous boiling rate.

Ammonia determination

The determination of ammonia by the microdiffusion technique

has been discussed in detail by CONWAY (4) and CONWAY and O'MALLEY (5). Using this procedure the checking and control necessary in distillation is eliminated, and several analyses can be run simultaneously on a very small bench space. The main advantage of employing the microdiffusion technique, apart from the economy in space and material, is the fact that ammonia determinations on the digest solution can be replicated with ease, each replication requiring only an additional 4 to 5 minutes, if calculated on the time required per unit for 30 or more units. The preparation of the units is a simple and rapid procedure, since only one addition (that of the diluted digest) requires an accurate delivery.

In the application of this method for analysis of soil and plant digests it is necessary to employ a strong alkali to release ammonia from the outer chamber, owing to the high acid concentration. For this purpose NaOH has been found preferable to KOH, the latter causing considerable precipitation in the outer chamber.

A comparison of microdiffusion and distillation methods of analysis is given below.

Nitrogen recovery and standardisation

Table 1 shows the results of analyses on compounds of known nitrogen content. The recovery is reasonably good, but it must be emphasised that the compounds employed were not definitely known to be pure.

TABLE 1

Nitrogen analysis of known compounds

Compound	Theoretical	Experimental	Error
	%	%	%
Cystine	11·66	11·47	−1·63
Valine	11·96	11·85	−0·92
Serine	13·33	13·20	−0·98
Casein (light, white soluble)	14·0 ± 0·2*	13·90	—

*Analysis figures kindly supplied by British Drug Houses, Ltd.

In Table 2 is presented a comparison of the following methods:—

(*a*) Se Catalyst and Microdiffusion: 0·28 g. plant material or 1 g. soil; selenium catalyst; NH_3 determination by microdiffusion (i.e., the method reported in this paper).

(*b*) Se Catalyst and Distillation: 2 g. plant material (not applied to soils); selenium catalyst; NH_3 determination by distillation. The digestion procedure is the same as that for (*a*) but on a macro scale.

(*c*) A.O.A.C. Method: 2 g. plant material or 10 g. soil: mercury catalyst + Na_2SO_4 for plants, Fe-Cu catalyst + Na_2SO_4 for soils; NH_3 determination by distillation.

All three methods were found to give consistent results.

TABLE 2

Comparison of methods

Sample	Se Catalyst and Microdiffusion	Se Catalyst and Distillation	A.O.A.C. Method
	% N	% N	% N
1. Mixed Herbage	1·96	1·94	1·95
2. Mixed Herbage	1·45	1·46	1·44
3. Mineral Soil	0·30	—	0·30
4. Peaty Soil	2·05	—	2·09
5. Compost	1·66	—	1·69

(Each figure represents the mean of two or more analyses).

The types of samples employed were, (1) pasture of timothy—red clover mixture; (2) pasture of ryegrass—cocksfoot—red clover mixture; (3) dark brown silty light loam of granular structure; (4) very dark brown peaty soil on limestone, friable, and of velvety, though gritty, texture; (5) compost of peat mould and sewage sludge (analysis treatment as for soil).

Reproducibility and accuracy

The sampling error, plus variable (chemical and glass) errors, are indicated by the results of ten analyses (Table 3) on a soil sample (dark grey friable medium loam, surface soil) and a plant tissue sample (experimental pasture of timothy-red clover mixture).

The mean percentage deviation from the mean for the plant tissue sample was 0·74%; for soil, 1·09%. The maximum percentage deviation from the mean for the plant sample was ±1·80%; for the soil, ±2·54%. These results suggest a greater sampling error for soil, as might be expected. Further investigation of sampling error is in progress.

TABLE 3

Replicated analyses on the same sample

Replication Number	Plant Sample		Soil Sample	
	% Nitrogen	% Deviation from Mean	% Nitrogen	% Deviation from Mean
1	1·935	−0·51	0·550	−0·18
2	1·930	−0·77	0·554	+0·54
3	1·930	−0·77	0·544	−1·27
4	1·955	+0·51	0·551	0·00
5	1·980	+1·80	0·565	+2·54
6	1·945	0·00	0·560	+1·63
7	1·955	+0·51	0·551	0·00
8	1·960	+0·77	0·540	−2·00
9	1·920	−1·28	0·555	+0·73
10	1·935	−0·51	0·540	−2·00
Mean ...	1·945	0·74	0·551	1·09

(Each figure for N represents a single digestion with duplicate microdiffusion analysis on the digest.)

The method compares favourably with standard methods in regard to nitrogen recovery and reproducibility, and is considered suitable for routine nitrogen analysis of soil and plant tissue. As a routine method, it is particularly suited to laboratories which are not specially equipped for large-scale macro-KJELDAHL digestion and distillation. It offers further advantages with regard to speed and economy of material. Due to the ease with which replicated analyses may be carried out, the method may be regarded as an improvement on the standard distillation procedure. Only a small fraction of the digest is required for the determination of ammonia and the remainder may be used for the inorganic analysis of the plant or soil.

Summary

The method described offers a rapid and convenient procedure for routine determination of total nitrogen in soil and plant material. KJELDAHL digestion is conducted on a semimicro scale and ammonia is determined by the CONWAY microdiffusion technique, with considerable economy in time, space and material. No sacrifice of accuracy is involved in this microanalytical procedure for ammonia determination and the remaining digest solution may be used for inorganic analysis.

Acknowledgements

The authors gratefully acknowledge the valuable help and advice of Dr. T. WALSH, and the assistance of Mr. J. LEONARD, in the experimental work.

REFERENCES

(1) "Official Methods of Analysis," 1950. The Association of Official Agricultural Chemists, Washington, D.C.
(2) BRADSTREET, R. B. *Ind. Eng. Chem., Anal. Ed.*, **12**, 657 (1940).
(3) CHIBNALL, A. C.; REES, M. W.; and WILLIAMS, E. F. *Biochem. J.*, **37**, 354 (1943).
(4) CONWAY, E. J. "Microdiffusion Analysis and Volumetric Error." Crosby, Lockwood & Son, Ltd., London (1947).
(5) CONWAY, E. J., and O'MALLEY, E. *Biochem. J.*, **36**, 655 (1942).
(6) GERRITZ and ST. JOHN. *Ind. Eng. Chem., Anal. Ed.*, **7**, 380 (1935).
(7) JONNARD, R. *Ind. Eng. Chem., Anal. Ed.*, **17**, 246 (1945).
(8) KIRK, P. L. *Adv. in Protein Chem.*, **3**, 139 (1947).
(9) LAURO, M. F. *Ind. Eng. Chem., Anal. Ed.*, **3**, 401 (1931).
(10) OSBORN, R. A. and WILKIE, J. B. *J. Assoc. Off. Agr. Chem.*, **18**, 604 (1935).
(11) PIPER, C. S. *Australian Chem. Inst. and Proc.*, **5**, 312 (1938).
(12) PIPKOWITZ, L. P. and SHIVE, J. W. *Ind. Eng. Chem., Anal. Ed.*, **14**, 914 (1942).
(13) THOMPSON, J. F. and MORRISON, G. R. *Anal. Chem.*, **23**, 1153 (1951).

SESSION 2

PHOSPHATES

21*st July*. Chairman: J. A. PRESCOTT (Australia)

E. G. WILLIAMS. Evaluating the Phosphorus Status of Soils (Volume I, page 31)

L. A. DEAN. The Evaluation of Phosphorus Ferility of Soils through the Medium of Radio Phosphorus (Volume I, page 48)

G. BARBIER et Mlle. E. TYSKIEWICZ. Mobilité des Ions Phosphoriques " Fixés " dans le Sol etudiée au moyen de P_{32} (Volume I, page 331, and Volume II (below).

MOBILITÉ DES IONS PHOSPHORIQUES " FIXÉS " DANS LE SOL, ÉTUDIÉE AU MOYEN DE P_{32}

G. BARBIER ET Mlle. E. TYSZKIEWICZ
Station Centrale d'Agronomie, Versailles, France

On sait que l'absorption par un sol des ions phosphoriques d'une solution phosphatée radioactive (P_{32}) s'accompagne d'une diminution de la radioactivité spécifique de P_2O_5 en solution ; on peut en conclure que le sol cède au liquide des ions phosphoriques en même temps qu'il lui en prend. Ce fait suggère que le système en équilibre est le siège d'un va et vient continuel d'ions phosphoriques entre le solide et le liquide. OLLE GUNNARSSON et LARS FREDRIKSSEN ont observé, sur 11 sols différents, que les ions phosphoriques de chaque origine, ceux ajoutés et ceux préexistant dans le sol à l'état mobile, tendent à se répartir en proportion uniforme dans les diverses phases du système (y compris la plante éventuellement).*

La présente note rend compte de quelques expériences préliminaires ayant pour but de préciser quelles sont les formes de P minéral du sol susceptibles de participer à cet échange d'ions phosphoriques, ainsi que d'apprécier dans la mesure du possible la vitesse du phénomène pour chacune d'elles.

On ne saurait admettre a priori que les substances colloïdales du sol soient seules capables de donner lieu à de tels échanges : ayant agité un phosphate bicalcique bien cristallisé, avec une solution diluée de phosphate calcique P_{32} (12 mg. P_2O_5 par litre à pH 6,6) laquelle a dissous partiellement le phosphate, nous avons constaté que la quantité d'ions phosphoriques P_{32} en solution a fortement diminué.

Les faits exposé ci-dessous ont été observés dans des conditions expérimentales telles que les phosphates calciques n'interviennent pas ou très peu.

Marche de l'échange au cours du temps

Un sol argileux légèrement acide (limon des plateaux) riche en P_2O_5 (parcelle à superphosphate d'un champ d'expériences) a été agité avec une solution de phosphate calcique (P_{32}) de composition

*Communication privée (Uppsala).

telle que sa concentration en P_2O_5 ne diminue pas au contact du sol (1,23 mg. P_2O_5 par litre). On a déterminé au bout d'un temps variable la radioactivité de la solution et sa concentration en P_2O_5.

5 *gr. de terre* + 100 *cc. de solution de phosphate calcique contenant* SO^4Ca 0,015 *N ; pH*=6,7.

Durée d'agitation	0 (avant contact)	10 m.	3 h.	15 h.	24 h.	5 jours
mg. P_2O_5 par litre de solution						
P_2O_5 total	1,23	1,76	2,21	2,40	2,66	3,03
P_2O_5 marqué	1,23	0,4	0,22	0,16	0,145	0,14
P_2O_5 marqué retenu par le sol % d'ajouté ...	..	67,1	81,5	86,4	87,9	88,1

Ces résultats montrent que l'échange des ions phosphoriques ajoutés contre des ions phosphoriques préexistant dans le sol, d'abord rapide, se poursuit ensuite lentement.

Or, dans le cas où il n'y a pas seulement échange d'ions PO_4, mais où le sol s'enrichit effectivement en PO_4 (aux dépens d'une solution plus concentrée), on observe également, après une adsorption rapide, une évolution lente, qui se traduit par un abaissement progressif de la concentration en P_2O_5 du solvant, et par un changement d'état de P_2O_5 antérieurement retenu (diminution de P_2O_5 récupérable par les acides dilués). Etant donné que l'absorption lente de PO_4 ajouté s'accompagne d'un passage en solution d'ions PO_4 préexistant dans le sol (d'après les observations faites à l'aide de P_{32}), on peut en conclure qu'elle comporte un équilibre, et ne conduit pas à une fixation irréversible.

Échange de PO_4 extractible par les acides dilués contre PO_4 extractible par les alcalis dilués

Un sous-sol de limon (pH=7,2, non calcaire) a été agité pendant 15 jours avec une solution neutre de phosphate calcique (P_{32}), renouvelée plusieurs fois. Après séparation du sol et dessication à l'air, on a dosé P_2O_5 extractible par épuisements successifs rapides au moyen de SO_4H_2 dilué, puis au moyen de KOH dilué.

P_2O_5 extractible

	par SO_4H_2 0,002 N.	par KOH 0,005 N.
par million de terre...	430	182
pour cent d'extractible — provenant de P_2O_5 ajouté	82%	80%
pour cent d'extractible — provenant du sol.	18%	20%

Aux erreurs près, le phosphates de l'une et l'autre origine sont en même proportion dans les deux formes. Nous disposions donc d'une terre ayant fixé P_2O_5 marqué, dont la radioactivité spécifique était sensiblement égale aux 4/5 de celle du phosphate radioactif utilisé (à un même instant bien entendu).

Plusieurs prises d'essai de cette terre ont été rapidement épuisées par percolations sur le vide au moyen de SO_4H_2 0,002 N (traitement I) puis immédiatement reneutralisées par Ca $(OH)^2$ et additionnées d'une solution de phosphate calcique P_{31} (traitement II), de telle sorte que le sol absorbe approximativement la même quantité de P_2O_5 que celle enlevée par le traitement acide précédent. Puis après un temps variable, le sol a été épuisé par SO_4H_2 et KOH dilués comme précédemment (traitement III).

Traitement III

Temps écoulé entre traitements II et III	Extractions acides			Extractions alcalines		
	P_2O_5 total ‰ de sol	P_2O_5 marqué		P_2O_5 total ‰ de sol	P_2O_5 marqué	
		‰ de sol	% de P_2O_5 total		‰ de sol	% de P_2O_5 total
0 ...	..	0*	0*	..	..	100 (1)
15 minutes ...	0,425	0,106	25%	..	..	..
6 heures ...	0,474	0,112	24	0,179	0,74	41,5
24 heures ...	0,481	0,137	28,5	0,177	0,69	39
8 jours ...	0,413	0,139	33,5	0,184	0,66	36

*ces chiffres ne correspondent pas à des dosages ; ils indiquent quelle serait la répartition s'il n'y avait pas d'échange.

Ces résultats montrent que les ions phosphoriques présents sous les deux formes se sont mélangés par permutation, bien que les deux formes soient restées sensiblement en équilibre, puisqu'il n'y a pas eu finalement transport d'une masse notable de P_2O_5 d'une forme à l'autre. La proportion de P_2O_5 des deux origines tend à devenir la même dans les deux formes : 33,5 et 36 de P_2O_5 resté fixé dans le sol après la première extraction acide (traitement I) pour 100 de P_2O_5 finalement présent sous l'une ou l'autre forme ; la limite de ces 2 nombres, environ 35%, n'est pas très différente de la proportion de P_2O_5 extractible par les alcalis à l'origine, soit :

$$\frac{182}{430+182} = 30\%.$$

La légère infériorité de cette dernière valeur sur la limite en question, si elle n'est pas due aux erreurs de mesure, peut tenir à ce que le mode opératoire adopté pour les extractions ne comporte qu'une courte durée de contact (1/2 heure environ en tout) et ne parvient pas de ce fait à séparer la totalité de P_2O_5 retenu après l'extraction acide.

Conclusion

Les résultats précédents sont en accord avec ceux obtenus antérieurement sans l'aide de P_{32}*, à savoir que la fraction de P_2O_5 incorporé (sous forme soluble) devenue inextractible par les acides dilués demeure en équilibre, dans le sol, avec celle demeurée extractible, du moins en majeure partie et pour de nombreux sols de la zone tempérée.

Ni les présentes recherches, ni les recherches d'ordre chimique, n'ont apporté jusqu'à présent la preuve que les phosphates puissent subir de la part des argiles de ces sols une fixation irréversible (en entendant par ce dernier terme, que l'activité de P_2O_5 du sol s'abaisserait en dessous de son niveau initial après que le sol a cèdé une quantité de P_2O_5 égale à celle incorporée sous forme soluble). Si la rétention des ions phosphoriques par les argiles a pour effet de ralentir leur absorption par les plantes, en diminuant leur activité à chaque instant, elle peut constituer par contre une protection contre des insolubilisations plus profondes, notamment sous forme de résidus apatitiques de phosphates calciques d'abord relativement solubles.

SESSIONAL DISCUSSION

W. KUCZAROW : La remarque avait pour objet la comparaison des résultats obtenus par deux méthodes de dosage du P_2O_5 dans quelques types des sols du Congo Belge.

Les méthodes suivantes ont été appliqueés :

(*a*) extraction par H_2SO_4 N/20

(*b*) extraction par H_2SO_4 N/500 (meth. de TRUOG)

Le ressort des résultats obtenus que la methode d'extraction par H_2SO_4 N/20, malgré tous les inconveniants inhérants à l'emploi d'un extrayant fort, fournit des données relatives intéressantes pour les divers types des sols.

Des rélations étroites ont été observeés entre la teneur en matière organique et le phosphore determiné dans l'extrait par H_2SO_4 N/20.

L'emploi de la methode de TRUOG originale (prise d'essai de 2g. pour 400 ml. de l'extrayant) ne renseigne dans les principaux types des sols de la Curette Congolaise que de valeurs de P_2O_5 extrêmement basses. L'augmentation de la prise d'essai (10g.) permit l'obtention des résultats plus élevés et plus expressifs.

Pour les sols rouges des Vélés, riches en fer, la methode de TRUOG s'est montrée inapplicable. Les résultats obtenus avec les prises d'essai diverses (2, 10 et 20g.) étaient extrêmement bas, soit nuls. Cette constatation peut trouver une explication dans la fixation energique du phosphore par les composés de fer de ces sols.

R. K. SCHOFIELD : The aim of a series of experiments carried out in the Physics Department at Rothamsted has been to characterise the physico-chemical environment of plant roots. We have found that products of ion activities such as $(Ca^{\times\times}) \times (H_2PO_2)$ and ratios such as $(H^+)/(Ca^{++})$ are characteristic of a soil sample which has

*BARBIER, G. et CHABANNES, J. *Ann. Agron.*, 343 (1949).

had the opportunity to reach a state of equilibrium. They are independent of the concentration of added chloride so long as the total concentration in the equilibrium solution does not much exceed 0·02 N.

Hence if such a soil sample is shaken up with 0·02 N $CaCl_2$ there is very little disturbance of the state of equilibrium already existing. Moreover, if the sample initially contained only small amounts of free anions then the final concentration of $Ca^{++}+Mg$ will be nearer to 0·02 N and need not be determined. Measurements of pH are easily made in the presence of this concentration of $CaCl_2$ which also makes the filtrates uncoloured and perfectly clear so that very low concentrations of phosphate may be measured by the molybdenum blue colour. Samples taken from different spots should not be mixed and should be kept at field mosture until shaken with dilute $CaCl_2$ solution. The results are sensitive to temperature but not to soil/solution ratio which should, however, be as high as possible.

E. WELTE : Die Bedeutung des Bodentyps bzw. der Bodenart auf den P_2O_5-Gehalt der Bodenlösung, die durch chemische Extraktionsmittel erhalten wird, ist auf die Auswertung der erhaltenen P_2O_5-Werte von grosser Bedeutung. Eigene Untersuchungen über die Anwendbarkeit der Doppelaktatmethode EGNÉR-RIEHM auf Humuskarbonatböden (Reud-Zina-Böden) haben ergeben, dass eine eindeutige Beziehung zwischen dem P_2O_5-Gehalt der Laktatlösung und der Schüttelzeit mm. dem pH-Wert des Filtrates besteht.

Mit zunehmender Schüttelzeit (untersucht bis zu 2 Stunden) steigt der pH-Wert der Laktatlösung (Ausgangs pH-3, 6) je nach dem Gehalt und den Löslichkeitseigenschaften des im Boden vorhandenen Kalkes an. Hierbei können Endwerte über 6.0 pH in dem angegebenen Zeitbereich erreicht werden.

Bis zum pH=Wert von etwa 4,6-4,8 erfährt die laktatlösliche Phosphosäure nach anfänglichem Ansteigen bis zu einem Maximalwert keine nennenswerten Veränderungen mehr. Wird jedoch dieser Schwellenwert überschritten, sinkt die P_2O_5-Konzentration kontinuierlich und rasch ab. Dieser Effekt ist auf die Bildung von schwerlöslichen Ca–Phosphaten in der Laktatlösung während den Schüttelung zurückzuführen. Das erklärt, warum die mit der Doppellaktatmethode auf karbonathaltigen Böden erhaltenen P_2O_5–Werte stets zu niedrig gefunden werden und daher in ihrer pflanzenphysiologischen Wirkung höher bewertet werden müssen.

R. CHAMINADE : Il peut être intéressant d'examiner la répartition de P_2O_5 sur le fractions de sols de differentes dimensions.

L'étude d'un sol de limon a montré que près de la moitié de l'acide phosphorique du sol était fixé sur les particules de diamètre $<1\mu$ et près de 70% sur les particules de diamètre inférieur a 2μ.

L'enrichissement du sol en acide phosphorique ne modifie pas cette répartition.

READILY SOLUBLE PHOSPHORUS VALUES AND CROP RESPONSES FOR DIFFERENT SOILS

E. G. WILLIAMS, J. W. S. REITH AND R. H. E. INKSON

Macaulay Institute for Soil Research, Aberdeen, Scotland

The experiments reported in this paper are part of a long-term investigation of the phosphorous relationships of Scottish soils (8, 9, 10, 11, 14, 15, 16, 17, 18). Two of the main objectives of this work are assessment of the significance of pedological differences and the improvement of methods for evaluating phosphorous status. The basis for the investigation is provided by field experiments covering different soils mapped in the Soil Survey (5, 6, 8). The aim is to build up an adequate body of information for each soil group on points such as the immediate and residual effects of phosphate on different crops, and the interactions of phosphate with other nutrients, lime and dung. Much remains to be done in this direction, but sufficient data are available for swedes and turnips on four of the main soil associations to justify a preliminary examination of the interrelations of some of the conventional readily soluble phosphorus values and their correlations with field responses.

Experimental

Soils. The experimental centres cover four of the principal soil associations occurring in N.E. Scotland (5,8), and were chosen on the basis of soil survey information with the emphasis on phosphate responsive soils. The predominant nature of the parent drifts, together with the numbers of experiments in the different groups, is given in Table 1. The soils cover a normal pH range of about 5–6·5 and represent the main classes of acid, phosphate-deficient land in the region. In texture, they are practically all light to medium loams. The majority are freely drained mineral soils, but a few imperfectly drained and a few humose soils are also included.

TABLE 1

Numbers of soils extracted by different methods

Soil Association	Predominant Character of Parent Material	Acetic	NH_4F	NH_4F + HCl	TRUOG	Lactate
All Associations	—	74	74	65	65	65
Insch ...	Basic Igneous	19	19	16	16	16
Countesswells ...	Granitic	28	28	22	22	22
Stonehaven and Laurencekirk.	Old Red Sandstone	13	13	13	13	13
Foudland ...	Slate	14	14	14	14	14

Laboratory extractions. Readily soluble phosphorus values were obtained by the following methods:—(1) 2 hr. extraction of 20 g. soil with 800 ml. 2·5% by vol. acetic acid, pH 2·8 (14); (2) 30 min. extraction of 2 g. soil with 400 ml. ·002N H_2SO_4, pH 3, according to

TRUOG (12); (3) 2 hr. extraction of 5 g. soil with 250 ml. ·02N Ca-lactate in ·01 N HCl, pH 3·8, according to EGNER (4); (4) 1 hr. extraction of 1 g. soil with 50 ml. 0·5N NH_4F, pH 7, according to BRAY and KURTZ (1); and (5) 40 sec. extraction of 1 g. soil with 10 ml. ·03N NH_4F in 0·1 N HCl, pH about 1, according to BRAY (2). Air-dry soil < 2 mm. was used throughout, and inorganic phosphorus was estimated in the extracts by the TRUOG and MEYER method with the aid of a "Spekker" absorptiometer (13). With lactate extracts, the appropriate amount of extractant, usually 25 ml., was added to the standards used for calibrating the instrument. The same principle was used with fluoride extracts, but boric acid was also added to minimize interference (1). The values refer to soil samples taken from the actual experiment areas before any treatment was applied in the field.

Field technique. All the experiments conformed to modern statistical requirements and several designs, including randomized blocks, latin squares, lattice squares and factorial arrangements were used. The plots were generally 1/100th acre, and except for turnips at a few centres the crop was swedes. Ordinary superphosphate was used throughout, and broadcast at two or three rates immediately before the land was ridged. In the majority of experiments, yield responses to 40 and 80 lb. P_2O_5 per acre were obtained directly. Where these rates were not used, the values were estimated from the response curve. All responses are expressed as cwt. fresh bulbs per acre and refer to plots which received a suitable basal dressing of N and K, but no lime or dung.

Statistical treatment. Correlation coefficients between the various P values were calculated for each soil association separately and also for the total of all soils, eliminating differences between associations! The effect of readily soluble phosphorus on the response to the two rates of superphosphate was also investigated first of all by means of the correlation coefficients. A more complete examination of the nature of the response to phosphate was then carried out by calculating a multiple regression equation of the form.

$$\text{Response} = a + b_1x_1 + b_2x_2 + \text{- - - -}$$

where x_1, x_2, etc., represent various soil characteristics such as P value, pH, acetic-soluble Ca and K, mechanical composition, and loss on ignition. Those variates which did not account for a significant proportion of the variability in the response were omitted. This type of regression analysis was carried out for both responses on each soil association, and for the total of all soils, eliminating the differences between associations. In these analyses the acetic-soluble P values were used. These regression equations provide the estimates of response given in Table 4. Similar analyses were also carried out using the P value with the most significant effect on response.

Correlation between P values. The various factors, such as pH, period of extraction, extractant/soil ratio and nature of the anion, governing the extraction of phosphorus from soils are discussed in a separate paper (19). In general, the results in Table 2 are compatible with what might be expected from consideration of the different methods on this basis.

TABLE 2

Correlation coefficients between P values

Pairs of extractants	Correlation coefficients for soil groups				
	All soils	Basic Igneous	Granitic	Old Red Sandstone	Slate
Acet.—TRUOG	0·8215‡	0·7785‡	0·6363†	0·9866‡	0·8513‡
Acet.—Lact.	0·7355‡	0·5709*	0·6727‡	0·9679‡	0·8675‡
Acet.—NH_4F+HCl	0·5487‡	0·0675	0·6157†	0·8291‡	0·7192†
Acet.—NH_4F	0·1178	−0·3981	0·5481†	0·4850	0·7031†
Truog—Lact.	0·8411‡	0·7386†	0·8291‡	0·9539‡	0·7701†
Truog—NH_4F+HCl	0·7148‡	0·4309	0·7282‡	0·8562‡	0·7075†
Truog—NH_4F	0·3119†	−0·0395	0·5965†	0·4871	0·6395*
Lact.—NH_4F+HCl	0·7900‡	0·5934*	0·6876‡	0·9186‡	0·8136‡
Lact.—NH_4F	0·4436‡	0·1289	0·5849†	0·6412*	0·7622†
NH_4F+HCl—NH_4F	0·7521‡	0·7796‡	0·8700†	0·7933†	0·8574‡

* Denotes significance at 5% level.
† Denotes significance at 1% level.
‡ Denotes significance at 0·1% level.

There are highly significant correlations between the acetic, TRUOG, and lactate values, the majority of the coefficients being significant at the 0·1% level. Even so, there are clear indications that the degrees of correlation differ for the different soils. Despite the rather small number of samples included, all three coefficients for the Old Red Sandstone group are extremely high. The relationships are also very good in the slate group. In comparison, most of the relationships in the granitic and basic igneous group are clearly poorer, and it is noteworthy that the acetic-lactate coefficient for the basic igneous soils is less than ·6 and significant only at the 5% level. The close relationships between the three extractants are in keeping with the fact that each one is a buffered dilute acid solution. Since the anions present have no great capacity for displacing phosphate, their extracting power can be assessed largely on the basis of pH, period of extraction and extractant/soil ratio. Compared with the TRUOG method, the acetic method gives a somewhat lower final pH and has a longer period of extraction, but the former usually extracts appreciably more phosphorus. The main reason for this is almost certainly the much wider extractant/soil ratio in the TRUOG method. This wider ratio not only favours dissolution and desorption but, coupled with the shorter period of extraction, it also makes the conditions less favourable for secondary adsorption of phosphate. Secondary reactions during extraction are probably important in relation to the differences between soil groups. The lactate method gives a final pH about 0·8-1 unit higher than the other two methods. In keeping with this difference, the lactate values are always much lower.

Compared with the acetic, TRUOG and lactate solutions, neutral NH_4F extracts much higher amounts of phosphorus. It represents a different type of extractant and was designed to extract adsorbed as distinct from acid-soluble phosphorus; it gives a final pH above 7 and its dominant characteristic is the high displacing power of the fluoride ion (7) which forms a strong complex with Al and, to a lesser

extent, Fe (19). Not surprisingly, therefore, the correlation coefficients between the neutral fluoride values on the one hand, and the three dilute acid values on the other are variable and in several instances very low or not significant. There are also marked variations according to soil group. The acetic-fluoride coefficient is significant for granitic and slate soils, but is negative for the basic igneous group and not significant for the Old Red Sandstone. The same applies to the TRUOG-fluoride coefficient, but it is also significant for all the soils considered together. Except for the basic igneous group, all the lactate-fluoride coefficients are significant. The better relationship in this case is probably associated with the higher pH of the lactate solution compared with the acetic and TRUOG extractants.

NH_4F+HCl is a rather drastic extractant and despite the very short extraction period it brings out considerably more phosphorus than do the dilute acid extractants. Because of its low pH, it could be expected to show a better relationship with the three dilute acid solutions than does neutral fluoride. It is clear from the results that this is so; the appropriate NH_4F+HCl coefficients are in every case higher than the corresponding NH_4F coefficients. But it is also clear that the fluoride ion is still a dominant factor because: (*a*) the coefficients between the three dilute acid values are in every case higher than their corresponding coefficients with NH_4F+HCl; (*b*) as in the case of NH_4F, the correlations of NH_4F+HCl with the acetic and TRUOG methods are not significant for the basic igneous group; and (*c*) there is a very strong correlation between the NH_4F and NH_4F+HCl values, the coefficients being significant at the 0·1% level in all groups except Old Red Sandstone.

The varying interrelationships of the different extractants point to inherent differences in the phosphorus relationships of the soil groups. The markedly different behaviour of basic igneous soils towards NH_4F is particularly noteworthy. The reasons of these differences are being investigated and will be treated in a future publication.

P values and field responses. The correlation coefficients are given in Table 3. Considering all the soils together, the lactate method gives the best correlation with response, but the TRUOG, acetic, and NH_4F+HCl methods are almost as good. The correlation coefficients for all four methods are significant at the 0·1% level. The coefficients for NH_4F are smaller but are significant at the 1% level. There are however some clear variations in the relationships for the different soil groups.

For the slate and basic igneous groups, the only significant correlation is that between 80 lb. P_2O_5 responses and TRUOG values for the basic igneous soils. The TRUOG method gives the best relationships for both groups, with lactate and acetic next, followed by NH_4F+HCl. The correlations with NH_4F are very poor, especially for basic igneous soils. In considering the slate group, it should be kept in mind that the number of experiments is rather small.

For the granitic group, which has the largest number of experiments, acetic acid gives the best relationships, both coefficients being significant at the 1% level. NH_4F also gives significant correlations; but for the lactate, TRUOG and NH_4F+HCl methods the only significant correlation is that between the lactate values and the responses to 80 lb. P_2O_5.

TABLE 3

Correlation coefficients between P values and field responses to P

Super-phosphate rates. lb. P_2O_5 per acre	Correlation coefficients for different extractants				
	Acetic	NH_4F	NH_4F+HCl	Truog	Lactate
	All soils				
40	−0·4337‡	−0·3425†	−0·4579‡	−0·4406‡	−0·4848‡
80	−0·4720‡	−0·3158†	−0·4505‡	−0·4798‡	−0·5289‡
	Basic Igneous				
40	−0·3329	0·0881	−0·2253	−0·4435	−0·3554
80	−0·3804	0·0779	−0·2003	−0·5574*	−0·4436
	Granitic				
40	−0·5754†	−0·5095†	−0·3857	−0·3448	−0·3788
80	−0·5258†	−0·4595*	−0·3593	−0·2576	−0·4241*
	Old Red Sandstone				
40	−0·5090	−0·7903†	−0·6677*	−0·4955	−0·6489*
80	−0·6329*	−0·7705†	−0·7176†	−0·6230	−0·7290†
	Slate				
40	−0·2823	−0·1685	−0·2091	−0·5063	−0·4327
80	−0·2984	−0·1048	−0·2787	−0·5316	−0·3866

*Denotes significance at 5% level.
†Denotes significance at 1% level.
‡Denotes significance at 0·1% level.

The number of experiments on Old Red Sandstone soils, Table 1, is rather small, but most of the correlations for this group are significant. The best relationships are those for NH_4F, the correlation coefficients being nearly ·8 and significant at the 1% level. NH_4F+HCl and lactate also give significant correlations. The relationships for the acetic and TRUOG methods are poorer, the only significant correlation being that between acetic values and the responses to 80 lb. P_2O_5.

Responses at two acetic-soluble P levels. For practical advisory purposes it is necessary to consider field responses at different levels of readily soluble P. Table 4 gives the responses to be expected at acetic levels of 3 and 8 mg. P_2O_5 per 100 g. soil. These levels cover the main range of values in the present soils and are typical of the region.

As already mentioned, the responses were obtained from linear regression equations expressing response in terms of acetic-soluble P_2O_5. There were highly significant linear regressions of the responses to 40 and 80 lb. P_2O_5 on acetic values for all the soils considered together and for the granitic group ($p<0·001$). The regression was also significant for the 80 lb. P_2O_5 response on Old Red Sandstone

TABLE 4

Estimated responses to 40 and 80 lb. P_2O_5 per acre at acetic levels of 3 and 8 mg. P_2O_5 per 100 g. soil—cwt. fresh bulbs per acre

Superphosphate rates, lb. P_2O_5 per acre	Estimated responses at	
	3 mg. Acetic P_2O_5	8 mg. Acetic P_2O_5
	All soils	
40	128 ± 8·9	84 ± 9·7
80	167 ± 10·3	111 ± 11·1
	Basic Igneous	
40	115 ± 17·1	90 ± 15·5
80	146 ± 18·3	127 ± 16·4
	Granitic	
40	168 ± 13·4	63 ± 18·8
80	208 ± 17·3	83 ± 24·3
	Old Red Sandstone	
40	136 ± 29·3	92 ± 24·7
80	182 ± 28·5	123 ± 24·0
	Slate	
40	87 ± 15·9	42 ± 41·8
80	121 ± 17·4	68 ± 45·8

soils ($p<0·05$). The other relationships were not significant but the responses were estimated by the same method. The silt content of the granitic soils had a significant positive effect on both responses ($p<0·05$) when considered along with acetic P_2O_5 and was, therefore, taken into account in obtaining the responses. Similarly, in the basic igneous group, pH which had a significant negative effect on the response to 80 lb. P_2O_5 ($p<0·05$) was taken into account.

The results in Table 4 show that very large increases in the yields of swedes and turnips are to be expected from the application of phosphate on these soil groups when the acetic value is in the region of 3. For these crops at least, this level represents a very inadequate phosphorus status. In this respect, the results support the normal advisory practice followed by one of the authors (J.W.S.R.), of classifying soils with a value of 3 or less as being quite low in phosphate. The responses at the 8 level are smaller but still marked, and it appears that a dressing of 80 lb. P_2O_5 per acre is still fully justifiable at this level. Since there are very few soils with acetic values higher than 8 included, the acetic levels corresponding to zero response cannot be adequately estimated. For the granitic group, however, the regression line indicates a value of about 11 mg. P_2O_5 per 100 g. soil, which is compatible with practical experience. Since several of the regression relationships were not significant and some of the standard errors are rather high, no conclusions are drawn from the comparisons between soil groups.

TABLE 5

P levels corresponding on basis of estimated responses to acetic levels of 3 and 8 mg. P_2O_5 per 100 g. soil

Extractant	mg. P_2O_5 per 100 g. soil corresponding to:	
	3 mg. Acetic P_2O_5	8 mg. Acetic P_2O_5
	All soils together	
Lactate	1·5	3·0
TRUOG	5	9
NH_4F+HCl ...	11	22
NH_4F	11	35
	Old Red Sandstone soils	
NH_4F	15	24
	Slate soils	
TRUOG	6	9
	Basic Igneous soils	
TRUOG	6	8

To illustrate further the general comparison between the different extraction methods, pairs of P values corresponding, on the basis of estimated responses, to the acetic levels of 3 and 8 are given in Table 5. These were obtained using the appropriate regression equations as already described. Over all the soils, an acetic value of 3 corresponds to a lactate value of 1·5, a TRUOG value of 5, an NH_4F+HCl value of 11 and an NH_4F value of 11. At these levels, responses of the order of 128 and 167 cwt. fresh bulbs per acre can be expected from the application of 40 and 80 lb. P_2O_5 per acre, respectively. Similarly, an acetic value of 8 corresponds to a lactate value of 3, a TRUOG value of 9, an NH_4F+HCl value of 22, and an NH_4F value of 35. In this case the corresponding estimated responses are of the order of 84 and 111 cwt. per acre.

The two lactate values in Table 5 are of particular interest, because, as already noted, this method gives the best relationships when all the soils are considered together. For Old Red Sandstone soils, NH_4F gives the best correlations, and in this case the P values become 15 and 24, compared with 11 and 35 for all soils together. This difference serves to illustrate the likelihood that that with some methods at least, different limiting values may be necessary for different soils. In estimating the responses to 80 lb. P_2O_5 on the Old Red Sandstone soils, the clay content, which had a significant negative effect, was taken into account; this increased the significance of the regression on the NH_4F values ($p<0·001$).

On the slate and basic igneous groups, the TRUOG method gave the best relationships. The regressions were not significant, but the TRUOG values corresponding to the two acetic levels have been estimated for each group and are included in Table 5. They are very similar to the corresponding values for all the soils considered together.

Discussion

Relatively simple laboratory extractions can hardly be expected to integrate fully the numerous and fluctuating factors which influence field responses (19). It is not surprising, therefore, that many of the relationships in the present results are poor. Even so, it is clear that the methods do have a very definite diagnostic value. The most interesting feature of the results is the evidence they provide that the interrelations of the various P values and their relative and absolute usefulness as criteria of field response differ considerably in soils derived from different parent materials. The most striking example is the virtual uselessness of NH_4F on basic igneous soils compared with its superior, highly significant correlations with response on Old Red Sandstone soils. There are also clear variations in the usefulness of the acetic, TRUOG, and lactate methods. As a result, it cannot be said that any one method is clearly better than all the others. The lactate and TRUOG methods are more uniform in their behaviour over the soil groups, but to obtain the best results the apparent choices would be: TRUOG's method for slate and basic igneous soils, acetic acid for granitic soils, and NH_4F for Old Red Sandstone soils. Even with these combinations, there is considerable room for improvement, and it is hoped that some of the other methods which are being tested will prove superior. However, it is clearly important that pedological differences should be taken into account in comparisons of this kind if misleading conclusions are to be avoided. This in turn emphasises the desirability of distributing field experiments over recognised soil groups.

The statistical calculations have revealed several other points of interest, such as the significant positive effect of silt content on the regression of response on acetic-soluble P in the granitic soils. These require further investigation, however, before they can be adequately discussed.

REFERENCES

(1) BRAY, R. H. and KURTZ, L. T. *Soil Sci.*, **59**, 39 (1945).
(2) BRAY, R. H. Article on diagnostic techniques for soils and crops. *American Potash Institute*, 65 (1948).
(3) DICKMAN, S. R. and BRAY, R. H. *Soil Sci.*, **52**, 263 (1941).
(4) EGNER, H. Centralanst. f. försökv jordbruksomr. Medd. 425 (1932).
(5) GLENTWORTH, R. *Trans. Roy. Soc. Edin.*, **61**, 149 (1944).
(6) GLENTWORTH, R. and DION, H. G. *J. Soil Sci.*, **1**, 35 (1949).
(7) KURTZ, L. T., DE TURK, E. E. and BRAY, R. H. *Soil Sci.*, **61**, 111 (1946).
(8) Macaulay Institute. *Ann. Rep.* (1942-1951).
(9) REITH, J. W. S. and WILLIAMS, E. G. *Emp. J. Exp. Agric.* **17**, 265 (1949).
(10) REITH, J. W. S. *Emp. J. Exp. Agric.*, **20**, 103 (1952).
(11) STEWART, A. B. *Proc. Fert. Soc.*, **12**, London (1950).
(12) TRUOG, E. *J. Amer. Soc. Agron.*, **22**, 874 (1930).
(13) WILLIAMS, E. G. and STEWART, A. B. *J. Soc. Chem. Ind. Trans.* **60**, 291 (1941).
(14) WILLIAMS, E. G. and STEWART, A. B. *J. Agric. Sci.*, **33**, 179 (1943).
(15) WILLIAMS, E. G. and REITH, J. W. S. *Emp. J. Exp. Agric.*, **16**, 1 (1948).
(16) WILLIAMS, E. G. *J. Sci. Food and Agric.*, **1**, 244 (1950).
(17) WILLIAMS, E. G. *J. Soil Sci.*, **2**, 110 (1951).
(18) WILLIAMS, E. G. *Scottish Agric.*, **31**, 68 (1951).
(19) WILLIAMS, E. G. Int. Soc. Soil Sci. Comm. 2 and 4., Dublin, Trans. **1**, 31 (1952).

RADIATION EFFECTS WITH PHOSPHORUS$_{32}$ IN BARLEY AND TOMATO GROWN IN SOIL

C. BOULD, D. J. D. NICHOLAS and W. D. E. THOMAS

Long Ashton Research Station, University of Bristol, England

Before radioactive isotopes can be used in plant nutrition experiments, it is important to establish whether radiation from the disintegration of the tracer affects the metabolism of the plant. There are considerable differences in the results obtained by various workers in regard to the extent of radiation injury in plants. On the one hand, HENDRICKS and DEAN (1947), DION *et al.* (1949), concluded that there were no harmful effects due to the tracer used in their experiments, whilst RUSSELL *et al.* (1949, 1950), claim that radiation injury may be considerable.

Before using P_{32} in nutritional studies with plants grown in soil we carried out extensive investigations to determine whether radiation effects occurred under our experimental conditions. Two crops, barley and tomato, were used with two carrier levels of P_{31}, equivalent to 200 and 500 lb. superphosphate per acre, labelled with a range of P_{32} activities from 0·5 to 500 μC per pot. At harvest the plants were subdivided into "tops" and "roots." The dry weights, total phosphate content, fertilizer and soil phosphate uptakes were determined and also various ratios derived from them. We define radiation effects as changes in any of these quantities that can be attributed to the tracer. No attempt was made to study the cytological changes that may have occurred in our experiments, as they do not directly concern our investigations.

The experimental details are summarized in Table 1.

Results

In the statistical analysis of the data, which are too extensive to include in this short paper, effects significant at the 1% level only are considered.

Experiment 1

Statistical analysis of the data indicated that at certain levels of P_{32} treatment, barley plants showed significant increases in dry weights of "tops" and "roots" and "tops" combined. The fertilizer P uptake/total P, and fertilizer P uptake/soil P uptake were also affected by the "tracer" at the 400 μC level only. The other functions were not affected.

Significant differences in dry weights of tops were shown even from low radioactive levels, viz., 5 μC per pot. The effects did not show a regular increase with increasing tracer level. It is noteworthy that the dry weights of the roots were not significantly affected by the "tracer."

The fertilizer phosphate and total phosphate content of the roots and tops respectively and in the total plant showed no significant differences with increasing "tracer" level. The ratio of fertilizer phosphate in tops/fertilizer phosphate in the root and percentage fertilizer phosphate absorbed (range 8·6 to 9·0 per cent.) was not affected.

Table 1

Experimental details

Experiment No.	1	2	3	4
Crop	Barley var. Spratt Archer	As for Experiment 1	Tomato var. Market King	As for Experiment 1
Soil	Medium loam derived from New Red Sandstone, pH6, citric soluble P_2O_5, 0·03%	As for Experiment 1	As for Experiment 1	Sandy loam derived from the Ross series, pH 5·0
Layout	144, 6" pots randomised in 4 blocks	120, 6" pots randomised in 4 blocks	As for Experiment 2	72, 6" pots in 6 blocks
No. of pots per sampling unit	3	3	1	2
P_{31} application	NaH_2PO_4 at two levels equivalent to 200 and 500 lb. per acre	As for Experiment 1	As for Experiment 1	NaH_2PO_4 at 500 lb. per acre
P_{32} levels as μC per pot	0, 1, 5, 25, 150, and 400 respectively	0, 0·5, 4, 25, and 500 respectively	As for Experiment 2	0, 1, 5, 25, 125, and 400
Barley seeds sown or tomato transplanted into test soil	February 28th	October 19th	June 30th	September 4th
Application of tracer solutions	March 1st	October 20th	July 2nd	September 5th
Sampling	March 22nd	November 14th	August 12th and September 2nd	September 28th

Experiment 2

No effects were observed in the dry weights of tops and roots singly or in combination.

In the total phosphate figures, one significant increase was shown in roots (500 μC level) and one significant decrease in tops (4 μC level). None of the derived ratios, nor percentage fertilizer phosphate uptake was affected by P_{32}.

Experiment 3

In the first sampling the only significant effect was in soil phosphate uptake (" tops ") at 500 μC per pot.

In the second sampling, 3 weeks later, there were no significant changes in any of the functions despite the very high fertilizer phosphate uptake (range 25 to 29 per cent.).

Experiment 4

Tracer level had no significant effect on dry weights, uptake of fertilizer, soil and total phosphate nor on any of the ratios derived from these values.

Discussion

The results of our experiments show that radiation effects occurred infrequently. In experiment 1, a 13 per cent. increase in the weight of barley tops occurred at the 5 μC phosphorus$_{32}$ level but this effect did not become more pronounced with increasing levels of phosphorus$_{32}$, and at the 400 μC level there was no significant difference compared with control treatment. On the other hand, the 400 μC treatment was the only one that had a significant effect on the following ratios: fertilizer P uptake/total P, and fertilizer P uptake/soil P uptake. In all other experiments reported in this paper the dry weights of tops and roots were not affected by the level of phosphorus$_{32}$, but small differences in other values occurred occasionally. In no instance, however, was fertilizer phosphate uptake affected by tracer level, although we used far higher levels of phosphorus$_{32}$ than would normally be used in tracer experiments, and a wider range of specific activities (from 12 to 29,760 μC of P_{32} per gm. P_{31}) than those employed by other workers (see Table 4, BOULD *et al.* (1951).)

Thus, in using P_{32} in plant nutrition experiments in soil, occasional radiation effects may occur. It is, therefore, imperative to employ a well-replicated design, containing more than one level of P_{32}, capable of statistical analysis and interpretation, to determine whether radiation effects have occurred. If no significant effects on the functions under investigation can be attributed to the tracer, and isotopic exchange does not affect the interpretation of the results, then it should be possible to use P_{32} satisfactorily in soil nutrition experiments, employing the lowest tracer level that is practicable.

REFERENCES

(1) BOULD, C., NICHOLAS, D. J. D. and THOMAS, W. D E.: Radiation effects in plant nutrition experiments with phosphorus$_{32}$. *Nature*, **167**, 140 (1951).

(2) DION, G., BEDFORD, C. F., ARNAUD, R. J. and SPINKS, J. W. T.: Plant injury from phosphorus$_{32}$. *Nature*, **163**, 906 (1949).

(3) HENDRICKS, S. B. and DEAN, L. A.: Basic concepts of soil and fertilizer studies with radioactive phosphorus. *Soil Sci. Soc. Amer. Proc.*, **12**, 98 (1947).

(4) RUSSELL, R. S., ADAMS, S. N. and MARTIN, R. P.: Radiation effects due to phosphorus$_{32}$ in fertilizer experiments. *Nature*, **164**, 993 (1949).

(5) RUSSELL, R. S., MARTIN, R. P. and ADAMS, S. N.: The problem of radiation damage in fertilizer studies with labelled phosphate. Fourth Intern. Cong. Soil Sci. Trans **2**, 138 (Amsterdam, 1950).

THE ADAPTABILITY OF RAPID TEST FOR AVAILABLE PHOSPHORUS IN THE CENTRAL EBRO VALLEY SOILS

EUSEBIO CARQUÉ

Agricultural Experimental Farm, Zaragoza, Spain

Superphosphate is the most common fertilizer at Central Ebro Valley. No use is made of potassium fertilizers for supposing a high content in these soils, while the use of nitrogen fertilizers is subordinated to the disposal from the different carriers of nitrogen.

Use of superphosphate is governed by custom and is not related to estimates of nutrient deficiencies of soils. Thus unsuitable quantities are often applied.

During the last years many rapid tests for determining the availability of soil nutrients have been developed. All these quick tests differ considerably in their adaptability for use under various soil conditions and cannot be used for making fertilizer recommendations if they are not previously correlated with crop yields.

Nevertheless rapid soil tests, when properly correlated with crop responses to fertilizers on every soil, can give valuable information for the purpose of fertilizer recommendations.

This study was undertaken to determine which method is the most suitable for use in the soils at the Central Ebro Valley (Zaragoza).

It includes comparisons between pots receiving various amounts of superphosphate and correlation with crop response after the biological method of JENNY (2) which consists of growing romaine lettuce in pots.

Experimental procedure

Samples were taken from a calcareous soil in a field at Miraflores (Zaragoza) belonging to the writer. The samples were taken with a soil auger to a depth of 0·20 meters. The soils were prepared for analysis by air drying. Many borings were composite from the field.

Some of the characteristics of the soil are the following:

Colloid 42·4%; pH 7·8; organic matter 2·98%; nitrogen 0·172%, readily available K_2O 1·35 M.E./100 grams carbonates 21·2%. It is a loamy calcareous soil following the SIGMOND method.

This soil gives good crop response when heavy dressings of superphosphate are applied.

TRONTON, CONNER and FRASER (5); TRUOG (6); LOHSE and RUHNKE (3); SPURWAY (4); and BURRIEL and HERNANDO (1)* methods for determining available phosphorus were chosen for comparison.

The tests were correlated with the yields obtained in the pots after the biological determination of soil nutrients by the JENNY'S technique of the lettuce pot culture test (2).

The bulk sample was passed through a 0·50 mts. mesh sieve to eliminate stones and the pots were filled with the soil (2 kgs. per pot).

JENNY'S technique was followed with the exception that the amount of P_2O_5 added per pot, as superphosphate was varying as 0, 80, 100, and 240 mgs. per pot corresponding to 0, 112, 280 and 420 kgs. per hectare.

These relatively large quantities were applied before transplanting the lettuce plants, having account of the rapid fixation, at this soil, of applied phosphorus into forms which are not available to plants.

Results and discussion

The mean weights of the dried plant material from the replicated pots and as percentage of the highest application are given in Table 1.

TABLE 1

Dry weight yields of lettuce plants grown in pots with four fertilizer treatments (phosphorus variable)

Treatments	Dry Weight				Mean dry weight	Relative dry weight
Mgs. P_2O_5, as superphosphate, added per pot	1 gms.	2 gms.	3 gms.	4 gms.	gms.	
0	0·80	0·95	1·02	0·93	0·925	31·2
80	0.96	1·02	0·98	0·86	0·960	32·3
160	1·92	1·98	2·17	2·45	2·130	71·7
240	3·04	2·87	2·90	3·07	2·970	100

*With slight modifications proposed by the authors of the method (5 grs. of soil instead 0·5 grs. and 500 ml. of extractant solution instead 50 ml.)

TABLE 2

Analysis of variance of the dry matter yields from the Table 1.

Source of variation	Degrees of Freedom	Sum of Squares	Variance	F
Series	3	0·05	0·016	
Treatments	3	1·75	0·583	22·5
Error	9	0·24	0·026	
TOTAL	15	2·04		

F (a y 3 degrees of freedom 1% level) = 6·42.

The treatments are highly significant.

Standard deviation between two samples = 0·013. The differences between treatments are significant in the 1% level for each of them except between the first and second where the difference is significant only in the 5% level.

Table 2 presents the available phosphoric acid, as determined by the four methods studied, a month after the application.

TABLE 3

Comparing various methods for testing available phosphorus

Grams P_2O_5 added per pot	Yields as per cent. from full treatment	Method of determining available phosphorus				
		TRUOG p.p.m.	LOHSE and RUNKE p.p.m.	THORNTON p.p.m.	SPURWAY p.p.m.	BURRIEL and HERNANDO p.p.m.
0	31·2	26	41	162	15	58
0·080	32·3	34	115	190	15	65
0·160	71·7	76	110	205	27	117
0·240	100	85	143	205	53	215

TABLE 4

Correlation coefficients between various methods for testing available phosphorus and the dry weight yields

Correlation Coefficients	TRUOG†	LOHSE* and RUNKE	THORNTON*	SPURWAY†	BURRIEL‡ and HERNANDO
r	0·968	0·723	0·792	0·960	0·988

r calc. 1% level=0·990 ; r calc. 5% level=0·950

* Not significant

† Moderately significant

‡ Highly significant

As may be seen, the HERNANDO and BURRIEL method correlated better with crop response.

At the same time field trials with wheat have given results in agreement with the pot experiments.

112 kg./ha. (100 lb./acre) of P_2O_5 give no significant effect and it is more easy to know that in the field than in the pots, and we have found that soils with low amount of P_2O_5 available give no answer to applications of usual amount of superphosphate. We think that this low effect of superphosphate applications in these soils may be produced for the high and quick fixation of the phosphorus in this type of soil, calcareous and with high amount of clay.

In these soils amounts as 1,500 kg./ha. (approx. 1,340 lb./acre) of superphosphate give results similar at 300 kg./ha. (approx. 268 lb./acre) of superphosphate in soils with 10% of colloidal material and very low content of calcium carbonate.

Summary and Conclusions

Analysis of variance showed the yields and the increases in active phosphoric acid to be statistically significant.

The superphosphate applied increases the weights of the dried plant material from 0·925 grams to 2·970 grams and the available phosphoric acid from 58 to 215 p.p.m.

The data shows that this soil, containing less than 58 p.p.m. available phosphoric acid, by the HERNANDO and BURRIEL method, gave an excellent response to applied superphosphate in large quantities. This method may be used to estimate nutrient deficiencies at the soil studied.

The data presented in Tables 1 and 2 show that the use of JENNY's technique for detecting soil deficiencies correlates better with the rapid test of HERNANDO and BURRIEL than the other methods studied for this soil.

Heavy applications of superphosphate increases more the yields than light applications, owing to phosphorus fixation.

LITERATURE

1. BURRIEL, F. and HERNANDO, V.: Nuevo método para determinar el fosforo asimilable en los suelos. *Anal. Inst. Edaf. Fis. Veg.*, **IX**, 611-622 (1950).
2. JENNY, H.: Diagnostic techniques for soils and crops, 202-206. American Potash Institute, Washington.
3. LOHSE, H. W. and RUHNKE, G. W.: *Soil Sci.*, **35**, 437-459 (1933).
4. SPURWAY, C. H.: Soil Testing. Agrc. Exp. Station. Mich. State College Tech., Bull, 132.
5. THORNTON, S. D., CONNER and FRASSER, R. R.: Purdue University. Agr. Exp. Stat. Lafayette, Indiana. Circular, 204.
6. TRUOG, E.: *Jour. Am. Soc. Agro.*, **22**, 874-882 (1930).

A NEW CHEMICAL PROCEDURE FOR THE DETERMINATION OF THE SOLUBLE PHOSPHATES OF SOIL

CARLO FERRARI

Institute of Agricultural Chemistry, University of Bologna, Italy

A new chemical procedure for the colorimetric determination of the soluble fraction of soil mineral phosphates, characterized by the fact that " phosphorated molybdenum blue " is produced in the presence of the soil itself, is described. By this original procedure any possible equilibria of the phosphates between soil and solution should be ruled out, these being completely shifted towards the formation, firstly of the phosphomolybdic acid and subsequently of the " phosphorated molybdenum blue." The chromatic reaction is carried out at pH levels (4 - 5) which may be considered as physiological ; they may be commonly found in aqueous suspensions of acid and sub-acid soils saturated with carbon dioxide.

The numerous chemical methods so far proposed for the determination of the soluble phosphate content of the soil, differ in respect to the extracting solution and soil/solution ratios, but a characteristic is shared : phosphoric acid determination is carried out in extracts separated from the soil samples. By all these methods phosphoric exchangeable ions are not determined in their totality, but only their fraction corresponding to a certain equilibrium between soil and solution, according to the experimental conditions (pH, soil/solvent ratio, extraction time, temperature, a.s.o.).

Phosphoric acid determination in the soil extracts is mostly based upon the blue-molybdenum reaction : interference from soluble silica, often present in large amounts in the soil extracts, is avoided by the use of a molybdic reagent to which sulphuric acid is added up to a concentration sufficient to bind molybdic acid, so that silico-molybdic complex formation is completely inhibited, leaving the formation of phospho-molybdic acid quite unaffected (1).

The need for such a strongly acidified reaction mixture (pH below 1) is a drawback, because the hydrolysis of the labile phosphoric esters cannot be prevented.

On the basis of the results of the experimental work carried out in this Institute, problems such as the blue molybdic micro-dosage of mineral phosphoric acid in the presence of relatively large amounts of soluble silica (2) and the determination of mineral phosphates in the presence of labile phosphoric esters (3), can be considered definitively solved.

The routine work is a simple one and reliable for " serial " determinations, owing to the fact that coloured solutions are very stable, so that readings can well be taken long after mixing ; such a procedure might be so advantageously applied to the mineral phosphates determination in soil extracts as obtained with common chemical methods. The formation of the " phosphorated molybdenum blue " at pH values between 4 and 5, higher than in the customarily followed blue-molybdimetric methods, is the salient feature of this analytical procedure.

It must be noted that such pH levels are not incompatible with the plant growth; they may be commonly found in aqueous suspensions of carbonate-poor or -free soil samples, when they are saturated with carbon dioxide, conditions comparable with those naturally occurring in such soil types.

Recently (4) the "phosphorated molybdenum blue" has been recognized as being not practically adsorbed, under the mentioned low acidity levels (pH 4 or 5), either by soil or by filter paper, while considerable adsorption occurs in more acid solutions (pH below 1). This particular soil behaviour prompted us to formulate a new procedure for the determination of soil soluble phosphates, the novelty consisting in that the "phosphorated molybdenum blue" is formed in the presence of the soil sample itself: after a convenient time of contact between soil and extracting reagent, the suspension is filtered through filter paper in order to obtain a clear solution for photometric reading.

By this procedure any possible equilibria of the phosphates between soil and solutions should be ruled out and so it should be possible by a single operation to dose all the phosphoric acid which in a given time and under the chosen conditions (pH, soil/extracting solution ratio, temperature a.s.o.) may pass in solution: P_2O_5 values so obtained should correspond more closely than those furnished by any other common procedure, to the actual fraction of mineral phosphates at the disposal of the plant radical apparatus. As the phosphoric acid is going into solution, it is immediately and irreversibly taken away from any equilibrium, being firstly transformed into phospho-molybdic acid and then into "phosphorated molybdenum blue."

There is experimental evidence that the figures obtained by the new procedure after a given time of contact between soil sample and extracting solution (1 hour for instance with a 1 : 50 soil/solution ratio) are notably higher than those one may obtain following common extraction procedures under the same conditions of pH and soil/solution ratio even if the extraction is repeated several times under renewal of the solvent at the end of each one hour extraction.

Such a chemical withdrawal might be compared not unsoundly to what the plant roots do, in absorbing irreversibly the phosphoric acid from soil solution.

That the new procedure can actually give more reliable results than others, concerning the phosphate availability of the soil, can be only judged from a field-scale large comparative work.

In the hope of contributing somehow to the solution of such an important question as the determination of the plant-available soil phosphates, the opportunity offered by this Meeting has been taken to refer to the new procedure fundamentals and characteristics, it being desirable, in our mind, that an agreement could be reached upon the most important experimental conditions to be followed in the determination of the soluble phosphates of the soil, mainly the extracting pH and the most suitable soil/extracting solution ratio.

If a pH level should be chosen in the range permitting the formation of the "phosphorated molybdenum blue" in the presence of the soil sample, then the application of the procedure referred to in this paper might be recommended, as in our opinion it has advantages over any other chemical method.

On the basis of the previous works (2–3–4), the following general procedure is proposed : a convenient weight (2·5–5 g.) of air-dry 1–2 mm. mesh soil is mixed in an appropriate vessel (fig. 1) with a suitable volume (125–250 ml.) of the extracting solution, eventually buffered in the range of pH 4–5. The extracting solution is freshly prepared as follows : 20 ml. of 1·44% ammonium molybdate solution (1 ml. corresponds to 12 mg. of MoO_3 approximately) are diluted up to about 90 ml. with H_2O ; 8 ml. of the reductant (2·5% ascorbic acid solution freshly prepared) are then added, and the mixture brought up to 100 ml. with H_2O, care being taken to avoid any excessive aeration. When buffering is desired, 50 ml. of WALPOLE's buffer mixture (5) of the chosen pH (total acetate 0·4 molecular to reach the final concentration 0·2 molecular) will be employed.

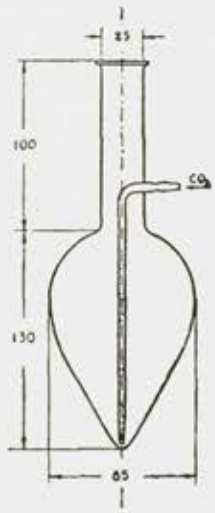


Figure 1
Reaction vessel (capacity—30 ml. dimensions in mm.)

Through the inlet tube of the reaction vessel (fig. 1), the suspension is thoroughly gassed with carbon dioxide : by the saturation of the liquid with CO_2, conditions are established analogous to those existing in soil solutions, ascorbic acid oxidation by air (otherwise noticeable at such pH levels) is prevented and finally intimate contact between soil and solvent is favoured.

After a convenient time of gassing (10-30 minutes, one or more hours) or, better, after different times in separate vessels to evaluate the dissolution rate as well, the suspension is filtered through SCHLEICHER and SCHÜLL n° 589² filter paper, so that in a few minutes clear solution is obtained.

The filtrate will be more or less coloured according to the quantities of phosphoric acid and soluble silica which have reacted ; the fraction of soluble silica which may induce the formation of silico-molybdic acid and then " silicated molybdenum blue " may be in fact considerable under the conditions of low acidity (pH 4–5) employed.

For determining the amount of mineral phosphate that reacted, and the interference degree from the soluble silica, two 25 ml. aliquots of the filtrate (they must contain 60 mg. of MoO_3 each) are transferred into 250 ml. conical flasks, where both are added with 50 ml. of H_2O and 17 ml. of 8 N H_2SO_4 in the order.

The content of a flask is then heated over a boiling water bath for 15 minutes and brought, after cooling, to 100 ml. with H_2O: the extinction of this solution corresponds to the extinction of both the "phosphorated" and "silicated molybdenum blue."

The other aliquot is oxidized with N $KMnO_4$ until reddish colour persists, mixed immediately with 2 ml. of the ascorbic acid solution, then warmed, cooled and diluted as before. The extinction of this aliquot is due to the "silicated molybdenum blue" only. From the difference between the two values one obtains the extinction of the "phosphorated molybdenum blue" and herefrom the amount of mineral phosphates withdrawn from the soil sample by the extracting solution. This value may be conveniently expressed as a percentage of the total P_2O_5 of the soil as determined by a separate analysis.

A requisite of primal importance in such a determination is, of course, the rapidity and the possibility of operating serially: the exactness ought not to be overlooked especially when this may be gained by a negligible loss of time and reagents.

As a rough indication a single determination may be performed in one hour when the time of contact with the extracting solution will be limited to 10-15 minutes. By "serial" operating one or two analysts may easily perform daily several dozen determinations.

Acknowledgments:

Thanks are due to Dr. VITTORIO SCARDOVI, of the Institute of Agricultural Microbiology, Bologna University, for his assistance in translation work.

REFERENCES

(1) FERRARI, C.—Osservazioni sul comportamento dell'acido silico-molibdico in soluzione acquosa (Some observations on the behaviour of silico-molybdic acid in aqueous solution)—*Gazzetta Chimica Italiana*, **81**, 692-709 (1951).

(2) FERRARI, C. e LUGO, P.—Sulla micro-determinazione fotometrica degli acidi fosforico e silicico presenti contemporaneamente in soluzione (Photometric determination of both mineral phosphate and soluble silica in the presence of each other)—*Annali della Sperimentazione Agraria*, nuova serie, **VI** (1952).

(3) FERRARI, C.—Sul micro-dosamento fotometrico dell'acido fosforico minerale in presenza di esteri fosforici (Photometric determination of inorganic phosphoric acid in the presence of its esters)—*Annali della Sperimentazione Agraria*, nuova serie, **VI** (1952).

(4) FERRARI, C.—Sul potere assorbente della carta da filtro e del terreno verso il "bleu di molibdeno fosforato" (The adsorptive power of filter paper and soil towards "phosphorated molybdenum blue")—*Annali della Sperimentazione Agraria*, nuova serie, **VI** (1952).

(5) CLARK, W. M.—The determination of hydrogen ions—Baltimore, Md., II Ed., Williams & Wilkins Company, 115 (1925).

THE DETERMINATION OF SOLUBLE PHOSPHATES IN ACID AND SUB-ACID SOILS BY THE NEW FERRARI PROCEDURE

GIOVANNI SANDRI, PAOLO CORADUCCI AND PIETRO LUGO

Institute of Agricultural Chemistry, University of Bologna, Italy

The new FERRARI procedure for determining the soluble phosphates is firstly applied to acid and sub-acid soils samples. Authors fix a conventional 1 : 50 soil/extracting solution ratio and buffer the reacting mixture at the pH level reached by the aqueous suspension of the soil, saturated by carbon dioxide. The manuality followed is detailed. The results show that this procedure can be advantageously applied to the determination of the soluble phosphates in such soils and to kinetic investigations on the phosphate solubilization processes.

In a previous FERRARI contribution submitted at this Meeting, a new procedure has been proposed for the colorimetric determination of the soluble phosphates of soil, where, as a chief feature, the " phosphorated molybdenum blue " is formed in the presence of the soil sample itself. According to FERRARI, this procedure should prevent the establishing of any possible equilibria between soil and extracting solution, making possible, therefore, a rapid determination of the fraction of mineral phosphates that may pass into solution at a given time and under the followed experimental conditions.

Trials have been made in order to evaluate the practical suitability of the procedure : awaiting for pH of the extraction and soil/extracting solution ratios most convenient for the different soil types being fixed, we have confined our work to the application of the new procedure to acid and sub-acid soil types, practically $CaCO_3$-free, a 1 : 50 ratio soil/extracting solution having been arbitrarily selected.

Being convinced, as several authors are, that the experimental conditions most closely copying the natural ones, may be established by the use, for the extraction purposes, of carbon dioxide saturated aqueous diluted solutions, such soil types have been chosen because their aqueous suspensions at a 1 : 50 ratio, simply saturated with carbon dioxide, show pH levels in the optimum range for FERRARI's new procedure (pH 4-5), so that any arbitrary pH adjustment is avoided.

With acid and sub-acid soils, as the case in point, pH must as a preliminary be determined in the soil aqueous suspension (1 : 50 soil/water ratio), saturated with carbon dioxide. With the reactive ammonium molybdate and ascorbic acid containing in the proportions suggested by FERRARI, pH is somewhat lowered owing to the ascorbic acidity (100 ml. of the reactive contain 200 mg. of ascorbic acid). It has been confirmed, by preliminary investigations, that any even slight shift of the reacting mixture pH, is able to exert a considerable influence upon the P_2O_5 which goes into solution at a given time : buffering with WALPOLE's buffer (acetic acid and sodium acetate) is so preferable. A buffer concentration of 0·2 total molarity does not disturb to any extent the ceruleo-molybdate reaction, being sufficient, however, for buffering the pH level within $\pm$ 0,05.

In order to have the phosphate availability of a soil more adequately pictured, the solubilization rate of mineral soil phosphates is, in our

opinion, of primal importance: with such a goal several trials have been performed with the same soil specimen, varying only the time of contact between soil and extracting solution (10, 30, 60 and 120 minutes). Modifications will be likely introduced by larger future work; now attention is only drawn to the opportunity to have a series of figures whereupon kinetics of phosphates solubilization may be visualized.

Kinetic investigations almost impossible to be performed by all the common chemical methods, are instead made feasible, in our opinion, by this new procedure, mainly because of its rapidity in the determination of soluble phosphates, being their equilibria between solid and liquid phases, shifted towards the formation of the "phosphorated molybdenum blue."

The highly reproducible results obtained by this procedure is, in this respect, of capital importance, being possible to compare figures from separate trials performed with the same soil sample.

Experimental

Reagents:

(*a*) *molybdic reagent:* 1·44% ammonium molybdate aqueous solution (1 ml. = ÷12 mg. of MoO_3);
(*b*) 8 N H_2SO_4, arsenic-free;
(*c*) *reductant:* 2·5% ascorbic acid aqueous solution, freshly prepared;
(*d*) *buffers:* total acetate 0·4 molecular of WALPOLE's mixtures. The reacting solution is buffered at the chosen pH and diluted up to a final buffer concentration of 0·2 total molarity;
(*e*) ÷N $KMnO_4$.

Photometric readings have been taken with COLEMAN Universal Spectrophotometer, Mod. 14, at 650 mμ; pH values with BECKMAN pH-meter, Mod. "G."

Procedure:

The pH of 1 : 50 aqueous CO_2- saturated soil sample suspension is firstly measured and taken as extracting pH.

Four 2 g.portions of air-dry 1 mm.mesh soil are prepared. The extracting solution is made up by pipetting orderly into a 100 ml. volumetric flask, 50 ml. of buffer (*d*) (pH as before determined), 20 ml. of the molybdic reagent (*a*), 20 ml. of distilled water, 8 ml. of the reductant (*c*) and immediately brought to the mark with distilled water, care being taken to avoid excessive aeration.

50 ml. of this solution is poured into the reaction vessel (1), a rapid flowing of carbon dioxide from gas cylinder is immediately started, the soil portion is introduced and finally the remaining solution added. This is to avoid inlet tube obstruction by the soil particles. Remaining three soil portions are treated similarly. After graded lapses of time (10 - 30 - 60 - 120 minutes) CO_2 flow is stopped, final pH is checked and the mixture is filtered, under vacuum, through BUCHNER funnel, using absolutely phosphates-free 9 cm. Φ paper disks (for instance SCHLEICHER and SCHÜLL, No. 589[2]). Filtration

Characteristics of the soils (sampled from 0-20 cm. deep)	$CaCO_3$ %	Total P_2O_5 %	Soil pH	CO_2-saturated soil aqueous suspension (1:50) pH	CO_2-saturated reacting mixture pH	Extraction time in minutes	Extracted mineral P_2O_5 %	Extracted mineral P_2O_5 % of the total
1. **Heath land** near Ferno, province of Varese	0·0	1·77	5·95	4·35	4·38	10	0·005	0·28
						30	0·009	0·51
						60	0·012	0·67
						120	0·022	1·24
2. **Heat-pine forest** near Tradate, province of Varese	0·0	0·94	5·48	4·05	4·08	10	0·006	0·64
						30	0·015	1·60
						60	0·023	2·45
						120	0·031	3·30
3. **"Ferretto" soil** near Ronchi, province of Parma, in wheat	0·0	1·00	5·50	4·55	4·52	10	0·068	6·80
						30	0·085	8·50
						60	0·087	8·70
						120	0·090	9·00
4. **Peat-clay soil** near Oltrebella, province of Ferrara, in rice	0·0	1·18	4·50	4·20	4·22	10	0·028	2·37
						30	0·057	4·83
						60	0·079	6·69
						120	0·108	9·15
5. **Humus-clay soil** near Lozzo Atestino Colli Euganei, province of Padova, in sugar beets	2·0	1·45	7·40	4·95	5·00	10	0·079	5·45
						30	0·129	8·90
						60	0·156	10·76
						120	0·189	13·03
6. **Volcanic soil** near Ottaviano, province of Napoli, vineyard and vegetable garden	0·0	7·75	7·05	4·75	4·75	10	0·152	1·96
						30	0·251	3·24
						60	0·378	4·88
						120	0·462	5·96
7. **Volcanic soil** near S. Giuseppe Vesuviano, province of Napoli, vineyard ...	0·0	7·25	7·20	4·50	4·52	10	0·050	0·68
						30	0·090	1·24
						60	0·127	1·75
						120	0·206	2·84
8. **Volcanic soil** near Somma Vesuviana, province of Napoli, vineyard ...	0·0	7·37	7·90	5·00	5·00	10	0·150	2·03
						30	0·223	3·02
						60	0·271	3·68
						120	0·352	4·78
9. **Volcanic soil** near Pollena Trocchia, province of Napoli, in vegetable crops	0·0	6·91	6·93	4·74	4·78	10	0·091	1·32
						30	0·158	2·29
						60	0·285	3·40
						120	0·395	5·72

must be as quick as possible to avoid any further contact between soil and extracting solution, still reacting with the soluble phosphates. When the filtration is too slow or difficult, the addition of some absolutely phosphate-free asbestos fibres helps considerably: the asbestos does not adsorb the phosphorated molybdenum blue.

In two 25 ml. aliquots of the clear filtrate, P_2O_5 and interfering soluble silica which have reacted in the considered time, are separately determined as follows: the two aliquots are introduced into 250 ml. ERLENMAYER flasks, diluted with 50 ml. of distilled water and added, by constant swirling, with 17 ml. of the 8 N H_2SO_4. The content of a flask is then heated on a boiling water bath for 15 minutes and brought, after cooling, to 100 ml. with distilled water in a volumetric flask: the extinction of this solution corresponds to the extinctions of both "phosphorated" and "silicated molybdenum blue." The other aliquot is oxidized with $KMnO_4$ solution (*e*), until reddish colour persists, added immediately with 2 ml. of the reductant (*c*), then warmed, cooled and brought to the mark as before. The extinction of this aliquot is due to the "silicated molybdenum blue" only. From the difference between the two values, one obtains the extinction of the "phosphorated molybdenum blue," and herefrom the P_2O_5% extracted.

In the Table 1 some figures are reported, obtained by the described procedure, from several soil samples of different origin and composition, selected as representatives of various Italian acid and sub-acid soil types. Selected types are: 2 heath-land soils of Lombardia (Ferno and Tradate); 1 sub-Appenninic soil of the "ferretti" zone (Parma); 1 peat-clay soil of the "Ferraresi" reclamations; 1 humus-clay soil of the "Colli Euganei" zone (Lozzo Atestino) of a 2% $CaCO_3$ content (its aqueous solution, however, CO_2-saturated, presents a pH value near 5); 4 volcanic soils of the Vesuvian zone, which, though not acid, are completely $CaCO_3$-free and the pH of their aqueous suspensions is rapidly lowered by CO_2 saturation to the optimum range.

Figures reported witness to the suitability of the procedure to the cases in point: this is not devoid of importance, the soil types investigated being rather extensively represented all over the European lands.

Differences have been brought to light in respect to the mineral phosphate amounts released in a given time by the soil and to the solubilization rates.

Fertility conditions, as judged from the actual cultures, well agree with the figures reported.

Acknowledgments:

Thanks are due to Dr. VITTORIO SCARDOVI, of the Institute of Agricultural Microbiology, Bologna University, for his assistance in translation work.

REFERENCES

(1) FERRARI, C.—A new chemical procedure for the determination of the soluble phosphates of soil.—Transactions of the Joint Meeting of Commissions II and IV of the International Society of Soil Science, Volume II (submitted at the Meeting, Dublin, Ireland, July 21st-31st, 1952).

STUDIES ON PHOSPHATE IN SOME SPANISH RICE SOILS

V. HERNANDO AND L. JIMENO

Institutio de Edafología y Fisiología Vegetal, Madrid, Spain

Introduction

The soils of the Spanish rice fields were previously studied in order to ascertain the causes of the progressive decrease in their crop yields observed for some time past. These soils are characterized by their high pH and high carbonate content. Their texture varies between loam and sandy loam. We studied soils from the most important zones (Tortosa and Valencia).* In the previous paper the results referring to total and assimilable phosphorus were published. In general, the available phosphorus content is low, which does not agree with the idea generally held about these rice fields, since they were considered to be rich in phosphorus, especially when the large doses of superphosphates they continually received were borne in mind.

As, on the other hand, the total phosphorus gives high values, we thought it interesting to ascertain in what form it is present in these soils and for what reason phosphorus had to be supplied in order to maintain the level of crops.

As the causes of the decrease in production are still unknown, we studied the phosphorus with special attention so as to find out whether the defect had to be attributed to this fertilizer or to other causes. In any case, knowledge of the distribution of the phosphorus forms in extremely calcareous soils would be useful.

Experimental

In the present paper the following determinations are included: total phosphorus (2), available phosphorus (3) modified by taking 5 gr. of soil instead of 0·5 gr., and 500 c.c. of solution instead of 50 c.c. Moreover, the assimilable phosphorus was determined by MORGAN'S method (4) and also by the acetate buffer method indicated by BONDORFF (5), the phosphorus soluble in 2N H_2SO_4 (6) (the sulphuric acid was taken at 2N instead of 0·2N in order to reduce the effect of calcium carbonate), and the organic phosphorus (6). Extraction in 0·1N NaOH was used to determine the content of adsorbed forms, of iron and aluminium phosphates and bi-calcium phosphates according to techniques used in the Soil Fertility Department of the Macaulay Institute in Aberdeen (Scotland).

Following the works of STELLY and PIERRE (7) solubility curves of phosphorus were made of these soils to determine the different classes of phosphorus present. By the same system fixation curves of superphosphates were drawn at different pH. The fixation power (3) was determined, and later 0·1 NaOH was used to find out which part of the fixed phosphorus is soluble in it.

*From the geological point of view these soils belong to the Quarternary alluvions.

The colorimetric determination of phosphorus in the extracts was carried out by the method of F. BURRIEL and V. HERNANDO, with some modifications (8).

The authors want to state that on account of the limits of this paper no more details can be given, but that in the *Anales de Edafología y Fisiología Vegetal* the techniques used will be dealt with more extensively.

Results and Discussions

Table 1 shows the determination of phosphorus in its various forms.

TABLE 1

SAMPLE	mg. of P_2O_5 per 100 gr. of soil				ASSIMILABLE	* C%	* N%	* ORG. MAT.
	TOTAL	2N SO_4H_2	ORG.	1/10N NaOH				
482- I	173	—	—	—	8	3·19	0·41	5·48
482- II	219	78·75	36·25	—	4	3·06	0·39	5·26
483- I	227	110·0	76·25	—	6	4·64	0·41	7·98
483- II	192	104·16	35·84	—	4	4·42	0·39	7·60
483 III	167	68·3	63·36	—	4	3·86	0·36	6·63
484- I	219	110·0	52·50	—	6	1·74	0·21	2·92
484- II	177	102·0	38·0	—	2	1·47	0·16	2·52
485- I	163	52·5	12·1	—	5	0·75	0·80	1·29
485- II	123	63·0	17·5	—	6	0·84	0·09	1·44
485-III	86	—	—	—	8	0·95	0·09	1·63
485-IV	83	72·5	11·0	—	2	0·94	0·09	1·61
487- I	84	60·0	24·3	—	10	1·05	0·06	1·80
487- II	110	—	—	—	7	0·44	0·04	0·75
488- I	92	60·0	7·0	0·10	6	0·71	0·06	1·22
488- II	94	60·0	10·0	2·00	8	0·76	0·05	1·30
488-III	153	61·0	2·5	0·40	6	0·83	0·05	1·42
489- I	174	73·0	24·5	2·62	4	0·60	0·11	1·07
489- II	127	79·0	24·0	1·30	9	1·09	0·11	1·87
489-III	106	76·6	21·7	8·00	10	0·09	0·11	1·54
492	269	212·5	60·0	2·13	23	1·60	0·16	2·75
493	167	114·0	36·0	0·30	13	1·32	0·11	2·30
494	168	102·5	35·0	—	14	1·34	0·11	2·30
495	192	85·7	61·8	1·10	8	1·51	0·13	2·50
496	204	102·5	37·5	1·60	8	2·45	0·26	4·21
497	159	66·25	30·05	1·00	7	2·24	0·21	3·85
498	191	78·75	23·75	1·00	8	1·89	0·22	3·25
499	137	53·75	36·23	1·33	4	1·96	0·23	3·37
500	207	103·0	18·25	1·50	10	1·54	0·18	2·64
501	160	—	—	0·30	8	2·04	0·22	3·50

*Data taken from the paper of F. BURRIEL and ALEIXANDRE already mentioned. The description of the samples used in this study, can be seen in (1).

From this Table we learn that phosphorus soluble in 2N H_2SO_4 is very high and that phosphorus soluble in 0·1N NaOH is very low. This indicates that the forms present are calcium phosphates which are highly soluble in sulphuric acid but of low solubility in NaOH. Moreover, this seems to prove that the adsorbed aluminium phosphate and iron phosphate contents must be very small.

Organic phosphorus is variable. In some cases as, for instance, in that corresponding to sample No. 483–I it is high, and in others extremely low, as in sample No. 488—III, although it is true that these values agree with the larger or smaller content of organic matter which was confirmed by the calculation of the correlation coefficient of these values.

In more than half the cases, the sum of phosphorus soluble in acids plus phosphorus soluble in NaOH, plus organic matter is approximately the total; this seems to indicate that in these cases inert phosphorus is equal to zero.

A study was made of the correlation between the different forms of phosphorus, as well as between organic phosphorus and the carbon, nitrogen and organic-matter content of these soils. In this paper we shall only report the data obtained in the conclusions.

It was found that the correlation coefficient between total and assimilable phosphorus is of no importance statistically, just as there is no correlation between total, assimilable and organic phosphorus and phosphorus soluble in 0·1N NaOH.

On the other hand, there was found a significant correlation between the organic phosphorus and nitrogen, carbon and organic matter.

To prove whether, contrary to the general opinion, the assimilable phosphorus was really low, we used MORGAN's method and the acetate buffer method indicated by BONDORFF. The results showed that these soils are deficient in assimilable phosphorus in close agreement with the first method.

Solubility curves were drawn to characterize the forms of the phosphorus present in these soils. In the accompanying graphs, some results are shown. It can be seen that the samples from San Jaime show characteristic apatite curves, and, in the others, that the phosphorus is a mixture of rock-phosphate and apatite, the latter prevailing.

On the other hand, in the samples from the region of Alfalfar, the curves are typical for apatite or rock phosphate and mixtures of apatite and rock phosphate, the latter form prevailing. This confirms the suggestions of Table 1.

It may, perhaps, appear strange that phosphates from rocks and apatite are not assimilable, but bearing in mind the large calcium carbonate content of these soils the difficulty of assimilation (10) and (11) is not surprising.

The fixation curves of superphosphate at different pH values were obtained and the authors observed two fundamental types, both of great solubility in the acid zone, and of less solubility in the alkaline zone. But there are some that show a maximum between pH 5 and 7, whilst in others the maximum occurs about pH 8. The latter are generally those of greater calcium carbonate content.

It was also observed that in the pH zone of the soil the solubility curve obtained in NaOH is lower than in KOH. In others the reverse occurs.

But there are other soils where solubility in NaOH is much greater than in KOH and precisely in these latter a greater carbonate content is to be found. Some typical curves are shown (Figs. 6 and 7).

fig.1

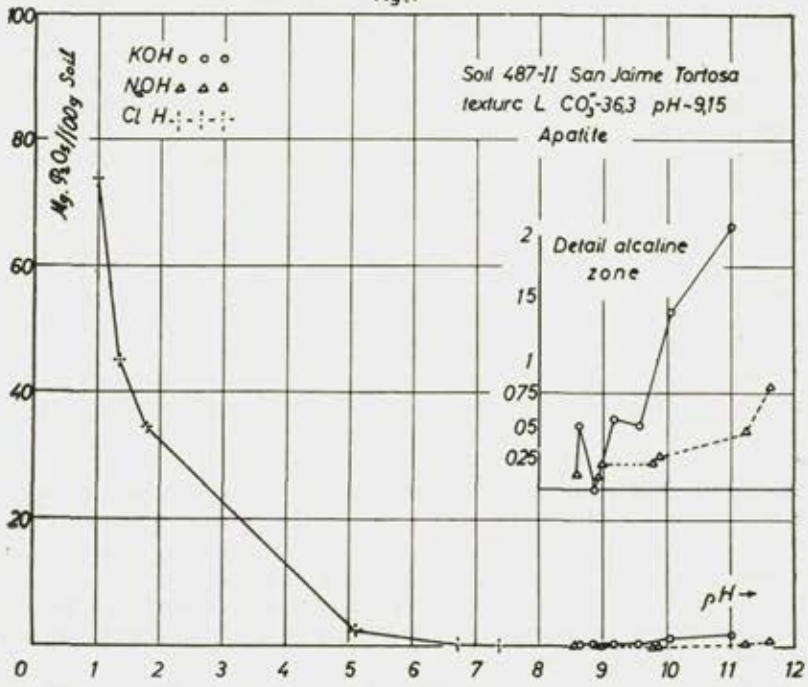

KOH
NaOH
Cl H
Soil 487-II San Jaime Tortosa
texture L $CO_3^=$-36,3 pH-9,15
Apatite
Detail alcaline zone
pH

fig.2

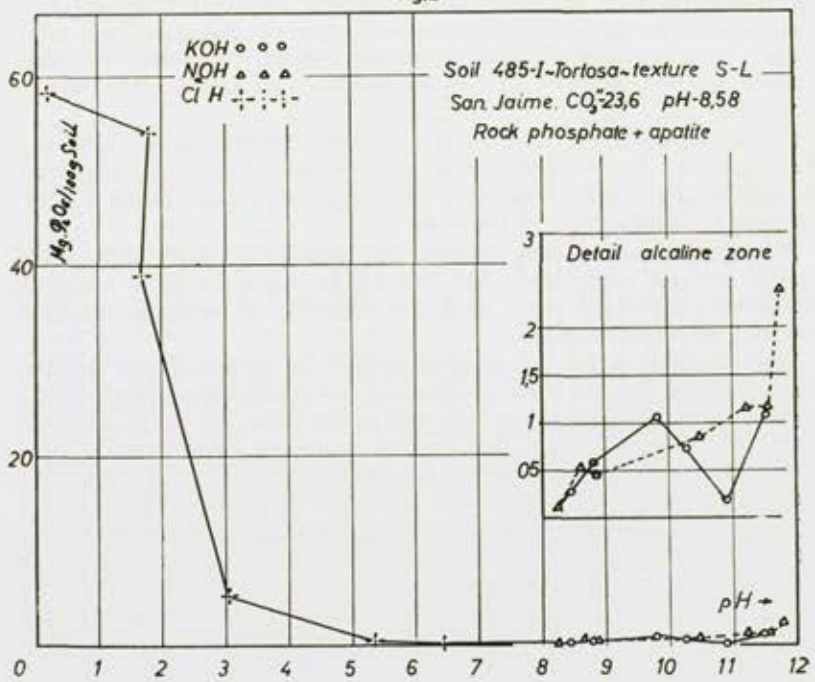

KOH
NaOH
Cl H
Soil 485-I-Tortosa-texture S-L
San Jaime. $CO_3^=$-23,6 pH-8,58
Rock phosphate + apatite
Detail alcaline zone
pH

fig.3

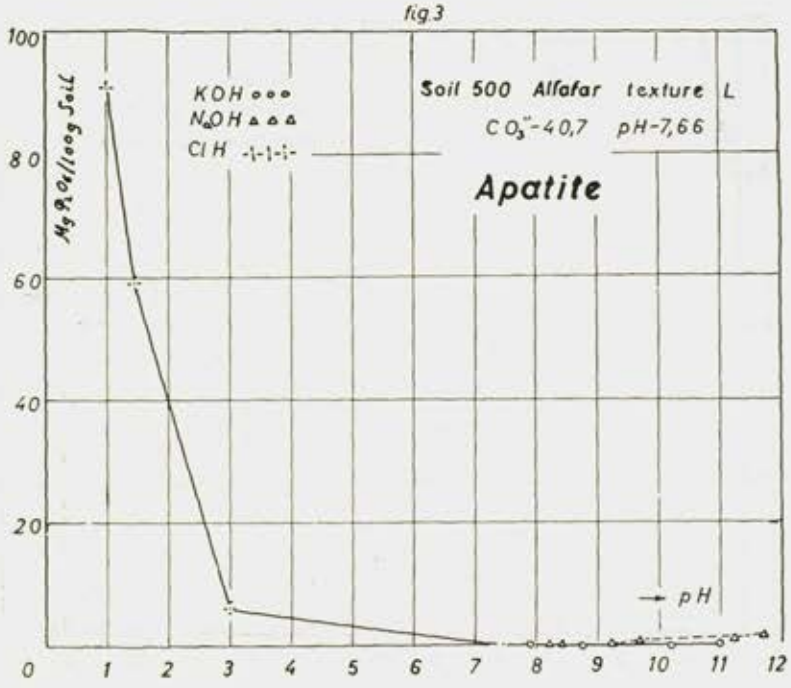

KOH ooo
N₂OH △△△
ClH -·-·-·-
Soil 500 Alfafar texture L
CO₃⁻⁻-40,7 pH-7,66
Apatite
pH
mg P₂O₅/100g soil
100
80
60
40
20
0
1 2 3 4 5 6 7 8 9 10 11 12

fig.4

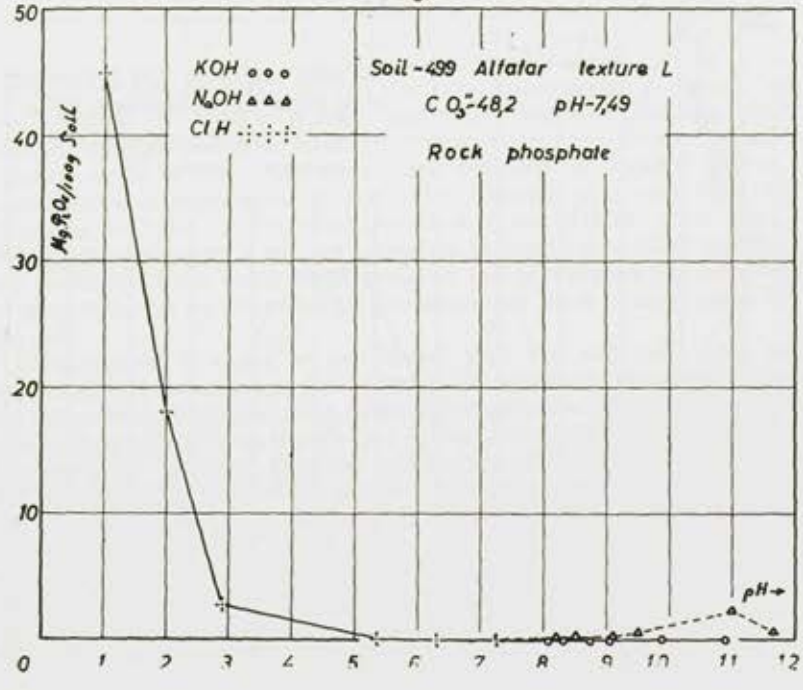

KOH ooo
N₂OH △△△
ClH -·-·-·-
Soil -499 Alfafar texture L
CO₃⁻⁻-48,2 pH-7,49
Rock phosphate
pH
mg P₂O₅/100g soil
50
40
30
20
10
0
1 2 3 4 5 6 7 8 9 10 11 12

fig.5

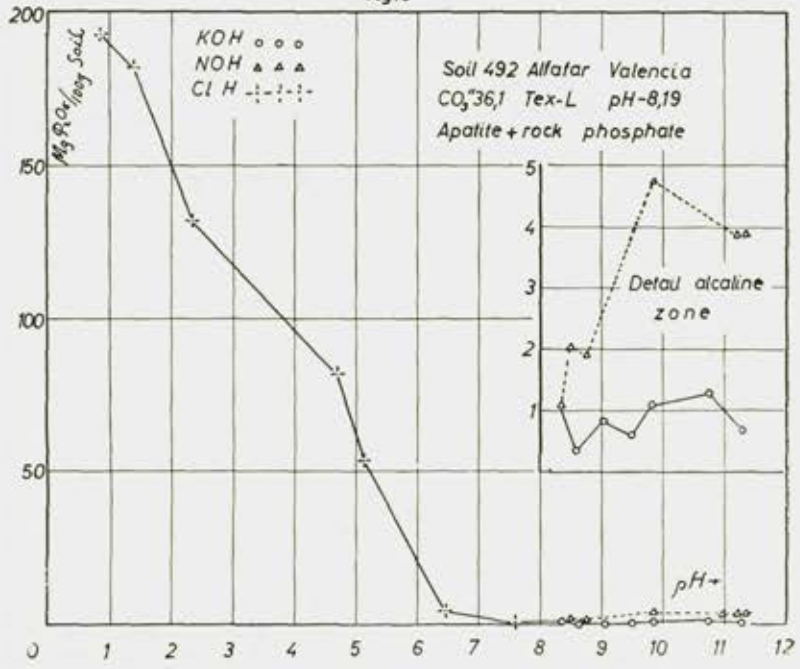

KOH ○ ○ ○
NOH △ △ △
Cl H
Soil 492 Alfafar Valencia
$CO_3^{=}$36,1 Tex-L pH-8,19
Apatite + rock phosphate
Detail alcaline zone
pH→
200
150
100
50
0 1 2 3 4 5 6 7 8 9 10 11 12
1 2 3 4 5

fig.6

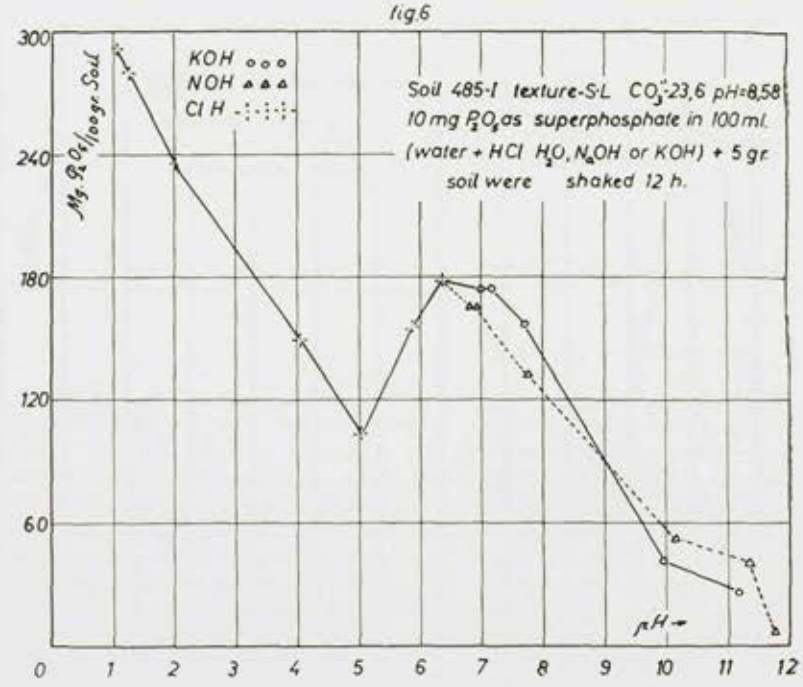
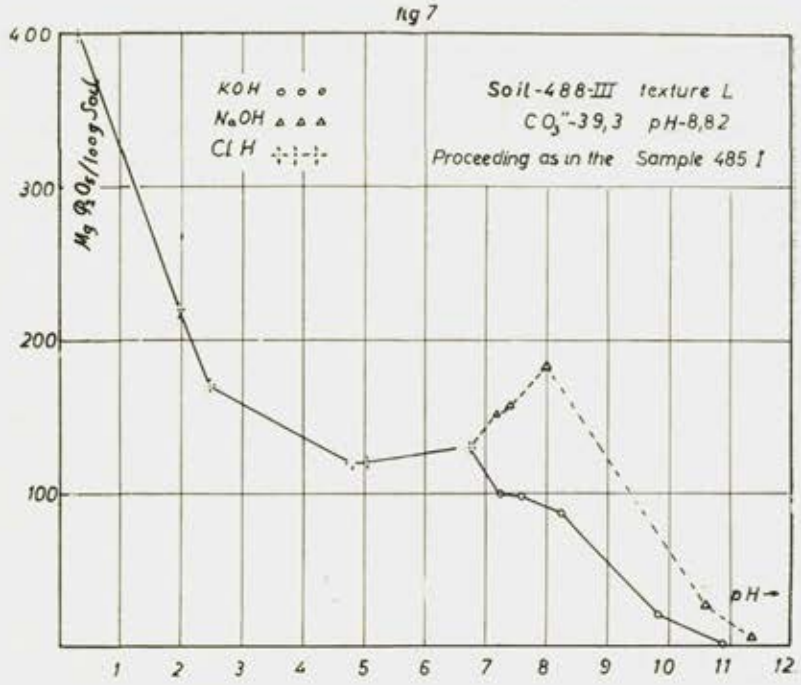

KOH ○ ○ ○
NOH △ △ △
Cl H
Soil 485-1 texture-S-L $CO_3^{=}$-23,6 pH=8,58
10 mg P_2O_5 as superphosphate in 100 ml.
(water + HCl H_2O, N_aOH or KOH) + 5 gr.
soil were shaked 12 h.
pH→
300
240
180
120
60
0 1 2 3 4 5 6 7 8 9 10 11 12

fig 7



In view of this we consider that a better utilization of these fixed phosphates in the soil is practicable if we make the clay of the soil more sodic; in others, potassium salts may be added. Moreover, (and this is general), the acidification of these soils will result in a greater utilization of the phosphorus. As this can be obtained by the addition of organic matter, one quite logically deduces that favourable effects will be obtained.

Since many of these soils are very deficient in organic matter, a concentrated application of the latter, besides improving the soil structure, will give the benefits mentioned above. On the other hand, the humic acids exert a solvent action on calcium phosphates because the particles of the acids block those of the phosphates (on account of their different micellar charges), maintaining them in suspension in the soil.

Furthermore, it must be considered that the soils are poor in nitrogen (even more than in phosphorus) and, therefore, this is probably the factor that limits the crops, since rice requires an abundant supply of nitrogen, as has been shown (11) in the soils of the French Sudan. Consequently, we think that the application of ammonium sulphate, which at the same time exerts a useful acidifying action, together with the highest dose of organic matter, would nearly eliminate the decrease in the crops observed during recent years. In this manner there would be no need to increase the supply of superphosphates. In any case, we consider a thorough study of the fertility of these soils most desirable, in order to determine which is the limiting factor or whether there are several.

Fixation seems to vary, being above 50% in most cases, which represents a high fixation degree. This makes greater care necessary in the application of superphosphates in order to avoid the increase of forms which are not easily utilized.

After our study of fixation by method (3), we thought it interesting to carry out soda extraction to see whether this phosphate had been fixed to form calcium phosphate or had been adsorbed by the soil, which would give us an idea of what had occurred in the soils. The results obtained are given below:

TABLE 2

	mg. of P_2O_5 per 100 gr. of soil				
	1/10N NaOH	Solut. Extract Monocal. Phosphate	% Fixation	1/10N* NaOH	% of the Total Fixed
483-III	—	50	54	—	—
484- II	—	42	60	12·5	20·8
485- I	—	81	24	15·0	62·6
485- II	—	64	42	13·9	33·0
485-IV	—	70	32	22·7	84·5
488-III	0·40	22	82	8·3	10·1
489- I	2·62	36	68	13·1	19·3
489- II	1·30	47	62	23·3	37·6
486	1·60	50	58	27·4	47·2
499	1.00	45	59	27·4	46·5

*Carried out after treatmeat of the extracting solution with mono-calcium phosphate.

A notable increase of phosphorus adsorbed after fixation can be observed, although more than half has passed to tri-calcium phosphate, apatite, etc.

It must also be borne in mind: (1) that the method used to measure the fixation is not very energetic and therefore the values are not so high as might be obtained by other methods; (2) that soda can extract bi-calcium phosphate from the soil as mentioned above.

Conclusions

From the study carried out the authors concluded that the phosphorus is present in these soils in the optimum conditions for their utilization and that the low availability is due to the presence of high quantities of calcium carbonate. The same cause explains the high fixation degree of the superphosphates. They contain organic phosphorus in variable amounts, although in correlation with the content of organic matter.

In all these soils phosphate is present in the form of apatite or rock phosphate, which are of low availability. Phosphorus soluble in 2N H_2SO_4 is high and that of N/10 NaOH is low, which agrees with the observations made above.

It has been observed that acidifying treatments (organic matter, ammonium sulphate, etc.) as well as the application of potassium

salts in some cases and of sodium salts in others, lead to a better utilization of the phosphorus present in the soil.

Finally, the authors consider that the poor crop yields may be due not only to phosphorus deficiency but even more to nitrogen deficiency, which is much more marked in most cases than that of phosphorus.

LITERATURE

1. BURRIEL, F. y ALEIXANDRE, V.: *Anal. Edaf. y Fis. Veg.* (in Press).
2. BURRIEL, F. y HERNANDO, V.: *Anal. Edaf. y Fis. Veg.*, **7**, 489-527 (1948).
3. BURRIEL, F. y HERNANDO, V.: *Anal. Edaf. y Fis. Veg.*, **9**, 611-622 (1950).
4. LUNT, H. A., SWANSON, C. L. W. and JACOBSON, A. G. M.: Connect. Agric. Exp. Sta., Bull. 541 (1950).
5. BONDORFF, K. A.: Bull. Docum. Digest. No. 6, 16-35 (1949).
6. MATTSON, S., WILLIAMS, E. G. and BARKOFF, E.: *Ann. of the Roy. Agr. Coll. of Sweden*, **17**, 107-120 (1950).
7. STELLY, M. and PIERRE, W. H.: *Soil Sci. Soc. of Am. Proc.* **7**, 137-147 (1942).
8. BURRIEL, F. y HERNANDO, V.: *Anal. Edaf. y Fis. Veg.* (in Press).
9. DEMOLON, A. and BOISCHOT, R.: Bull. Docum. Digest. No. 10 1-5 (1951)
10. BOISCHOT, P., COPPENET, M. and HEBERT, J.: *Am. Agron.* **19**, 103-112 (1949).
11. METGE, M.: Serv. Agron. Off. Niger. 1950. Bull. Docum. Digest No. 10 69-72 (1951).

SESSION 3

POTASH

22nd July. Chairman: T. WALLACE (United Kingdom)

R. F. REITEMEIER. The Availability af Native and Fixed Non-exchangeable Soil Potassium (Volume I, page 53)

S. HENIN. Problème de la Fixation du Potassium considéré du Point du v.ie Minéralogique (Volume I, page 64)

F. ALTEN und W. RATHJE. Zum Mechanismus des Kalium—Stoffwechsels lebender Zellen (Volume I, page 72)

POTASSIUM AND CALCIUM INTERRELATIONSHIPS IN TROPICAL SOILS AND IN TOBACCO LEAVES

H. A. MIDDELBURG

Laboratory of Agricultural Chemistry of the Agricultural College at Wageningen, Netherlands

Introductory remarks

The sum total of catenary conditions covers a fair proportion of the land surface in tropical regions, resulting from differences in soil drainage and aeration.

For a rational agricultural use of the soil it is necessary to know the fundamental differences in reaction (in respect to the vegetation) between the associated members of the soil catenas. This paper deals with the relations of potassium to calcium in tropical soils and in tobacco leaves, regarded as the results of DONNAN distributions in the two colloidal phases of the plant-soil system.

K/Ca ratios in tropical soils

The application of the DONNAN equilibrium to the study of cation exchange in soils has led to some significant consequences.

The DONNAN distribution of K and Ca ions between the micellar and the outside soil solution may be expressed as follows

$$\frac{(K^+)i}{(K^+)o} = \frac{\sqrt{(Ca^{++})i}}{\sqrt{(Ca^{++})o}}$$

The divalent Ca-ions enter as the square root of their activities. This means that the adsorption of monovalent K-ions relative to calcium-ions will be favored by a concentrated outside solution and an inside suspension of low activity.

So, other things being equal, the lower the exchange capacity of the material the higher will be the ratio between exchangeable K and Ca.

Weathering in the tropics results in extensive solvation and eluviation of the silica and formation of ferallitic soils of low exchange capacity. Accordingly, a high K/Ca ratio is expected in the eluviated tropical red earths and a low K/Ca ratio in the lower lying (catenary associated) illuvial siallitic grey and black earths, with high base exchange capacity.

Some analytical data of Java soils confirm the above mentioned expectation of the K/Ca distribution in tropical soils.

Results of the analyses by SPRUIT (8) of soil types from a cinchona estate on Mount Malabar in Java are given in Table 1.

TABLE 1

Soil types of Mount Malabar Java	m.e./100 g. soil exchangeable		K/Ca ratio
	K	Ca	
Higher ground (eluvial)	0·6	2·3	0·26
Lower ground (illuvial)	1·1	11·6	0·09

The findings of my experiments with soils in Central Java (Table 2) show more clearly the great difference in ion distributions between eluvial and illuvial soil types in the tropics (7).

TABLE 2

Soil types of Central Java	m.e./100 g. clay $< 5\mu$			K/Ca + Mg ratio
	exchange capacity	exchangeable K	exchangeable Ca+Mg	
Red earth (eluvial)	53	3	23	0·13
Grey earth (illuvial)	75	1	68	0·01

These Java soils have similar andesitic parent materials.

The relations of the SiO_2/R_2O_3 ratio and of the exchange capacity to the ratio of replaceable K and Ca, in other regions than Java, are demonstrated by the analyses of VAN DER MERWE (5) for South Africa (Table 3) and of ALBRECHT (1) for North America (Table 4).

The tested soils in South Africa are derived from different parent materials, whereas the clay fractions under study by ALBRECHT are developed from similar loessial parent materials, but under different climatic conditions.

TABLE 3

Soil types in South Africa	$\frac{SiO_2}{R_2O_3}$ of the clay fraction	m.e./100 g. soil exchangeable		K/Ca ratio
		K	Ca	
Red earths nr. 1	0·53	0·04	0·09	0·44
(eluvial) nr. 2	0·96	0·26	1·26	0·21
nr. 3	1·07	0·20	3·78	0·05
Black earth (illuvial)	3·27	1·00	58·80	0·02

ALBRECHT (1) suggests with his data in Table 4 that the ratio potassium to calcium might be used as an index of soil development and productivity.

TABLE 4

Top soils from	Annual rainfall in inches	Exchange capacity of clay m.e./ 100 g.	$\frac{SiO_2}{R_2O_3}$	K/Ca ratio
Mississippi	55	44	2·56	0·04
Kentucky	48	50	3·24	0·03
Missouri	40	66	4·03	0·03
Iowa	27	73	5·06	0·01

The highly developed soil in Mississippi is an anionic eluviated soil type with high K/Ca ratio, whereas the properties of the soil formed in a dry climate of Iowa suggest that this siallitic soil may be looked upon as an illuvial soil type with very low K/Ca ratio.

K/Ca ratios in tobacco leaves

In view of the systematic shifting K/Ca ratios with increasing degree of development of tropical soils, the important question arises whether vegetation reflects corresponding differences in composition. The K/Ca ratio in the leaves is especially of interest for the tobacco crop, in respect to the positive correlation between this ratio and the glowing capacity of the cured tobacco produce.

ALBRECHT (1) assembled chemical analyses of different crops, allocated according to dominance on the different soil types and he showed, that increasing replaceable potassium in relation to calcium in the soil, gives correspondingly increasing potassium over calcium in the plant composition.

The results of ALBRECHT further demonstrated that the decrease of potassium relative to calcium in the soil types of dry climates resulted in crops of more proteinaceous nature, containing low concentrations of potassium relative to calcium. ALBRECHT thought that the low K/Ca ratio of the soil caused the proteinaceous nature of the crops, but we believe that a dry climate and a high oxygen tension in the soil have rather more influence on nitrogen absorption and protein synthesis of the vegetation. Dry-season crops have generally a more proteinaceous nature than wet-season crops.

Proteinaceous crops have high contents of acidoids and consequently high exchange capacities of the roots. ELGABALY, WIKLANDER (4) and DRAKE with co-workers (3) demonstrated that the ratio of the uptake of monovalent and divalent ions can also be explained on the basis of the DONNAN theory of membrane equilibria in the plant roots. In other words, a proteinaceous crop may absorp cations in a

lower K/Ca ratio than a carbonaceous one. So the low K/Ca ratio in the vegetation is probably more closely associated with the high protein content of the crop than with the low K/Ca ratio of the clay.

When comparing different crops on varying soil types and under divergent climate conditions, one may easily arrive at wrong conclusions.

To find out how the climate affects the K/Ca ratio of tobacco leaves, we use the data of DARKIS, DIXON, WOLF and GROSS (2), who analyzed the tobacco of the same experimental field several years successively under widely divergent rainfall conditions (Table 5).

TABLE 5

Climate	Year	Composition of tobacco leaves					
		Unlimed plots			Limed plots		
		%N	K/Ca ratio	K/Ca+Mg ratio	%N	K/Ca ratio	K/Ca+Mg ratio
Wet	1929	2·12	0·47	0·43	1·97	0·39	0·30
	1931	2·61	0·62	0·51	2·90	0·49	0·35
Dry	1930	2·26	0·37	0·32	2·38	0·33	0·25
	1932	3·39	0·36	0·31	3·84	0·32	0·23
	1933	2·89	0·36	0·30	3·14	0·31	0·23

The influence of the weather is generally toward a higher nitrogen content in the tobacco grown in dry seasons. Liming accentuates the influence of dry weather. The 1931 crop was classified as a wet-weather crop, except for its high nitrogen content due to a lack of maturity at harvest time.

These results of DARKIS c.s. confirm the hypothesis that a dry climate supports a low K/Ca ratio in the tobacco leaves.

In the tropics, however, the eluvial and the illuvial catenary associated soil types are not intimately related to climate, because they occur side by side under identical climatic conditions.

Therefore, for successful soil management and adequate fertilization, one ought to know how the crop reacts upon the different K/Ca ratios of the eluvial and illuvial soil varieties, under similar climatic circumstances.

The most accurate method of eliminating the influence of the weather and measuring the exact effect of the soil type, is the pot experiment with artificial water supply.

Carrying out pot experiments with tobacco in Central Java the writer had the opportunity of assembling some data that may be useful in elucidating the problem of the potassium and calcium interrelationships.

Using the soils mentioned in Table 2, the tobacco experiments gave the results summarized in Table 6.

TABLE 6

Soil types of Central Java	Exchange capacity m.e./100 g. clay	Composition of Soil K/Ca ratio	Composition of Soil K/Ca+Mg ratio	Composition of Tobacco leaves K/Ca ratio	Composition of Tobacco leaves K/Ca+Mg ratio	Selectivity* coefficient K/Ca+Mg of tobacco
Red earth (eluvial)	53	0·27	0·13	0·57	0·36	3
Grey earth (illuvial)	75	—	0·01	0·72	0·55	55

*The selectivity coefficient $= \frac{\text{K/Ca+Mg ratio in tobacco}}{\text{K/Ca+Mg ratio in soil}}$

The great difference between the selectivity coefficients indicates (as contrasted with the hypothesis of ALBRECHT), that, under similar climatic conditions, potassium, relative to calcium and magnesium, is much easier released from the illuviated grey earth with high exchange capacity, than from the eluvial red earth with low exchange capacity.

With the results obtained, support is given to the DONNAN conception, that, other things being equal, the same plant is expected to take up larger proportions of the monovalent cations and smaller amounts of the divalent cations, the higher the exchange capacity of the clay.

We can confirm this with the results (shown in Table 7) of another pot experiment with tobacco in andesitic red earth and in recent andesitic volcanic ash (6, 7).

TABLE 7

Soil types in Central Java	Exchange capacity m.e./100 g. clay	K/Ca ratio of soil	K/Ca ratio of tobacco leaves	Selectivity coefficient K/Ca of tobacco
Lateritic soil	57	0·27	0·57	2
Recent ash soil	86	0·12	0·47	4

Conformable to the DONNAN conception, indicated by the selectivity coëfficients, the tobacco takes up potassium relative to calcium most easily from the soil with the highest exchange capacity. The tobacco leaves from both soils had similar potassium contents, although the laterite possessed 25 and the ash 12 m.e. exchangeable K per litre of soil.

The conclusion is, that (when no fixation into non-replaceable potassium takes place) a potassium fertilizer is expected to be most effective in soils with a high exchange capacity.

Our experiences in field experiments and in practice were generally in agreement with this conclusion.

Summarized conclusions

1. Highly developed eluvial tropical red earths, having low SiO_2/R_2O_3 ratios and low exchange capacities, contain more replaceable potassium, relative to calcium, than illuvial grey earths with high SiO_2/R_2O_3 ratios and high exchange capacities.

2. Still, under identical climatic conditions, potassium relative to calcium and magnesium is easiest released by the tobacco from the soil type having the highest exchange capacity and the lowest K/Ca ratio.

3. Accordingly, when after fertilization no fixation into non-replaceable form takes place, the responses to potassium of tobacco are most satisfactory in the soil types with high exchange capacities.

4. A dry climate supports a proteinaceous crop with a high acidoid content and a high exchange capacity of the roots. As a result a dry-season crop may absorb cations in a lower K/Ca ratio than less proteinaceous wet-season crops.

5. Therefore, determinations of exchangeable K and Ca in tropical soils have little value for an adequate diagnosis of the potassium requirement, unless the results of the examination are interpreted in their proper relationships to degree of weathering and exchange capacity of the soil type and to climatic conditions and nature of the vegetation.

REFERENCES

1. ALBRECHT, W. A.: *Soil Science*, **55**, 13–23 (1943).
2. DARKIS, F. R., DIXON, L. F., WOLF, F. A. and GROSS, P. M.: *Ind. Eng. Chem.*, **29**, 1030–1039 (1937).
3. DRAKE, M., VENGRIS, J. and COLBY, W. G.: *Soil Science*, **72**, 139–149 (1951).
4. ELGABALY, M. M. and WIKLANDER, L.: *Soil Science*, **67**, 419–424 (1949).
5. MERWE, C. R. VAN DER: Red and Yellow earths; Subtropical black clays. Fourth International Congress of Soil Science Trans. **2** (Amsterdam, 1950).
6. MIDDELBURG, H. A.: Thesis Wageningen and Med. Proefstation voor Vorstenlandsche Tabak No. 75 (1932).
7. MIDDELBURG, H. A.: Lime requirements of lateritic soils. *De Bergcultures*, **21**, 126–130 (1952).
8. SPRUIT, C.: Verslag 12*e* Vergadering van de Vereeniging van Proefstations Personeel in Ned. Indië (1951).

SESSIONAL DISCUSSION

E. VON BOGUSLAWSKI: Zu den interessanten Ergebnissen von Herrn REITEMEIER teile ich mit, dass wir in den Jahren 1934/35 Gefässversuche mit Hafer auf sehr verschiedenen Böden durchführten (*Landw. Jahrb.* **83** (1936), 711–773). Die Versuche erstreckten sich über zwei Vegetationen, so dass nach der Aberntung am Ende der 1. Vegetation im darauffolgenden Jahr eine neue Aussaat erfolgte.

Die Ergebnisse waren folgende: Während auf manchen Böden schon in der ersten Vegetation "nicht austauschbares" Kali aufgenommen wurde, erfolgte dies auf anderen Böden auch in der zweiten

Vegetation nicht. Eine Korrelation zum Feinerdegehalt konnte nicht festgestellt werden. Dagegen war der Einfluss anderer Wachstumsfaktoren wie der Kationen Kalzium und Natrium nachzuweisen. Bei allen Böden, bei welchen die aufnehmbare Kalimenge im ersten Jahr weitgehend erschöpft wurde, erstellte sich die Kaliaufnahme der zweiten Vegetation weitgehend aus dem im Böden verbliebenen Wurzelkali.

Die Bestimmung des austauschbaren Kalis kann infolgedessen nur einen ungefähren Anhaltspunkt über die Kaliaufnahme durch den Pflanzenbestand geben, da die Aufnahme des Bodenkalis von allen anderen Wachstumsfaktoren und auch von dem Vorkommen anderer Kaliformen im Boden abhängt.

Die Bestimmung des austauschbaren Kalis erfolgte in wiederholten Ausschüttelungen in NH_4Cl. Es erfolgte eine Extrapolation der Austauschkurve bis zum Endwert, wobei die Austauschkurve eine logarithmische Kurve repräsentierte.

P. SCHACHTSCHABEL: Die Bedeutung des nichtaustauschbaren Kaliums darf nicht nur in der Einsparung von Dünger-Kali gesehen werden sondern auch im Einfluss auf die Bodenfruchtbarkeit. An Hand eines 25-jährigen Dauerdüngungsversuches an einem Lösslehm konnten wir beim Vergleich der NP- mit der NPK-Parzelle auf röntgenographischem Wege feststellen, dass bei der NP-Parzelle eine Verringerung des Illits zu Gunsten des Montmorillonits stattgefunden hatte. Diese Umbildung ist bei schweren Böden (z.B. Tonböden) mit einer Verringerung der Bodenfruchtbarkeit verbunden, da ein hoher Gehalt an Montmorillonitmineralen mit ihrem hohen Quellungsvermögen eine Verschlechterung des Lufthaushaltes zur Folge hat. Bei leichten Böden mag dagegen diese Umbildung erwünscht sein. Wir sollten daher bestrebt sein, den Gehalt der Böden an austauschbarem Kali nicht unter 20–30 mg K_2O je 100 g Boden absinken zu lassen. In Deutschland wird dieser Forderung indirekt dadurch Rechnung getragen, dass bei der Kalibestimmung nach der Methode EGNÉR-RIEHM als Grenzwert für mit Kali gut versorgte Böden 20 mg festgelegt sind. Wir vermeiden auf diese Weise nicht nur der Gefahr der K-Festlegung in klimatisch ungünstigen Jahren, sondern erreichen auf diese Weise gleichzeitig die Erhaltung der glimmerartigen Minerale.

R. K. SCHOFIELD: In one of the slides shown by Dr. REITEMEIER it was seen that different values for exchangeable potash were obtained according to the cation of the extracting acetate solution. Minimal disturbance of the exchangeable cations already present results from the use of 0·20 N or 0·01 N $CaCl_2$ solution. If two experiments are made using different soil/solution ratios and the potash released from the soil (m.e./100 g.) is plotted against the concentration of K found in the solution (m.e./1) extrapolation of the straight line joining these points gives the K concentration that must be present in $CaCl_2$ solution in order that no change in K concentration shall be produced by contact with the soil. The equilibrium concentration can then be determined more accurately by making a direct test. It is a well defined characteristic of the soil sample that a given concentration of dilute $CaCl_2$ may prove to be more useful than the amount of

exchangeable potash. It would be interesting to find out how it falls off with removal of K by cropping and increases by the application of K.

M. M. ELGABALY: There are three points in connection with the papers which have been presented which I would like to make:—

(*a*) What is meant by exchangeable K and is it defined in terms of exchangeability of the NH_4^+ ion?

(*b*) In view of the fact that NH_4^+ may be fixed is it desirable to use this cation in determining exchangeability?

(*c*) The uptake of exchangeable K is governed by the type of clay mineral and plant species and thus the term becomes of little value when we are considering absorption by plants in different soils.

A. JACOB: In my investigations of clay minerals with the aid of the electronic microscope I found in many soils minerals which could not be distinctly classified either as illite or as montmorillonite. This led me to the hypothesis that there must be transformations from one class of minerals to the other.

H. GREENE: Will Dr. MIDDELBURG give the amounts of exchangeable calcium and magnesium in the red and grey earths for which he gave $\frac{K}{Ca+Mg}$ ratios?

H. A. MIDDELBURG: The exchange capacity of the red earth is expressed in terms of m.e. per 100 gm. of clay $< 5\mu$. This may be the explanation of the rather high exchange capacity. The content of exchangeable ions was as follows:—

H 10, Ca 18, Mg 5, K 3, Na 17, Total 53 m.e.

P. BRUIN: DR. SCHACHTSCHABEL indicated that in Germany dressings of potash were advised in order to prevent a decrease in soil fertility, caused by mineralogical changes relating to potash conditions. At the same time he remarked that K deficiency was not to be found in river clay soils in Germany. Referring to the research of FERRARI on the river ridge soils in the Netherlands, the question arises if it is quite certain that K deficiencies do not occur in Germany, how large are the potato yields and how are large differences in yield to be found in one agricultural district? It has to be kept in mind that the river soils of Germany and the Netherlands have many similarities.

F. A. VAN BAREN: Dr. SCHACHTSCHABEL has indicated that after 25 years of cultivation mica-like clay minerals have been transformed to montmorillonite. As Dr. HÉNIN has shown us the change taking place after the application of potash I should like to know whether the occurrence of montmorillonite has been ascertained by X-Ray analysis and/or the determination of exchange capacity.

Referring to the paper by Dr. REITEMEIER I would like to know whether the differences in the release of exchangeable K correlate with exchange capacity and type of clay minerals of the six soils as discussed.

Je voudrais bien demander à M. HÉNIN s'il a trouvé des minéraux d'argile ayant une structure différente de celle de vermiculite. VAN DER MAREL de Groningen (Netherlands) m'a raconté qu'il a trouvé un minéral que fixe fortement le potassium ayant une structure cristalline pas conforme à la vermiculite ou quelque autre minéral d'argile connu. Ce fait était constaté par l'analyse rontgenographique. Je dois ajouter que VAN DER MAREL a constaté le même effet de la fixation sur la réflection basale $d_{(001)}$ diminuant de 14A° à 10A°.

S. HÉNIN : *Il est très possible que l'on trouve dans les sols des minéraux qui diffèrent de ceux que nous connaissons par des caractères secondaires. Ainsi, bien qu'il ne s'agisse pas d'un nouveau minéral, la saponite a un compartiment un peu différent de la montmorillonite. On pourrait à certains égards classer ce minéral entre la montmorillonite et la vermiculite.*

Considérant maintenant la question posée par le Professeur VAN BAREN au Professeur SCHACHTSCHABEL, je crois utile de préciser un résultat dont j'ai fait état dans ma communication. Les minéraux " fermés " par fixation de potassium et même certains micas peuvent être " ouverts " par fixation d'ions divalents. Ces phénomènes sont donc reversibles mais comme ils demandent plusieurs mois pour se produire les ions bloqués entre les feuillets paraissent non échangeable quand on emploie les techniques d'extraction ordinaire qui comportent des traitements de quelques heures.

R. F. REITEMEIER (In reply to Dr. VAN BAREN) : The exchange capacities of the soils and the mineral composition of the < 2 micron clay fractions and of the 2–50 micron silt fractions have been determined and published (U.S. Department of Agriculture, Tech. Bull. 1049, October, 1951). The exchange capacities range from 10 m.e. per 100 g. for Wooster silt loam to 25 for Sible silty clay loam with the other soils intermediate. All the clay fractions except that of Decatur clay loam, a predominantly Kaolinitic soil, have estimated contents of hydrous mica ranging from 60% to 90%.

I am interested in DR. SCHOFIELD's ideas concerning the value of dilute salt solutions in the equilibration of soil potassium and am cognisant of his interest in the use of such solutions in studying nutrients such as K_2O, P_2O_5, etc. His statement concerning similarity of behaviour of Ca, and Ca-Mg solutions remind me of some results with 0·5 normal solutions which I had not discussed in my paper. With 6 p.p.m. of K as impurity added to 0·5 normal acetate solutions not only does the Ca solution release K to Mardin silt loam but the Mg acetate solution even more so, while Na and H acetate solutions release K to the soil but less than the Ca solution. Contrariwise 6 p.p.m. of K does not reduce the ability of NH_4Ac to remove K from this same soil.

(In reply to Dr. MIDDELBURG) I wish to say that the availability of exchangeable potassium as defined in my written paper was not under discussion in my paper and it should not be assumed that I consider exchangeable potassium completely available. Actually I hold a contrary opinion, i.e., all the exchangeable potassium is not available. It will be remembered that two of the charts shown

during the paper indicated that during extensive cropping a soil tends to reach a characteristic minimum exchangeable potassium level which is not further reduced during the subsequent growth of the plants in that particular soil/plant system.

(In reply to Dr. HÉNIN.) The total chemical composition, including such values as the contents of K_2O, Na_2O, CaO, MgO, SiO_2, Al_2O_3, Fe_2O_3 etc., of the whole soil, the <2 micron clay fraction and the 2-50 micron silt fraction have been determined and are reported in U.S. Dept. Agr., Tech. Bull. 1049 (Oct., 1951). More recent and as yet unpublished, data include the chemical composition of the $<0{\cdot}2$ micron fraction.

ESSAIS EN POTS ET DE PLEIN CHAMP SUR L'UTILISATION DES RESERVES POTASSIQUES DU SOL

J. GARAUDEAUX, P. QUIDET ET H. MALICORNET

Société Commerciale des Potasses d'Alsace, Mulhouse, France

Introduction

Il est d'observation courante que, dans un certain nombre de cas et pour de nombreux sols, les quantités de potasse assimilée par les plantes sont supérieures à celles que des tests chimiques avaient fait considérer comme disponibles.

On sait, en particulier, que l'étude des sols de limon permet de distinguer, en plus de la potasse échangeable, une forme de potasse apparemment fixée mais pourtant accessible aux plantes dans certaines conditions. Inversement, une partie de la potasse ajoutée à un tel sol peut être provisoirement dissimulée aux réactifs d'échange.

Depuis quelques années, divers auteurs ont cherché à mettre en évidence cette forme particulière de la potasse des sols, soit par des méthodes physico-chimiques (broyage, alternance de dessiccations et d'humectations, combinées ou non à des variations de température), soit par des méthodes biologiques (cultures successives en vases de végétation).

Il est apparu, dans le cadre général des études techniques poursuivies par la Société Commerciale des Potasses d'Alsace, comme désormais indispensable de *rechercher l'incidence de ces phénomènes sur l'alimentation des récoltes en potasse.*

Dans ce but, il semblait opportun d'expérimenter sur des sols ayant reçu, depuis plusieurs années, des fumures ne différant que par les quantités d'engrais potassiques et qu'on pouvait penser, de ce fait, être distincts non seulement par leur taux de potasse échangeable, mais encore par l'évolution de leurs réserves potassiques.

De tels sols purent être trouvés sur les " champs de démonstration " de la S.C.P.A. Ces derniers comportent, en effet, trois bandes contiguës divisées en soles correspondant à un assolement normal pour la région. Chaque sole, qui comprend ainsi 3 parcelles, reçoit une fumure NP uniforme, tandis que l'apport de potasse est nul sur la première parcelle (bande K_0), correspond à une fumure potassique moyenne de la région sur la seconde (bande K_1), reçoit une fumure potassique renforcée pouvant aller parfois jusqu'au double de la dose précédente sur la troisième (bande K_2).

Le contrôle local des facteurs : température, humidité, cycle végétatif, étant impossible, la présente étude ne pouvait être poursuivie qu'en vases de végétation. Elle a été entreprise à la Station Agronomique de la S.C.P.A. à Aspach-le-Bas et la présente communication est un compte-rendu sommaire et partiel des premiers résultats obtenus.

Caractéristiques des sols étudiés

Le tableau ci-après indique quelques caractéristiques des sols lors de la mise en place des champs de démonstration de Lieusaint (Seine-&-Marne) et St. Jean de Cardonnay (Seine-Inférieure) pour lesquels les résultats culturaux sont particulièrement détaillés :

		Argile %	Sable fin %	pH	N total o/oo	P_2O_5 assimilable o/oo (1)	K_2O assimilable o/oo (1)
Lieusaint (S. & M.) (1931)	sol.....	16,4	56,0	7,6	1,68	0,14	0,15
	sous-sol	28,1	46,1	7,4	0,90	0,02	0,07
St. Jean du Cardonnay (S. Inf.) (1946)	sol.....	10,2	65,1	7,0	1,05	0,18	0,11
	sous-sol	11,5	65,4	7,3	0,75	0,12	0,07

(1) méthode SCHLOESING DE SIGMOND.

A *Lieusaint*, l'effet des engrais potassiques a été assez rapide et soutenu, spécialement sur pomme de terre.

Dans les parcelles K_0, on observe de grosses variabilités des rendements d'une année à l'autre. Mais on constate que lorsque les facteurs climatiques sont particulièrement favorables, les rendements peuvent être encore normaux, quoique généralement bien inférieurs à ceux correspondant aux fumures complètes ; les quantités de potasse prélevées par les récoltes apparaissent alors comme très importantes vis-à-vis du niveau initial du K_2O assimilable. C'est ainsi qu'une luzerne a exporté 176 kg./ha. de K_2O sur une parcelle K_0, en 1951, soit après qu'on ait cherché depuis 20 ans à épuiser les réserves potassiques de ce sol.

Avec la fumure potassique normale (K_1), la variabilité des rendements a été moins grande et ceux-ci ont presque toujours été nettement supérieurs à ceux des parcelles K_0 correspondantes.

La fumure renforcée (K_2) n'a pas toujours amené un supplément de récolte par rapport à la fumure normale, notamment sur céréales certaines années. Elle a même pu occasionner des dépressions s'expliquant parfois par des effets secondaires. C'est ainsi, qu'en 1951, un blé Yga, fait sur défriche de luzerne, a souffert de la verse particulièrement dans la parcelle K_2.

A St. Jean du Cardonnay, où le sol était, à l'origine, moins riche en K_2O " assimilable," l'action des fumures potassiques fut pourtant moins rapide. Cependant, cette action est maintenant régulière et peut être parfois très spectaculaire.

Methode expérimentale

Pour pouvoir séparer l'utilisation, par une plante, d'une fumure potassique récente et celle des reliquats des fumures potassiques anciennes, il a été choisi de constituer le dispositif factoriel suivant :

types de fumures précédentes { K_0.. / K_1.. / K_2.. } × fumure nouvelle { k_0.. / k_1.. / k_2.. }

soit 9 combinaisons qui ont été répétées chacune 4 fois, avec randomisation simple. Les traitements " types de fumures anciennes " sont représentés chacun par une terre prélevée en 1951 sur une parcelle d'une sole particulière de chaque champ de démonstration.

La plante choisie fut l'avoine, particulièrement apte à utiliser les formes de potasse peu accessibles. D'autre part, la fumure nouvelle k_2 correspondit à la dose double de k_1.

Pots : grès drainés, diamètre 0,25, hauteur 0,25, renfermant 9 kg. de terre additionnée de 5 kg. de sable quartzeux.

Dose des éléments fertilisants :

N : 1.200 mg. sous forme de NO_3NH_4 apportés en 3 fois.

P_2O_5 : 1.800 mg. sous forme de bicalcique.

K_2O { k_0 : 0 mg. ; k_1 : 900 mg. sous forme de KCl. ; k_2 : 1800 mg. sous forme de KCl.

Arrosage : journalier à saturation.

Récolte : fin floraison.

Résultats obtenus

Les dosages et études de laboratoire permettant l'exploitation d'ensemble des résultats obtenus dans ces cultures en pots n'étant pas encore complètement terminés, il n'est présenté ci-après que les rendements relatifs à la matière sèche des parties aériennes des récoltes.

TERRE DE LIEUSAINT

Rendements moyens de M.S. par traitements exprimés en gr. par pot

		Type de fumures précédentes			Moyenne
		K_0	K_1	K_2	
fumures nouvelles	k_0	125,851	123,570	111,690	120,404
	k_1	134,137	127,971	121,967	128,025
	k_2	129,947	126,194	123,366	126,502
Moyenne		129,978	125,945	119,008	124,977

L'étude statistique montre que l'ensemble des effets des traitements est significatif au seuil 5%. L'effet principal " fumures nouvelles " ainsi que l'effet principal " type de fumures précédentes," le sont également, au même degré de signification ; par contre, l'ensemble de l'interaction de ces deux facteurs ne l'est pas. La plus petite, différence significative entre moyennes de deux quelconques des traitements est 10,469 et celle entre moyennes relatives aux effets principaux est 6,043.

TERRE DE ST. JEAN DU CARDONNAY

Rendements moyens de M.S. par traitements exprimés en gr. par pot

		Type de fumures précédentes			Moyenne
		K_0	K_1	K_2	
fumures nouvelles	k_0	96,035	109,904	122,273	109,404
	k_1	115,191	120,818	135,320	123,776
	k_2	132,338	122,377	135,839	130,183
Moyenne		114,521	118,870	131,144	121,122

L'étude statistique montre que l'ensemble des effets des traitements est significatif au seuil 1%, ainsi que les effets principaux " fumures nouvelles " et " types de fumures précédentes." L'ensemble de l'interaction de ces deux facteurs n'est pas significatif au seuil 5%.

La plus petite différence significative (5%) entre deux moyennes de deux quelconques des neuf traitements est de 15,340 et celle entre moyennes relatives aux effets principaux est 8,703.

Discussion

Résultats de Lieusaint

On peut voir que l'effet principal de la " fumure nouvelle " est bénéficiaire pour les deux doses k_1 et k_2, sans que la fumure k_2 se différencie de k_1. D'autre part, l'effet principal du " type de fumures précédentes " indique une tendance à la dépression pour K_1 vis-à-vis de K_0, qui devient significative pour K_2 vis-à-vis de K_0.

L'interaction des deux facteurs n'étant pas significative et les effets principaux des deux facteurs étant, de ce fait, additifs, il semble que l'on puisse en déduire que l'action dépressive du " type de fumures précédentes " ne soit pas due à la potasse de ces fumures. En effet, la potasse de la " fumure nouvelle " a une action bénéficiaire, même dans les terres soumises précédemment à la fumure K_2. Or, il semble que si la dépression générale observée dans ce sol K_2 était due à un excès de l'alimentation potassique, elle aurait dû être aggravée par l'addition de nouvelles quantités de potasse.

Sans présumer des conclusions à tirer de l'ensemble des résultats après l'établissement des bilans, on peut donc déjà estimer que, dans ce cas particulier, l'état des réserves en potasse du sol n'a pas été le seul facteur influençant les récoltes. On est, par conséquent, amené à supposer qu'une étude ne portant que sur les doses ou les formes de la potasse de ce sol n'est pas suffisante pour préjuger l'efficacité de ses réserves potassiques.

Résultats de St. Jean du Cardonnay

On peut voir ici que l'effet principal de la fumure nouvelle k_1 est bénéficiaire vis-à-vis de k_0 et qu'il en est de même de k_2. L'effet principal

du " type de fumures anciennes " K_1 indique une tendance bénéficiaire vis-à-vis de K_0, qui devient significative pour K_2 vis-à-vis de K_0.

Ces deux effets peuvent encore ici être considérés comme additifs (ensemble de l'interaction non significative), mais ils jouent ici dans le même sens.

Dans ce cas, il semble donc que ce simple essai permette une conclusion relative à l'effet général de la potasse sans qu'il soit actuellement nécessaire de considérer d'autres facteurs.

Conclusions

L'essai factoriel précédent a permis de séparer les effets d'une " fumure potassique nouvelle " des effets principaux de " types de fumures anciennes " ne différant que par les doses de potasse :

Tant qu'aucun facteur étranger à l'évolution de cet élément fertilisant n'intervient—cas de la terre de St. Jean du Cardonnay les deux facteurs cumulent leurs actions et la potasse anciennement apportée a une action résiduelle jouant comme un nouvel apport. Dans un tel cas, l'alimentation potassique des récoltes peut, par conséquent, être reliée aux disponibilités en potasse accessible aux plantes, donc à l'état d'évolution de cet élément, c'est-à-dire en dernière analyse, à la proportion actuelle des diverses formes de potasse. On peut donc supposer qu'ici l'étude isolée de ces possibilités d'évolution conduirait à des conclusions transposables dans la pratique.

Dans le cas où certains facteurs étrangers interfèrent—cas de la terre de Lieusaint—les actions propres de la potasse, tant sous forme de fumure nouvelle que sous forme résiduelle, peuvent être complètement masquées. C'est ainsi que les rendement des traitements K_0k_0, K_1k_1, K_2k_2 examinés seuls feraient croire à une inaction de la fumure potassique, alors qu'elle a, en fait, un effet positif. Ces trois traitements correspondent à ceux qui sont réalisés annuellement sur le champ de démonstration. On observe bien, parfois, une pareille inaction qu'on peut, à la suite du présent essai, considérer comme plus apparente que réelle. Tout se passe alors comme si, sous l'action de causes non contrôlées, la plante était à peu près indifférente à la forme de potasse se trouvant dans le sol. On peut, dans ce cas, douter que la seule étude, même très détaillée, des possibilités d'évolution de la potasse du sol puisse faire prévoir le comportement des cultures.

Ces deux exemples montrent donc, sur deux sols de même type physique et de constitution minéralogique voisine, qu'avant d'essayer de relier l'alimentation en K_2O des récoltes à l'état d'évolution des réserves du sol en cet élément, il parait opportun de s'assurer par un essai préalable qu'on peut effectivement isoler ce facteur dans la variation des rendements.

Summary

On two loam soils which differed little initially, a factorial pot experiment was carried out in order to try and separate the effects of annual potash applications from the residual effects of previous potassic manuring.

Each type of loam soil included three samples coming from neighbouring plots which had received for several years manures differing

only in the quantities of potash used. Then each of these samples received the same manuring, with three doses of potash.

On one of these loams, there was a favorable and cumulative action of the residual and annual effects of the potassic manures.

On the other one, the effects of previous and annual manures, although still additive (no interaction) acted in two different ways, demonstrating the intervention of factors foreign to potash.

Following the different behaviour of the two soils, the authors think that before trying to link the potassic nutrition of plants to the state of evolution of soil potash, one has to make sure of having numbered and controlled the main factors likely to interfere with this nutrition.

This pot experiment may explain some abnormal trends observed on the field.

ACTION DES ENGRAIS POTASSIQUES SUR LA POMME DE TERRE ET NATURE MINÉRALOGIQUE DES ARGILES

P. J. J. FRANC DE FERRIÈRE

Société Commerciale des Potasses d'Alsace, Mulhouse, France

Le graphique ci-joint figure les rendements moyens de quatre années en pomme de terre obtenus durant des périodes assez longues dans trois champs d'essais d'engrais potassiques recevant régulièrement des fumures minérales azotées et phosphatées et comportant des parcelles K_0 ne recevant jamais d'engrais potassiques, des parcelles K_1 à dose moyenne d'engrais potassiques et des parcelles K_2 à dose forte d'engrais potassiques.

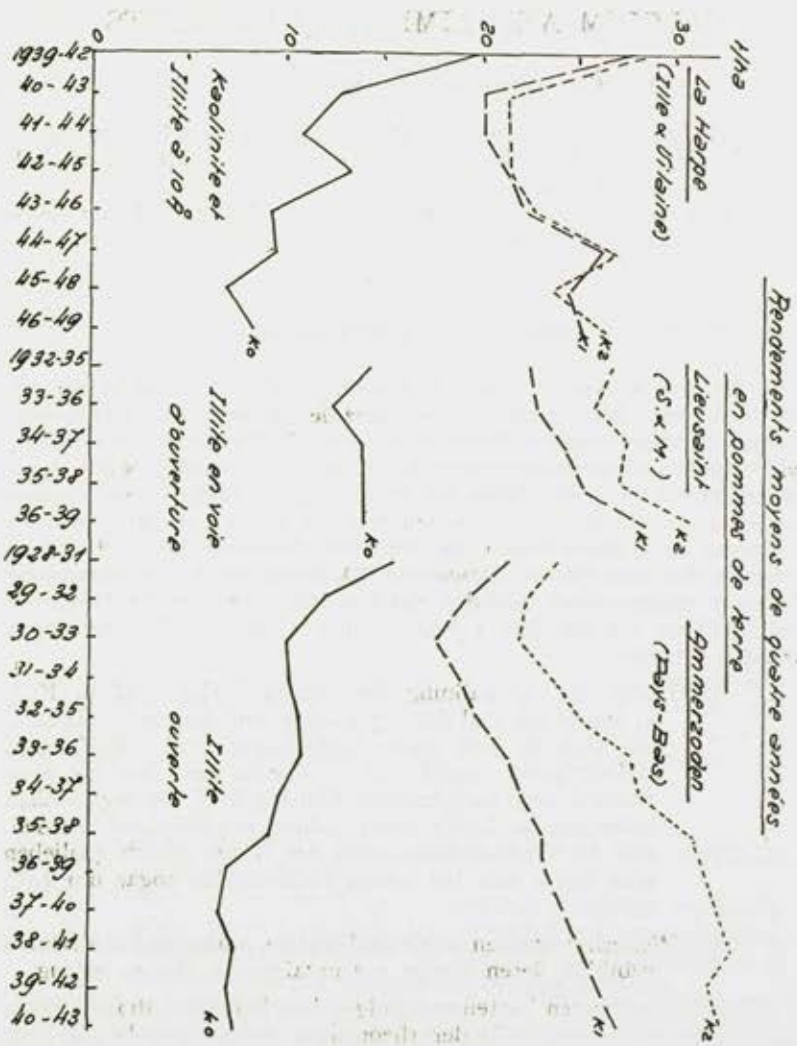
(1) Le sol du champ de la Harpe, près de Rennes (Ille-et-Vilaine) est formé de limon fin contenant 14% d'argile constituée, d'après M. HÉNIN, de *Kaolinite et d'Illite à* 10 Å. On y a observé d'abord une baisse rapide et uniforme des rendements attribuable à la cessation de l'apport de fumier de ferme ; puis dans les parcelles K_0 une baisse régulière des rendements jusqu'à un minimum voisin de 7 t/ha et dans les parcelles K_1 K_2, une augmentation des rendements en tubercule jusqu'à une stabilisation vers 26 t/ha atteinte dès la 6ème année, les rendements en K_1 et K_2 étant très voisins.

(2) Le sol du *champ de Lieusaint* (S. & Marne) est formé de limon fin contenant 16% d'argile constituée, d'après M. HÉNIN, *d'Illite en voie d'ouverture*. On y a observé dans les parcelles K_0, une uniformité remarquable des rendements en tubercules au voisinage de 14 t/ha due sans doute à une libération lente des ions K de l'argile du sol, et dans les parcelles K_1 et K_2 une augmentation assez régulière des rendements, nettement plus élevés en K_2 qu'en K_1 due sans doute à une fixation progressive des ions K apportés par l'engrais potassique.

(3) Le sol du *champ d'Ammerzoden* (Pays-Bas) est formé de limon fin contenant de 24 à 28% d'argile constituée, d'après M. VAN DER MAREL, *d'Illite ouverte*, fixant très fortement les cations K. Après une baisse brusque et générale des rendements, due à la cessation des fumures au fumier de ferme, les rendements ont continué à baisser régulièrement en K_0 pour se stabiliser vers 7 t/ha. En K_1, on a observé une augmentation régulière et continue des rendements, en rapport semble-t-il, avec une saturation progressive en ions K de l'Illite ouverte. En K_2, rendements en tubercules nettement plus élevés qu'en K_1, avec stabilisation des rendements vers 32 t/ha à partir de la 9ème année, le pouvoir de fixation des ions K par l'Illite ouverte paraissant cesser à partir de ce moment de concurrencer l'assimilation du K par les pommes de terre en voie de croissance.

Summary

At " la Harpe " with an " unexpanded " clay (Kaolinite and Illite of 10 Å) the regular absence of potash fertilizers produces a rapid decrease in the potato yields, thus bringing about a very low production : about 7 tons per hectare. On the other hand, potassic manures react unrestrainedly : the efficiency of moderate potash applications nearly equals the heavier ones, promoting a rapid increase of the potato yields, which may attain 26 tons per hectare.



At "Lieusaint," with an illitic clay partially "expanded," the absence of potash fertilizers does not induce a gradual decline in the yielding, but the regular supply of potash fertilizers enhances a regular increase in the crop yields these being distinctly higher with the heavier dressings.

At "Ammerzoden," with an "expanded" illitic clay bearing a strong fixing power towards the K cations, the absence of potash fertilizers produces a decrease in the potato yields, nearly as rapid as at "la Harpe" and just as much pronounced. A regular supply of moderate potash dressings increases regularly the potato yields but with liberal dressings the yields are distinctly higher and the production may attain a level of 32 tons per hectare by the ninth year.

SESSION 4

CALCIUM AND LIME REQUIREMENTS

23rd July. Chairman: P. BRUIN (Netherlands)

S. TOVBORG JENSEN. The Liming Problem (Volume I, page 93)
E. J. HEWITT. A Biological Approach to the Problems of Soil Acidity (Volume I, page 107)
W. A. ALBRECHT and G. E. SMITH. Soil Acidity as Calcium (Fertility) Deficiency (Volume I, page 119)

SESSIONAL DISCUSSION

P. SCHACHTSCHABEL: Die Kalkung wirkt sich in hohem Masse auf die Umbildung der organischen Substanz des Bodens aus. Aus diesem Grunde wird bei manchen Böden nicht der pH-Wert im Felde erreicht, wie er sich aus der Bestimmung des Kalkbedarfs nach JENSEN theoretisch errechnet. Wir haben bei verschiedenen Böden diese Zusammenhänge untersucht. Dabei wurden die Böden in geschlossenen Gefässen im Laboratorium im feuchten Zustande bei 20° stehen gelassen, das vom Boden abgegebene CO_2 bestimmt und in organische Substanz umgerechnet. Bei den gleichen Böden wurden Feldversuche durchgeführt, die zur Zeit 3 Jahre laufen. Folgende Feststellungen wurden getroffen:

(1) Durch die Au kalkung der sauren Böden (pH in KCl-5) wurde ein Teil der organischen Substanz mineralisiert, ein anderer Teil unter Neubildung von COOH- und OH-Gruppen umgeformt. Obwohl bei den bis zum Neutralpunkt aufgekalkten Böden 5–10% der organischen Substanz im Laufe eines Jahres mineralisiert wurden, war die Umtauschkapazität der Böden gleich geblieben oder hatte sich bei einem Podsolboden sogar um 10% erhöht.

(2) Weiterhin wurden niedermolekulare, wasserlösliche Säuren gebildet, deren Menge 1–2 mval/100 g. Boden betrug.

Diese Umsetzungen hatten zur Folge, dass bei den Laboratoriumsversuchen in keinem Falle der theoretisch zu erwartende pH-Wert erreicht wurde. Die Diskrepanz war besonders bei den Podsolböden sehr hoch. So wurde z.B. bei einem Boden mit einem Ausgangs-pH von 5 und nach Aufkalkung auf pH 6,5 nur ein pH von 5,4 erreicht (nach einem Jahre).

Bei den Feldversuchen wurde zwar der angestrebte pH-Wert zunächst annähernd erreicht, lag jedoch schon nach einem Jahre bedeutend tiefer. Hier sind allerding die Ergebnisse infolge der Auswaschungsverluste getrübt. Die Höhe der organischen Substanz hatte sich selbst bei hoher Aufkalkung nicht nachweisbar geändert, begründet in der laufenden Zufuhr von organischer Substanz durch Vegetationsrückstände. Dies bedeutet, dass die Höhe der organischen Substanz im Freilande weniger von der Höhe des pH-Wertes des Bödens sondern weit mehr von den klimatischen Verhältnissen und der Fruchtfolge abhängig ist.

Weiterhin folgt aus diesen und anderen Versuchen, dass der pH-Wert der Böden in gewissem Ausmasse von der Durchlüftung der Böden abhängig ist. Da diese infolge des dauernden Wechsels zwischen mehr aeroben und mehr anaeroben Verhältnissen auf dem Felde laufenden Schwankungen unterworfen ist, kann nicht erwartet werden, dass der pH-Wert des Bodens zu allen Zeiten des Jahres den gleichen Wert hat.

F. STEENBJERG: In Denmark we have for the past few years observed some cases of magnesium deficiency especially in garden soils. In connection with this a general discussion of climatic conditions in Denmark seems to be merited. The rainfall varies between 20" and 30" a year and the temperature during summer time may be compared to that of England. In the western part of the country where sandy soils comprise about 75% of the area the heaviest rainfall occurs while it is smallest in the Eastern part of the country, where loamy soils dominate. For the past 50 years potassium fertilizers with a rather low content of magnesium have been used. My question is this:

Has Dr. HEWITT experience with respect to soil and climatic conditions in England which predispose towards magnesium deficiency and if so what position might be expected to obtain in different parts of Denmark?

E. J. HEWITT: Magnesium appears to be readily leached from many soils and requirements are greatly increased by high levels of potassium manuring or lack of nitrogen. The following circumstances would be expected to lead to an increased incidence of magnesium deficiency.

(1) Sandy soils easily leached.
(2) High rainfall areas hastening the leaching process.
(3) Soil acidity where base status is low frequently results in magnesium deficiency.
(4) Heavy or continued use of potassic fertilizers especially when these fertilizers are subjected to manufacturing processes that remove the magnesium impurities or if derived from non-magnesium bearing minerals.
(5) Low nitrogen status of the soil.
(6) Use of crops that are specially sensitive to magnesium deficiency or that have high potassic requirements, e.g., apple, raspberry, potato, tomato.

These factors are probably all additive and the severity of magnesium deficiency will be an overall result of their respective effects.

W. R. DOMINGO: I wish to draw attention to the fact that it is not safe to base the calibration for lime requirement on the pH of a soil-water suspension as it is a well known fact that this pH shows seasonal fluctuations which can give pH tests up to about 0·5 pH unity or even more.

The pH of a soil-1 N KCl suspension is steady throughout the season and should for this reason be used for the purpose mentioned above. The determination of this pH is to a certain degree quite reliable using the quinhydrone electrode. With a glass electrode

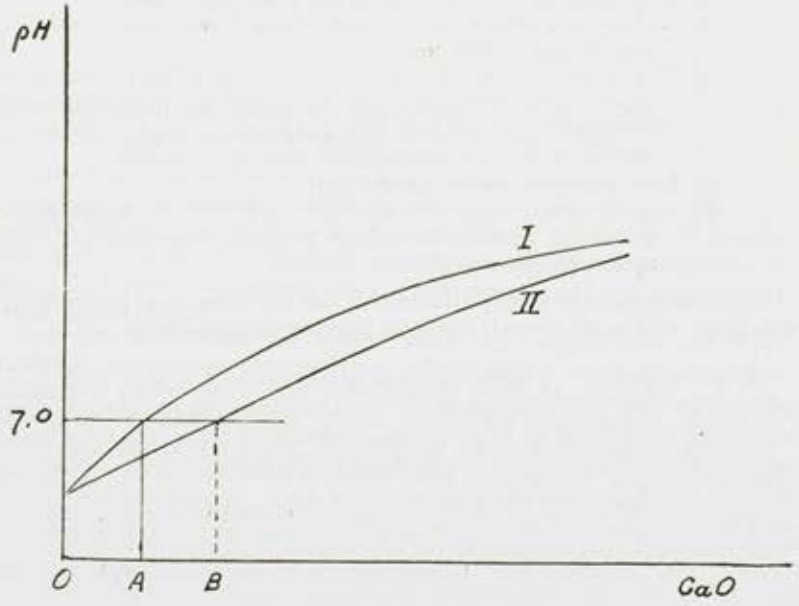
greater care is necessary because different glass electrodes have different sensitivities and differ in their behaviour in 1-N KCl solutions. Experiments in our laboratory with glass electrodes of different origin showed that in soils containing calcium carbonate they differ in the time needed for reaching the equilibrium on which the pH reading could be made from about 5 seconds to 6 minutes using a 1-N KCl. From a chemical and physico-chemical point of view it should be better to use a $CaCl_2$ solution instead of a KCl solution. Experiments have shown that glass electrodes mentioned above used in a soil 0·2N $CaCl_2$ suspension all behave alike, all reaching the same equilibrium in about 5 seconds. On this basis it is suggested that all soil 0·2N $CaCl_2$ suspensions should be used when pH is measured with a glass electrode for determining lime requirements.

F. A. AAN BAREN: I would like to ask Dr. HEWITT at what pH may we expect aluminium toxicity to become evident and secondly is it known under natural field conditions in which forms this toxic aluminium occurs and in which way the toxic effect is counterbalanced by applying calcium carbonate.

I would like to know from Dr. SMITH if he has any information on which way the minerals supplying plant nutrients are determined. Have quantitative investigations with the aid of the petrographic microscope been carried out and if so has a correlation between natural fertility and mineral content been ascertained ?

R. CHAMINADE: Le "facteur de chaulage" auquel fait allusion le Professeur JENSEN (Volume I, p. 101) peut s'expliquer de la façon suivante.

Lorsqu'on etablit une courbe de saturation d'un sol



acide par l'eau de chaux on obtient une courbe analogue a I. Si l'on part du sol saturé et qu'on réalise la courbe de désaturation, on obtient une courbe II non superposable à la précédente.

Les quantités de CaO necessaires pour amener le sol à pH 7,0 sont très notablement plus élevées d'aprés la courbe de désaturation que d'après la courbe de saturation.

L'addition au sol, en place, de chaux ou de CO_3Ca provoque, dans la premiére phase de la neutralisation, un surchaulage d'une fraction limitée de sol.

Dans la seconde phase de la neutralisation la fraction surchaulée cède au reste du sol une portion de la chaux fixée en excès.

Le sol parcourt ainsi la courbe II et son besoin en chaux véritable peut être déterminé par l'abscisse OB, compte tenu de la fraction du sol surchaulée dans la premiére phase de la neutralisation.

S. HÉNIN : Pour des raisons qu'il n'est pas possible d'exposer en quelques minutes, nous pensons que l'action de Ca, n'est ni dûe à une modification de la matière organique ni à une saturation du complexe, mais à un effet " floculant " des sols de Ca libre dans le milieu.

Les expériences suivantes sont en accord avec ces idées :

A. 3 parcelles ayant reçu CO_3Ca, scories, et le témoin, pendant 10 ans et sans culture (42 parcelles de Versailles) ont des pH de 8·3, 7·5, 6·8.

La structure du sol en place est très bonne (porosité élevée, faible cohésion) à pH 8·3, moins bonne à 7·5 et encore moins bonne à pH 6·8.

B. Un champ, à pH 7·2 ne recevant pas de matière organique depuis 30 ans était en mauvais état physique (mauvaise germination du blé en année pluvieuse). Par apport de CO_3Ca le pH a été remonté à 7·8 la structure a été améliorée (bonne germination).

C. Nos agriculteurs estiment que l'on diminue la tendance à la formation de croûte par chaulage.

Il est à noter que cette amelioration de la structure n'apparait pas à l'analyse des aggrégats. Évidemment ces pH élevés peuvent avoir des inconvénients mais du point de vue structure le plein effet du chaulage n'est pas obtenu avant pH 7·8 correspondant à la présence de quelques pour mille de CO_3Ca dans le sol.

F. A. VAN BAREN : Il m'intéresse beaucoup de savoir lequel mineral d'argile characterise le sol dont M. HÉNIN a parlé.

P. BRUIN : Professor TOVBORG JENSEN gave the relation between the applied $CaCO_3$ (tons per Ha) and the loss by leaching. It may be concluded from the graphs that these losses are proportionately equal. From this two questions arise :—

1. Is the variation in leaching with regard to the mean curve found a large one and may soil conditions be instanced which are responsible for deviations ?

2. Is the conclusion right that the most economical way of liming lies in the application of relatively small amounts of marl or limestone ? This may be doubtful because the losses of lime are proportionately equal. When a rather low lime status of the soil occurs large applications of lime may be preferred.

R. PIOT : Je constate que vous avez comparé le $CaCO_3$ avec le $Ca(OH)_2$. La question que je voudrais poser est la suivante :

Avez vous constaté une influence differente de ces deux formes de chaux sur la teneur en humus et sur la matière organique du sol ?

S. TOVBORG JENSEN : According to the thesis set forth by ALBRECHT and SMITH you may draw upon the natural reserve of plant nutrients in the soil by keeping it suitably acid. This may be true for certain regions only. In most Western European countries such a reserve is non-existent. When the point is reached where our soils have been leached to such a degree that they show a pronounced acid reaction, this reserve has disappeared and the soil is poor in plant nutrients.

To correct this soil acidity must be eliminated by liming and the application of fertilizers in liberal quantities. This is the only way in which soil fertility may be restored. If instead of acid-tolerant soya beans a more sensitive crop had been used the result and the conclusions drawn from the experiments might have been different.

(In reply to M. PIOT.) In comparing the effects from $CaCO_3$ and $Ca(OH)_2$ used as liming materials no difference in crop response to liming was found.

(In reply to Dr. SCHACHTSCHABEL.) In liming experiments on soils of the same type no increase in the soil's absorbing capacity was observed. In fact, the increase in pH found after liming was slightly larger than the rates calculated from titration curves using a liming factor of 2·5.

In Denmark we have observed similar seasonable fluctuations of pH to those indicated by Dr. DOMINGO. This occurred when measurements were carried out in aqueous suspension. When measured in 1MKCl no fluctuation was found, the pH remaining constant the year round and nearly one unit lower than in aqueous suspension. Consequently the measurement in 1MKCl is now used for practical work. The results of these investigations were published in *Archiv. für Pflanzenbau* under the title " Investigations on Soil Reaction and Liming Conditions in Some Danish Soils, 1933."

(In reply to Dr. CHAMINADE.) When soils are acidified under natural conditions the Ca ions passing into solution are gradually removed from the systems by leaching. When the same reaction is studied in test tubes in the laboratory they remain in the system. This may explain the hysteresis observed.

(In reply to Dr. HÉNIN.) The liming of heavy soils close to their saturation point (pH 7·5 to 8·0) will, no doubt, improve their structure, rendering them more friable and easier to cultivate. This is one of the beneficial effects from liming on soils of that type.

(In replying to Dr. BRUIN.) It seems justifiable to believe that the rate of leaching is directly proportional to each one of the following factors :—

1. Percolation.
2. The production of CO_2 and other acids in the soil.
3. The area of the active surface from which Ca is leached away.

Therefore, the largest loss will occur on easily permeable sandy soils of high lime status in which a rapid decomposition of organic material takes place. The annual loss may here exceed 1,000 Kg. per hectare. On clay soils it would probably be slightly less. The heavy losses observed in Dr. BRUIN'S experiments may probably be due to the presence of stronger acids than H_2CO_3. Soils should be brought to the correct lime status and kept there by the application of frequent relatively small lime applications in order to avoid unnecessary loss by leaching.

FIELD ASPECTS OF SOIL ACIDITY USING INDICATOR PLANTS

WILLIAM PLANT

Long Ashton Research Station, University of Bristol, England

The study of the acid soil complex in relation to crop behaviour as exemplified by visual symptoms, crop yields and chemical leaf analysis is complementary to any investigation either in sand or water culture.

During a period of 3 years, 1948–50, two experimental centres were established and maintained on acid soils of differing parent material. One centre was situated in Somerset on the Old Red Sandstone; the other was in Devon on Granite.

The lay-out was designed to include 2 identical plots at each centre. The plots received treatments consisting of control, gypsum, ground limestone and ground magnesium limestone. The five crops grown consisted of oats, barley, kale, potatoes and sugar-beet. All treatments were given NPK in order that these nutrients should not be limiting factors in growth.

Effect of treatment on the visual syndrome

It can be seen from Table 1 that the Somerset centre (Old Red Sandstone) was more affected by nutritional disorders than the Devon centre. Whilst deficiencies and excesses are listed separately they are in some cases interrelated. This means, in fact, that the acidity complex may show both deficiency and excess symptoms in the same plant.

For example, aluminium toxicity gives rise to symptoms comparable with phosphate deficiency.

TABLE 1

	Centre: Somerset			Centre: Devon		
	p.m. Old Red Sandstone			p.m. Granite		
Treatments for 5 crops	pH	Defic.	Excess	pH	Defic.	Excess
Control	4·7	P Mg Mo	Al Mn	5·0	P	Al
Calcium Sulphate ...	4·4	P Mg Mo	Al Mn	4·7	P	Al
Calcium Carbonate ...	6·0	B.	—	6·2	B.	—
Calcium Mag. Carb. ...	6·0	B.	—	6·2	B.	—

The control treatment showed deficiencies of phosphate, magnesium and molybdenum and excesses of manganese and aluminium. Manganese excess did not occur on the granite soil. The application of calcium sulphate (gypsum) gave a similar range of symptoms except that magnesium deficiency was accentuated and manganese excess

lessened. The addition of calcium in the form of calcium sulphate showed no effect and any possibility of this element being deficient was thereby eliminated. The effects of calcium carbonate (lime) and calcium magnesium carbonate (dolomite), apart from increasing yields generally, was to eliminate all the symptoms present on the control and gypsum treatments. There was, however, a deficiency of boron in the sugar-beet crop and it is assumed that this deficiency was induced by raising the soil pH.

Effect of treatment on yield and mineral status

In Table 2 are given the overall mineral contents of the five crops together with yields for the last year of the experiment (1950).

TABLE 2

The mineral contents of P, K, Cu, Mg, and Mn expressed on leaf dry matter (1950)

	Oats	Barley	Kale	Potatoes	Sugar-beet
$\%P_2O_5$					
	±0·025	±0·015	±0·021	±0·014	±0·105
Control	0·75	0·55	0·77	0·63	0·80
$CaCO_3$	0·77	0·74	0·72	0·60	0·88
$CaMgCO_3$	0·72	0·71	0·70	0·62	0·93
$CaSO_4$	0·84	0·60	0·68	0·62	0·93
Mean	0·77	0·65	0·72	0·62	0·86
%CaO					
	±0·024	±0·036	±0·139	±0·119	±0·070
Control	0·66	0·79	2·16	2·04	1·85
$CaCO_3$	0·88	0·87	3·40	3·25	1·60
$CaMgCO_3$	0·74	0·76	3·17	2·88	1·44
$CaSO_4$	0·83	0·88	2·77	2·56	2·25
Mean	0·78	0·83	2·88	2·69	1·78
%MgO					
	±0·013	±0·015	±0·021	±0·068	±0·082
Control	0·24	0·27	0·30	0·91	1·02
$CaCO_3$	0·29	0·32	0·26	1·06	0·75
$CaMgCO_3$	0·44	0·44	0·54	2·14	1·56
$CaSO_4$	0·17	0·19	0·14	0·54	0·64
Mean	0·29	0·31	0·31	1·16	0·99
$\%K_2O$					
	±0·161	±0·111	±0·139	±0·115	±0·159
Control	4·64	3·71	3·27	5·19	2·76
$CaCO_3$	4·21	3·61	3·07	5·46	4·44
$CaMgCO_3$	3·92	3·57	3·19	4·32	3·78
$CaSO_4$	4·96	3·67	2·89	5·46	3·17
Mean	4·43	3·64	3·10	5·11	3·54
Mn p.p.m.					
	±15·0	±19·2	±92·5	±36·8	±56·1
Control	233	164	786	642	1310
$CaCO_3$	102	56	145	240	431
$CaMgCO_3$	96	46	151	197	332
$CaSO_4$	226	138	372	488	1052
Mean	164	101	363	392	781

Yields : per acre (1950)

	Oats : cwt.	Barley : cwt.	Kale : tons	Potatoes : tons	Sugar-beet : tons
	±1·60	±2·47	±0·63	±0·44	±0·84
Control	38·8	6·6	19·1	10·1	4·8
$CaCO_3$	49·2	53·5	26·4	11·2	23·4
$CaMgCO_3$	46·5	54·5	24·9	11·1	25·6
$CaSO_4$	39·8	12·3	21·1	10·5	6·8
Mean	43·6	31·7	22·9	10·8	15·1

An inspection of the yields at the bottom of the table show that oats, barley, kale and sugar-beet showed a yield response when lime or dolomite were added. The effect of gypsum in increasing yields was negligible. The potato showed no response to treatment.

In attempting to interpret why yields were increased when the soil pH was raised, the relevant values of P, K, Ca, Mg and Mn contents of the leaves indicate some of the problems involved (see Table 2).

The P, K, Ca values show little variation between treatments. Thus symptoms of P deficiency recorded in Table 1 are possibly induced by another element.

Although gypsum fails to correct the conditions of the acid complex it causes both the Mg and Mn contents to fall in all crops. The fall of the latter decreased the severity of manganese toxicity but in the former element (Mg) acute symptoms of Mg deficiency resulted.

In the control treatments the manganese contents are high. The overall figures for the four plots fail to show the severity of manganese toxicity on one plot situated on Old Redstone Soil (2–3,000 p.p.m. Mn were found). The presence of manganese in excess is doubtlessly one of the most important factors in reducing crop yields.

Whilst symptoms of aluminium toxicity were observed on the control and gypsum treatments no increase in the aluminium content of the leaves was found.

An examination of the molybdenum content of these five crops showed that the levels were low, particularly in kale (0·08 p.p.m. Mo). The effect of adding lime increased the Mo content considerably.

It is concluded from these experiments that the manifestations of the acid soil complex in the presence of added NPK, will vary according to the parent material of the soil series. In these experiments deficiencies of magnesium, molybdenum and boron were recorded in association with excesses of Al. and Mn.

SESSION 5

MAGNESIUM AND MINOR ELEMENTS

24th July. Chairman: S. HENIN (France)

W. MORLEY DAVIES. Magnesium and the Micro-Nutrients (Volume I, page 136)

F. C. GERRETSEN. Some Aspects of the Micro-Biological Determination of Magnesium, Zinc, Copper and Boron (Volume I, page 151)

E. B. DAVIES. Minor Element Problems in New Zealand (Volume I, page 167) (Read by E. MARSDEN)

SESSIONAL DISCUSSION

Magnesium

A. JACOB: Until now magnesium fertilizers have, in general, been applied only where visible symptoms of magnesium deficiency have been exhibited by a crop. If potash was applied only in cases where visible symptoms of potash deficiency are shown the use of potassic fertilizers would not have attained its present level. Hundreds of thousands of fertilizer experiments have, however, shown that potash pays also where there are no visible symptoms of potash deficiency. Probably we would come to the same conclusion regarding magnesium if fertilizer experiments with this nutrient were carried through on a similar scale. As this, for obvious reasons, is scarcely possible, it would seem that a solution might be approached by way of soil analysis. I know quite well that soil analysis cannot tell the farmer whether fertilization pays in a special case but it at least tells him whether his soil is rich or poor in a certain element of plant food. Now annually in Germany nearly a million soil tests for K_2O and P_2O_5 are made by the EGNER method. It should be possible to extend this method also to the determination of magnesium provided a reliable and cheap method could be found for determining Mg in the lactate extract.

M. NICHOLSON: In addition to the factors outlined by Mr. W. M. DAVIES on page 138 (of Volume I) a growth (time) factor is operative under certain conditions and with certain crops. By the time visual symptoms appear it may be too late to apply remedial measures for that particular crop if the crop be one in which the time factor is operative. A good example is magnesium deficiency of tomatoes under glass. The soil may contain sufficient available magnesium for the crops *in toto* but insufficient during a certain growth period when the roots do not appear to be able to take up sufficient magnesium for both growth and fruiting purposes. During this period demands on soil magnesium are relatively great and previous application of heavy dressings may be needed to meet them but these are uneconomic and may not always be effective. It is, therefore, necessary to anticipate the incidence of the deficiency and apply remedial measures in the way of sprays before visual symptoms actually appear. In the case of tomatoes the " time factor " is operative when the first three trusses of fruit are formed in the swelling. At this stage the chlorophyll in the leaf is broken down and the chlorophyll magnesium transferred to the fruit because sufficient magnesium uptake by the roots at this

stage in growth is not taking place. The lower and older leaves are affected first and in these leaves the chlorosis first appears and develops more progressively up the plant.

After the first three trusses have been removed the soil can again keep pace with the subsequent demands for magnesium and further spraying treatment is unnecessary. A realisation of the effect of this time factor on production is, therefore, economically important and enables the grower to take steps to put matters right before they go wrong. Varietal differences are quite marked, deficiency troubles generally being worst in heavy cropping varieties or those having inferior root symptoms.

C. BOULD: In fruit in Great Britain magnesium deficiency is one of our most serious problems. It is caused largely by excessive applications of potassic fertilizer. The exchangeable K/Mg ratio in the soils is often in the region of 5–6. It is, therefore, important to determine not only the magnesium status of the soil but also the potassium status. It is, however, difficult to correct magnesium deficiency in fruit trees by soil application of magnesium salts when the exchange K/Mg ratio in the soil is high.

E. M. CROWTHER: Dr. JACOB has suggested that it should be possible to treat the magnesium problem in the same way as the potassium problem by using rapid and cheap soil tests. I think that the difficulties are far greater with magnesium. Although leaf symptoms of magnesium deficiency are common in our gardens and orchards and are to be expected to an increasing extent on some of our poor light soils, I can recall very few results of field experiments of ordinary arable crops in which the addition of soluble magnesium salts have increased yields. Until we can establish reliable average responses for certain crops and kinds of soil we shall have no sound basis for standardising analytical methods for advisory work on magnesium fertilizers. I should like to ask Mr. M. DAVIES and chemists from other countries in N. W. Europe whether they have any clear evidence of yield increases from soluble magnesium salts on ordinary arable crops excluding recently reclaimed soils and special garden or horticultural crops.

P. BRUIN: In reply to the question of Dr. CROWTHER about the increase of yields by dressings of magnesium advised on the basis of soil analysis, I wish to say that the Soil Testing Laboratory in the Netherlands is advising magnesium dressings on the basis of soil testing in the same way as it is doing for other nutrients. The Agricultural Experiments Station and Institute for Soil Research, Groningen, evaluated this testing on its experimental plots. Considerable yield increases may be got by applying magnesium to our light soils (humus sandy soils) which are deficient in magnesium. Magnesium leaches out rather quickly in the low pH conditions of these soils. A good lime status is profitable also in this respect but we are not quite certain if a higher pH of itself is decreasing the need for magnesium.

The clay soils of the Netherlands are on the whole richer in magnesium because they originally contained a certain amount of calcium magnesium carbonate.

M. M. ELGABALY: Most of the papers presented report Mg deficiency but we suffer from magnesium excess which increases with the introduction of perennial vegetation. Soil deteriorates physically and yield

is lowered with the increased exchangeable magnesium. It is necessary to reduce this value by the addition of gypsum and the lowering of the water table.

M. V. L. HOMES: In soils from the Belgian Congo a definite increase in yield by the addition of magnesium fertilizer was obtained. This addition made an incomplete mineral fertilizer into a complete one and so enabled it to produce a positive effect increasing the yield of maize.

H. LEES: I think confusion is likely to arise in connection with some of the problems raised. A plant which has a healthy appearance and whose chemical composition indicates adequate nutrition is not necessarily a big plant. For maximum yield some malnutrition of the plant may be desirable. To use an analogy from the sphere of animal nutrition, a slight deficiency of iodine in the diet may produce some degree of hypothyroidism with resulting lethargy. As a consequence an animal with slight iodine deficiency may be fatter than an optimally nourished animal. I do not think that in the sphere of plant nutrition maximal trace-element supplies are necessarily always a prerequisite of a high yield.

T. WALSH: I was very interested in the points relative to magnesium deficiency by Dr. NICHOLSON. In our experience, magnesium deficiency in crops is mainly a problem of high potash levels in the soils. Some of our worst problems with magnesium deficiency in potatoes have arisen in sea coast areas where a high potash status has been built up by use of seaweed. Under such conditions also the soils were deficient in nitrogen and a striking response to both magnesium and nitrogen was obtained, the best response being got when these two nutrients were added together. Analysis have shown that these soils have moderately high to high magnesium levels but extremely high levels of potash. This is also the picture in orchards and glasshouses, where magnesium deficiency is concerned. In a survey which is in progress on nutritional problems in tomato house soils we have found potash levels of up to 2,000 lb. of readily available K per acre.

Undoubtedly, we have found some areas where the magnesium level of the soil is sub-normal but such areas are relatively limited. Apart from the question of K/Mg ratios in the soils it has been our experience that where the problem of magnesium deficiency is concerned the K/Mg ratio in plant tissue is of very considerable importance. Much more research needs to be carried along in this field and I thoroughly agree with Dr. JACOB that the development of a quick and accurate method for determining the Mg content of soil extracts is urgently needed.

N. H. PIZER: In the experiments in the eastern counties, the application of magnesium sulphate to sugar-beet has removed the symptoms of magnesium deficiency and increased the size of the tops but has not increased the yield of roots or of sugar. On grasslands, magnesium sulphate has increased the yield of grass. The analysis of soils for magnesium is complicated by relation between magnesium and nitrogen. Magnesium deficiency occurs in crops in soils that are very low in organic matter and therefore in nitrogen. Application of nitrogen and nitrate of ammonia has removed the symptoms of magnesium deficiency.

Iron

F. C. GERRETSEN: Mr. MORLEY DAVIES has noted that as far as is known no damage to crops arises from excess quantities of mobile iron in well aerated soils (page 139, Volume I of Transactions). I wish to ask the speaker in which form mobile iron occurs in well aerated soils. Generally, the mobile iron present in excess quantities is ferrous hydrocarbonate but in well aerated soils this will very soon be oxidised to insoluble ferric hydroxide, which is harmless. Excess of mobile iron will occur most frequently in reduced soils and as such might be quite harmful. In the Netherlands, there is a disease in oats, called " Black oats " by the farmer. The leaves begin to show brown spots and after some time the tips of the leaves and finally the whole leaf become black. The leaves contain large amounts of ferrous iron up to 1,400 to 3,000 p.p.m. and the presence of the iron in the leaves can be easily demonstrated by the usual chemical reactions. Yields are considerably reduced, but when the aeration of the soil is improved the plants recover. The disease is observed on soils which contain easily decomposed organic matter and have been too wet for some time. I have observed it on our reclaimed marshlands which had been covered with a layer of sand but were insufficiently drained.

T. WALSH: For a number of years past on certain soils a chlorosis of oats very similar to the condition which has been described by Professor WALLACE and others as symptomatic of iron deficiency has been a problem in certain areas. It has been especially a problem on very acid organic cutaway peat soils. In the development of these soils top sphagnum peat to a depth of 2′ to 3′ was laid to one side. The intermediate layers of more highly decomposed sphagnum and other plant remains were cut away for peat and the top sphagnum material deposited on the cut away material to form the soil. The chlorosis which has appeared in oats growing on these soils leads to practically complete failure and spraying experiments with iron soils has given a very definite response. However, from experimental evidence which we have now obtained, it would seem that the occurrence of this condition in this crop is closely associated with molybdenum deficiency. In soils of this nature, we have obtained striking responses from the addition of both lime and marl for certain clovers, and liming has eliminated the trouble in oats. In the latter crop, we have also obtained promising results from the addition of molybdenum to the soil. The condition is possibly due to iron deficiency induced by a molybdenum deficiency. It has also occurred in a mineral soil of pH 5·4 where one particular variety of oats was especially affected. Under these conditions, it was also eliminated by liming and it is of interest that in the meantime definite response has been obtained from the use of molybdenum for swedes in adjacent plots with soil conditions similar. Consequently, it would seem that iron deficiency may not be confined to soils of alkaline reaction as there may be factors present under acid conditions which may in fact lead to induced iron deficiency also.

Professor WALLACE and Drs. HEWITT and NICHOLAS also took part in the discussion.

Boron

J. D. GOLDEN: From a short paper which is being published in this Volume (page 167), it has been shown that boron deficiency is a

considerable feature of acid soils in certain Irish districts. In defining such areas a determination of water soluble boron has been found very valuable. I should like to know if any of the delegates have any experience where the occurrence of boron deficiency on acid soils with reaction below pp 5·5 and, if so, what has been the origin of such soils.

S. McCONAGHY: Cases of boron deficiency have been encountered in Northern Ireland under similar conditions of acidity to those mentioned by Mr. GOLDEN. In some such cases, the deficiency may be quite acute and may give rise to severe "raan" in swedes, but the use of a dressing of about 20 lb. of borax per acre, which is normally recommended for such crops, prevents the occurrence of the disease.

J. TINSLEY: From the table on page 149 of Volume I, it appears that the Advisory Chemists in Britain use extraction with water for assessing the available boron status of soils. This is presumably the hot water extraction method of BERGER and TRUOG. I should like to inquire if any correlation has been established in England between the amounts of boron extracted with water and the incidence of deficiency symptoms in field crops.

I would like also to suggest a new approach to the assessment of boron status of soils. One feature of chemical and biological research in recent times is the reaction of boric acid with a wide range of organic compounds having adjacent hydroxyl groups, for example, sugars. ZETTLE has given a review of these borate complexes in *Advances in Enzymology*, for 1951. It has been suggested that the boron associated with soil organic matter is of great importance for plant nutrition. If so, the extraction of soils with a suitable glycol or sugar solution should pull out the borate complexed with soil organic matter as well as that bound to inorganic soil colloids.

This suggestion is offered on theoretical grounds in the hope that anyone studying boron in soils who may care to try that approach will attain further insight on the forms and availability of this element in soils.

Drs. BARBIER, NICHOLAS and BRUIN and Professor WALLACE also joined in the discussion on boron.

Copper

J. VUORINEN: In the last few years in Finland many new settlements have been developed, especially on organic soils. In cultivations on these settlements, very bad copper deficiency has occurred in some instances. With normal use of complete fertilizer no corn crops have been obtained from some of these new cultivations. The addition, however, of copper sulphate at the rate of 50 kg. per ha. under those conditions resulted in good crops, i.e., oats and corn yields of 3,000 to 7,000 kg. per ha. Copper containing phosphates is now also in use. Some one-third of our land is of organic soils and the use of copper as a fertilizer is now very important.

N. H. PIZER: On Fen peats in the eastern counties the application of copper sulphate has increased the yield of cereals from 1 to 30 cwts. per acre. Soil applications of 40 to 60 lb. per acre of copper sulphate were much less effective than ¾ lb. copper sulphate per acre applied as a foliage spray. Regarding Dr. ROACH's remarks on the benefit to cereal crops from minor element sprays, experience in the Eastern

counties is that where a crop is apparently normal the application of minor elements as foliage sprays may reduce yields. With this uncertainty as to effects, the use of minor elements cannot be generally recommended for advisory work for there is no means of knowing beforehand whether they will be harmful or beneficial.

Drs. ROACH, BRUIN and DEAN also took part in this discussion.

Cobalt

T. WALSH: The paper of Dr. E. B. DAVIES contains very much of interest to us. In work which has been proceeding on a survey of the cobalt status of soils and herbage in relation to some nutritional disorders in cattle and sheep, it has been found that a determination of cobalt in a HCl extract of soil provides in most cases a useful criterion of the cobalt supplying power of the soils to herbage. With us, cobalt deficiency is a very big problem extending over a very considerable acreage. Apart from the cases where definite pine shows up, there are a number of instances where a sub-clinical condition is of very great importance. In general, our experience has shown that where the cobalt level of soils falls below about 2·5 p.p.m., pining may occur but the worst cases are found where the cobalt level is below 1 p.p.m. Soils from recovery areas generally show levels above 5 p.p.m. but in interpreting these results the soil type must receive consideration. In some instances, a sub-clinical condition of pining has been found where the cobalt level of soils varies between 7 to 12 p.p.m. Where herbage is concerned, the worst cases of pining in both cattle and sheep occur with cobalt content of less than 0·05 p.p.m. Where the herbage shows values above this, cobalt deficiency does not appear to be a problem where cattle are concerned but between 0·05 and 0·08 a severe pining condition has been found in sheep, with a sub-clinical condition occurring in the region of 0·07 to 0·09 p.p.m. cobalt. In some herbages, values as low as 0·01 p.p.m. have been obtained. There is much room for further research in this whole sphere of work and in this connection the correlation between soil type and cobalt deficiency which has been shown in DR. DAVIES' paper sets a very good basis for research.

E. MARSDEN: In reply to the questions of Dr. WALSH regarding analytical criteria and symptoms of cobalt deficiency, I think the New Zealand experience is that the best confirmatory diagnosis arises from the analysis of livers. In the case of marginal areas, there is considerable variation in the severity of cobalt unthriftiness from season to season and from year to year and pasture analysis do not provide an exact criterion. There is also the question of soil contamination of samples. Clovers appear to take up nearly twice as much cobalt as grasses. There is the factor arising from movement of stock. Cases have been reported in which the condition of sheep has been improved merely as a result of driving them over roads with road metal or covering derived from outside the affected area. Speaking from memory of an unpublished experiment many years ago in which radio cobalt was fed to an affected sheep, it appeared that the radio cobalt concentrated itself in the liver and to a certain extent in the pancreas. It may be that the function of cobalt is indirect and that there are ancillary factors. The result reported by NICHOLAS of Long Ashton regarding the production of Vitamin B_{12} by *A. Niger* in the presence of cobalt

may be significant and some analogous reaction may occur in the flora of the rumen or intestinal tract.

S. McCONAGHY: An examination of the cobalt status has shown that the lowest cobalt contents occur on soils in the granitic region of the South-East and on the acid schistose soils of the western part of the province. The basaltic soils of Antrim and East Derry show a high cobalt status, with total values ranging from about 20 to 100 p.p.m. Yet the only recorded case in the province of pining in young cattle which responded to cobalt administration occurred on a farm in the basaltic area in East Antrim. The total cobalt contents of the soils range from 40 to 80 p.p.m. and the acetic acid $\left(\frac{N}{2}\right)$-soluble cobalt contents averaged about 1·2 p.p.m. which is much higher than the threshold value suggested by MITCHELL.

The cobalt contents of the feeds were not low if we accept the level of 0·05 p.p.m. of D.M. as a threshold value. But there is some doubt about the value of cobalt determinations on herbage in relation to cobalt nutrition of animals and it is interesting, as mentioned by Dr. MARSDEN, that the cobalt contents of livers may be of more value in the study of cobalt pining. The possibility must be considered, however, that there may be some variation in the cobalt content of different parts of the liver.

T. WALSH: The remarks of Mr. McCONAGHY are of special interest and stress the need for a thorough fractionation of the cobalt in soils and the initiation of research to investigate climatic, soil type, and plant species effects in relation to the incidence of cobalt deficiency. In our experience, it is very difficult to tie up the whole matter with the geological origin of soils, especially when there is an admixture of different geological materials.

Molybdenum

M. NEENAN: We have for some time been interested in the element molybdenum in this country, and some of our findings on the subject are in the Press. Some results which have since come to hand may be of interest.

We have obtained a response from molybdenum in two soils, one of them an organic soil. The responses were obtained in the crops S. 100 White Clover and Swedes. Symptoms similar to those described by Dr. HEWITT, but not so severe were observed in the control plots of the Swede experiment, a good response being obtained to the application of molybdenum. During the past few seasons, symptoms of molybdenum deficiency have been observed in a number of swede crops and on one soil series at least it appears to constitute a major problem where Swede growing is concerned. Research is at present in progress on the molybdenum status of this series of soils.

For some years back, we have received reports of cases of unthriftiness in cattle, the condition being associated with a green scour and a staring depigmented coat. Feeding trials were carried out and in all cases a recovery was effected by dosing with copper. The copper content of the herbage was in no instance less than 7 p.p.m. which in normal circumstances would be regarded as a satisfactory level. The molybdenum content of the herbage, however, varied from 8 p.p.m. to 25 p.p.m., although the total Mo content of the soils varied from

0·8 to 3·65 p.p.m. The condition was found to be associated with calcareous soils, heavy applications of phosphatic fertilisers especially basic slag, and the presence in abundance of leguminous plants in the pastures. A survey is now in progress throughout the country and experiments are proceeding at fourteen local centres. The treatments being tested are basic slag, sulphate of ammonia, superphosphate and copper sulphate. Some preliminary results are as follows:

Treatment	*Mo in the herbage p.p.m.*
Control	8·0
Superphosphate	13·5
Slag	20·0
Copper Sulphate	11·0
Sulphate of Ammonia	15·0
Sulphate of Ammonia + Copper Sulphate	13·5

From investigations carried out in a number of centres in regard to the occurrence of this unthrifty condition in livestock, it would appear from our results that the levels fixed for herbage Mo where excess effects begin to operate are too high and in this connection our results would seem to indicate that levels above 5 p.p.m. must be taken into consideration. Also when selecting herbage samples, in order to investigate this effect, a consideration of the individual species in the herbage is of primary importance. Various methods including the use of *Aspergillus niger* were tried for the estimation of molybdenum in soils but by far the most satisfactory was found to be that of DAVIES and GREIG, who used TAMM's oxalate buffer as an extracting solution. At the time of his communication to us last autumn, DAVIES quoted the range of New Zealand soils as being from 0·02 to ·24 p.p.m. of Mo; in his paper at this session he has extended the upper limit to 1·42 p.p.m. Meanwhile we have found the range in Irish soils examined to date, to be 0·08 to 0·712 p.p.m. Provisionally, we regard 0·400 as the critical level above which the syndrome occurs. Where we obtained a response to Mo, the soil test gave a value of 0·12 p.p.m. which again is in agreement with the findings of Dr. DAVIES and his co-workers. When this soil was fertilized with sodium molybdate at 6 ozs. per acre, the value then went up to 0·513 p.p.m.

It is of interest that the New Zealand workers and ourselves working independently found that our figures coincided almost exactly both for range of Mo values and for level at which one obtained a response from this element.

E. J. HEWITT: The observations recorded by Dr. DAVIES on molybdenum deficiency in New Zealand are especially interesting in the light of work recently carried out in England at Long Ashton.

The leaf malformation found in rape further emphasises this feature of molybdenum deficiency in Brassica crops, as leaf malformation or death of the growing point which are part of the Whiptail syndrome, have been produced in molybdenum deficient sand cultures in marrow-stem kale, thousandhead kale, savoy cabbage and swedes, as well as in cauliflowers.

Reports that apparent Whiptail symptoms were observed in cauliflowers on soil apparently provided with a normal molybdenum content but high in manganese may reflect the antagonism observed

between these elements. Excess manganese has been shown to accentuate injury due to lack of molybdenum or to cause greater injury when molybdenum is deficient. The statement that the origin of Whiptail lies in the check to nitrate assimilation when molybdenum is deficient requires some qualification. It has now been shown beyond reasonable doubt that Whiptail is induced by moderately deficient levels of molybdenum when nitrogen is given as nitrate, ammonium or urea nitrogen and possibly other sources also. There is not necessarily a detectible accumulation of nitrate in such Whiptail plants; but the bright mottling is always associated with the supply and accumulation of nitrate.

Finally, it may be mentioned that in regard to micronutrient deficiencies in general it has been shown that the reserves of Mo, Cu and Zn in the seeds of large seeded legumes exert a critical effect on the incidence of deficiencies of these elements. By growing the plants in sand culture without each element, deficient seed has been produced and compared in control and deficient cultures with seed of the same strain grown outside. The differences were striking and the recently reported results of STOUT *et. al.* (1952) for Mo were fully confirmed for pea, runner, dwarf and broad bean, for Mo deficiency and extended also to copper and zinc deficiencies. The conclusions of WILSON, regarding the origin and incidence of "scald" in beans due to Mo deficiency were also confirmed by this work.

Other minor elements

M. M. ELGABALY: I have found that portion of the zinc added to Montmorillonite is absorbed as monovalent ion, e.g., $Zn\ OH^+$ and $Zn\ Cl^+$. The zinc as such may form a part of the inner layer and thus becomes non-exchangeable or unavailable to plants. In addition, part of the zinc may substitute Mg^{++} within the crystal structure of certain minerals such as saponite and vermiculite and in this way is rendered unavailable to plants. On this basis, an explanation is offered as to why zinc deficiency may occur on certain soils under certain conditions.

G. A. FLEMING: As pointed out in my contribution to this Volume, selenium toxicity has been shown to be a major problem in certain soils in this country. This is of importance in so far as previous instances of selenium toxicity have been mainly associated with dry land of semi-arid conditions while also in other work the plant species appears to have played a very important part where uptake is concerned. It would be interesting to hear of other instances where under humid conditions livestock problems arising from excess selenium, are met with in cattle. In relation to this it should be of particular importance to have data obtained on the selenium content of different types of rock materials, especially shales.

S. HÉNIN: Je crois très utile que le Dr. ELGABALY ait attiré l'attention sur ce mécanisme. Les charges parties par les feuillets d'argile semblent généralement unitaires. Si l'on fixe un ion polyvalent, divalent par exemple, il se fixe en un point et l'autre charge n'est pas directement compensée par les charges restantes de l'argile.

Le *nombre* d'ions fixes peut être alors plus grand qu'on ne peut le prévoir d'après les rapports équivalent avis et les ions peuvent alors

fixer des anions. Il semble que tous les éléments mineurs intervenant comme cation puissent présenter ce phénomène.

D'autre part un certain nombre d'entre eux peuvent se loger dans la couche octaedrique.

Ils ne sont pas nécessairement inutisables par la plante, mais leur mise en liberté dépend des phénomènes d'alteration, qui sont compliqués. Cela peut expliquer les divergences existant entre la determination de la quantité de ces éléments presents dans le sol detérminée par des méthodes chemiques et le compartiment des plantes.

BIOLOGICAL ESTIMATION OF MAGNESIUM IN SOIL

H. L. JENSEN

State Laboratory of Plant Culture, Lyngby, Denmark

The method of biological assay of plant nutrients in soil by means of microorganisms, especially the fungus *Aspergillus niger*, is by no means of recent date and has been applied with more or less success to the estimation of both macro- and micro-nutrients. Among the latter copper may readily be estimated through its effect on the formation of pigment in the conidia of *Aspergillus* (MULDER, 1938, 1948; NICHOLAS and FIELDING, 1951). The method appears serviceable for determination of molybdenum and zinc (MULDER, 1948; GERRETSEN, 1948; NICHOLAS and FIELDING, 1951) and possibly manganese (NICHOLAS, 1950). Its use for determination of the macro-nutrients phosphorus and potassium, which was first suggested nearly fifty years ago, has not in general practice been able to replace the chemical methods, although in most cases the biological determination offers no special difficulties and is sometimes stated to compare favourably with the chemical methods in respect of both economy and accuracy (GERRETSEN, 1948). As an example it may be mentioned that in this laboratory a number of soil phosphorus determinations by GERRETSEN's method showed an extremely close correlation ($r = +0{\cdot}96$) with the amounts of phosphorus soluble in 0·2 N. sulphuric acid; the figures, however, suggested that the method simply indicates the content of soil phosphorus soluble in citric acid, 1·0% of which is included in GERRETSEN's medium.

Biological estimation of soil magnesium has also been attempted, and this method seems to offer certain possibilities. MULDER (1948) employed a method based on visual comparison between *Aspergillus*-cultures in magnesium-free medium + soil, and a standard series of similar cultures in medium with increasing doses of magnesium. In this way MULDER estimated 8-33 p.p.m. magnesium in 11 soils where rye and oats showed varying degrees of magnesium deficiency, and 33–>170 p.p.m. in 9 soils that supported normal plant growth; the study comprised only acid sand soils and a few peat soils. GERRETSEN (1948) devised a modified procedure based on the measurement of light absorption in the conidial layer, the pigmentation of which increases with increasing magnesium content; no actual results of this method, however, were given. NICHOLAS and FIELDING (1951) used the dry weight of the *Aspergillus* mycelium as criterion and found 50–70 p.p.m. magnesium in soil where potatoes showed signs of deficiency, compared with 140–160 p.p.m. in normal soil. Chemical determination showed 40–50 p.p.m. and 140 p.p.m., respectively, of exchangeable magnesium; no correlation was found between magnesium deficiency and the content of exchangeable potassium.

In Denmark, CHRISTENSEN (1922) and TOVBORG JENSEN (1936) have carried out a number of determinations of magnesium exchangeable against ammonium chloride. TOVBORG JENSEN obtained the following results:

In 45 sand soils: 12–182 p.p.m. exchangeable Mg
In 50 loam soils: 19–319 ,, ,, ,,
In 20 humus soils: 49–474 ,, ,, ,,

No correlation was observed between soil pH and magnesium content.

Apart from these data, little information is available about the magnesium status of agricultural and horticultural soils in Denmark. Symptoms of magnesium deficiency are on the other hand said to occur frequently in garden crops and fruit trees, and have also been suspected in agricultural crops, but the few field experiments in these have never shown any effect of a dressing with magnesium sulphate. The possibility that magnesium deficiency may arise seems not altogether remote when it is remembered that field crops may carry away some 20 to 40 kg. of magnesium per hectare annually, and that in many soils, especially sandy, the content of exchangeable magnesium is less than 50 p.p.m., or 125 kg. per hectare of top soil (TOVBORG JENSEN, 1936). Furthermore the low percentage potassic fertilizers, which formerly represented the chief extraneous source of magnesium, have during the last 25 years been replaced by

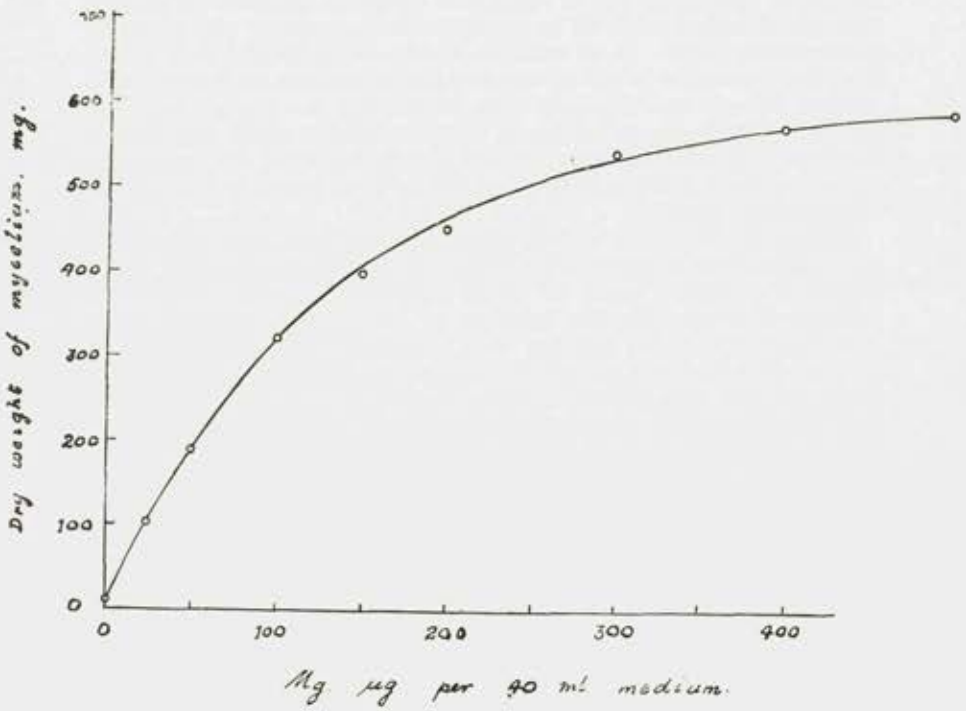


Fig. 1

Explanation of Fig. 1: Standard growth curve of *Aspergillus niger* "M" in glucose solution with increasing content of magnesium (as $MgSO_4 . 7H_2O$). Average of 10 experiments.

practically magnesium-free fertilizers of high potassium content, while the agricultural crop yield has been approximately doubled within the last half century. On the other hand an unknown but probably important proportion of the magnesium in the crops is returned to the soil in the form of farmyard manure, and considerable reserves of non-exchangeable magnesium may be present as HCl-soluble compounds (TOVBORG JENSEN, 1936); finally the lime and marl commonly used contain a certain amount of magnesium.

TABLE 1

Magnesium content of various soils as indicated by Aspergillus niger

Soil	No. of samples	Assimilable Mg, p.p.m.	Remarks
Sand soils, Jyndevad Exp. Station, South Jutland :			
(*a*) Artificial fertilizers	8	12–23	Very poor growth of beets
(*b*) Farmyard manure	8	25–45	Beet crop better than (*a*)
Reclaimed heath soils from Central Jutland :			
(*a*) Ulfborg	8	16–24	Cu-deficiency
(*b*) Sønder Omme ...	8	24–34	,, ,,
(*c*) Grindsted	2	26–54	,, ,,
Sand soil, Skive, North Jutland	1	90	,, ,,
Sand soils from orchards, Hornum Exp. Station, North Jutland :			
(*a*) No fertilizer ...	1	22	Mg-deficiency in apple trees
(*b*) $MgSO_4$, 200 kg./hectare	1	42	Deficiency less than in (*a*)
(*c*) No fertilizer ...	1	18	Mg-deficiency in apple trees
(*d*) $MgSO_4$, 600 kg./hectare	1	31	(No observations yet)
Loam soils from orchards, South Sealand ...	14	40–80	—
Loam soils, Vollebek, Norway. Fertilizer experiment in orchards :			
(*a*) N alone	4	30–50	Mg-deficiency in apple trees, aggravated by potassium, relieved by dolomite and to a smaller extent by calcium
(*b*) N+K	3	30–37	
(*c*) N+Ca	4	44–66	
(*d*) Dolomite 3 tons/hectare	4	270–300	
Gardens soils (loam), Lyngby	2	100–140	In one soil Mg-deficiency in tomato plants
Tropical soils (Tanganyika)	6	(> 400)	—

A number of biological tests for available soil magnesium has recently been made at this laboratory. *Aspergillus niger* (strain " M ", obtained through the courtesy of Dr. E. G. MULDER, Groningen) was grown in the glucose medium employed by MULDER (1948), without calcium but supplemented with certain extra micronutrients (cobalt, vanadium, and gallium) as recommended by NICHOLAS and FIELDING (1951). After 5 days' growth at 30°C. in 300-ml. Pyrex-glass ERLENMEYER flasks with 40 ml. medium plus 1·0 g. air-dry soil the mats of mycelium were removed, washed, dried at 100°C. and weighed, and the amount of assimilable magnesium was calculated by reference to a standard curve of mycelial weights from medium containing 0 to 500 μg magnesium per culture. The type of curve obtained is shown in Fig. 1.

Table 1 gives the results of determinations in 76 soil samples. The biological method is seen to bring out quite striking differences in magnesium content, and upon the whole the figures are of the same magnitude as those shown by the chemical determinations of TOVBORG JENSEN (1936). In many soils the magnesium content is on the same level as found by MULDER (1948) and NICHOLAS and FIELDING (1951) in soils known to be deficient in this element, and in the orchard soils from North Jutland and Norway the relatively low magnesium contents are seen to coincide with the appearance of visual deficiency symptoms in fruit trees. The field soils have sometimes even lower contents, but the significance of these figures cannot be evaluated until the results of field experiments become available.

Moreover, the level of magnesium supply necessary to ensure normal plant development seems to depend not only on the nature of the crops but also on the type of soil. Thus a garden soil from the State Laboratory of Plant Pathology, Lyngby, where tomato plants showed definite symptoms of magnesium deficiency, was found biologically to contain no less than 100 p.p.m. magnesium ; in this soil the deficiency symptoms were alleviated by spraying of the plants with magnesium sulphate solution, but not by application of the same salt to the soil in a quantity of 500 kg. per hectare. An important factor may be represented by heavy liming which according to TOVBORG JENSEN (1936) tends to lower the content of exchangeable magnesium, and excess of potassium is sometimes said to induce magnesium deficiency. The latter appears to be the case in the orchard soils from Norway (Table 1), although no definite influence on the availability of magnesium to *Aspergillus* is noticeable. Another example of the same phenomenon is seen in two soil samples from a fertilizer experiment in garden vegetables, Hornum Experiment Station :

Potassic fertilizer, kg. per hectare	Assimilable Mg, p.p.m.	Condition of crops
300	44	Normal growth
2000	40	Heavy Mg-deficiency in beans, less in tomatoes and horse-radish.

A comprehensive investigation of the interaction between magnesium and other nutrients will thus be necessary before the significance of either microbiological or chemical magnesium determinations can be finally assessed.

Summary

The method of biological assay by means of *Aspergillus niger* appears to lend itself readily to the determination of magnesium in soil. Contents of 18 to 50 p.p.m. magnesium were found in orchard soils where fruit trees showed visual signs of magnesium deficiency. In another case tomato plants showed deficiency in a soil containing 100 p.p.m. magnesium. No significantly reduced availability of magnesium to *Aspergillus* was seen in experiments where heavy applications of potassic fertilizer had induced symptoms of magnesium deficiency. Magnesium contents as low as 12–16 p.p.m. were found in certain field soils; the evaluation of these figures must await the results of field experiments.

REFERENCES

CHRISTENSEN, H. R. *Tidsskr. f. Planteavl.*, **28**, 1-62 (1922).
GERRETSEN, F. C. *Analytica Chimica Acta*, **2**, 782-792 (1948).
MULDER, E. G. Thesis, Wageningen (1938).
MULDER, E. G. *Analytica Chimica Acta*, **2**, 793-800 (1948).
NICHOLAS, D. J. D. *The Fertilizer Society, Proceedings*, No. **10** (1950).
NICHOLAS, D. J. D., and FIELDING, A. H. *J. Hort. Sci.*, **26**, 125-147 (1951)
TOVBORG JENSEN, S. *Tidsskr. f. Planteavl*, **41**, 571-650 (1936).

SOME ASPECTS OF THE USE OF FUNGI AS TEST ORGANISMS FOR DETERMINING Mg AND TRACE METALS IN SOILS AND PLANTS

D. J. D. NICHOLAS

Long Ashton Research Station, University of Bristol, England

Aspergillus niger and *Penicillium glaucum* require the macronutrients N, P, K, Mg, S and the micronutrients Fe, Cu, Zn, Mn and Mo for optimum growth (1–6). The two fungi can be used to determine trace metals in biological materials (2, 3, 4). A short description only of the bioassay method for determining Mg, Cu, Zn, Mn and Mo in soils is given in this paper as fuller details have been given elsewhere (3, 4).

Essentiality of mineral nutrients

A mineral nutrient is essential when the microorganism is unable to complete its life cycle without it. Moreover the effect of the nutrient must be specific and direct as distinct from an interaction with other mineral nutrients in the culture solution resulting in increased growth. The essentiality of trace metals for fungi must be distinguished from so-called stimulation effects which may also result in increased growth activity. Stimulation effects are usually achieved by adding trace metals to a culture solution containing all the known essential elements when a small and variable increase in yield may be recorded. It is only by withholding the trace metal from a pure culture solution and showing that subsequent graded additions of it result in a direct, specific, quantitative and reproducible growth response, that the essentiality of an element can be satisfactorily determined. The claims for Ga and V as essential nutrients for *A. niger* are still in doubt. Increased fat synthesis by the fungus as a result of adding Co, W and Cr may well be stimulatory effects.

Bioassay method

When an essential mineral element is withheld from the basal culture solution the growth of either *A. niger* or *P. glaucum*, as judged by dryweight yields and intensity of spore formation, is markedly reduced. Moreover the addition of graded amounts of the essential element, from deficiency to sufficiency levels, when others are present in adequate supply, result in a specific and a quantitative increase in growth. Standard growth series for the various essential elements may be made either for use in making visual comparisons, taking into account the growth of the mycelium felt, development, intensity and colour of spores or for quantitative determinations of the weights of the fungus. Thus for bioassay of test materials, known amounts of these are added to a sterile culture solution containing all the mineral elements other than the one to be determined. The growth of the fungus, under these conditions, will depend on the amount of the mineral nutrient it derives from the added material which can be quantitatively determined by reference to a standard growth series for the element.

Basal culture solution

Composition. A suitable basal culture solution is as follows :—

Macronutrients in g.		*Micronutrients in mg.*	
Dextrose	.. 50	$FeCl_3.6H_2O$ ..	.. 3

KNO_3 ..	.. 5	$ZnSO_4 . 7H_2O$	.. 2
NaH_2PO_4	.. 2·5	$MnSO_4 . 4H_2O$	.. 0·3
$MgSO_4$ ..	.. 1	$Na_2MoO_4 . 2H_2O$	.. 0·5
$Ca(NO_3)_2$	.. 0·6	$CuSO_4 . 5H_2O$	.. 0·6
		$Ga(NO_3)_2 . 8H_2O$	.. 0·2
		$Co(NO_3)_2 . 6H_2O$	.. 0·1
		$Ni(NO_3)_2 . 2H_2O$	.. 0·08

The above salts are dissolved in 1 litre of glass-distilled water and 50 ml. used per culture. The pH of the basal solution is approximately 3·8.

Purification. The methods used to remove trace metals from the macronutrients and dextrose are given in Table 1 together with their efficiency.

TABLE 1

Removal of trace metals from a solution of inorganic macronutrients and dextrose (200 ml.)

Trace metal removed	Method used for its removal	Residual metal (after purification) as μg/50 ml
Copper	1. Addition of 1 ml. 5% W/V copper sulphate, precipitation of sulphide at pH 2 (adjusted with redistilled hydrochloric acid), with hydrogen sulphide. Latter eliminated by boiling, pH adjusted to 3·0 with 2% W/V sodium hydroxide in glass-distilled water.	0·05
Zinc and Iron ...	1. Solution adjusted to pH 5 with 5% W/V sodium hydroxide in glass-distilled water, shaken 4 times with 20 ml. portions of 5% 8-hydroxyquinoline in chloroform on an electric shaker. Quinolates are extracted with redistilled chloroform and then with ether. Ether removed by aerating the solution at 70° C. pH adjusted to 4 with redistilled hydrochloric acid.	0·01
Molybdenum ...	1. As for coprecipitation method for the removal of copper.	0·00005
Manganese ...	1. Coprecipitation of manganese and copper diethyldithiocarbamate at pH 5·5 by adding 10 ml. 0·2% W/V sodium diethyldithiocarbamate in water and 5 ml. 5% W/V copper sulphate. Excess organic reagent precipitated with copper and the latter removed at pH 3 as a sulphide with hydrogen sulphide.	0·01
	2. Cation exchange method with Amberlite IR. 100 or Zeocarb 215 using H cycle.	0·01
Gallium ...	1. 8-hydroxyquinoline extraction as for removal of iron or zinc; ten extractions required. Extraction process can be checked as gallium quinolate is fluorescent under U.V. illumination.	0·01

Preparation of spore suspensions and inoculations

A. niger and *P. glaucum* are subcultured on sterile nutrient agar slopes at 25° C. for 6 days by a spore transfer technique. The spores from a slope are collected by means of a sterile platinum wire and deposited in glass-distilled water containing a small amount of an organic detergent, e.g., " teepol," to provide for an even distribution of spores. There is little advantage in using spores from fungi deficient in trace elements, as there appears to be little carry over of metal in the inoculum.

50 ml. of basal culture solution is put in 500 ml. or 1 litre ERLENMEYER flasks and pyrex beakers are inverted over the necks instead of using cotton wool plugs to avoid metal contamination. About 0·1 ml. of spore suspension is added to the sterile culture solution. *A. niger* is incubated for 6 days at 25° C. whereas *P. glaucum* requires 10 days at 25° C.

Preparation of biological material

Soils must be taken from the rooting zone of the plants. 1 gm. air-dry soil is used for Mg assay, whereas 0·5 gm. is taken for the assay of trace metals.

TABLE 2

Trace metal assay series for A. niger and P. glaucum (as μg per 50 ml. basal solution)

		Standard Deviation	Method of Assessment
Magnesium ...	0, 25, 50,* 100, 150, 200, 250, 300, 400,* 500	±20	Weight of mycelial felt
Iron	0, 0·1,* 0·5, 1, 2·5, 5* 10 ...	±0·1	Weight of mycelial felt
Copper ...	0, 0·05,* 0·1, 0·2, 0·4, 0·6, 0·8,* 1, 1·5, 2, 4	±0·1	Weight of mycelial felt and colour of spores in *A. niger*
Zinc ...	0, 0·5,* 1, 2, 3, 4, 5,* 10 ...	±0·5	Weight of mycelial felt
Molybdenum	0, 0·0005,* 0·001, 0·002, 0·003, 0·004, 0·005, 0·0075,* 0·01	±0·001	do.
Manganese ...	0, 0·01,* 0·025, 0·05, 0·1, 0·5, 1,* 5	±0·01	Mycelial characters including intensity of sporulation

*Effective range for assay coinciding with the maximum differences in mycelial characters including spore cover and dry weights of felts.

Tissue homogenates of plants are prepared in special glass maceraters using glass-distilled water. Minute amounts of Mo can be determined in ash constituents of plants (HNO_3 $HClO_4$ digests in which excess acid has been removed). Analyses are always made in triplicate and the cultures are randomised in the incubator.

Application of the bioassay method

The results given were obtained in the main with *A. niger* (M) although *P. glaucum* (K) may also be used. *A. niger* is preferable as it grows more quickly. Table 2 shows the effective range for the assay of Mg, Fe, Cu, Zn, Mo and Mn using either fungus.

Soils

Magnesium. Soils containing below 6 mg. per cent. Mg in air-dry soil by the *A. niger* method often fail to supply sufficient Mg to crop plants requiring relatively large amounts of the element e.g. *s* brassica and potato crops. Normal soils usually have about 20 mg. per cent. air-dry soil. It is possible to determine Mg deficiency in the presence of K deficiency in soils by this method, a point which may not be shown by the plants as K deficiency is usually dominant over Mg deficiency.

Micronutrients. The results of assay of Cu, Zn, Mn and Mo in soil are illustrated in Table 3. Cu and Zn in soils are assayed in culture solution with a pH of 3·8, whereas maximum differences between normal and Mn deficient soils is obtained by adjusting the pH to 7·5 with pure NaOH solution and between normal and Mo deficient soils by adjusting the pH to 2 (3, 4) with pure HCl.

TABLE 3

Bioassay of Cu, Zn, Mo and Mn in soils

Location	Trace metal deficiency	Bioassay results as μg/gm. air-dry soil and standard deviations			
		Copper	Zinc	Molybdenum	Manganese
Long Ashton, Somerset	Nil	30±6	30±7	0·5±0·005	5±0·5
Wisley, Surrey	Copper and zinc deficiencies in apple and pear	1·29±0·4 0·33±0·20	5±0·8 4±0·6	— —	— —
Bromham, Wilts. St. Ives, Cornwall	Molybdenum deficiency in brassica crops	—	—	0·01±0·002 0·02±0·002	—
Hanham, Bristol	Manganese deficiency in susceptible crops	—	—	—	0·1±0·01

It has not been possible to show differences in available Fe between normal soils and those that give rise to iron deficiency in fruit trees (lime-induced chlorosis). This is not surprising as there is an abundance of total iron in the chlorotic leaves which is immobilised in the tissues. Thus the availability of iron in these soils is of secondary importance.

It is well known that Co is essential for the rumen. *A. niger* produced Vitamin B_{12} but in media vigorously freed from Co it does not. The dryweight yields of felts are, however, unaffected by the apparent deficiency of cobalt so that the vitamin is probably a by-product of its metabolism. In Table 4 are shown the results of Vitamin B_{12} production by *A. niger* in the presence and absence of Co.

TABLE 4

Assay of Vitamin B_{12} in cultures of A. niger by Lb. leichmannii

µg Cobalt in 50 ml culture solution of *A. niger*	Vitamin B_{12}	
	Undried felt µg B_{12} per gm.	*Broth* µg B_{12} per 50 ml. culture solution
0	0· to 0·00018	not detected
1	0·001	0·001

Experiments are now in progress to explore the possibility of making an assay of Co in soils indirectly by the *A. niger* method by determining Vitamin B_{12} production of the organism grown in Co free culture solution with various soils added. These values are related to Vitamin B_{12} production of *A. niger* in pure culture given graded amounts of Co.

Plants

In Table 5 are given results of assay of Mo in homogenates and acid digests of healthy and Mo-deficient cauliflower. It is possible to determine Mo at levels below those detected by chemical methods.

TABLE 5

The molybdenum content of the water extracts and in the ash of cauliflower leaves as determined by the A. niger method

Ash Content µg Molybdenum/g. dry matter		*Water extracts of leaves* µg Molybdenum extracted/g. fresh weight	
Normal	*Molybdenum deficient*	*Normal*	*Molybdenum deficient*
0·5 to 1 ...	0·03 to 0·1	0·1 to 0·2	0·001 to 0·01
S.D. ±0·005 ...	S.D. ±0·002	S.D. ±0·002	S.D. ±0·001

Function of trace elements

A study of the rôle of mineral nutrients in metabolism of fungi is fundamental to the proper use as a test organism to bioassay complex materials such as soils and tissue homogenates. An intensive study of this aspect is in progress (4) with particular reference to vitamin B_2 and B_{12} contents, enzyme activity including polyphenol oxidase, catalase peroxidase, cytochrome oxidase and peroxidase.

REFERENCES

(1) FOSTER, J. W. *Bot. Rev.*, **5**, 4, 207 (1939).
(2) MULDER, E. G. *Antonie van Leeuwenhoek*, **6**, 99 (1939).
(3) NICHOLAS, D. J. D. and FIELDING, A. H. *J. Hort. Sci.*, **26**, 2 (1951).
(4) NICHOLAS, D. J. D. Proceedings 1st Int. Conf. Anal. Chem. Oxford. Analyst, (in the press) (1952).
(5) PERLMAN, D. *Bot. Rev.*, **15**, 195 (1949).
(6) STEINBERG, R. A. *Bot. Rev.*, **5**, 6, 327 (1939).

A NOTE ON THE REDUCTION OF MANGANESE IN NEUTRAL TO ALKALINE SOILS

L. H. P. JONES

Macaulay Institute for Soil Research, Aberdeen, Scotland

Some recent work on the reduction of manganese oxides in soils promises to throw more light on manganese compounds and the problem of estimating their availability.

The starting point was an apparent difference between two Australian soils in their ability to reduce added manganese oxides. One is a black clay from Penola, South Australia, with pH 6·9 in aqueous suspension, the other is a black calcareous peat from Yambuk, Victoria, with pH 8·0 and both are naturally low in total manganese. The Penola soil, however, is much more actively reducing toward added oxides than the Yambuk soil. This was originally thought to be due to a difference in the organic matter of the two soils but liming experiments have shown that it may be attributed to the difference in pH.

A bulk sample of the Penola soil was limed to pH 8·0 by treating with calcium hydroxide and maintaining at 50% water-holding capacity for three weeks. A higher oxide of manganese* was intimately mixed with 6 gm. samples of limed and unlimed Penola soil and the Yambuk soil. Sodium azide was incorporated to inhibit the manganese oxidizing organisms (2) and so shift the equilibrium in favour of the bivalent ion. The mixtures were brought to 50% of their water-holding capacities and held there at 20°C. for periods of 0, 4, 8, 16 and 32 days. At the set times they were extracted by shaking for one hour with 60 ml. of semi-molar magnesium nitrate, the magnesium nitrate solution being first adjusted to pH 7. The manganese was estimated by the colorimetric-periodate method.

The results (Fig. 1) show that liming of the Penola soil from pH 7 to 8 decreased the manganese extracted from approximately 2000 γ to 500 γ at 32 days and brought it to the level of that extracted from the Yambuk soil.

These results make it desirable to investigate the part played by the soil pH in the estimation of available manganese. JONES and LEEPER (1) have suggested that this should be done by looking for active oxides, since they can cure deficiency. Their method is a modification of the extraction with quinol in solution with electrolyte and consists essentially of separating reduction and exchange by successive treatments with solutions of quinol and electrolyte. This ensures that reduction is confined to the outermost layers of the oxide particles thus giving a more sensitive test and a better correlation with the health of plants.

10 mg. samples of the oxide used above were mixed with 6 gm. samples of the Penola soil at pH 6·9 and 8·0 and the Yambuk soil at pH 8·0. The soil-oxide mixtures were shaken for half-an-hour with 60 ml. of 50% aqueous alcohol containing 0·05% quinol, centrifuged and filtered. Quinol was removed by washing three times with 50% aqueous alcohol using a centrifuge. The mixtures were then shaken for one hour with 60 ml. semi-molar magnesium nitrate and finally leached with three successive 20 ml. lots of magnesium nitrate.

*Manganous manganite prepared by slow addition of $MnSO_4$ to $Ca(MnO_4)_2$ solution.

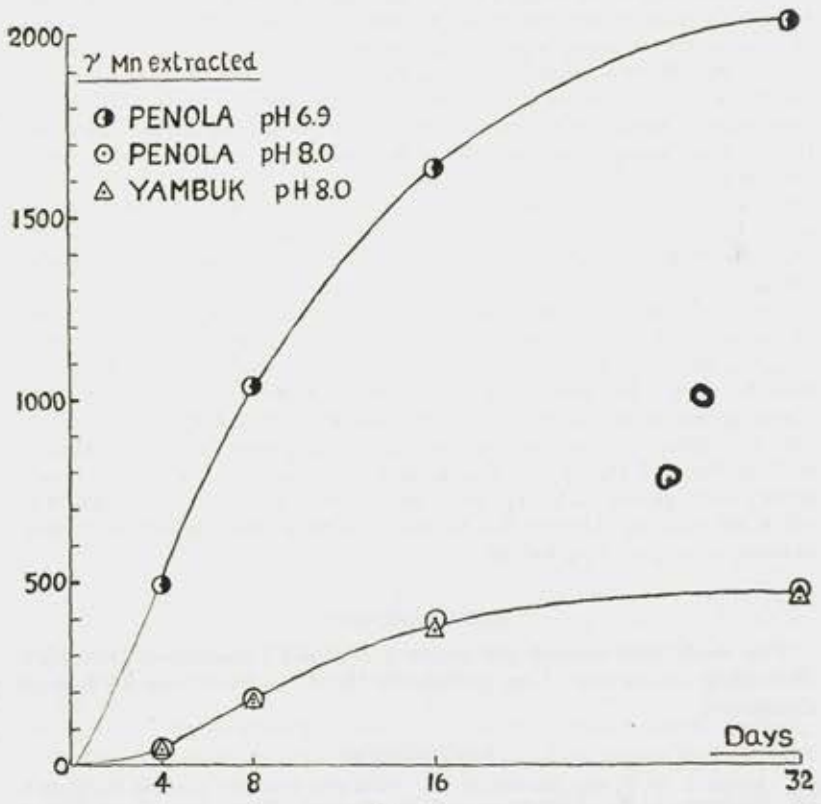


Figure 1

Manganese extracted from 10 *mg. oxide in soil mixtures after incubating with sodium azide at* 20°C. *(soil blanks deducted). Extractant: semi-molar magnesium nitrate.*

Alcoholic and magnesium nitrate solutions were adjusted to pH 7 before use in extraction. The manganese in the combined filtrates was estimated by the colorimetric-periodate method.

Again the results (Table 1) show that the manganese extracted from the Penola soil is considerably decreased when it has been limed to pH 8·0 and that it is at much the same level as that extracted from the Yambuk soil. It is of interest to note that in both experiments (Fig. 1 and Table 1) the amounts of manganese extracted at pH 8 are about one quarter of those extracted at pH 7.

Table 1

Mn extracted from 10 *mg. oxide in soil mixtures using* 0·05% *quinol followed by semi-molar magnesium nitrate (soil blanks deducted).*

Penola pH 6·9	Penola pH 8·0	Yambuk pH 8·0
666	169	154

These decreases in extraction of manganese from soils limed from pH 7 to 8 may be the result of two effects. The first is the reduction of manganese dioxide which may be written formally as: $MnO_2 + 4H^{++} + 2e = Mn^{++} + 2H_2O$. The reducing agent which supplies the electrons may be either a component of the organic matter as in the experiments with sodium azide, or quinol as in the latter chemical test. The manganese dioxide potential falls more rapidly with increasing pH than most redox systems, including quinol and this is probably the main reason for the decreased release of the bivalent ion. The second possibility is a tighter binding of manganese by the colloids at pH 8 than at pH 7, resulting in a somewhat less efficient extraction.

The main point of this note is to draw attention to these relations of the soil pH. It was suggested in an earlier paper that the activity of manganese oxides in soils is determined by their surface area and disorder—we must now include soil pH even within the range 7 to 8. There appear to be two possible improvements in making the described test to determine the manganese supplying power of soils. One is to lime the soil, to say pH 8, and then carry out the successive treatments with quinol and displacing salt. The other is to disregard the pH when making the test but to take it into account where necessary in establishing limiting values.

Acknowledgment

This work was carried out under a Nuffield Foundation Dominion Travelling Fellowship. I am grateful to Dr. E. G. WILLIAMS for helpful discussion.

REFERENCES

(1) JONES, L. H. P. and LEEPER, G. W. *Plant and Soil*, **111**, 141 and 154 (1951).
(2) QUASTEL, J. H. Lecture on Soil Metabolism. Royal Inst. Chem., Great Britain and Ireland (1946).

THE BORON STATUS OF IRISH SOILS IN RELATION TO THE OCCURRENCE OF BORON DEFICIENCY IN SOME CROPS IN ACID AND ALKALINE SOILS

T. WALSH AND J. D. GOLDEN

Department of Agriculture, Ireland

Boron deficiency has been recognized for a considerable time as playing an important part in crop production under Irish conditions, especially in relation to the growth of certain crops such as sugar-beet, swedes and mangels. More recently its importance in connection with other crops such as Lucerne, clover and raspberries has been under investigation. Information in this sphere has previously been summarised by WALSH (3) who reported the occurrence of "brown heart" in swedes in acid soils mainly derived from certain shales. In order to get some specific data on the boron status of Irish soils and related problems, field and laboratory investigations have been in progress for some time past. This paper presents a summary of findings in relation to one aspect of the investigation, i.e., the diagnostic value of a water-soluble boron method for soils.

During the course of this investigation it has been clearly established both by field experimental work, tissue analyses and deficiency symptoms that in addition to being a highly important problem on alkaline soils, boron deficiency also occurs to a considerable extent on strongly to moderately acid soils, especially in relation to the growth of swedes. Other crops may also be affected. Consequently in investigating he diagnostic value of a water-soluble boron method, a considerable range of soils where pH and calcium status is concerned was available.

Method used

After a number of methods were investigated that of HAAS (2) with some modifications was found to be the most suitable. It is not intended to describe fully the method used here. Briefly, one part of soil is refluxed with two parts of distilled water in a boron-free glass flask for 10 minutes and filtered. After colour development the concentration is read on a defraction grating spectrophotometer at a wave-length of 540 Mu. Plant samples were analyzed for total boron content by the same method after dry ashing as recommended by DIBLE *et al.* (3).

Results

In presenting the data from this investigation it has been found desirable to differentiate between the results from the acid soils and those from the high lime alkaline soils.

Acid soils

A number of instances of boron deficiency especially as reflected in the occurrence of "brown heart" in swedes have been recorded. The soils where this condition develops in a severe form are generally

coarse textured sandy loams derived from sandstones and quartzite. However, it has also been found on relatively fine textured medium loams to clay loams derived from Silurian and Carboniferous shales. In all some hundreds of soil samples from affected areas have been examined ; the results from selected cases being presented in Table I. In this table data for pH (glass electrode on a 1 : 1 soil-water suspension) and available calcium as determined on a 1 : 5 soil MORGAN extract are also given. The numbers refer to laboratory numbers used during this investigation. A summary of some of the characteristics of the soils is given as a footnote to the Table.

TABLE I

Lab. Nos.	pH	Available Calcium lb. per ac.	Water Soluble Boron p.p.m.	Plant Species	Incidence of Boron Deficiency
B.We. 654	4·8	400	0·34	Swedes	Badly diseased
655	4·6	400	0·40	,,	Badly diseased
656	4·7	400	0·40	,,	Badly diseased
657	4·4	400	0·62	,,	Healthy
671	5·3	800	0·10	,,	Badly affected
672	5·3	800	0·37	,,	Badly affected
B.Cl. 278	5·9	1,200	0·25	,,	Badly affected
279	5·5	1,200	0·35	,,	,, ,,
281	6·0	2,500	0·40	,,	,, ,,
282	5·3	1,200	0·35	,,	,, ,,
283	5·7	1,200	0·40	,,	,, ,,
159	5·2	1,200	0·20	,,	,, ,,
B.Co. 348	5·5	1,200	0·37	,,	Badly affected
349	5·2	1,200	0·33	,,	,, ,,
350	5·4	1,200	0·42	,,	Healthy
351	5·5	1,600	0·47	,,	,,
B.Kd. 18	5·9	2,000	0·30	Raspberries	Severe
21	5·7	2,000	0·30	,,	Severe
22	5·8	2,000	0·70	,,	Healthy

Note : B.We. : These samples were taken from a soil series in South Wexford where boron deficiency has been identified as severe. They are mainly coarse sandy light and medium loams with a considerable quartzite influence. They appear to be highly weathered soils and in addition to quartzite have been influenced to a lesser extent by Cambrian and Silurian shales. Swede samples taken from area represented by samples 654 to 657 showed 10·2 p.p.m., 14·2 p.p.m. and 8·3 p.p.m. B in roots, stalks and leaves respectively. Moderately healthy swedes under similar conditions showed 16·0 p.p.m. B in roots. Under these conditions rye grass showed 6·30 p.p.m., Cocksfoot 7·20 p.p.m. and Red Clover 21·80 p.p.m. boron (dry matter), the samples strictly uniform relative to soil type.

B.Cl. : These soils are generally free-draining coarse sandy light and medium loams derived from Old Red Sandstone in Co. Clare. Swede samples analyzed from site 159 showed 14 p.p.m. B in leaves and 16 p.p.m. in crowns.

B.Co. : Similar nature to the Co. Clare soils.

B.Kd. : These soils are derived from fluvio-glacial materials mainly derived from Carboniferous shales and somewhat influenced also by Silurian rocks.

Slightly acid and alkaline soils

The incidence of boron deficiency is more widespread in slightly acid and alkaline soils than under more acid conditions. The most severely affected areas are on freely draining high lime soils on fluvio-glacial materials and, as with experience elsewhere, the condition is worst in dry seasons, these areas being particularly susceptible to drought conditions. There are also a number of other soils which are free of boron deficiency when unlimed, but which when limed become very boron deficient. Analytical data for selected numbers of these soils are given below :

TABLE II

Lab. Nos.	pH	Available Calcium lb. per ac.	Water Soluble Boron p.p.m.	Plant Species	Incidence of Boron Deficiency
B.Cl. 658	5·7	4,500	0·69	S. Beet and	Healthy.
659	7·3	10,000	0·37	Swedes	Severe.
B.Co. 663	6·8	3,500	0·47	S. Beet	Severe.
665	6·9	2,500	0·91	S. Beet	Healthy.
B.Ca. 651	6·5	5,000	0·77	S. Beet	Healthy.
652	7·3	6,000	0·62	,,	Very severe.
653	7·8	10,000	0·62	,,	Very severe.
B.Kd. 184	7·4	10,000	0·30	S. Beet	Very severe.
185	7·3	10,000	0·20	,,	Extremely severe.
B.Kd. 210	6·7	3,000	0·25	Raspberries	Severe.
B.Kd. 196	7·1	10,000	0·35	,,	
B.Of. 350	7·8	10,000	0·53	Lucerne and S. Beet.	Severe.
B.Of. 354	7·5	10,000	0·64	Swedes	Severe.
355	7·6	10,000	0·70	,,	Severe.
B.	6·8	10,000	1·04	Raspberries	Very healthy.
B.We. 1	6·7	3,000	0·4	S. Beet	Severe.

Note : B.Cl. : Is derived from Old Red Sandstone. These soils were limed, this applying also to the B.Co. soils. They are coarse sandy medium loams.

B.Ca. : These soils are light to medium loams derived from calcareous fluvio-glacial materials naturally rich in lime.

B.Kd. : Belonging to the same soil series as B.Ca.

B.Of. : Similar series to B.Ca. Swede samples and roots, inner leaves and outer leaves taken from B.Of. 354 and 355 soil showed boron contents of 3 p.p.m., 12 p.p.m., and 6 p.p.m. respectively. Lucerne samples taken from "no boron" plots here showed boron values of 28·2 p.p.m.

B.We. : Similar to We. soils indicated in footnote to Table I but limed.

Discussion

In using water-soluble boron as a diagnostic method it is obviously necessary to distinguish between the occurrence of boron deficiency in moderately and strongly acid soils and under slightly acid and alkaline conditions, in fixing threshold values. There may also be other factors such as susceptibility of soil to drought. From the experience gained in this study a threshold value of 0·40 p.p.m. of boron has been fixed for acid soils while a threshold value of 0·75 p.p.m. is considered desirable for alkaline soils. For acid soils which are to be limed and sown with boron sensitive crops it is desirable that a boron level of at least 0·60 should be present and when the liming material has become intimately mixed with the soil it is desirable that this level should be raised to that fixed for naturally alkaline soils. Other investigations which have proceeded have shown the water-soluble boron method to reflect the addition of borax to soils two years after application. For instance, in an experiment conducted on the We. soils indicated, the following results were obtained. In this experiment each treatment was replicated 12 times and the results here are the average of these treatments.

TABLE III

No Borax	.. 0·37 p.p.m.
25 lb. per acre Borax	.. 0·63 p.p.m.
50 lb. per acre Borax	.. 0·74 p.p.m.

It can be seen, therefore, that the water-soluble boron method has proved very useful in connection with boron deficiency studies on Irish soils. It has in fact been of very considerable value in ordinary routine soil fertility diagnostic work in allowing the possibility of boron deficiency being determined before the sowing of crops. Its use has also brought to light the existence of boron deficiency in areas which were previously non-suspect in this connection, and has also raised the problem of the effect of boron deficiency in a number of other crops, especially legumes in pasture swards.

It may also be of interest to record that where boron deficiency has been observed on some acid soils that lime deficiency effects are extremely severe and this effect may be due to the low intake of boron observed by some workers at low levels of calcium, in nutrient culture solutions. In this connection it may be desirable to consider boron deficiency as an important factor in the soil acidity complex. It is also of interest that in three of the cases investigated molybdenum deficiency has been found to co-exist with boron deficiency in strongly acid soils.

Summary

An account is presented of the application of a water soluble boron method to a study of the boron status of some soils. Attention is drawn to the occurrence of boron deficiency in a severe form on some acid lime-deficient soils. In interpreting water-soluble boron figures for soils it is considered desirable to take into account the pH and lime status of the soil, a threshold value for moderately and strongly acid soils being 0·40 p.p.m. boron and for alkaline soils at 0·75 p.p.m. For acid soils to be limed and sown with boron sensitive crops a level of 0·60 p.p.m. is considered desirable. Some boron values for different crops and parts of crops under boron deficient conditions are given.

LITERATURE

(1) DIBLE, W. T. *et al.* Personal Communication (1951).
(2) HAAS, A. R. C. *Soil Sc.*, **58**, No. 2 (1944).
(3) WALSH, T. *J. Dept. Agr., Irelana*, **39**, No. 1 (1942).

COPPER AND ZINC DEFICIENCIES IN SOIL AND FRUIT TREES IN BRITAIN

C. BOULD, D. J. D. NICHOLAS AND J. TOLHURST

Long Ashton Research Station, University of Bristol, England

In 1948 our attention was drawn to a serious failure of apple and pear trees at the National Fruit Trials, Wisley, and we have been able to show that the main cause was due to copper and zinc deficiency (1, 2). Since then we have confirmed copper and zinc deficiency in apples and other fruits at further centres in the South of England by means of chemical and *Aspergillus niger* (M) soil tests, and by leaf and bark analyses. Control measures have also been tested, including foliage and dormant season sprays and stem and branch injection. These results constitute the first record of copper and zinc deficiency in fruit trees in Britain, although cereal crops in E. Anglia are known to suffer from copper deficiency. Full experimental details of this work will be appearing shortly in the *J. Hort. Sci.* (in press).

Experimental

Soil

Wisley. The soil at Wisley is a medium-coarse sand and gravel overlying deep gravel. A typical profile is as follows :—

0–13″ Dark brown medium sand, single grain structure, compact, with few medium-sized stones.

13–48″ Sharp change in colour at 13″ to a yellow coarse sand, less compact with increasing amounts of ½″ to 1″ gravel. This horizon is fairly moist with a water table at 48″ (8.3.50).

The soil was acid until 1943 when two tons per acre of ground chalk were applied followed later by a further two tons per acre of dolomite. In 1948 the pH of the profile from the surface to below 12″ decreased with depth from 7·2 to 6·8. Further information is given in Table I.

Other Centres. Zinc and copper deficiencies have been found in fruit growing on other soils derived from the Greensand and Corallian formations and on coarse alluvial deposits. Data on the available copper and zinc content of these soils are given in Table II.

TABLE I

Chemical data for soil from an area at Wisley where fruit trees showed severe zinc deficiency

Depth	pH	Organic* Matter		μg Zn per gm. of soil (p.p.m.)			
			% P_2O_5 soluble in 1% citric acid	Ex. Zn N. neutral ammonium acetate method	Zn soluble in N. ammonium acetate adjusted to pH 4·5	Zn soluble in cold 0·1 N. hydrochloric acid	*Aspergillus niger* method
0– 6″	7·2	1·29	0·059	1·31	8·9	10·2	1·5
6–12″	7·0	0·83	0·030	0·74	2·9	4·0	0·5
12″+	6·8	0·45	0·022	0·90	2·7	3·6	—

*Organic carbon × 1·724

TABLE 2

The available zinc and copper in soils as determined by the Aspergillus niger method

Location	Depth of soil sample	as μg per gm. of air-dry soil		Zn and Cu deficiency symptoms in fruit trees
		Zn	Cu	
Wisley (Surrey)	0– 6″ 6–12″	1·5 0·5	0·8 0·4	Severe
,, ,, ,, ,,	0– 6″ 6–12″	4·0 2·0	1·2 0·8	Slight
,, ,, ,, ,,	0– 6″ 6–12″	9·0 4·0	3 to 4 2	Nil
Liss (Hants) ,, ,,	0– 6″ 6–12″	— —	0·8 0·6	Severe die-back
Long Ashton (Somerset) ,, ,, ,,	0– 6″ 6–12″	30·0 20·0	25 15	Nil

Symptoms

Zinc deficiency. In apple trees the first symptoms appear at the time of flowering. The affected shoots carry sparse foliage and show typical short internodal growths with leaf rosetting and shoot die-back. (This is a winter die-back not to be confused with the summer die-back due to copper deficiency). The leaves are much reduced in size and tend to be lanceolate, with wavy margins and diffuse intervenal chlorosis often with a narrow dark-green marginal rim. Shoots and spurs are markedly brittle and the bark of older growths may be somewhat rough. It is unusual for the whole tree to be affected. Certain branches may show deficiency effects whilst others on the same tree appear normal. Fruits on affected spurs are much reduced in size.

In pear the symptoms are not so clearly defined as in apple. The leaves are much reduced in size, with a tendency for the edges to curl upwards but without the marginal waviness shown by apple. Pear leaves may also show a diffuse intervenal chlorosis.

Apple and pear trees that are severely affected by the deficiency are stunted and make little extension growth.

Copper deficiency. In apple the first symptoms appear in early July on the terminal leaves of the current-year shoots as large irregular necrotic areas accompanied by upward curling and distortion of the leaves. The lower leaves on affected shoots are usually lustreless and frequently show numerous small irregular necrotic areas. Towards the end of July defoliation of the shoots occurs, progressing basipetally and from September onwards they wither and die, hence the names "wither tip" and "summer die-back." In older trees, when the deficiency is severe, the bark of the main branches and trunk becomes very rough and deeply fissured. This is followed by localised death and shedding of bark tissues, and profuse sucker development from the basal portions of the tree.

In pear the symptoms are similar to those in apple. The terminal leaves on current-year shoots are first to be affected. The leaf tips become yellow and this stage is followed rapidly by necrosis and death. The dead shoots are usually black in colour.

Chemical data. Chemical data on soil from an area at Wisley showing zinc deficiency are given in Table I. Further information on soils from Wisley and elsewhere is given in Table II. Zinc and copper were determined chemically by the method of HOLMES (3) and biologically by the *Aspergillus niger* method (4). The results of plant analyses are given in Table III.

TABLE 3

The copper and zinc content of healthy and deficient leaves of fruit trees

Fruit and Location	Zn as μg per gm. dry matter	Symptoms	Cu as μg per gm. dry matter	Symptoms
Apple				
Laxton's Pearmain (Wisley)	9·6	Normal from deficient tree	1·4 to 2·3	Shoot die-back
	1·2	Little leaf and rosettes		
Hereford Cross (Wisley)	3·0	,,	1·3 to 3·0	,,
Lanes Prince Albert (Long Ashton)	18–30	Normal	5·1 to 7·9	Normal
Pear				
Conference	22–23	Normal	8·0	Normal
Conference (Exeter)	—	—	1·1	Severe die-back
Cherry				
Sweet Cherry (Holland)	13	Rosettes	14·2	Rosettes
Morello Cherry (Exeter)	17·6	Slight rosetting	3·1	Shoot die-back
Almond (Exeter)	41·5	Normal	3·1	Shoot die-back
Almond (Exeter)	21·6	Little leaf	—	Shoot die-back

Discussion

The results in Table II indicate that when the available zinc in the soil, as determined by the *Aspergillus niger* method, falls below 5 μg Zn per gm. (p.p.m.) in the top 6" of air-dry soil the trees are liable to suffer from zinc deficiency. When the value is as low as 1 to 2 p.p.m. the deficiency becomes severe. A normal soil contains more than 10 p.p.m. of available zinc.

Plant analyses also differentiate between normal and zinc deficient trees. In apple, from July onwards, the threshold value appears to

be about 10 p.p.m. of zinc in the dry matter of leaves and bark. When the value falls to 5 p.p.m. or less "little leaves" and "rosettes" appear and the trees become stunted.

The deficiency is easily remedied by foliage or dormant sprays. Foliage sprays of 0·1% zinc sulphate, plus a wetting agent, should be applied at petal-fall or shortly afterwards. Zinc sulphate at 4 to 5% may be applied during the dormant season. Injection of solid zinc sulphate into the trunk and branches will correct the deficiency but the method is tedious and liable to cause local damage to the tissues.

The threshold value for available copper in soil, as determined by the *Aspergillus niger* method, is about 2 μg Cu per gm. of air-dry soil. The threshold copper level in apple and pear leaves, associated with the onset of visual symptoms, is less than 5 μg Cu per gm. of dry matter.

Copper deficiency can be remedied by soil application, foliage sprays, dormant sprays and injection of copper salts. From ¼ to ½ lb. of copper sulphate applied round each tree is effective and causes no damage. Dilute foliage sprays of copper sulphate at 0·05% concentration, plus a wetting agent, applied in June and early July will prevent the onset of leaf symptoms. Dormant sprays of 4 to 5% copper sulphate are equally effective. Bordeaux and other proprietary compounds are also effective when applied as foliage sprays, but sometimes cause damage to the leaves.

REFERENCES

(1) BOULD, C., NICHOLAS, D. J. D., TOLHURST, J. A. H., WALLACE, T. and POTTER, J. M. S.: Zinc deficiency of fruit trees in Britain. *Nature*, **164**, 801 (1949).

(2) ————: Copper deficiency of fruit trees in Britain. *Nature*, **165**, 920 (1950).

(3) HOLMES, R. S.: Determination of total copper, zinc, cobalt and lead in soils and soil solutions. *Soil Sci.*, **59**, 77 (1945).

(4) NICHOLAS, D. J. D. and FIELDING, A. H.: The use of *Aspergillus niger* (M) for the determination of magnesium, zinc, copper and molybdenum available in soils to crop plants. *J. Hort. Sci.*, **24**, No. 2, 125 (1951).

THE MOLYBDENUM CONTENT OF SOME BRASSICAE AND LETTUCE CROPS IN ACID SOILS

WILLIAM PLANT

Long Ashton Research Station, University of Bristol, England

Molybdenum deficiency in England and Wales has only been recorded on acid soils. The soils affected have been derived from a wide range of parent material; Granite, Devonian, Old Red Sandstone, Keuper and Lower Greensand.

As molybdenum deficiency occurs in the soil acid complex the visual syndrome can be masked by other symptoms due to other elements present in excess. This, however, will depend on the particular soil and its parent material.

Using a range of crops grown in a molybdenum deficient soil the cauliflower, brussel sprout and lettuce have been the most susceptible.

Evidence of molybdenum deficiency has been obtained by the crop response to application of sodium molybdate and the analysis of leaf material for molybdenum content. The effect of lime on raising the soil pH and in turn making molybdenum more available to the plant is a complementary treatment to the application of sodium molybdate.

In the following table the relative values of molybdenum content of some crop plants are given.

TABLE 1

Molybdenum content of some crops in relation to soil pH

Crop	Symptoms of Mo deficiency	Soil p.m.	Soil pH	p.p.m. Mo in leaf dry matter
Cauliflower	severe	Old Red Sandstone	4·5	0·07
,,	none	,,	6·5	0·30
Cabbage	medium	,,	4·5	0·09
,,	none	,,	6·5	0·42
B. Sprout	severe	,,	4·5	0·09
,,	none	,,	6·5	0·61
Kale	trace	,,	4·5	0·15
,,	none	,,	6·5	0·90
Rape	none	,,	4·5	0·20
,,	none	,,	6·5	1·00
Oat	none	,,	4·5	0·17
,,	none	,,	6·5	0·60
Barley	none	,,	4·5	0·18
,,	none	,,	6·5	0·41
Potato	none	,,	4·5	0·09
,,	none	,,	6·5	0·34
Lettuce	severe	Lower Greensand	5·2	0·06
,,	none	,,	6·4	0·10

It is seen from Table I that of the 5 brassicae the cauliflower and brussel sprout are most susceptible to Mo deficiency. Rape failed to show the deficiency and it is interesting to note that the Mo value of this crop did not fall below 0·20 p.p.m. even where the soil reaction dropped to pH 4·5. Oat, barley and potato showed no symptoms of the deficiency. Lettuce, however, showed severe symptoms of Mo. deficiency.

In order to demonstrate that the Mo content of the leaf is no criterion of the presence of symptoms the results from 2 experimental centres are recorded in Table 2.

TABLE 2

The symptoms in cauliflowers on different acid soils

Crop	Symptoms	Soil p.m.	Soil pH	Leaf Dry Matter	
				p.p.m. Mo	p.p.m. Mn.
Cauliflower	Mo. deficiency	Lower Greensand	5·0	0·05	100
,,	Mn. Al toxicity	Old Red Sandstone	4·5	0·06	3,510

It is noticeable from Table 2 that the cauliflower growing on the Lower Greensand contained only 100 p.p.m. Mn whereas the plants growing on the Old Red Sandstone contained 3,510 p.p.m. Mn. This latter content of Mn in itself would be enough to prevent the cauliflower from growing satisfactorily. Under such conditions, therefore, molybdenum deficiency would not occur although, as in the other case, the Mo content was exceedingly low.

It is thus evident that the correlation between molybdenum content and the occurrence of deficiency symptoms is dependent upon the parent material, soil pH reaction and the type of crop.

The experimental data described in this paper deals entirely with the unavailability of Mo to certain crops under conditions of soil acidity. The visual syndrome and the mineral content of crops growing in Mo deficient soils of neutral reaction might present a different set of conditions.

SELENIUM LEVELS IN ROCKS, SOILS AND HERBAGE FROM A HIGH SELENIUM LOCALITY IN IRELAND

T. WALSH AND G. A. FLEMING

Department of Agriculture, Ireland

Selenium Poisoning or Alkali Disease as it was at one time called in the U.S., has been reported from a number of arid and semi-arid areas in countries such as China, Turkestan, Hawaii, Mexico, the Western States of the U.S. and in Canada. Apart from an instance reported by WALSH *et al.* (11) this condition does not appear to have been reported under humid climatic conditions. In a preliminary report (11) it has been shown that this condition in its chronic form is associated with a series of soils in County Limerick. In this area the condition has for many years been known to develop in livestock confined to affected areas and has on occasion set a serious farming problem especially where any appreciable area of a single holding is affected.

In horses the disorder in its severe chronic form is shown by the loss of hair from mane and tail with alteration in the growth and eventually loss of hoof. A less severe form is shown in hoof deformation. In cattle the hooves are also deformed with eventually the sloughing off of the old hooves and loss of tail. Cattle so affected show poor condition and are unable to move any appreciable distance, assuming a kneeling posture when grazing. White coloured cattle appear to be the most sensitive.

Since this preliminary report further investigations have proceeded and this paper summarises some of the more important findings to date. These investigations have taken the form of herbage and soil sampling from affected and nearby non-affected areas, botanical analysis of affected pastures, the examination and analysis of geological strata which may have influenced soils, the carrying out of field experiments and preliminary soil surveys to segregate the affected areas, and some livestock experiments.

Determination of selenium in soils and plants

Methods of examination

It is generally agreed (4) that extraction of selenium from soil and herbage is best accomplished by digestion of the samples (in the case of herbage after wet oxidation) with constant boiling point hydrobromic acid to which a little bromine has been added, and subsequent distillation in an all glass apparatus. This method which has been outlined by NOYES and BRAY (6) and developed by ROBINSON *et al.* (9) removes the following elements if present, As, Sb, Sn, Ge and Se. On decolourisation of the distillate with SO_2 selenium alone is precipitated so that this element is hereby separated from all others.

Many workers have employed this method (9), (1), (7), (8) and the original papers and articles may be consulted for exact details. The final evaluation of the element may be accomplished turbidimetrically

(1), (7), colorimetrically using codeine sulphate (2) or volumetrically using the NORRIS-FAY reaction (5).

$$4HBr + H_2SeO_3 + 4Na_2SeO_3 \quad Na_2S_4O_6 + Na_2S_4SeO_6 + 4NaBr + 3H_2O$$

$$1 \text{ ml. } \frac{N}{100} Na_2S_2O_3 = 198 \text{ micrograms Se.}$$

The turbidimetric method is liable to subjective errors unless in the hands of a skilled operator and matching of coloured suspensions is not easy, a fact which has been commented upon by ROBINSON (9).

Colour fading has been found to cause trouble in the codeine sulphate method (3) but a method for combating this has also been described (2).

The volumetric method which has been discussed by KLEIN (4) would appear to be the best and it has been adopted in the soil laboratory of the Department of Agriculture.

Geological

The area rests on carboniferous limestone covered by glacial drift. To the immediate west lie shale beds and these appear to have considerably affected the nature of the local drift. These shale beds are known to contain appreciable pockets of iron pyrites which may be of significance as it has been shown by U.S. work that such pyritiferous shales can be a source of selenium. Some rock samples selected from nearby outcrops showed the following selenium levels :

TABLE 1

Lab. No.	Site No.	Type of Rock	Se content p.p.m.
Se. 21 ...	1	Pyritiferous Shale	8·9
22 ...	1	do.	28·5
27 ...	2	Shale Bed	0·85
28 ...	2	do.	5·8
29 ...	3	Shale Bed in Limestone	2·0
30 ...	4	Calp Limestone	0·97

By comparison with U.S. and other figures some of these samples show relatively high levels of selenium. It is seen that the highest level was obtained in the pyritiferous shale. It is of interest also that such shales are also found in other parts of the country.

Soils

The soils on which the condition occurs are low-lying dark coloured valley soils with a moderately high organic matter content of about 15%. An important feature of these soils is the moderate to severe degree of drainage impedence and hence the incidence of periodic reducing conditions. The surface soil to a depth of about 1 ft. is a dark coloured somewhat colloidal organic soil which is underlain by a calcareous grey black fine textured clay loam. At a somewhat higher elevation normal brown loams typical of soils formed on predominantly limestone drift in this country are found. Preliminary

selenium estimations from soils in the affected area showed levels between 30 and 324 p.p.m. of selenium, whereas samples from immediately adjoining healthy areas showed levels less than 2 p.p.m. The latter is not an unusual figure for many soils as a trace of selenium at least appears to occur in most normal soils. In pursuing these investigations further, samples were taken along a cross-section of a valley on a profile basis. The results of the analysis for selenium are recorded in Table II.

TABLE II

(Showing p.p.m. Selenium in soils in relation to topography)

Depth of Sample	Profile No.				
	1	2	3	4	5
	Se p.p.m.				
0–6″	0·53	—	1·85	63·40	53·50
6–12″	1·24	6·16	3·17	207·00	
12–24″	0·71	5·89	1·40	119·00	
24–30″	0·68	4·12	2·05	225·00	35·60

Profile 1. These samples were taken from a uniform free draining brown loam situated midway up a moderate slope rising gradually from the valley bottom.

Profile 2. Essentially similar to Profile 1 but further down the slope.

Profile 3. Is situated close to the valley bottom and practically at the junction of the two different soil series.

Profile 4. These samples were taken at the lowest point in the valley and from the soil series affected.

Profile 5. These samples were taken at a short distance from Profile 4 but at a somewhat higher level where drainage was somewhat less impeded.

The figures show a striking difference between the two different local soil series and also show that little in the way of selenisation of the surrounding area has taken place. However, with a herbage species of selenium accumulating ability and possibly a change in the soil conditions towards greater availability of the selenium present, the selenium content of the soil as represented by Profile 2 might be sufficiently high to be dangerous. In terms of selenium levels those shown by Profile 4 can be regarded as extremely high, a sample showing 324 p.p.m. having also been obtained from the same valley. In connection with soil conditions in general it may be noted that so far all soils examined from toxic areas have been alkaline in reaction and manganese deficiency for cereals is generally a serious problem in these soils. It is also of considerable interest that molybdenum is present in sufficient quantity to bring about herbage containing enough molybdenum to cause molybdenum conditioned copper deficiency in animals. This latter may be a complicating factor where the poor condition in the animals is concerned. It is of interest in

this connection that ROBINSON *et al.* (10) have shown that molybdenum toxicity may accompany selenium toxicity in certain areas. Herbage samples taken here have shown molybdenum levels in the region of 20 to 30 p.p.m. while readily available molybdenum in the soil is in the region of 0·60 to 0·80 p.p.m. which is well within the dangerous range as defined by WALSH, NEENAN and O'MOORE (12).

Herbage

Some very high selenium values have been recorded for mixed herbage samples taken from this area. Where the selenium level of the soil was highest these samples showed a selenium level of 500 p.p.m. while herbage samples taken from the area represented by Profile 4 above showed values in the region of 150 to 500 p.p.m. So far it has not been possible to examine in sufficient detail the selenium content of all the different grass and herbage species found in the area but in some preliminary work in conjunction with field experiments on one farm where different manurial treatments, including sulphur, are being investigated the following results were obtained (see Table III). The soil in this case showed levels of selenium varying from 40 to 88 p.p.m.

TABLE III

Herbage Species	Manurial Treatment	Se p.p.m. (dry matter)
Spirea Ulmaria (Meadow Sweet)	Sulphur	32·57
do.	No treatment	29·60
Festuca Pratensis (Meadow Fescue) ...	do.	117·30

These figures show meadow fescue as containing much more selenium than meadow sweet. The samples analysed were selected from the same sward, and sulphur did not appreciably affect selenium intake under these conditions. Investigations are also proceeding on the selenium content of cereals and other crop plants from this area. Barley grain grown under exactly similar conditions as the herbage species recorded in Table III showed a selenium content in the grain of 7·2 p.p.m. which according to U.S. figures would be reckoned as in the danger region where cereal grains are concerned. This is one of the highest figures recorded for barley grain.

Botanical composition of affected pastures

In view of the known high selective absorption effect of some herbage species such as *Astragalus Spp.* for selenium it was decided to obtain information on the distribution of the different herbage species in affected pastures. From a botanical analysis of four farms none of the species normally listed as selenium accumulators was found.

In the pastures examined there were some 40 different species present, a typical analysis being as follows (percentages approximate) :— Carex panicea and Carex diversicolor, 30% ; Spirea ulmaria, 20% ; Juncus inflexus, 10% ; Agrostis stolonifera, 10% ; Festuca pratensis, 5% ; Festuca rubra, 3% ; Ranunculus species, 3% ; Anthoxanthum odoratum, 2% ; Holcus lanatus ; Hydrocotyl vulgaris ; Cnicus pratensis ; Moss ; Scabiosa Succisa ; Potentilla anserina ; Potentilla tormentilla and some 24 other species. All these species are being examined for selenium content.

General remarks

The occurrence of selenium toxicity under these conditions is of interest in so far as it appears to be the first recorded instance under humid conditions. In this connection it is significant that the environment of its occurrence is not particularly unusual where the local geological, soil, or topographic conditions are concerned, as such conditions can be found in other areas in the country. In influencing the occurrence of selenium toxicity in these soils two factors are of obvious importance : (1) the presence of considerable quantities of selenium in local rocks and (2) the impeded drainage and somewhat organic condition of the soil. Under the latter conditions accumulation might be expected from surrounding drainage inflow, while loss through leaching is at a minimum. In addition, under the reducing conditions operating, optimum conditions exist for selenium uptake by ordinary herbage species, while it is on record that humans eating the produce from some of these soils in the past have been affected through the loss of finger and toe nails and hair. It is also of interest that water available to livestock when depastured on these soils contains appreciable amounts of selenium.

Summary

This paper presents an account of some aspects of selenium toxicity which have been identified with an Irish soil series. Among local rocks examined pyritiferous shale showed 28·2 p.p.m. of selenium. Data are also given for the selenium content of soils and herbage species from affected and nearby non-affected areas. A botanical examination of the area did not reveal anything unusual in the way of accumulator plants. Meadow fescue showed a higher level of selenium than meadow sweet, while barley grown under such conditions gave a value of 7·2 parts per million of selenium in the grain. It is thought that the high level of selenium found in the herbage is considerably influenced by the impeded drainage conditions of the soil, the reducing conditions set up leading to enhanced availability of selenium, and the impeded drainage preventing loss through leaching.

We wish to thank Mr. J. J. PRENDERGAST for the botanical examinations.

LITERATURE

(1) BYRES, H. G. *et al.*
(2) GORTNER, R. A., and LEWIS, H. B. *Ind. Eng. Chem.* (*Anal. Ed.*), **11**, 198 (1939).
(3) HORN, M. J. *Ibid.*, **6**, 34 (1934).
(4) KLEIN, A. K. *J. Assoc. Official Agric. Chem.*, **24**, 363 (1941).
(5) NORRIS and FAY. *Amer. Chem. J.*, **18**, 705 (1896).
(6) NOYES, A. A. and BRAY, W. C. Qual. Annl. for Rare Elements. McMillen & Co., New York, 1927.
(7) MOXON, A. L. Sth. Dak. Agr. Expt. Stn. Bul. 311, 1937.
(8) TREATISE and BEATH. Champlain Printers, Burlington.
(9) ROBINSON, W. O., *et al. Ind. Eng. Chem.* (*Anal. Ed.*), **6**, 274 (1934).
(10) ROBINSON, *et al. Soil Sc.*, **72** (1951).
(11) WALSH, T., *et al. Nature*, **168** (1951).
(12) WALSH, T., NEENAN, M., and O'MOORE, P. B. *Nature*, **170** (1951).

SESSION 6

BASE EXCHANGE, NUTRIENT BALANCE AND INTERACTIONS

24th July. Chairman: R. K. SCHOFIELD (United Kingdom)

A. C. SCHUFFELEN. Soil Fertility, Ion Intake, Ion Activity and Ion Exchange (Volume I, page 180)

L. WIKLANDER. On the Release of Plant Nutrients (Volume I, page 189)

M. M. ELGABALY. Nutrient Balance and Interaction Effects on Soil Fertility (Volume I, page 195)

SESSIONAL DISCUSSION

E. M. CROWTHER: Dr. SCHOFIELD has asked whether different soils brought into equilibrium with the same solutions would supply nutrients in the same way to plants. I think that they could do so only for a very short time. A soil consisting of almost pure quartz would give up its reserves and become exhausted far more quickly than a well-buffered soil. In treating soil systems in terms of equilibria and chemical potentials, I think that Dr. SCHOFIELD is neglecting the very important factor of time in plant growth. We may be more concerned with diffusion and kinetics than with equilibria.

H. GREENE: As a comment on the paper of Professor ELGABALY will Professor HOMES tell us of his observation that a mixture of plant nutrients found satisfactory for oil-palms in water culture and in sand culture will be equally satisfactory when applied as fertiliser in the presence of soil? This would not be expected with Egyptian soils, for example. Perhaps the observation of Professor HOMES applies to the leached and feebly-buffered soils of the Belgian Congo where plants are growing, as it were, in water culture, but does not apply so clearly to unleached soils of Egypt where most plant nutrients are present in ample amounts and the main need is for water and for nitrogen.

M. V. L. HOMES: The results obtained from water culture experiments in the determination of the requirements of the plant cannot be applied without caution to field conditions. However, the absolute plant requirements (i.e., regardless of the soil), is a component of the general conditions determining the yield level. It is possible, by an adequate method, to determine the actual requirements of a plant in a given soil as a complex consequent on its absolute requirements and the soil supplying power. The special case of the oil-palm tree is not due to the fact that under the conditions in Yangambi, its growth might be compared to growth in water cultures. On the contrary, the soil of the Plateau near Yangambi (Belgian Congo) where oil-palm is grown has a low retention power for water.

H. LEES: On the excellent slides Dr. HEWITT has shown us, the iron-deficient chlorotic plants were bigger than their non-chlorotic

companions supplied with iron. This illustrates the point I tried to make yesterday. Undoubtedly the plants supplied with iron were happier than those not so supplied ; but we do not want happy plants, we want (in general) big plants. This is, of course, an over-simplification and I fully recognise that size is not the only criterion of successful plant husbandry. Nevertheless, size (or rather dry-weight) is usually of major importance and I should like to hear Dr. HEWITT's views on his own very interesting results which seem to me to indicate that, in some cases, yields may be improved by deliberate malnutrition of the plants.

H. L. RICHARDSON : Problems of nutrient balance are complicated by reactions between ions in the growth medium. For example, CARSTEN OLSEN showed, in solution cultures at a range of pH values, that Fe-deficiency chlorosis occurred at reactions slightly below neutral. This was due to a precipitation of Fe by phosphate in the nutrient solution. It could be avoided by using organic salts of Fe, including the citrate. I should like to inquire whether such an effect was likely to happen in sand cultures.

M. M. ELGABALY : We must distinguish between :

(1) normal appearance of plants which require only balanced solution ;
(2) maximum growth requiring optimum concentration in addition to a balanced solution ;
(3) nutritional value of a solution may be high, yet unbalanced, as it may show deficiency or toxicity ;
(4) a dilute balanced solution may be of little nutritional value as measured by yield or rate of growth.

In dealing with the nutrient balance problem in soils it is necessary to :

(1) group plants according to optimum requirements ; this could be done in water cultures ;
(2) set measures for best growth ;
(3) express availability in terms of activity. It is more fruitful to work with clay or amberlite cultures in studying nutrient balance and interactions as results could be better applied to soils than those from solution or sand cultures.

Other speakers in this Session included Drs. SCHACHTSCHABEL, SCHUFFELEN, HEWITT, HOMES, WALLACE, DEAN, FLAIG and SCHOFIELD.

A STUDY OF THE INTERRELATIONSHIPS OF IRON AND POTASSIUM IN THE POTATO PLANT

E. W. BOLLE-JONES

Long Ashton Research Station

Potato plants, variety Majestic, were grown at factorial levels of iron and potassium in pots and cultures (1) during 1948-49-50 and 51 to study the interrelationship of iron and potassium in the plant and the effect of calcium carbonate and phosphorus on this interrelationship. Young and old foliage were sampled in regions which were visually most responsive to the different levels of iron and potassium supply. The laminae were analyzed for chlorophyll content, MORGAN's soluble and total nutrient contents and also extracted with various reagents to obtain fractions of "active" iron (2) which could be correlated with chlorophyll content. The main findings are summarised below.

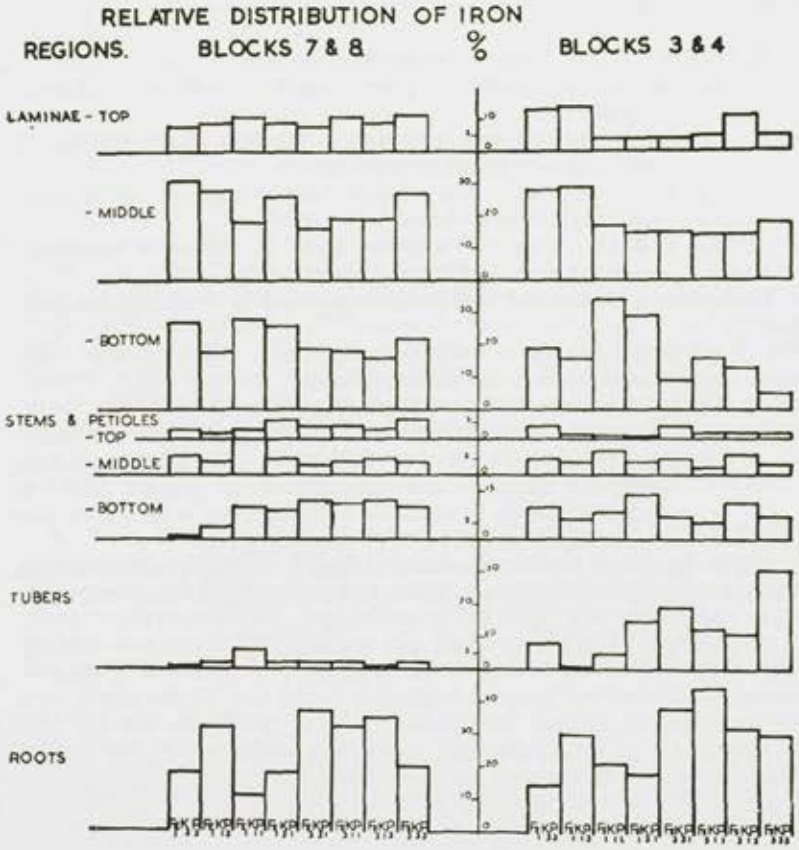


Figure 1—Relative distribution of iron within the potato plant 6 weeks (blocks 7 and 8) and 10 weeks (blocks 3 and 4) after planting. Deficiency levels of Fe, K or P are indicated by sub "1" and high levels by sub "3".



Plate 1

Plants grown at low levels of iron and potassium: left—Fe_1 K_1 P_3 (high phosphorus); right—Fe_1 K_1 P_1 (low phosphorus).
Iron deficiency chlorosis cured by a reduction in phosphorus level.



Plate 2

Plants grown at a low level of iron and a high level of phosphorus : left—$Fe_1 K_1 P_3$ (low potassium) ; right—$Fe_1 K_3 P_3$ (high potassium).
Note (i) Severe apical chlorosis in young leaves and potassium deficiency in old leaves of $Fe_1 K_1 P_3$ plant; (ii) absence of chlorosis, of potassium deficiency and the relative paling off of the midstem leaves in the $Fe_1 K_3 P_3$ plant.

Iron and potassium were shown to be interrelated in the metabolism of the potato plant and a marked similarity existed between the visual effects caused by the addition of either iron or potassium. The nature of this interrelationship was dependent on the phosphorus level, e.g., the efficiency of the absorption of potassium from seed tuber and nutrients decreased with iron application at the lower levels of phosphorus supply but increased at the higher levels.

When iron supplies were limiting, chlorosis was induced or accentuated by the addition of calcium carbonate, by the addition of phosphorus, Plate 1, or by a reduction in the supply of potassium. This iron deficiency chlorosis was cured by the addition of high levels of potassium which promoted the growth of tall vigorous pale-green plants, Plate 2. This response to potassium was associated with an increased soluble (Fig. 5) and total iron content in the lamina and with a greater efficiency per unit weight of iron in chlorophyll formation.

It is suggested that the effect of potassium on the iron content of the lamina was due to an increased mobility of iron in the plant—inferred from a study of nutrient uptake and distribution. This enhanced mobility was associated with a reduction in the proportion of iron localised in the roots in the presence of a plentiful supply of phosphorus, Fig. 1.

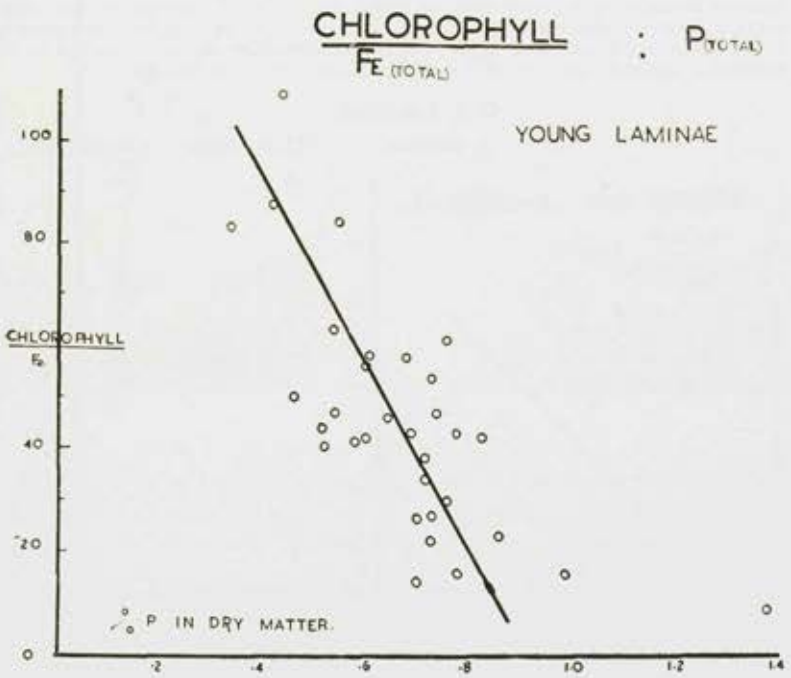


Figure 2—Graph illustrating decrease of efficiency of iron utilisation in chlorophyll formation (chlorophyll/Fe) with increase in the phosphorus content of the young laminae.

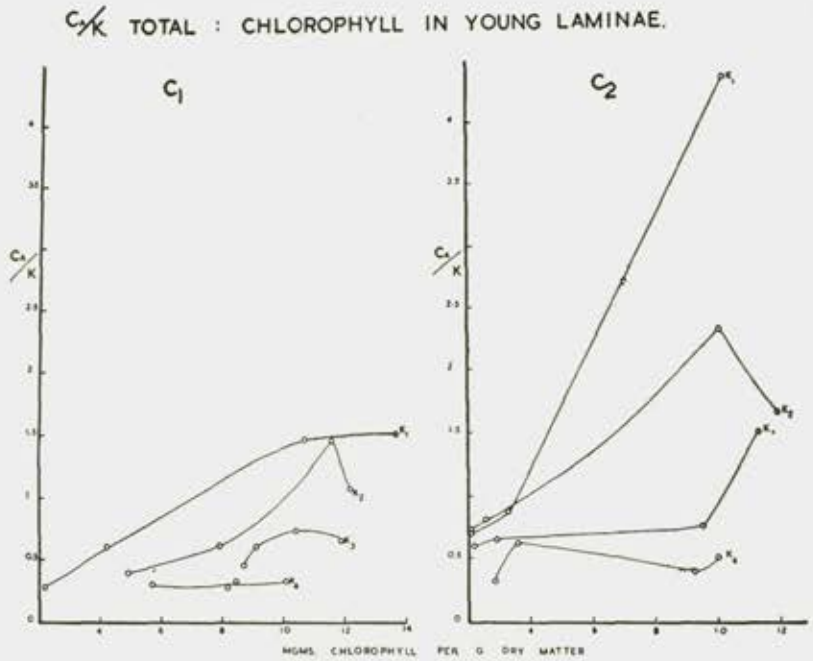


Figure 3—The variation of the Ca/K ratio with chlorophyll content of the young laminae produced at different levels of potassium. Note (i) increase in chlorophyll with Ca/K ratio at deficiency or low levels of potassium (K_1 and K_2) but little variation at the higher levels (K_3 and K_4); (ii) the relationship was more marked in the presence of calcium carbonate (C_2) but was also obvious in its absence.

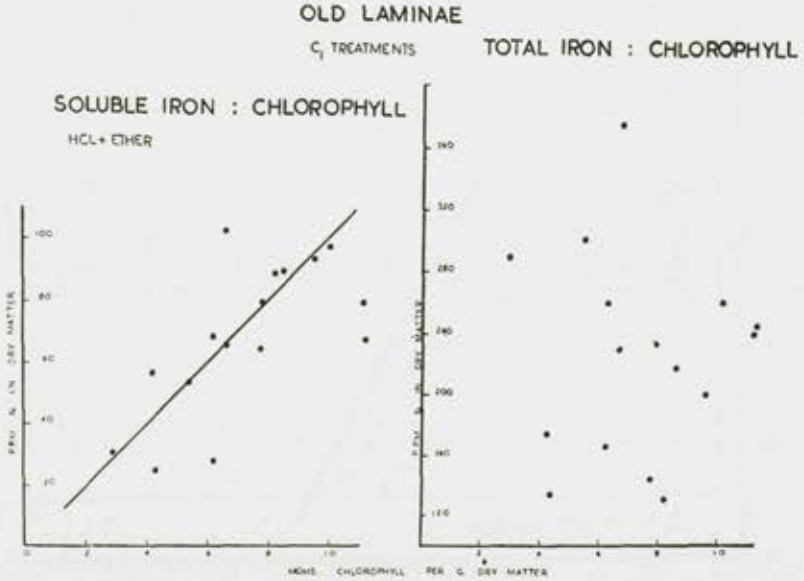


Figure 4—A comparison of the relationship between the soluble or total iron content and the chlorophyll content of the old laminae. Soluble iron extracted with 0·1 N, hydrochloric acid saturated with ether. Note better correlation obtained with soluble iron.

The increased efficiency of iron utilisation obtained on the addition of potassium was attributed both to the depression in the total phosphorus content of the lamina, Fig. 2, and to a decrease in the ratio of easily soluble to total phosphorus. Increased potassium supply resulted in a smaller proportion of inorganic phosphorus as determined by the WEIL-MALHERBE and GREEN method (3) in relation to the total. This decreased proportion of inorganic phosphorus probably permitted

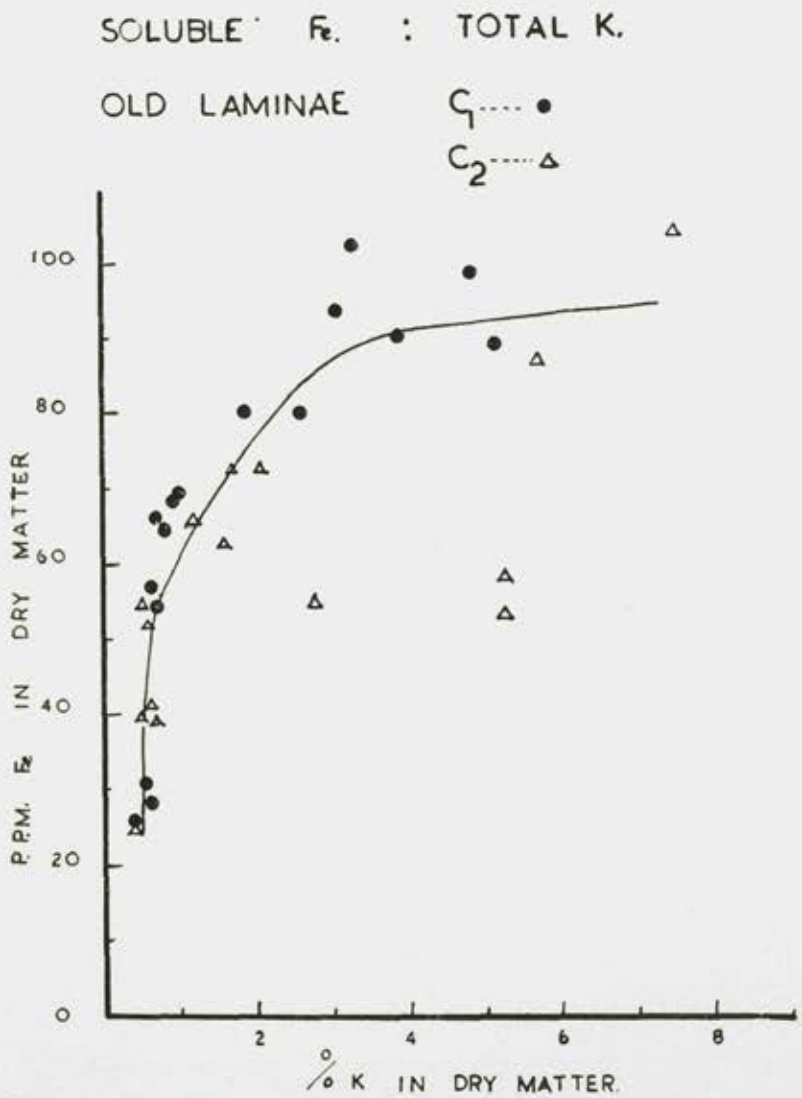


Figure 5—Graph illustrating increase in potassium content of old laminae with increase in the soluble iron content, extracted with 0·1 N, hydrochloric acid saturated with ether. The relationship is better marked in the absence (C_1) rather than in the presence of added calcium carbonate (C_2).

an increased efficiency of iron in chlorophyll production. This was supported by the increased chlorophyll content associated with the decrease in the ratio of MORGAN's-soluble phosphorus to total phosphorus determined after ashing.

The chlorophyll content of the young laminae of potassium deficient plants varied with the Ca/K ratio, Fig. 3; this relationship, mainly associated in the past with lime-induced chlorosis, was independent of the presence of calcium carbonate and was dependent on the iron and potassium status of the plant.

Iron status governed the distribution of potassium within the plant and the inception of potassium deficiency symptoms. High iron levels favoured the translocation of potassium to the tubers at the expense of the young shoot region and delayed the appearance of potassium deficiency in the "old" laminae. Potassium deficiency became ultimately more severe at the higher iron levels and spread to the youngest leaves.

The soluble iron values frequently gave a better correlation with the chlorophyll content of the lamina than the total iron values, Fig. 4, and also increased with increase in the potassium content of the lamina, Fig. 5.

The results of the statistical analysis illustrated the importance of the age of the plant and the morphological region sampled in assessing nutrient interrelationships and of the modifying effect of any one nutrient on the precise nature of the interaction between the others studied.

REFERENCES

(1) HEWITT, E. J. A technique for large scale pot sand cultures. *Ann. Rept. Long Ashton Res. Sta.*, 1946, 37 (1947).

(2) OSERKOWSKY, J. The quantitative relation between chlorophyll and iron in green and chlorotic pear leaves. *Pl. Physiol.*, **8**, 449 (1933).

(3) WEIL-MALHERBE, H. and GREEN, R. H. The catalytic effect of molybdate on the hydrolysis of organic phosphate bonds. *Biochem. J.*, **49**, 284 (1951).

Section B

SESSIONS 7 AND 8

SESSION 7

FIELD EXPERIMENTS AND POT CULTURE TECHNIQUES

24th July. Chairman: E. M. CROWTHER (United Kingdom)

F. VAN DER PAAUW. Evaluation of Methods of Soil Testing by Means of Field Experiments (Volume I, page 207)
E. VON BOGUSLAWSKI. Der Gefässversuch zur Bestimmung der Bodenfruchtbarkeit (Volume I, page 332 and Volume II, below)
H. L. RICHARDSON. The Use of Fertilizer Field Experiments as "Soil Tests" (Volume I, page 222)

DER GEFÄSSVERSUCH ZUR BESTIMMUNG DER BODENFRUCHTBARKEIT

E. VON BOGUSLAWSKI

Institut für Pflanzenbau und Pflanzenzüchtung der Justus-Liebig-Hochschule, Giessen, Deutschland

I. Einleitung

In der Erforschung der Faktoren der Bodenfruchtbarkeit ist der Gefässversuch als pflanzenphysiologische Methode schon frühzeitig zur Entwicklung und Anwendung gekommen.

Obwohl PALISSY im 16. Jahrhundert schon die Vielzahl der Fruchtbarkeitsfaktoren erkannt hatte, führte die erste Anwendung des Vegetationsversuches in Gefässen durch van HELMONT (1630) im Sinne der modernen Naturwissenschaft zunächst zu dem Ergebnis, dass der Vegetationsfaktor "Wasser" das Vegetationsprinzip zu klären vermöge. In der Mitte des 18. Jahrhunderts ist FRANCIS HOME für die Durchführung des Gefässkulturversuches neben der Pflanzenanalyse für die Erforschung der Fruchtbarkeit des Bodens eingetreten. Nachdem der Engländer WOODWARD (1699), und der Schwede WALLERIUS (1751) und ebenso der Altmeister der deutschen Landwirtschaftswissenschaft ALBRECHT THAER für die Humustheorie und damit die vorherrschende Bedeutung der organischen Wachstumsfaktoren eingetreten waren, versuchte 1834 CARL SPRENGEL die gleichzeitige Bedeutung der Mineralstoffe für das Wachstum der Pflanzen mit Hilfe des Gefässversuches zu erforschen. Im Anschluss an den Nachweis der "Mineralstofftheorie" durch JUSTUS v. LIEBIG (1840) und die Bestätigung durch die Pflanzenanalysen durch A. F. WIEGMANN und L. POLSTORFF (1842) hat der Vegetationsversuch in Gefässen in zunehmendem Masse Bedeutung für die Erforschung der Wachstumsfaktoren des Bodens erlangt. Im Anschluss an die bahnbrechenden Arbeiten von H. HELLRIEGEL, P. WAGNER, T. PFEIFFER und D. PRIJANISCHNIKOW ist es E. A. MITSCHERLICH gelungen, den Gefässversuch zu einer determinierten Methode zur Beurteilung der Bodenfruchtbarkeit zu entwickeln. Bei dieser Methode stehen die wichtigsten mineralischen Wachstumsfaktoren wie Kali, Phosphorsäure und auch Stickstoff und Kalk im Vordergrund. Daher ist hier der Begriff der Bodenfruchtbarkeit, wie häufig auch bei anderen Methoden

und Fragestellungen weniger in seiner weiteren Bedeutung zu definieren sondern vornehmlich auf die Bestimmung des "Nährstoffgehaltes" und des "Düngebedürfnisses" des Bodens zu beschränken. Darüber hinaus ist der Gefässversuch jedoch auch für die Ermittlung anderer Fruchtbarkeitsfaktoren geeignet und in Anwendung.

II. Die Durchführführung des Gefässversuches nach MITSCHERLICH (1, 4)

(a) Die Entnahme der Bodenprobe

Zur Gewinnung eines einwandfreien und verwertbaren Ergebnisses ist die richtige Entnahme der Bodenprobe von grosser Bedeutung. MITSCHERLICH geht von der Überlegung aus, dass eine spätere Übertragung auf den Feldschlag die Entnahme einer Durchschnittsprobe zur Voraussetzung hat. Diese wird dadurch gewonnen, dass von möglichst 50 Einzelproben ausgegangen wird, welche auf dem Feldschlag systematisch verteilt und aus einer Schicht von 15 cm. Krumentiefe mit Hilfe eines Spezialspatens (*Abb.* 1) entnommen werden. Bei Anwendung eines gewöhnlichen Spatens ist der erste Einstich jeweils wegzuwerfen, damit eine gleichmässige Probe von 15cm. Tiefe zur Entnahme kommt. Die aus 50 Einstichen gewonnene Bodenmenge wird sofort nach der Entnahme noch auf dem Feld sorgfältig durchmischt und anschliessend eine Probe von mindestens 25 kg. zur Einsendung an die Untersuchungsanstalt entnommen.

Indessen richtet sich die Menge nach dem Umfang des Versuches (sieheunten—Düngung). Es ist Wert darauf zu legen, dass die Probe in lufttrockenem Zustand eingesandt wird. Auf alle Fälle ist nach Eintreffen der Probe im Institut die Nachtrocknung zur Erzielung des lufttrockenen Zustandes sofort durchzuführen. Im Gegensatz zur Auffassung anderer Autoren (5), die eine feinere Siebung verlangen, führt MITSCHERLICH ein Sieben durch ein Maschensieb mit 1 cm. Maschenweite durch.

(b) Das Versuchsgefäss

Nachdem sich die früher teilweise benutzten Tongefässe ebenso wie die Glasgefässe (siehe auch Wasserkulturen) für den in Frage kommenden Vegetationsversuch im Gefäss nicht geeignet hatten und auch dem Zinkgefäss nur eine beschränkte Eignung zugesprochen werden kann (siehe EHRENBERG (6)), benutzt MITSCHERLICH das von ihm konstruierte Gefäss aus emailliertem Eisenblech. Das für die Bestimmung des Düngebedürfnisses hauptsächlich benutzte Emaillegefäss hat eine Höhe von 20 cm. (bei 15 cm. Füllhöhe) und einen Durchmesser von 20 cm. Die mit Boden ausgefüllte Oberfläche des Gefässes beträgt 308 cm^2. Zum Unterschied von den von P. WAGNER und T. PFEIFFER entwickelten Gefässen, welche unten geschlossen sind und infolgedessen einer besonderen Lüftungsanlage bedürfen, ist das MITSCHERLICH-Gefäss auf seiner nach unten gewölbten Unterseite entweder mit einem Schlitz oder in der neueren Ausführung mit einer 8 cm. weiten runden Offnung versehen. Diese Offnung ist mit einem 15cm. grossen, nach oben gewölbten Deckel bedeckt. Auf der Unterseite des Deckels ist Sand eingebrannt, so dass dieser Deckel eine Drainage gestattet und überschüssiges Wasser durch die Offnung nach unten

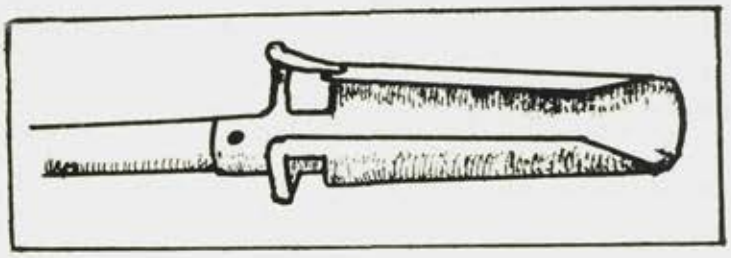


Abb. 1



Das Vegetationsgefäß.

Der Pflanzenhalter *a* steht mit seinen 3 Drähten auf dem Fuß des Vegetationsgefäßes *b*.

Das Gefäß *b* kann mit seinem überstehenden Fuße auf dem Untersatze *c* stehen, den es gegen Regen abdeckt.



Es kann aber auch auf dem Gefäßhalter *d* stehen, so daß man unter ihm den Untersatz *c* ein- und ausschieben kann.



Das Gefäß *b* von innen gesehen mit dem Loch am Boden, das durch eine kreisrunde, nach oben etwas gewölbte Einlegescheibe *e* überdeckt wird. Der Gefäßboden hat nach dem Loch zu etwas Gefälle.



Die Einlegescheibe *e* im Profil.

Abb. 2

austreten kann. Um die Drainagewirkung zu erhöhen, kann der Deckel mit einer schwachen, grobkörnigen, nahrstoffreien Quarzkies-Schicht belegt werden. Das in *Abbildung* 2 in seinen Teilen wiedergegebene Kulturgefäss hat am unteren Ende einen 2,5 cm. nach unten abstehenden Rand bzw. Gefässfuss. Durch letzteren wird ermöglicht, dass in den unter dem Gefäss stehenden Untersatz nur Sickerwasser aus der beschriebenen Offnung gelangen kann, ohne dass von aussen Regenwasser oder anderes aufgefangen wird. Die " Untersatzschale " hat einen Durchmesser von 24 cm. und eine Höhe von 7 cm. Sie lässt sich, wie dies gleichzeitig in *Abb.* 3 sichtbar ist, leicht unter das Gefäss schieben, wenn dieses auf den aus gepresstem Eisenblech hergestellten sogenannten " Gefässhalter " aufgesetzt wird.

Die Aussenseite des Gefässes und der 5 cm. breite obere Rand der Innenseite sind weiss emailliert, während das Innere des Gefässes und alle übrigen Teile dunkelblau oder schwarz lackiert sind. Mit zunehmendem Wachstum der Pflanzen wird ein " Pflanzenhalter " auf das Gefäss aufgesetzt (siehe *Abb.* 2), der aus 3 mm. starkem Eisendraht besteht, 80cm. hoch ist und durch 3 Ringe zusammengehalten wird.

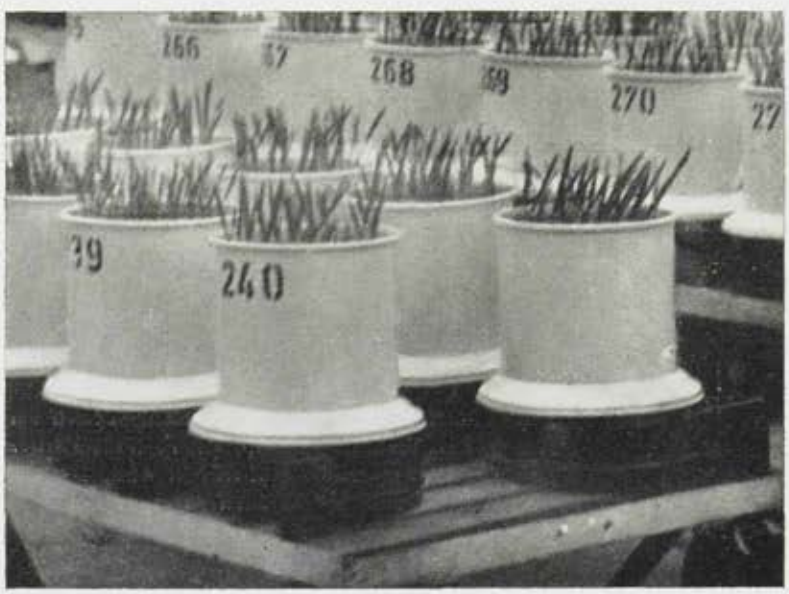


Abb. 3

(c) *Die Durchführung des Gefässversuches zur Bestimmung des Düngebedürfnisses*

Füllung des Gefässes

Der lufttrockene und gesiebte Boden wird zunächst unvermischt probeweise mit einer Füllhöhe von 15 cm. eingefüllt. Aus der das gesamte Füllvolumen einnehmenden Bodenmenge lässt sich nunmehr der gewichtsmässige Boden- und Sand-Anteil berechnen. Ursprünglich hat MITSCHERLICH für die Bestimmung des Stickstoffaktors mit reinem Boden gearbeitet, während er für die Ermittlung der im Boden wirksamen Kali- und Phosphorsäuremengen von einem Boden/Sandgemisch von 1/5 ausging. In neurer Zeit kam dagegen eine geringere Sandverdünnung bei einem *Boden/Sandgemisch von* 1/2 zur Anwendung. Wenn also der Füllraum des Gefässes bei Verwendung von reinem



Abb. 4

Boden 6,0 kg. Boden enthielt, so werden 2,2 kg. Boden und 4,4 kg. Sand eingefüllt .Bei dem Sand handelt es sich um möglichst nährstoffreien (in der Literatur als steril bezeichneten), feinkörnigen Quarzsand, der intensiv mit dem Boden vermischt wird.

Düngung

Das Mischen und die Zugabe der Düngung erfolgt in einer grossen Emailleschale mit abgerundetem Boden für jedes Gefäss gesondert. Dabei wird die Kalkdüngung in trockenem Zustand des Boden-Sandgemisches vermischt, während die 3 Hauptnährstoffe Stickstoff, Kali und Phosphorsäure in Lösungen aus automatischen Pipetten oder mit Hilfe von Tauchpipetten zugesetzt werden und zur Vermischung gelangen. Der Boden wird zusätzlich mit destilliertem Wasser soweit angefeuchtet, dass beim Mischen eine gute Krümelung erreicht wird. Es ist anzustreben, dass die Düngung möglichst wenig mit der Wand der Mischwanne in Berührung kommt. Das Mischen und Einfüllen des Bodens muss unter Verwendung von Gummihandschuhen mit der Hand durchgeführt werden. Beim Füllen der Gefässe, welches zweckmässig unter Verwendung eines weiten Trichters erfolgt (*Abb.* 4), muss vor allem am unteren Teil des Gefässes für eine ausreichend feste Lagerung gesorgt werden. Teilweise sind zum Einsparen von Menschenkraft für das Halten der Emailleschalen halbautomatische Füllapparate verwendet worden. Nach jeder Änderung der Düngung müssen alle benutzten Instrumente gewaschen werden, während zwischen den Parallelversuchen nur ein sauberes Reinigen mit der Hand bzw. mit einem Gummiwischer ausreicht.

Die von MITSCHERLICH benutzte *Volldüngung* besteht aus 1,5 g. $CaCO_3$ 1,1 g. N in NH_4NO_3, 1,5 g. K_2O in K_2SO_4, 1,0 g. P_2O_5 in primärem Calciumphosphat oder auch Superphosphat 1,0 g. $MgSO_4$ (kristallisiert) und 0,5 g. NaCl.

Ursprünglich wurde die Prüfung im Gefässversuch in zwei Teilversuchen ausgeführt. Einmal dienten 8 Gefässe für die Ermittlung des Stickstoffaktors, indem 4 mit Volldüngung ohne Stickstoff und 4 Gefässe mit Volldüngung zum Ansatz kamen. Es wurde also in vierfacher Wiederholung gearbeitet und die Prüfung des Stickstoffaktors in reinem Boden durchgeführt. In weiteren 12 Gefässen wurden mit einem Boden-Sandgemisch von 1/5 der Kali- und Phosphorsäurefaktor ermittelt, indem je 4 Gefässe Volldüngung ohne Kali, 4 Gefässe Volldüngung ohne Phosphorsäure und 4 Gefässe Volldüngung erhielten.

Sehr bald vereinfachte MITSCHERLICH diese sehr umfangreiche Versuchsanstellung, indem nur mit dreifacher Wiederholung gearbeitet und auf die genaue Ermittlung des Stickstoffaktors weitgehend verzichtet wurde. Bei einem Boden-Sandgemisch von 1/2 umfasste die Versuchsanstellung :

1 Gefäss Volldüngung ohne Stickstoff als Tastversuch.
3 Gefässe Volldüngung ohne Kali.
3 Gefässe Volldüngung ohne Phosphorsäure.
3 Gefässe Volldüngung.

So enthält der Versuch für jeden Boden 10 Gefässe. Diese Versuchsanstellung hat sich Jahrzehnte hindurch in vielen tausend Untersuchungen bewährt (*Abb.* 5).

In neuester Zeit hat MITSCHERLICH sich veranlasst gesehen, die Versuchsanstellung noch einmal zu vereinfachen, indem je Untersuchung nur 8 Gefässe zum Ansatz gelangen. Es kommen folgende Punkte zur Ausführung:

1. Volldüngung ohne Kali,
2. Volldüngung ohne Phosphorsäure,

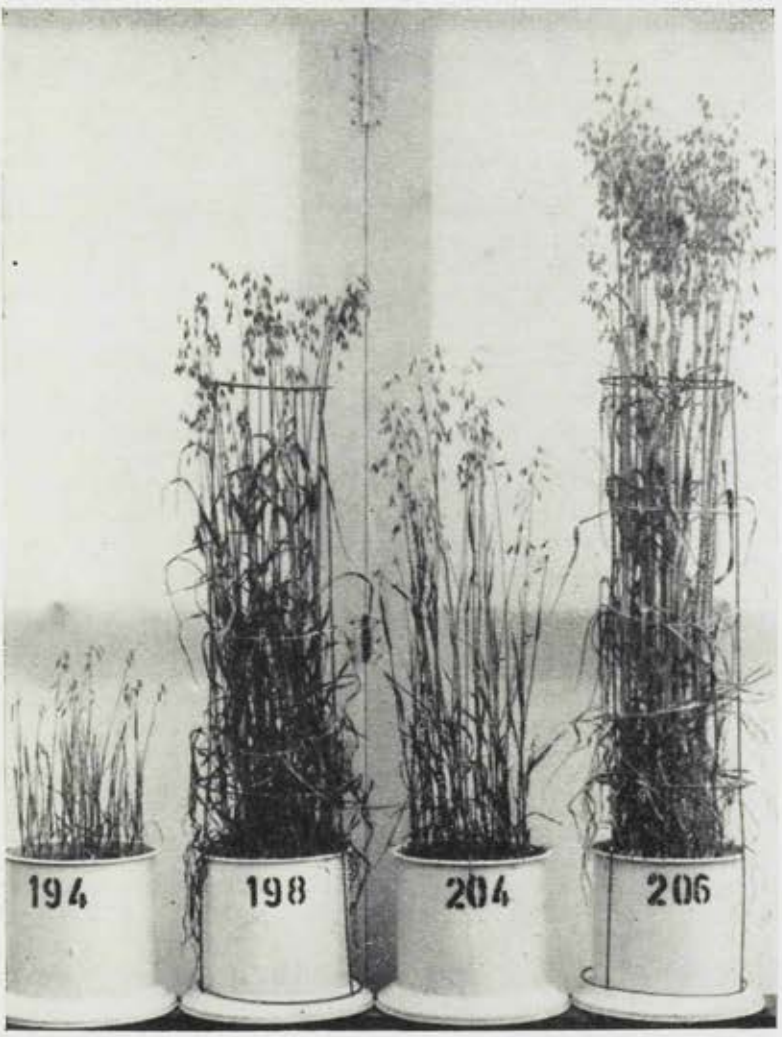


Abb. 5

Volldüngung ohne N. *Volldüngung ohne K.* *Volldüngung ohne P.* *Volldüngung*

3. Volldüngung ohne Phosphorsäure und Kalk,
4. Volldüngung.

Auf die Ermittlung des Stickstoffaktors wird jetzt ganz verzichtet, während beim Vergleich von Punkt 2 und 3 die Bedeutung des Kalkfaktors für die Ermittlung des Phosphorsäuregehaltes erfasst werden soll. Die einzelnen Punkte werden mit einer Wiederholung, also doppelt, angesetzt. Da hierdurch die Sicherheit der Auswertung leiden kann, empfiehlt sich naturgemäss die früher benutzte dreifache Wiederholung, wenn die Einrichtungen dies zulassen.

Die Versuchspflanze

Als Versuchspflanze empfiehlt MITSCHERLICH den *Hafer*, der sich im allgemeinen auch nach den Erfahrungen anderer Autoren für den Gefässversuch besonders eignet. Indessen ist grundsätzlich auch die Benutzung anderer Pflanzenarten möglich. Für subtropische und tropische Versuchsstationen werden *Reis-* (Oryza sativa) und *Sorghum-Hirsen* (Sorghum saccharatum und Sorghum sudanense) usw. empfohlen. Nach dem Ansetzen der Gefässe erfolgt die Aussaat des möglichst einwandfreien Saatgutes einer bewährten Sorte. Gewöhnlich werden auf der Gefässoberfläche nach Einebnung mittels eines Stempels oder Säbrettes die Saatlöcher markiert. MITSCHERLICH bringt 34-36 Körner zur Aussaat, so dass der Bestand nach etwa 14 Tagen auf eine konstante *Pflanzenzahl* von etwa 33-34 verzogen werden kann.

Wasserversorgung

Die Benutzung der Mitscherlichgefässe gestattet das bei Gefässversuchen an sich schwierige Problem der Wasserversorgung einfach zu lösen und so zu gestalten, dass während der ganzen Vegetation ausreichende Wassermengen zur Verfügung stehen. Nachdem die Gefässe während der ersten Wachstumszeit der Pflanzen mit etwa 50% der vollen Wasserkapazität versorgt werden, findet eine zunehmende Wassergabe in der Weise statt, dass *in* 4-5 *Wochen die volle Wasserkapazität erreicht ist*, d.h., dass jeden Tag einmal und während besonders heisser Perioden auch 2-mal täglich so stark Wasser zugeführt wird, dass bei Übersättigung des Bodens ein Durchlaufen in die Untersatzschalen erfolgt. Vor neuer Zuführung von Giesswasser muss stets die durchgesickerte Nährlösung quantitativ in das Gefäss zurückgegeben werden. Für die Wasserversorgung der Versuche ist "kalifreies" Wasser erforderlich, wofür auch einwandfrei gewonnenes Regenwasser neben destilliertem Wasser Anwendung finden kann. Keinesfalls ist die Verwendung von Brunnen- oder Leitungswasser möglich. Die Gefässe werden bis kurz vor der Ernte auf Durchfluss gegossen und nach Eintritt der Gelbreife allmählich abnehmend mit Wasser versorgt, so dass eine gute Ausreife erfolgt.

Ernte und Bestimmung der Trockensubstanz

Nach Eintritt der Vollreife wird der Pflanzenbestand mit einer Patentschere (Rosenschere) mit möglichst kurzer Stoppel dicht über den Bestockungsknoten abgeschnitten. Anfänglich hat MITSCHERLICH die Körner aus den Rispen mit der Hand abgestreift und so eine getrennte Stroh- und Kornernte durchgeführt. Dies ist jedoch nicht unbedingt erforderlich. Im Gegenteil muss bei der

Auswertung der Ernteergebnisse auf die Gesamternte (Korn+Stroh) Wert gelegt werden, zumal, wie dies auch WIESSMANN und SCHRAMM (7) feststellten, in den einzelnen Düngungs- bzw. Mangelgefässen das Verhältnis von Korn zu Stroh stark Schwankungen unterliegt. Die Ernte der einzelnen Gefässe wird in sogenannte Trockengefässe aus Zinkblech mit feinmaschigem Siebboden eingelegt, im Trockenschrank bei 105° getrocknet und so die Erntemenge in Trockensubstanz mit der Waage festgestellt. Damit beim Wiegen keine neuerliche Wasseraufnahme erfolgt, findet dies im warmen Zustand in einer abgeschlossenen Wiegebüchse statt. Wenn die Einrichtungen für die Bestimmung der Trockenernte nicht vorhanden sind, so genügt nach den Erfahrungen MITSCHERLICHS auch ein allerdings umständliches und langwieriges Nachtrocknen der geschnittenen Ernte an der Luft.

Die Auswertung der gewonnenen Ertragsergebnisse

Im Gegensatz zu den qualitativen chemischen Untersuchungsmethoden wie auch zur Pflanzenanalyse wird bei der MITSCHERLICH-Methode von der als Funktion der aufgenommenen Nährstoffmengen gebildeten Trockensubstanz—also *vom Ertrag*—auf *die im Boden zur Wirkung gekommene Nährstoffmenge geschlossen.*

Der quantitative Rückschluss vom Ertrag auf die im Boden "physiologisch wirksame" Nährstoffmenge war MITSCHERLICH durch die Anwendung seiner ursprünglich als "Gesetz der physiologischen Beziehungen" und später unter Mitwirkung von BAULE als "Wirkungsgesetz der Wachstumsfaktoren" bzw. als "Ertragsgesetz" gefundenen Gesetzmässigkeit auf die Wirkung der ertragsbildenden Faktoren möglich. In dem Differentialquotienten

$$\frac{dy}{dx} = c\ (A-y)$$

folgt nach MITSCHERLICH der Ertrag "y" als Funktion der Düngung "x" der logarithmischen Gleichung:

$$\log\ (A-y) = \log\ A - c.\ x$$

Der Anstieg des Ertrages "y" bis zum Höchstertrag "A" erfolgt asymptotisch mit jeder Nährstoffeinheit um die Hälfte des jeweils am Höchstertrag fehlenden Ertrages. Wenn bei der Durchführung eines Versuches ohne zusätzliche Düngung eines bestimmten Wachstumsfaktors schon auf Grund der im Boden vorhandenen wirksamen Menge des Faktors der Ertrag "y o" erzielt wird, so lautet die, Gleichung:

$$\log\ (A-y) = \log\ (A-yo) - c.\ x$$

Wenn der Ertrag "yo" mit der im Boden wirksamen Menge „b" erzielt wird, so gilt hierfür die Gleichung:

$$\log\ (A-yo) = \log\ A - c.\ b$$

Setzen wir diese in die allgemeine Gleichung ein, so ergibt sich:

$$\log\ (A-y) = \log\ A - c.\ (x+b)$$

Aus der vorletzten Gleichung lässt sich die im Boden wirksame Menge "b" wie folgt ererchnen:

$$b = \frac{\log A - \log\ (A-yo)}{c}$$

Unter Anwendung dieser Gesetzmässigkeit können wir also die im Boden wirksame Menge " b " errechnen, wenn wir neben dem im Versuch mit der Volldüngung erzielten Höchstertrag " A " und dem ohne die Düngung des jeweiligen Mangelfaktors erzielten Ertrag " yo " den nach MITSCHERLICH für die Winkung des jeweiligen Wachstumsfaktors typischen Wirkungsfaktor " c " kennen.

Auf Grund seiner vielseitigen und umfassenden Arbeiten über die physiologischen Beziehungen kommt MITSCHERLICH zu dem Ergebnis, dass der Wirkungsfaktor " c " für jeden Wachstumsfaktor eine konstante Höhe aufweist. Wenn uns damit die Beziehungen zwischen der im Gefäss wirkenden Nährstoffmenge " x " bzw. " b " und dem Ertrag " y " in seinem Anstieg bis zum Höchstertrag " A " unter Zugrundelegung des für jeden Wachstumsfaktor typischen Wirkungsfaktors bekannt sind, legen wir nach MITSCHERLICH die für jeden Wachstumsfaktor geltende Wirkungskurve (die für die 3 Hauptnährstoffe Stickstoff, Kali und Phosphorsäure geltenden Ertragskurven sind in *Abb.* 6 wiedergegeben) gewissermassen als

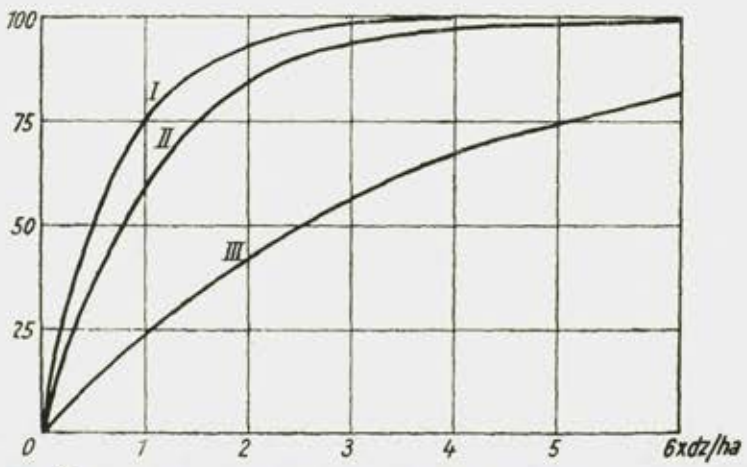


Abb. 6. Ertragssteigerungen durch Pflanzennährstoffe, *y* Erträge in %
x dz/ha I P_2O_5 II K_2O III N

Normalkurve zu Grunde und fällen in dieser Kurve von dem jeweilig gefundenen Ertrag " yo " auf die x-Achse das Lot, um in dem Schnittpunkt des Lotes mit der x-Achse die jeweilig wirksam gewesene Nährstoffmenge " b " abzulesen.

Die Wurkungsfaktoren für die 3 Hauptnährstoffe sind für :

N =0,65 gr. pro 308 cm² Gefäss =0,20 dz./ha.
K_2O =1,33 „ „ „ „ „ =0,40 „ „
P_2O_5=2,00 „ „ „ „ „ =0,60 „ „

Unter Anwendung dieser Gesetzmässigkeiten ergibt sich die Möglichkeit, dass wir aus der Errechnung des %-Ertrages (y_o in % von A) in den für jeden Nährstoff aufgestellten sogenannten Ertragstafeln jeweils die im Boden wirksame Nährstoffmenge " b " bzw. " x " in dz/ha ablesen, ohne dass wir bei jeder Versuchsreihe die gesamte

Ertragskurve und den c-Wert zu ermitteln brauchen. Die Ertragstafeln für Phosphorsäure und Kali sind in *Tabelle* 1 wiedergegeben.

TABELLE 1

Ertragstafel für Phosphorsäure (P_2O_5) und Kali (K_2O) Erträge y in Prozenten des Hochstertrages bei einem Nährstoffgehalt von x dz./ha.

x dz./ha.	y P_2O_5	y K_2O	x dz./ha.	y P_2O_5	y K_2O	x dz./ha.	y P_2O_5	y K_2O
0,01	1,4	0,9	0,26	30,2	21,3	0,69	61,4	47,0
0,02	2,8	1,8	0,27	31,2	22,0	0,73	63,5	48,9
0,03	4,1	2,7	0,28	32,1	22,7	0,77	65,5	50,8
0,04	5,4	3,6	0,29	33,0	23,4	0,81	67,3	52,6
0,05	6,7	4,5	0,30	33,9	24,1	0,85	69,1	54,3
0,06	8,0	5,4	0,31	34,8	24,8	0,90	71,2	56,3
0,07	9,2	6,2	0,32	35,7	25,5	0,95	73,1	58,3
0,08	10,5	7,1	0,33	36,6	26,2	1,00	74,9	60,2
0,09	11,7	8,0	0,34	37,5	26,9	1,05	76,6	62,0
0,10	12,9	8,8	0,35	38,4	27,6	1,10	78,1	63,7
0,11	14,1	9,6	0,36	39,2	28,2	1,20	80,9	66,9
0,12	15,3	10,5	0,37	40,0	28,9	1,30	83,4	69,9
0,13	16,5	11,3	0,38	40,8	29,5	1,40	85,5	72,8
0,14	17,6	12,1	0,39	41,6	30,2	1,50	87,4	74,6
0,15	18,7	12,9	0,40	42,4	30,8	1,60	89,0	77,5
0,16	19,8	13,7	0,42	44,0	32,1	1,80	91,7	80,1
0,17	20,9	14,5	0,44	45,5	33,3	2,00	93,7	84,1
0,18	22,0	15,3	0,46	47,0	34,5	2,20	95,2	86,8
0,19	23,1	16,0	0,48	48,5	35,7	2,40	96,4	89,0
0,20	24,1	16,8	0,50	49,9	36,9	2,60	97,2	90,9
0,21	25,2	17,6	0,53	51,9	38,6	3,00	98,4	93,7
0,22	26,2	18,3	0,56	53,9	40,2	3,50	99,2	96,0
0,23	27,2	19,1	0,59	55,7	41,9	4,00	99,6	97,5
0,24	28,2	19,8	0,62	57,5	43,5	4,50	99,8	98,4
0,25	29,2	20,6	0,65	59,3	45,0	5,00	99,9	99,0

Wenn auf diese Weise die im Gefäss ermittelte bzw. auf das Feld umgerechnete Nährstoffmenge des jeweiligen Wachstumsfaktors ermittelt ist, so müssen wir jetzt berücksichtigen, dass im Gefäss nur ein Teil der Ackerkrume zur Untersuchung gelangte. Dadurch, dass bei dem heute üblichen Verfahren das Boden/Sandverhältnis von 1/2 Anwendung findet, haben wir die bei der Probeentnahme berücksichtigten 15 cm. Krume nach ihrer Durchmischung auf 5 cm. reduziert. Wir können den Wert auf die 15 cm. Krume zurückführen, indem die gefundene Nährstoffmenge " b " mit dem Faktor 3 multipliziert wird. Da der Untergrund bzw. die Schicht unterhalb der Krume von 15 cm. keine Berücksichtigung bei der Untersuchung gefunden hat, kommt MITSCHERLICH zu dem Verfahren, alle Nährstoff liefernden Schichten unterhalb der 15 cm. Krume dadurch zu berücksichtigen, dass er den für die 15 cm. gefundenen Wert mit 2 multipliziert. Somit wird also der ursprünglich im Versuch ermittelte Wert für " *b* " *zur Übertragung auf den gewachsenen Boden mit* 6 *multipliziert.*

Neuerdings hat MITSCHERLICH unter Anwendung der normographischen Tafeln nach GARTNER eine graphische Auswertungsmethode angegeben, wie dies für den Wachstumsfaktor " Phosphorsäure "

in *Abbildung 7* wiedergegeben wird. Bei dieser Methode ist weder die Errechnung des %-Ertrages, noch die Umrechnung auf den Untergrund erforderlich, so dass alle weiteren Rechenmanipulationen wegfallen.

Graphische Auswertung der Ergebnisse der Gefäßversuche zur Bestimmung des Phosphorsäuregehaltes des Bodens.

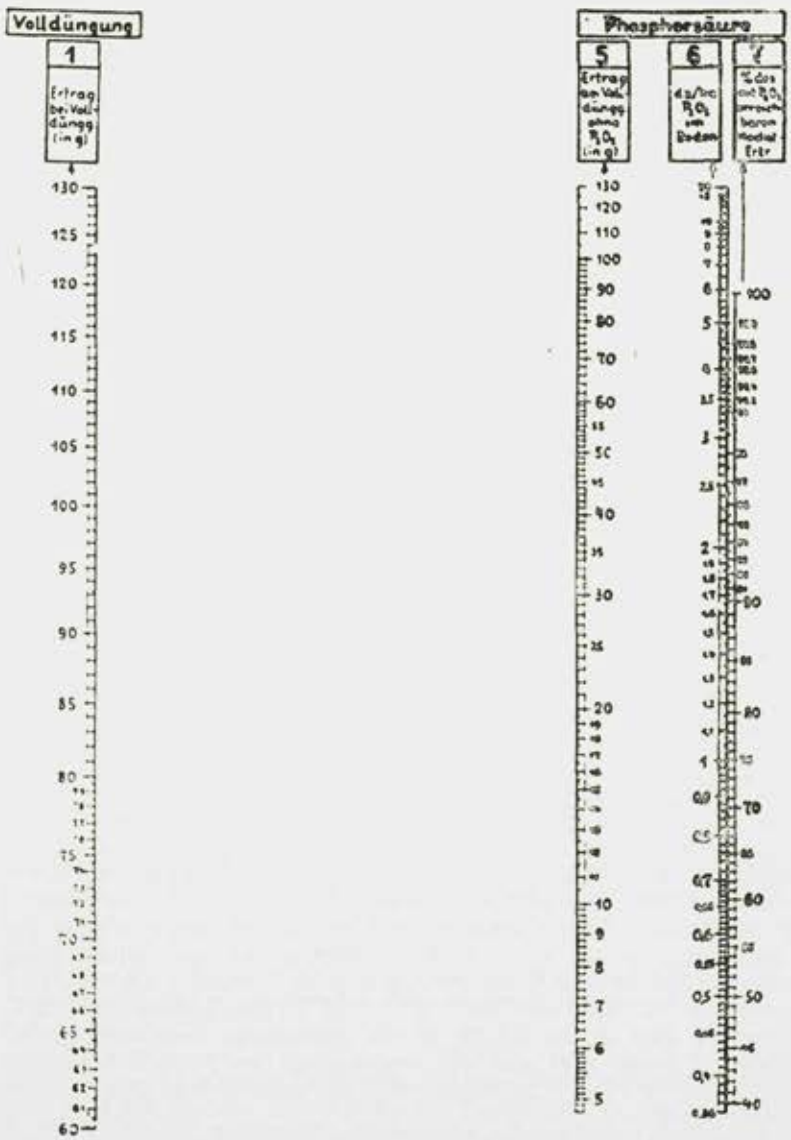


Abbildung 7

Die Durchführung der praktischen Düngerberatung

Für die Verwertung der im Gefässversuch gewonnenen Ergebnisse im praktischen Ackerbau ist die Zusammenarbeit zwischen den Untersuchungsanstalten, welche diese Ergebnisse liefern, und der praktischen Beratung erforderlich. Das *Düngebedürfnis des Bodens* ergibt sich theoretisch aus dem im Boden festgestellten bzw. errechneten Bestand an Kali und Phosphorsäure und den für die Erzielung des Höchstertrages erforderlichen Mengen, welche bei Einsatz von 99% des Höchstertrages 500*kg./ha.* K_2O *und* 330 *kg./ha.* P_2O_5 betragen sollen. Werden diese anzustrebenden Nährstoffmengen bei nährstoffarmen Böden stark unterschritten, so muss auf dem Acker eine verstärkte Düngung möglichst umgehend wenigstens so weit erfolgen, dass ein Bestand von 330 kg. Kali und 220 kg. P_2O_5 erreicht wird, womit zunächst etwa 95% des Höchstertrages erreichbar sind. Nach Möglichkeit ist aber in einigen Jahren die anzustrebende Höchstmenge zu erzielen. Gleichzeitig sind die durch Stallmist und andere organische Düngemittel aufgewendeten Nährstoffmengen zu berücksichtigen und im Laufe der Fruchtfolge die von den einzelnen Kulturpflanzenarten entzogenen Nährstoffmengen jeweils wieder in Abzug zu bringen. Auf diese Weise ergibt sich für die Feldbuchführung im landwirtschaftlichen Betrieb eine "Nährstoffstatik," wie diese im Laufe der Jahre zu ziehende Nährstoffbilanz von MITSCHERLICH bezeichnet wurde. Auf Grund der früheren Angaben von MITSCHERLICH und der Auswertung der vielseitigen Angaben in der Literatur sowie eigener Feststellungen ist in *Tabelle* 2 der Nährstoffentzug für die wichtigsten Kulturpflanzen mitgeteilt. Es wird hier jeweils mit zwei verschiedenen Ertragsstufen gearbeitet, weil die Höhe der Erträge, welche *gleichzeitig* von allen anderen Wachstumsfaktoren mitbestimmt wird, einerseits Berücksichtigung finden muss, andererseits jedoch nicht eine geradlinige Extrapolation entsprechend der Ertragshöhe zulässt. Die Nährstoffstatik wird auf Grund der mit ihr zwangsläufig verbundenen Unsicherheiten im Laufe der Fruchtfolge bzw. Jahre ungenau, so dass nach 4 bis 6 oder auch 8 Jahren eine neuerliche Untersuchung im Gefäss erforderlich wird. Die neue Probeentnahme soll nach einer abtragenden Frucht, also möglichst vor der Anwendung einer neuen organischen Düngung, und ausserdem nach der Ernte erfolgen.

Mit der Begründung und Durchführung der Nährstoffstatik ist es MITSCHERLICH erstmalig gelungen, die Nährstoffbilanz eines Bodens *quantitativ* zu verfolgen. Dieses ist nach dem gleichen Prinzip auch im Feldversuch möglich, entbehrt aber bei allen anderen Untersuchungsmethoden physikalisch-chemischer Art der Grundlage, weil alle anderen Verfahren nur qualitative Schlussfolgerungen zulassen.

TABELLE 2

Nährstoffentzug in kg./ha.

Fruchtart	Ernte dz./ha.	N kg.	K_2O kg.	CaO kg.	P_2O_5 kg.
Roggen	20 Korn 45 Stroh	50	57	16	28
Roggen	28 Korn 63 Stroh	71	80	23	39

TABELLE 2—*Nährstoffentzug in kg./ha.*—(contd.)

Fruchtart	Ernte dz./ha.	N kg.	K_2O kg.	CaO kg.	P_2O_5 kg.
Wi-Weizen	24 Korn 48 Stroh	64	59	18	31
Wi-Weizen	32 Korn 64 Stroh	86	79	24	41
So-Weizen	20 Korn 40 Stroh	57	51	15	25
So-Weizen	30 Korn 60 Stroh	86	76	22	37
So-Gerste	20 Korn 30 Stroh	45	51	16	24
So-Gerste	32 Korn 48 Stroh	73	82	26	39
Wi-Gerste	24 Korn 44 Stroh	60	65	20	26
Wi-Gerste	36 Korn 65 Stroh	89	96	30	39
Hafer	24 Korn 48 Stroh	66	95	23	33
Hafer	36 Korn 72 Stroh	99	142	34	49
Lein	8 Korn 56 Stroh + Kapseln	70	78	64	35
Futterrüben	500 Rüben 125 Kraut	123	228	46	37
Futterrüben	800 Rüben 200 Kraut	198	366	73	60
Frühkartoffeln	200 Knollen 100 Kraut	110	195	73	39
Spätkartoffeln	200 Knollen 66 Kraut	99	176	64	37
Spätkartoffeln	300 Knollen 100 Kraut	150	267	95	56
Zuckerrüben	300 Rüben 188 Kraut	119	158	63	46
Zuckerrüben	400 Rüben 250 Kraut	158	210	84	62
Erbsen	20 Korn 32 Stroh	123	73	63	31
Erbsen	25 Korn 40 Stroh	154	91	79	38

TABELLE 2—*Nährstoffentzug in kg./ha.*—(contd.)

Fruchtart	Ernte dz./ha.	N kg.	K_2O kg.	CaO kg.	P_2O_5 kg.
Saatmais	30 Korn 54 Stroh	77	96	26	34
Saatmais	60 Korn 108 Stroh	154	192	52	67
Ackerbohnen	20 Korn 30 Stroh	125	88	52	33
Ackerbohnen	24 Korn 36 Stroh	151	106	62	30
Saatwicke	20 Korn 30 Stroh	161	92	71	33
Gelbe Lupine	20 Korn 32 Stroh	140	93	47	34
Raps	16 Korn 34 Stroh	84	76	81	42
Raps	24 Korn 50 Stroh	125	113	121	62
Hanf	100 Stroh 17 Samen	143	119	215	54
Hanf	60 Stroh 10 Samen	86	71	129	32
Luzerne	140 Heu	393	232	424	103
Luzerne	100 Heu	281	166	303	73
Rotklee	80 Heu	193	172	198	48
Rotklee	100 Heu	241	215	248	60
Senf	120 Grünmasse	51	45	46	10
Buchweizen	120 Grünmasse	47	49	61	14
Spörgel	70 Grünmasse	42	30	15	15
Gemenge (Ackerbohnen-Peluschken-Wicken)	180 Grünmasse	94	72	48	31
Sudangras (als Stoppelfrucht)	250 Grünmasse	84	79	50	29
Sonnenblumen (als Zweitfrucht und Stoppelfrucht)	400 Grünmasse	98	148	132	37
Mais (als Zweitfrucht und Stoppelfrucht)	400 Grünmasse	87	125	49	39
Stoppelrüben	250 Grünmasse	80	93	146	30
Futterroggen	160 Grünmasse	90	105	20	25

III. Diskussion der Gefässversuchsmethode nach MITSCHERLICH *und einige ergänzende Angaben*

(a) Die Erfassung des Stickstoffaktors für die Düngerberatung

Wie dies in der Schilderung der Versuchsdurchführung bereits zum Ausdruck kam, hat MITSCHERLICH im Laufe der Zeit mehr oder weniger ganz auf die Erfassung des Stickstoffaktors im Gefässversuch verzichtet. Er geht dabei einmal von der Tatsache aus, dass vornehmlich im gemässigten Klima die Stickstoffbilanz unserer Böden eine sehr labile ist. Hierbei spielt infolge der starken Durchfeuchtung unserer Böden die jährlich stattfindende Auswaschung der nicht von den Pflanzen aufgenommenen Stickstoffmengen eine Rolle. Andererseits kann die zu errechnende Höchstgabe einer Stickstoffdüngung nicht verabfolgt werden, weil infolge physiologischer Störungen bei Anwendung höherer Stickstoffgaben " Ertragsdepressionen " eintreten. Deshalb muss sich die Stickstoffdüngung ebenso wie in der Form so auch in der Menge nach dem jeweiligen Boden, der Pflanzenart und den zu erwartenden Höchsterträgen richten. Dabei ist vor allem der Wasserhaushalt des Standortes zu berücksichtigen. Die in Frage kommenden Gaben hat MITSCHERLICH generell mit 60 kg. N/ha. für die Getreidearten und 120 kg./ha. für die Hackfruchtarten begrenzt. Zweifellos können bei manchen Arten dieser beiden Gruppen auch höhere Gaben zur weiteren Ertragserhöhung in Betracht kommen. Die Voraussetzung ist nicht nur die Verwendung entsprechender Pflanzenarten bzw. Rassen (z.B. standfeste Sorten), sondern die günstige Gestaltung aller übrigen Wachstumsfaktoren (vor allem von Kali- und Phosphorsäure Düngung). Im übrigen kann die *zweckmässige Höhe der Stickstoffdüngung nur auf Grund des " Feldversuches " festgelegt werden.*

Die im Gefässversuch angewendete Stickstoff-Volldüngung würde einer Stickstoffmenge von 360 kg./ha. entsprechen. Abgesehen von der Tatsache, dass die Höhe dieser Dungung von den noch zu besprechenden übrigen Versuchsbedingungen mitbestimmt wird, spielt für ihre Begrenzung zweifellos das von MITSCHERLICH empirisch gefundene optimale Verhältnis für viele Kulturpflanzen von $N : K_2O : P_2O_5 = 1{,}1 : 1{,}5 : 1$ eine wichtige Rolle. Unter Einhaltung oder nur geringer Verschiebung des Verhältnisses zu Gunsten von Kali wäre im Gefässversuch eine noch etwas höhere Stickstoffdüngung möglich, was jedoch für die Auswertung der Ergebnisse für die praktische Bestimmung des Düngerbedürfnisses wenig Bedeutung hat.

Nachden der Wirkungsfaktor für Stickstoff in früheren Arbeiten schon mit 0,8 g/Gefässoberfläche=0,25 dz./ha. festgestellt worden war, benutzte MITSCHERLICH lange Jahre hindurch die Faktoren von 0,4 (Gefäss) und 0,122 (Feld). Die Auswertungen von neuen umfangreichen Feldversuchen haben zu den oben angegebenen *Faktoren von* 0,65 (*Gefäss*) *bzw.* 0,20 (*Feld*) geführt (8). Der von CROWTHER aus Versuchen in Rothamsted und Woburn für das Feld ermittelte Wirkungsfaktor von 0,88 konnte—auch unter Berücksichtigung dieser Versuche—nicht bestätigt werden.

(b) Der Pflanzenbestand im Gefässversuch im Vergleich zum Feldversuch

Die von anderen Autoren empfohlenen Bestandsdichten im Gefässversuch weichen stark von den nach MITSCHERLICH verwendeten

ab. Insbesondere hat PFEIFFER (9) die Frage der optimalen Pflanzenzahl im Gefässversuch untersucht. Er kommt zu einer Bestandsdichte von 15 bis 25 Pflanzen bei der wesentlich grösseren Oberfläche seiner Gefässe von 625 cm² und versucht, sich dabei den Bedingungen im Ackerbau anzupassen. MITSCHERLICH hat in einschlägigen Versuchen festgestellt, dass der Ertrag als Funktion der Pflanzenzahl demselben Ertragsgesetz folgt wie in Abhängigkeit von der Düngung. Praktisch ergab sich aus diesen Versuchen die Folgerung, dass *von der Pflanzenzahl 20/308 cm² an* auf Grund der starken Entwicklung der Einzelpflanze die Höchsterträge, welche mit 30-40 Pflanzen zu erzielen sind, bereits erreicht werden. In Übereinstimmung mit anderen Autoren kommt KARPINSKI (10) zu der Ansicht, dass die Bedingungen im Gefässversuch andere seien als im Feldbestand, wobei er den höheren Stickstoffgehalt als Beispiel anführt.

Ich konnte früher bereits darauf hinweisen (11), dass es bei der Beurteilung des Pflanzenbestandes auf das physiologische Gleichgewicht zwischen allen Wachstumsfaktoren und dem Pflanzenbestand ankommt, zumal die Einzelpflanze auch im Feldbestand einen sehr wechselnden Standraum und damit Entwicklungsmöglichkeiten hat. Eine nähere Untersuchung dieser Frage führt zu dem Ergebnis, dass das Verhältnis vom Pflanzenbestand zu den wichtigsten Wachstumsfaktoren nicht so stark abweicht, wie es den Anschein haben kann. Für einige Daten kommt dies in *Tabelle* 3 zum Ausdruck.

TABELLE 3

Vergleich physiologischer Daten aus Feld-und Gefässversuch

	Feld	Gefäss umgerechnet auf ha.	Gefäss Feld
Ertrag dz./ha.	100	325	3,25
Aufnahme : N kg./ha.	86	260	3,02
K_2O kg./ha.	100	325	3,25
P_2O_5 kg./ha.	48	146	3,05
Wasserverbrauch mm.	400	1000	2,5
Pflanzenzahl/m²	300	900	3,0
N-Verwertung :			
Ertrag/N-Aufnahme : kg./ha.	116	125	1,08
K_2O-Verwertung :			
Ertrag/K_2O-Aufnahme : kg./ha. ...	100	100	1,0
P_2O_5-Verwertung :			
Ertrag/P_2O_5-Aufnahme : kg./ha. ...	208	223	1,07
Wasser Verwertung :			
Ertrag/mm. : kg./ha.	25	30	1,2

Es wurde vom Gefässversuch entsprechend der Oberfläche des Gefässes auf das Feld umgerechnet. Hierbei kommen wir zu dem Ergebnis, dass ähnlich wie der Ertrag auch die Aufnahme der wichtigsten Nährstoffe (Stickstoff, Kali und Phsophorsäure) ebenso wie der Wasserverbrauch und auch die Pflanzenzahl mit kleinen Abweichungen *im Gefässversuch etwa das Dreifache* betragen im Vergleich zu den Verhältnissen im Ackerbau. Dementsprechend weichen die im zweiten

Teil der Tabelle nach meinem früheren Vorgehen errechneten Verwertungszahlen nur wenig voneinander ab, so dass sich jetzt im Gefäss im Verhältnis zum Feld ein Faktor ergibt, der bei 1 oder wenig über 1 zu liegen kommt (siehe letzte Spalte in *Tab.* 3).

Solange die von uns gefundenen Relationen bestehen, ist also gegenüber der hohen Pflanzenzahl pro Flächeneinheit im Gefässversuch schwer etwas einzuwenden. Sobald einer der Wachstumsfaktoren in den Mangelgefässen das Reaktionsverhältnis stört, ist naturgemäss mit eine Verschiebung der Beziehungen zu rechnen, dies muss jedoch auch im Feldbestand mit vielleicht etwas geringeren Ausschlägen der Fall sein!

Wir können andererseits feststellen, dass MITSCHERLICH mit der verhältsnismässig grossen Bestandsdichte eine sehr intensive Durchwurzelung des beschränkten Bodenvolumens und somit die Möglichkeit einer starken Erschöpfung der Wachstumsfaktoren im Boden und ihre entsprechende Bestimmung ermöglicht. In diesem sehr aktiv reagierenden Pflanzenbestand haben wir zweifellos die Ursache für einige weitere Erscheinungen des Gefässversuches zu suchen.

TABELLE 4

Ertragswerte für Korn und Stroh in g/Gefäss $\pm\bar{m}$
Versuchspflanze So-Weizen

Wasser-gabe mm.	Pflanzenzahl			
	9	18	36	54
15,4	13,6±1,37	19,1±0,71	24,3±1,28	22,4±1,47
23,1	40,9±1,18	40,5±1,83	43,1±0,98	49,0±1,68
30,8	56,7±0,63	53,1±0,88	55,5±1,30	60,1±1,01
38,5	61,9±1,92	64,5±2,13	63,8±2,67	63,8±1,30

Wir führten Gefässversuche mit verschieden dichtem Pflanzenbestand zum Studium des Wasserhaushaltes von Boden und Pflanze durch (12). Die in *Tabelle* 4 angegebenen Gesamterträge, welche auf einem feinerdereichen Boden (30% <0,02 mm.) erzielt wurden, zeigen, dass bei niedrigen Wassergaben der Höchstertrag erst mit 36 bis 54 Pflanzen pro Gefäss erzielt wurde. Bei starker Wasserversorgung wurde schon mit 18 Pflanzen der Höchstertrag erreicht. Bei hoher Wasserversorgung zeigt sich eine starke Abhängigkeit der verschiedenen Pflanzenbestände, indem bei weniger Pflanzen die Einzelpflanze wesentlich stärker zur Entwicklung kommt. Bei schwacher Wasserversorgung ist dies nicht der Fall. Die Abhängigkeit schwacher Pflanzenbestände von der Stärke der Wasserversorgung kommt auch bei der Bestimmung des " physiologisch toten " Bodenwassers deutlich zum Ausdruck. Für das tote Bodenwasser (Wt) wurden folgende Werte bzw. das Vielfache der Hygroskopizität (Hy) bei den einzelnen Pflanzenbeständen festgestellt:

	Wt	Wt / Hy
bei 9 Pflanzen	11,4	1,37
bei 18 „	10,2	1,23
bei 36 „	9,0	1,09
bei 54 „	8,3	1,00

In der letzten Spalte sind die Unterschiede zwischen 36 und 54 Pflanzen wiederum gering, während sich bei 18 und 9 Pflanzen starke Abstufungen ergeben.

(c) Das Problem der Sandverdünnung

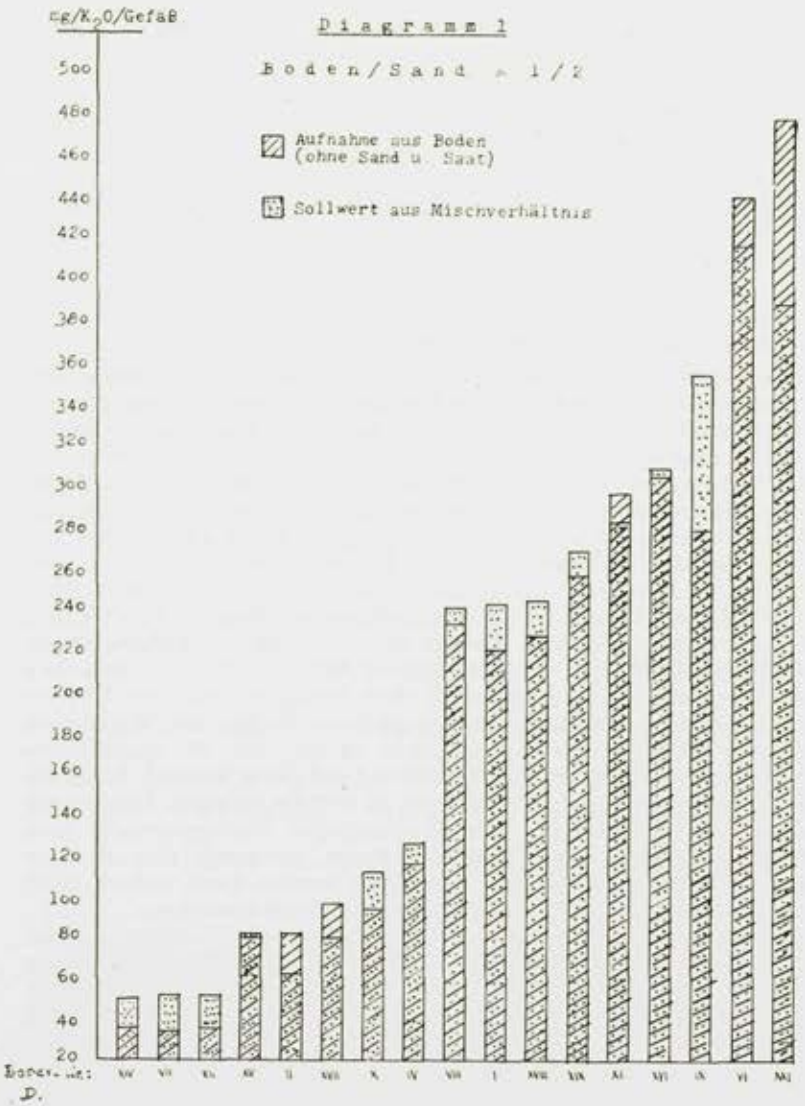
Zweifellos besteht zwischen der eben behandelten Frage des Pflanzenbestandes und der Sandverdünnung, welche MITSCHERLICH im Gefässversuch empfiehlt, eine Beziehung. Durch die intensive Durchwurzelung sowohl als auch durch die künstliche Verdünnung der Bodenkrume wird die weitgehende Erschöpfung des im Boden vorhandenen Nährstoffvorrates ermöglicht. Es ist deshalb verständlich, wenn LEMMERMANN (13) schon frühzeitig die Frage aufgeworfen hat, ob infolge der Vermischung des Bodens mit Sand eine andere Löslichkeit der Pflanzennährstoffe erzielt wird als in reinen Boden. Auch SCHEFFER (14) kommt zu der Schlussfolgerung, dass die Erschöpfung des mit Sand verdünnten Bodens relativ intensiver erfolgen müsste als in reinem Boden. Dagegen kommt MITSCHERLICH (15) in seinen einschlägigen Untersuchungen zu dem Ergebnis, dass die b-Werte in reinem Boden und unter sehr verschiedenen Boden/Sand-Mischungen dieselbe Höhe erreichen. Abgesehen davon, dass die quantitative Umrechnung von einem Krumenteil auf die ganze Krume innerhalb des Ertragsgesetzes zwanglos möglich ist und die geringere Ausnutzung höherer Nährstoffmengen im abnehmenden Ertragszuwachs zum Ausdruck kommt, ergibt sich die Frage, inwieweit eine stärkere Aufnahme in Sandgemischen festgestellt werden kann und ob nicht andere Gründe sehr für die Verdünnung mit Sand sprechen.

Gerade bei nährstoffreichen Böden muss die Verdünnung der Krume das Ergebnis ausserordentlich sichern. Unabhängig von der quantitativen Aufnahme der Nährstoffe führt die Wirkung derselben zu Erträgen, welche in der Nähe des Höchstertrages liegen und die Auswertung aus theoretischen und technischen Gründen schwierig gestalten.

Zur Klärung der aufgeworfenen Frage sind die Zusammenhänge zwischen der Aufnahme der Nährstoffe aus reinem Boden und Boden/Sand-Gemischen und die Ertragsbildung zu berücksichtigen. Eigene Untersuchungen (16) ergaben, dass *in* 11 *von* 17 *Fällen die Aufnahme im Boden/Sand-Gemisch=1/2 den Aufnahmen aus reinem Boden innerhalb der Fehler entsprach.* Das Ergebnis der Untersuchung ist in *Diagramm* 1 wiedergegeben.

Es handelte sich um Böden, welche in ihrem Kalivorrat grosse Unterschiede zeigten. Die Abweichungen vom Soll-Wert (aus dem Mischverhältnis errechnet) treten sowohl bei kalireichen als auch bei kaliarmen Böden auf.

- 24 a -



Auch bei zweijährigen Untersuchungen am gleichen Material wurden Aufnahmen festgestellt, die ganz dem Mischungsverhältnis entsprechen. Dies zeigt folgendes Beispiel:

	reiner Boden:	*Boden/Sand 1/2*
1. Versuchsjahr	97 mg. K_2O Aufnahme	38 (Soll 32) mg. K_2O-Aufnahme
2. „	102 „	37 (Soll 34) „

Auch bei dem Mischungsverhältnis Boden/Sand = 1/4 wurden weitgehend Übereinstimmungen in der Aufnahme mit den errechneten Werten gefunden, wenngleich hier auch verhältnismässig häufig Abweichungen auftraten.

Bei der Untersuchung des Einflusses der Sandverdünnung wirken offensichtlich andere Wachstumsfaktoren mit, welche die Beziehungen in einzelnen Fällen beeinflussen. Da neben der Aufnahme die Verwertung zur Substanzbildung Berücksichtigung finden muss, werden die Beziehungen in *Tabelle* 5 für vier Böden wiedergegeben.

TABELLE 5

Wirksames Kali und Kaliverwertung bei verschiedenen Boden und Bodensandgemischen

Werte in mg. K_2O/Gefäss (Versuchspflanze: Hafer)

	reiner Boden	Boden/Sand = 1/2	Boden/Sand = 1/4
Boden XVII:			
1. wirksames Kali*	231	111 (77)**	79 (46)
" b "†	225	142	71
3. Relativzahl für Verwertung‡ ...	1,15	1,22	0,84
Boden XI:			
1. wirksames Kali	1030	360 (343)	220 (206)
2. " b "	977	229	142
3. Relativzahl für Verwertung ...	0,93	0,77	0,78
Boden VIII:			
1. wirksames Kali	830	280 (277)	145 (166)
2. " b "	613	282	143
3. Relativzahl für Verwertung ...	0,97	0,96	0,97
Boden XII:			
1. wirksames Kali	121	48 (40)	
2. " b "	133	61	
3. Relativzahl für Verwertung ...	1,08	1,24	

*" wirksames Kali," berechnet aus Aufnahmen.
† " b " = physiologisch wirksames Kali, berechnet aus Erträgen.
‡ im Vergleich zu reinem Sand.
**In Klammern Soll-Werte aus Aufnahme in reinem Boden und Mischverhältnis berechnet.

In der ersten Reihe wird als " wirksames " Kali diejenige Kalimenge angegeben, welche auf Grund der effektiv gefundenen Aufnahmen und des Gleichgewichtes zwischen Pflanze und Boden als wirksame Kalimenge berechnet wurde. In der zweiten Reihe werden die ohne Rücksicht auf die Kaliaufnahme aus den Erträgen (A und y_0) errechneten Werte für " b " angegeben. Es zeigt sich, dass im reinen Boden die auf beiden Wegen ermittelten " wirksamen " Kalimengen mit einer Ausnahme (Boden VIII) weitgehend übereinstimmen. Bei Boden XVII werden nach beiden Methoden in der Gemischen verhältnismässig zu hohe Werte gefunden, während bei Boden XI die b-Werte niedriger liegen als die Soll-Werte und die aus den Aufnahmen

berechneten Werte mit den Soll-Werten übereinstimmen. Bei Boden VIII ergeben sich in den Boden/Sandgemischen Übereinstimmungen zwischen beiden Berechnungsarten. Bei Boden XII liegt der b-Wert etwas höher. In der dritten Reihe wird die "relative Verwertung" angegeben, welche die von den Pflanzen aufgenommene Kalimenge gegenüber der Verwertung bei reinem Sand fand. Diese Relativzahl gibt uns die Erklärung dafür, dass bei der Ermittlung von "b" die Verwertung in der Pflanze eine entscheidende Rolle spielt. So kommt bei dem Boden/Sandgemisch von 1/2 des Bodens XVII ein verhältnismässig hoher b-Wert zustande, während die b-Werte bei Boden XI infolge relativ schlechter Verwertung der Aufnahmen gegenüber dem reinen Boden niedrig liegen. Bei Boden VIII entspricht die Verwertung in den Sandgmischen weitgehend derjenigen im reinen Boden, so dass hier die b-Werte mit den Werten für "wirksames Kali" übereinstimmen. Bei dem letzten Boden ist die bessere Verwertung im Boden/Sandgemisch 1/2 für den höheren b-Wert verantwortlich.

Die Gegenüberstellung zeigt uns die Bedeutung des Gefässversuches als *pflanzenphysiologische Methode*. Wir stellen fest, dass sowohl die Aufnahme wie die Verwertung offensichtlich unabhängig vom Mischungsverhältnis beeinflusst werden können und dass infolge der verschiedenen physiologischen Verwertung in der Pflanze eine *konstante Beziehung zwischen Aufnahme und Substanzbildung nicht zu bestehen braucht*.

In *Tabelle* 6 wird an 2 Böden gezeigt, wie sowohl die Aufnahmen als auch die relative Verwertung bei verschieden hoher Kalidüngung durch den *Kalkfaktor* beeinflusst werden, worauf ich früher ausführlich hinwies. Während bei Boden XVIII die Verwertung durch zusätzliche Kalkdüngung im allgemeinen verbessert wurde, findet bei Boden X eine Verschlechterung der Kaliverwertung durch die Kalkdüngung statt. Die Aufnahmen zeigen zuerst gewöhnlich einen starken Anstieg, um sodann abzufallen.

Ähnlich kommt in *Tabelle* 7 die schon von MITSCHERLICH und anderen Autoren untersuchte Beeinflussung der Kaliwirkung durch *Natriumdüngung* zum Ausdruck, wobei sowohl die Kali-Aufnahme als auch die Kali-Verwertung durch die Natriumdüngung erheblich verbessert wird.

TABELLE 6

Kaliwirkung bei verschiedener Kalkdüngung

Werte in mg/Gefäss $\pm \bar{m}$ (*Versuchspflanze: Hafer*)

Düngung K_2O	Düngung CaO	K_2O-Aufnahme gefunden	K_2O-Aufnahme berechnet	Relativzahl für Verwertung
(*a*) Boden XVIII (reiner Boden) wirksames K_2O = 846				
300	0,0	806 ± 8,7		0,87
300	4000	980 ± 4,6	895	0,89
300	10000	928 ± 4,9		0,95
1000	0,0	1167 ± 4,8		0,91
1000	4000	1348 ± 10,2	1380	0,07
1000	10000	1298 ± 6,5		0,97

(*b*) Boden X (reiner Boden) wirksames $K_2O = 348$

0,0	0,0	278 ± 5.7	278	0,87
0,0	4000	281 ± 4.2		0,64
0,0	10000	166 ± 6.2		0,68
150	0,0	384 ± 6.7	398	0,86
150	4000	428 ± 5.3		0,65
150	10000	248 ± 8.2		0,67

TABELLE 7

Kaliwirkung bei verschiedener Natriumdüngung.

Werte in mg. Gefäss $\pm \bar{m}$ (*Versuchspflanze: Hafer*)

Düngung		K_2O—Aufnahme		Relativzahl für Verwertung
K_2O	Na_2O	gefunden	berechnet	
500	0,0	415 ± 3.2	395	1,14
500	250	415 ± 3.4		1,22
500	750	448 ± 3.7		1,29
500	1500	437 ± 3.8		1,33
1000	0,0	753 ± 3.5	700	1,13
1000	250	786 ± 11.3		1,21
1000	750	818 ± 3.9		1,25
1000	1500	812 ± 7.7		1,24

Die angeführten Versuche demonstrieren zwei Ursachen in der Beziehung zwischen Aufnahme und physiologischer Verwertung eines Wachstumsfaktors. Sie bestätigen die eben gemachte Schlussfolgerung, dass nur der erzielte Pflanzenertrag das Zusammenwirken der Wachstumsfaktoren zu erfassen gestattet, und die Zweckmässigkeit des Gefässversuches neben dem Feldversuch zur Bestimmung der im Boden "*physiologisch wirksamen Nährstoffmengen.*"

(*d*) *Die Berücksichtigung des Untergrundes*

Die Tatsache, dass MITSCHERLICH die in der 15 cm. Krume festgestellten Nährstoffmengen mit dem Faktor 2 multipliziert, um damit alle tieferen an der Versorgung des Pflanzenbestandes beteiligten Bodenschichten zu berücksichtigen, ist vielfach angegriffen worden. So hat GERLACH (17) seine Ablehnung der Methode mit auf diese Berücksichtigung des Untergrundes bezogen. MITSCHERLICH ist auf empirischem Wege zu diesem Vorgehen gekommen, indem er den experimentellen Vergleich zwischen Gefäss- und Feldversuch durchführte. Auch DENSCH und PFAFF (18) kommen bei einer kritischen Prüfung des Problems zu ähnlichen Ergebnissen wie MITSCHERLICH, wenigstens soweit es die Beratung der praktischen Landwirtschaft anbetrifft. MITSCHERLICH konnte schon bei der Wirkung der Krumentiefe bzw. der Tiefe der Bodenbearbeitung an Hand von Versuchen E. WOLLNYS nachweisen, dass mit zunehmender Bearbeitung und, Krumentiefe der Ertrag dem Ertragsgesetz folgt, also mit zunehmender Tiefe sich asymptotisch dem Höchstertrag nähert. Wenn auch diese Ergebnisse zur Begründung mit herangezogen werden können, so

wird die Klärung des Problems dadurch erschwert, dass unter intensiven Ackerbaubedingungen jährlich grössere Mengen mineralischen Düngers der Krume zugeführt werden. Eingehende spezielle Versuche, welche im Osten Deutschlands zur Durchführung kamen, sind leider durch die Ereignisse des Krieges verlorengegangen. MITSCHERLICH selbst hat es offen gelassen, dass die jeweiligen Bodenverhältnisse Berücksichtigung finden können, wobei vor allem die Tiefe des durchwurzelten Horizontes eine Rolle spielen dürfte. Es liegt also in der Hand des Versuchsanstellers und noch mehr des Beraters die richtige Verwertung der unter der Krume liegenden Schichten vorzunehmen und vor allem durch Feldversuche die Auswertung der Gefässversuche zu kontrollieren. Auch kann m.E dabei so vorgegangen werden, *dass entstelle der 15 cm.-Schicht die gesamte bearbeitete Krume bei der Probeentnahme Berücksichtigung findet*, so dass schon bei der Umrechnung von der Sandverdünnung auf die Krume die Stärke der zur Probeentnahme herangezogenen Schicht zu beachten ist.

(e) *Die Übertragung der Gefässversuchsergebnisse auf den gewachsenen Boden unter besonderer Berücksichtigung der methodischen Vorschläge von* H. WIESSMANN

Es soll an dieser Stelle darauf verzichtet werden, die zahlreichen in der Literatur erschienenen Auseinandersetzungen zu diskutieren, welche sich auf die richtige Höhe und vor allem auf die Konstanz der Wirkungsfaktoren "c" beziehen. Bei der Anwendung des Wirkungsgesetzes der Wachstumsfaktoren auf die Ermittlung des Düngebedürfnisses nach der Methode von MITSCHERLICH ist die Konstanz des jeweiligen Wirkungsfaktors der einzelnen Nährstoffe Voraussetzung. Die Diskussion ist insofern nicht erforderlich als bei der Bestimmung des Düngebedürfnisses im Gefässversuch stets unter den gleichen Bedingungen gearbeitet wird. Nicht nur die Wasserversorgung sondern auch die Grunddüngung ist in ihrer Höhe und im Verhältnis der einzelnen Nährstoffe zueinander optimal gestaltet. Auf diese Zusammenhänge wurde in eingehenden Untersuchungen früher schon hingewiesen (19). Intensive Ackerbauverhältnisse vorausgesetzt, wird auch auf dem Feld stets mit Volldüngungen gearbeitet, welche alle beeinflussbaren Wachstumsfaktoren berücksichtigen und infolgedessen die unter den klimatischen und sonstigen bodenmässigen Verhältnissen des Standortes erreichbaren Höchsterträge sicherstellen. *Diese Forderung ist ohnehin die Voraussetzung für die Auswertung jeglicher Methoden zur Bestimmung des Düngebedürfnisses.* Bei der Auswertung eines sehr umfangreichen Materials von 27000 Felddüngungsversuchen, die bei den verschiedensten Kulturpflanzen durchgeführt worden waren, konnte MITSCHERLICH die Anwendbarkeit des Ertragsgesetzes mit dem von ihm festgestellten Wirkungsfaktor nachweisen (20).

WIESSMANN (21) hat insofern eine Anderung des gesschilderten Verfahrens vorgeschlagen, als er in jedem Jahr eine Vergleichskurve für die Wirkung der einzelnen Nährstoffe (Kali und Phsophorsäure) in reinem Sand feststellt. Mit diesem Vorgehen stellt WIESSMANN gleichermassen für jedes Jahr den Wirkungswert in der dann benutzten "Normalkurve" fest. Ausserdem sieht er sich veranlasst, bei dem Vergleich der Volldüngungspunkte des Boden/Sandgemisches und des

reinen Sandversuches eine Korrektur des y_0-Wertes durchzuführen, weil er auf diese Weise den physikalischen Einfluss des Bodens gegenüber dem reinen Sand zu erfassen versucht. Auf die Berücksichtigung des Untergrundes verzichtet WIESSMANN völlig, weil er diesem offenbar gar keine Bedeutung für die Ernährung des Pflanzenbestandes zuspricht. In der Errechnung des Düngebedürfnisses macht sich WIESSMANN ebenfalls frei von der Anwendung der allgemeinen Gesetzmässigkeit, in dem er den *Bedarf* der anzubauenden Pflanzen und die *Ausnutzbarkeit* der einzelnen Nährstoffe (beides in Faustzahlen) neben der Ermittlung des Nährstoffzustandes zu Grunde legt. Abgesehen davon, dass das praktische Ergebnis dieser Manipulationen, jedenfalls soweit die Angaben WIESSMANNS vorliegen, wenig von dem MITSCHERLICHS abweicht, hat sich dieses Verfahren nicht durchgesetzt.

Das Verfahren von MITSCHERLICH ist in vielen Kulturländern zur Anwendung gekommen. In der früheren Provinz Ostpreussen wurden laufend Untersuchungen in 23000 Gefässen durchgeführt. Wenn der Verbreitung Grenzen gesetzt waren, so sind hierfür weniger wissenschaftliche als wirtschaftliche Gründe massgebend gewesen, weil das Verfahren teurer ist als die chemischen Schnellmethoden. Der Grund, dass das Verfahren MITSCHERLICHS zu lange Zeit in Anspruch nimmt, d.h. eine ganze Vegetation beansprucht, ist nicht stichhaltig. Neben dem Feldversuch ist der Gefässversuch das einzige Verfahren, welches eine quantitative Erfassung des Nährstoffumsatzes im Boden gestattet.

Da die Methode unabhängig vom klimatischen Wachstumsfaktor "Wasser" und auch sonst unter konstanten Versuchsbedingungen durchgeführt werden kann und auf einer einwandfreien Durchschnittsprobe eines Feldschlages aufbaut, hat sie gegenüber dem Feldversuch viele Vorteile, welche die Auswertbarkeit begünstigen. Hierin ist wohl der Grund zu suchen, dass die Gefässversuchsmethode nach MITSCHERLICH zusammen mit dem Feldversuch die Vergleichsmethode bei der umfassenden Vergleichsuntersuchung wurde, welche die 4. Kommission vor rund zwanzig Jahren durchgeführt hat und über welche MITSCHERLICH in einem ersten Bericht der Internationalen Gesellschaft für Bodenkunde im Jahre 1936 berichtet hat.

IV. Weitere Faktoren der Fruchtbarkeit, welche mit dem Gefässversuch bestimmt werden konnen

(a) Die Bestimmung des Kalkbedürfnisses des Bodens

Schon in seinen ersten Vorschlägen (1924) hatte MITSCHERLICH dargelegt, wie neben der Bestimmung des Kali- und Phosphorsäurezustandes auch das Kalkbedürfnis des Bodens mit Hilfe des Gefässversuches ermittelt werden kann. Zusammen mit der Methode von CHRISTENSEN, der das Wachstum von Azotobakter als Indikator für das Kalkbedürfnis benutzt, ist der Vorschlag von MITSCHERLICH das einzige pflanzenphysiologische Verfahren geblieben, welches unabhängig vom Feldversuch die Ermittlung des Kalkbedürfnisses gestattet. Abgesehen von gewissen Änderungen, welche die Methode im Laufe der Zeit erfahren hat, wird hierbei stets mit reinem Boden gearbeitet. Ferner wird als weitere Versuchspflanze der gegenüber dem Kalkzustand empfindlich reagierende Senf (Sinapis alba) neben

Hafer benutzt. MITSCHERLICH (22) empfiehlt die Anwendung von 8d Gefässen, von welchen je 4 mit Hafer und 4 mit Senf besät werden. Neben einer einheitlichen Grunddüngung von Kali erhalten je 2 der 4 einheitlich besäten Gefässe eine alkalische Düngung von Thomasphosphat und Natronsalpeter, während die beiden anderen eine physiologisch saure Düngung von Superphosphat und Ammonsalpeter erhalten. Ausserdem besteht die Möglichkeit, in zusätzlichen Gefässen Kalkgaben verschiedener Höhe bzw. bis zu 10 gr. $CaCO_3$ zu verabfolgen zumal hierbei das Kalkbedürfnis direkt ermittelt werden kann.

Das genannte Verfahren hat sich in der Praxis der Bodenuntersuchung gegenüber den chemischen Verfahren zur Bestimmung des Kalkbedürfnisses nicht durchgesetzt. Vor allem ist hier wohl die Ursache darin zu suchen, dass die billigeren Methoden zur " S "- und " T "- Bestimmung eine quantitative Errechnung des Sättigungsgrades und des Kalkbedürfnisses gestatten. Hierin unterscheiden sich die chemischen Methoden zur Bestimmung des Kali- und Phosphorsäurebedarfs, welche nur qualitative Schlussfolgerungen zulassen.

(*b*) *Die Ermittlung physikalischer Fruchtbarkeitfaktoren*

Aufbauend auf den Untersuchungen von E. WOLLNY hat MITSCHERLICH den Gefässversuch im weiteren Sinne einschliesslich des Kasten- und Kleinparzellenversuches zur Ermittlung der Wirksamkeit verschiedener physikalischer Faktoren herangezogen. So wurde der Einfluss der *Bodentemperatur* in einer klassischen Versuchsreihe gezeigt. Wie schon erwähnt, wurde der Einfluss der *Ackerkrume* sowie der *Bearbeitungstiefe* und der *Krümelung* des Bodens im Experiment zu erfassen versucht. Sehr wesentlich ist die Feststellung der Ertragssteigerung bei dem Zustandekommen der Höchsterträge auf verschiedenen *Bodenarten* einschliesslich einer Reihe von Gefässversuchen, in welchen der Einfluss der *Korngrosse* von Sandböden erfasst wird.

Aus diesen zahlreichen Versuchen erkennen wir, dass der Gefässversuch für die Isolierung und die Bestimmung der Wirksamkeit einzelner physikalischer Faktoren im Boden unentbehrlich ist. Andererseits wird hierbei der Gefässversuch stets ein Modellversuch bleiben. Es ist leider nur sehr schwer möglich, die Bedingungen des gewachsenen Bodens, vor allem was die Lagerung und Struktur in den einzelnen Bodenhorizonten anbetrifft, bei der Anstellung des Gefässversuches wieder herzustellen.

(*c*) *Die Ermittlung des Wasserhaushaltes im Boden*

Das eben Gesagte gilt zweifellos auch für den Wasserhaushalt im Boden. Dass der Gefässversuch als Modellversuch hier jedoch sehr wesentliche einzelne Aussagen machen kann, soll in einigen Beispielen gezeigt werden. Neben seinen früheren Versuchen, nach welchen auch der Wachstumsfaktor " Wasser " dem Wirkungsgesetz der Wachstumsfaktoren entsprechend wirkt, konnte MITSCHERLICH in neuerer Zeit die Wirkung einer Nährlösung gegenüber reinem Wasser zeigen, wie dies in *Abbildung* 8 zum Ausdruck kommt. Die Beziehungen zwischen *Feinerdegehalt* und *Wasserhaushalt* sowie *Substanzbildung* des Pflanzenbestandes konnten in einer Versuchsreihe eingehend geklärt werden (22). In Abhängigkeit vom Feinerdegehalt, der zwischen 0 und 40% schwankte, fielen die Erträge im allgemeinen geradlinig nach der Gleichung.

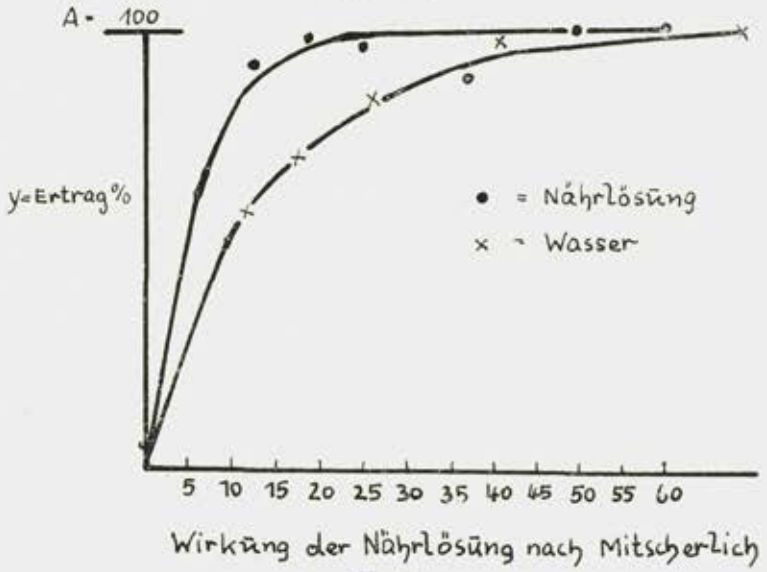


Abb. 8

$$E = Eo - k.\ x.$$

Hierbei bedeuten: E = Ertrag, Eo = Ertrag bei o% Feinerde, x = Feinerdegehalt in %, k = Proportionalitätsfaktor.

Dabei zeigen die Geraden verschiedene Neigung zur x – Achse (*Abb. 9*).

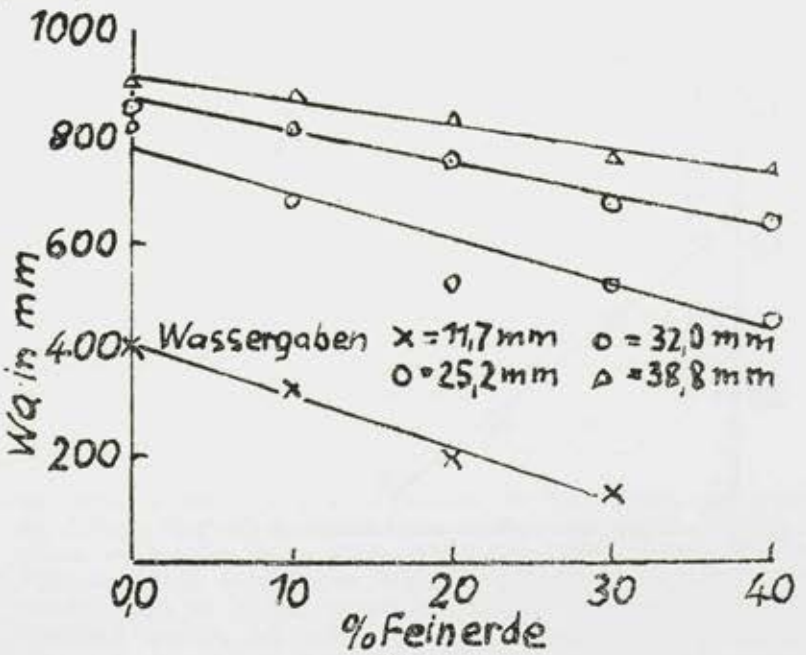


Abb. 9

Der Faktor " k " schwankt zwischen 0,20 und 0,65. Lediglich bei sehr hohen Wassergaben kann ein kurvenmässiger Verlauf festgestellt werden, weil hier die Sandgefässe keine Ertragssteigerung mehr erbrachten. Entsprechend dem Verlauf der Erträge liess sich auch der Gesamtwasserverbrauch in Abhängigkeit vom Feinerdegehalt nach der Formel

$$Wa = Wa_0 - k.\ x$$

berechnen (*Abb.* 10).

Hierin bedeutet: Wa = Wasseraufnahme, Wa_0 = Wasseraufnahme bei 0% Feinerdegehalt, x = Feinerdegehalt in %, k = Proportionalitätsfaktor.

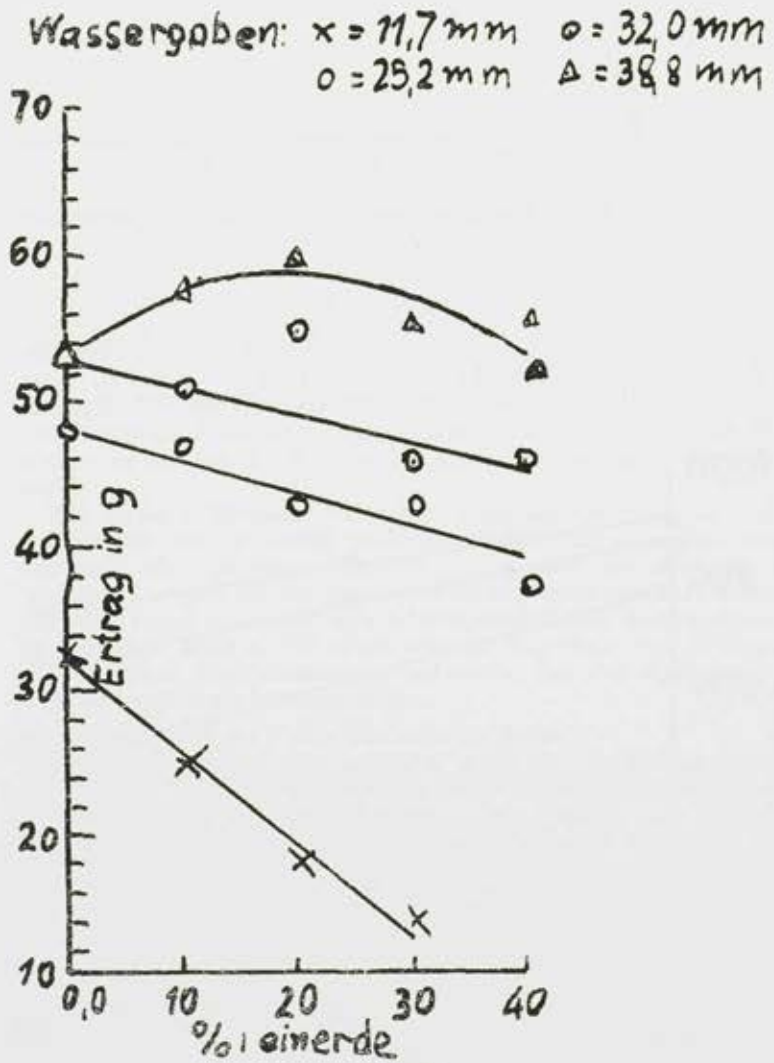


Abb. 10

So fällt auch der Wasserverbrauch proportional zum Feinerdegehalt. Bei Errechnung der Wasserverwertung (Ertrag/Aufnahme) ergeben sich die in *Tabelle* 8 angegebenen Werte.

TABELLE 8

Wasserverwertung bezogen auf Gesamtertrag

Werte in g./100 mm.

Versuchsplan zu So-Weizen

Wassergabe mm.	0% Feinerde	10% Feinerde	20% Feinerde	30% Feinerde	40% Feinerde
11,7	7,91	7,68	9,39	10,44	—
18,5	—	—	8,38	8,38	9,11
25,2	5,81	6,87	8,03	8,11	7,99
32,0	6,14	6,21	7,15	6,77	7,05
38,8	5,81	6,52	7,17	7,24	7,54
45,5	—	—	—	—	7,36

Bei allen Wassergaben nimmt die Verwertung des Wassers mit zunehmendem Feinerdegehalt zu. Der Einfluss des Feinerdegehaltes ist mindestens so gross wie der Einfluss der Höhe der Wassergaben. Während also der höhere Feinerdegehalt eine geringere Wasseraufnahme gestattet, ist die Verwertung zur Substanzbildung relativ günstiger.

Es ist verständlich, dass diese Beziehungen nur bei gleichmässiger Versorgung mit Wasser festgestellt werden können. Die Gleichmässigkeit der Wasserverteilung im Gefäss wurde dadurch erreicht, dass ein Giessrohr in den Boden eingelassen war (24). Dieses verhindert eine ausschliessliche Verteilung des zugegebenen Wassers in den oberen Bodenschichten.

Mit zunehmender Wasseraufnahme nähert sich die Verwertung asymptotisch dem Höchstwert A:

$$\log (A - y) = \log A - 0{,}00048 \cdot x,$$

worin x die aufgenommene Wassermenge angibt.

Der Gefässversuch lässt bei dieser Versuchsanstellung die genaue Unterscheidung zwischen totem Bodenwasser (Wt) und ungenutztem Bodenwasser (Wu) zu. Die Wasseraufnahmen in allen Bodenarten werden nach der allgemeinen Gleichung

$$\log (A - y) = \log A - 0{,}013 \cdot (x - Hy)$$

berechnet, so dass sich bei Extrapolation der Wasseraufnahmekurven die einfache Hygroskopizität als totes Bodenwasser ergibt (Wt=Hy). Genau wie bei den Nährstoffen verbleibt im Gleichgewicht mit dem Pflanzenbestand neben dem toten Bodenwasser das ungenutzte Wasser (Wu) im Boden zurück, welches, wie dies in *Tab.* 9 zum Ausdruck kommt, mit zunehmender Wassergabe erheblich steigt.

TABELLE 9

Ungenutztes Bodenwasser im Mittel aller Dehaden.
Werte in mm./Tag.

Wassergabe mm.	0% Feinerde Hy=0	10% Feinerde Hy=2,9	20% Feinerde Hy=5,8	30% Feinerde Hy=8,7	40% Feinerde Hy=11,6
	(*a*) ungenutztes Wasser (Wu)				
11,7	7,2	8,1	9,6	10,2	—
25,2	16,1	17,6	19,3	19,6	20,1
38,8	28,7	29,0	29,5	30,3	30,6
	(*b*) ungenutztes Wasser—totes Wasser (Wu—Hy)				
11,7	7,2	5,2	3,8	1,5	—
25,2	16,1	14,7	13,5	10,9	8,5
38,8	28,7	26,1	23,7	21,6	19,0
	(*c*) ungenutztes Wasser in Vielfachen der Hygroskopizität $\left(\frac{Wu}{Hy}\right)$				
11,7	—	2,79	1,65	1,17	—
25,2	—	6,07	3,32	2,25	1,73
38,8	—	10,00	5,08	3,48	2,64

In der zweiten Abteilung der Tabelle stellen wir fest, dass die Differenz zwischen dem ungenutzten Bodenwasser (Wu) und dem toten Bodenwasser (Hy) mit dem Feinerdegehalt sinkt. Hierfür bestehen zwei Ursachen. Einmal nimmt die Hygroskopizität und damit das tote Bodenwasser mit zunehmendem Feinerdegehalt zu (siehe Kopf der Tabelle). Andererseits wird die geringere Menge physiologisch wirksamen Bodenwassers der schweren Böden stärker ausgenutzt. Deshalb muss der im dritten Teil der Tabelle angegebene Faktor $\frac{Wu}{Hy}$ mit zunehmendem Feinerdegehalt des Bodens niedriger werden. Ausserdem steigt der Faktor mit zunehmender Wassergabe. Es zeigt sich, dass *der jeweilige Pflanzenbestand sowohl bei niedriger Wassergabe als auch bei feinerdereicheren Boden den Wasserhaushalt des Bodens stärker in Anspruch nimmt als bei höherer Wasserversorgung und sandigen Boden.*

Die Methode des Gefässversuches kann auf diesem Wege zweifellos eine exakte Unterlage für die Bestimmung des toten ebenso wie des ungenutzten Bodenwassers in den einzelnen Bodenarten liefern, da hier eine begrenzte Bodenschicht unter weitgehend konstanten chemischen und physikalischen Bedingungen gehalten werden kann. Der Gefässversuch kann in dieser Ausführung dagegen nichts aussagen über die Nachlieferung des Wassers in den einzelnen Böden, weil eine völlige Durchwurzelung des Bodenvolumens erfolgt. Dabei wurde früher schon darauf hingewiesen (25), dass der Nachlieferung des Bodenwassers an die Pflanze mur eine begrenzte Bedeutung zukommt, weil die Pflanze mit ihrem in der Zeiteinheit hohen Wasserbedarf während der Hauptvegetation gezwungen ist, das Wasser im durchwurzelten Profil durch eine entsprechende Entwicklung des Wurzelsystems aufzusuchen.

V. Schlussbemerkung

Wenn die von MITSCHERLICH entwickelte Gefässversuchsmethode zur Bestimmung des Düngebedürfnisses im Vordergrund der Behandlung dieses Themas geblieben ist, so geschah dies mit Rücksicht auf die frühzeitige Entwicklung und Bedeutung dieses Verfahrens. Dabei wurde auf die Darstellung der auf langjähriger Erfahrung beruhenden Technik des Verfahrens ebenso grosser Wert gelegt wie auf die Diskussion einiger Probleme, welche das Verfahren in seiner Anwendbarkeit begründen und begrenzen. Es musste darauf verzichtet werden, die Vielzahl der anderen Möglichkeiten zur Anwendung des Gefässversuches bei der Feststellung der Bodenfruchtbarkeit näher zu untersuchen. Die Ergebnisse über die Ermittlung des Wasserhaushaltes von Boden und Pflanze geben Hinweise über die Bedeutung des Gefässversuches für die Feststellung weiterer Fruchtbarkeitsfaktoren.

LITERATUR

(1) MITSCHERLICH, E. A. Die Bestimmung des Düngerbedürfnisses des Bodens, Berlin: P. Parey, 1924 in mehreren Auflagen.
(2) MITSCHERLICH, E. A. Bodenkunde f. Land- u. Forstwirte, Berlin: P. Parey, 1906, 6. Auflage 1950.
(3) MITSCHERLICH, E. A. Die Düngerberatung, Halle: Niemeyer, 1948.
(4) MITSCHERLICH, E. A. Die Ertragsgesetze, Berlin, Akademie-Verlag, 1948.
(5) PFEIFFER, T. Der Vegetationsversuch, Berlin: P. Parey, 1918.
(6) EHRENBERG, P. *Landw. Versuchsstationen* **72** (1910), 15-142.
(7) WIESSMANN, H., und SCHRAMM, E. *Zeitschrift für Pflanzenernährung, Düngung und Bodenkunde*, **8** (1929), 105.
(8) MITSCHERLICH, E. A., ATANASIU, N. *Zeitschr. für Acker- und Pflanzenbau* **94** (52), 253–280, siehe auch Willcox, Sugar, VI (1951), 46.
(9) PFEIFFER, Th. Der Vegetationsversuch, Berlin: Parey, 1918.
(10) KARPINSKI, A. *Zeitschr. f. landw. Versuchswesen in Oesterreich* (1898), 387.
(11) v. BOGUSLAWSKI, E. "Die Sortenleistung in Abhängigkeit von der Düngung und das N/K-Verhältnis in der Düngung," *Landw. Jahrbücher* **86** (1938), 207–244.
(12) v. BOGUSLAWSKI, E. *Zeitschr. f. Pflanzenernährung, Düngung u. Bodenkunde*, **24** (69) (1941), 265–303.
(13) LEMMERMANN, O. *Zeitschrift f. Pflanzenernährung, Düngung u. Bodenkunde*, **7** (1928), 352.
(14) SCHEFFER, F. *Die Ernährung der Pflanze*, **30** (1934), 101 und *Kühn-Archiv*, **38** (1933), 141.
(15) MITSCHERLICH, E. A. *Die Ernährung der Pflanze* **30** (1934), H.10.
(16) v. BOGUSLAWSKI, E. "Untersuchungen über das Bodenkali sowie seine Aufnahme und Verwertung durch Hafer," *Landw. Jahrb.* **83** (1936), 711–773.
(17) GERLACH, M. *Zeitschrift f. Pflanzenernährung, Düngung u. Bodenkunde*, **4**, 273 (1925).
(18) DENSCH, A. und PFAFF, A. *Ibid.*, 321.
(19) MITSCHERLICH, E. A., gemeinsam mit v. BOGUSLAWSKI, E. und GUTMANN, W. Studien zur Ernährung der Pflanze u. der Ertragsbildung bei verschiedener Düngung. *Schriften der Königsberger Gelehrten Gesellschaft*, Halle: Niemeyer, XII, Heft 2 (1935).
(20) MITSCHERLICH, E. A. Die Ertragsgesetze, Berlin: Akademie-Verlag, 1948, MITSCHERLICH, E. A. *Z. f. Pflanzenern., Düngg. u. Bodenkde.*, **38** (83), 22–35 (1947).
(21) WIESSMANN, H. *Landw. Versuchsstationen*, **107**, 277 (1928).
(22) MITSCHERLICH, E. A. Bodenkunde für Land- und Forstwirte, 6 Auflage, 1950.

(23) V. BOGUSLAWSKI, E. *Zeitschrift f. Pflanzenernährung, Düngung und Bodenkunde* **24** (69), 265–303 (1941).
(24) V. BOGUSLAWSKI, E. *Zeitschr. f. Pflanzenernährung, Düngung u. Bodenkunde* **17**, 236–252 (1940).
(25) V. BOGUSLAWSKI, E. Verhandlungen der IV Kommission der Internationalen Bodenkundlichen Gesellschaft, Stockholm (1939), 29–40.

SESSIONAL DISCUSSION

M. GREENWOOD: Could Dr. RICHARDSON say what information he had obtained from the trials in which three fertilizer levels were used? Was he satisfied that the responses to the dosages he was using were sufficiently economic to attract persons with low purchasing power to the use of fertilizers. In Northern Nigeria where the application of 10 lb. P_2O_5 per acre to groundnuts promised a sixfold capital return, it was not easy to persuade the peasant to spend 12/- on a ½ cwt. bag of superphosphate.

H. L. RICHARDSON: In experiments at three levels in China (nil, half and full rate of nutrient) with nitrogen, the half rate gave on the average a little more than half the response to the full rate; but with phosphate on most crops, the half rate gave almost as large a response as the full rate. Rapeseed and wheat were exceptions in which the phosphate response to the half rate was little more than half the response to the full rate. This was illustrated by response curves. The conclusion was that for most crops, the full rate of nitrogen would probably be worth using; but the half rate of phosphate would be more economic than the full rate except probably with rapeseed. In undeveloped or peasant countries, it was usually necessary to begin with small rates of application when introducing fertilizers to the peasant farmers. Later, as the benefits from fertilizers were appreciated, heavier applications could be used. In Japan, although the peasant farmers are poor, they now use very heavy rates of application of fertilizer.

(In reply to a question by Mr. R. F. INNES.) In doing field experiments among peasant farmers, it is true that some experiments may be spoiled; one has to accept a certain "casualty rate" and this is another reason for planning large numbers of experiments. With regard to unreplicated experiments or trials which are planned on the basis that several trials in one locality can be analyzed statistically as the randomised blocks of a single experiment, this has been done in some parts of China and, in good examples, the coefficient of variation was little higher than would be expected in an ordinary replicated experiment. In other examples, the variability was much higher. Much depends on careful location of the individual trials so that all those in one area are on similar soils. The method is a useful one where fully replicated experiments are difficult to carry out, but the latter are preferable when it is possible to do them.

V. HERNANDO: We in Spain have some problems with relation to the MITSCHERLICH Pot Experiments:

(1) When we try to carry out experiments with heavy clay soils we get results which are not in agreement with the

field experiments. That is because the sand improved the structure of these soils. On the other hand, if the sand is omitted, the results obtained are worse than those in the field because the soil becomes more compact through the addition of excess water ;

(2) The high Summer temperature produces such excessive evaporation that it becomes necessary to add water twice daily and sometimes the water completely evaporates. The use of large amounts of water each time brings on fungus diseases, attacks of which are not minimised by protecting the pot with straw. Furthermore, the watering requires to be done very early in the morning and very late in the evening, otherwise the plants suffer from burning by the sun.

E. VON BOGUSLAWSKI (*zu 1*) : Die Erfahrungen von Herrn HERNANDO stimmen mit unseren überein. Das Beispiel zeigt, dass der *Vorrat* an Nährstoffen im Boden nur im Gemisch mit Sand festgestellt werden kann. Im Feldversuch ist dies nicht möglich, zumal hier wegen des schlechten Lufthaushaltes keine Höchsterträge erzielt werden können.

(*zu 2*) : Auch in der Wasserversorgung der Gefässe bei starker Verdunstung stimme ich mit Herrn HERNANDO überein. Während des stärksten Wasserverbrauches muss auch bei uns zweimal täglich, und zwar möglichst früh am Morgen und gegen Abend Wasser zugeführt werden. Wenn die Versuchspflanze gegen das Auftreten von Pilzkrankheiten empfindlich ist, empfiehlt sich die Benutzung einer Kiesdecke, welche in 2-3 cm Stärke (etwa 700g/Gefäss) auf den Versuchsboden aufgeschichtet wird. Für Böden, welche zum Verschlämmen neigen, und für Wasserhaushaltsuntersuchungen habe ich ein Giessrohr* entwickelt, welches etwa 10 cm in den Boden eingeführt wird und eine schnelle Verteilung des zugeführten Wassers im Versuchsgefäss gestattet.

F. VAN DER PAAUW : Herr VON BOGUSLAWSKI hat uns klar gemacht dass der MITSCHERLICH sche Gefässversuch auf einer experimentellen Grundlage beruht. Ich möchte aber Folgendes fragen : Kann als eine *genügende* experimentelle Grundlage betrachtet werden, was in einem anderem Lande unter verschiedenen Umständen bestimmt worden ist ? Soll es nicht vielmehr sein, dass auch diese Methode bei Anwendung anderswo aufs Neue geprüft werden muss, und dass unsere Erfahrung mit anderen Untersuchungsmethoden auch in diesem Falle zutrifft, dass es sehr gefährlich ist, eine Methode anzuwenden, welche unter anderen Bedingungen geprüft worden ist ? Ich kann darauf hinweisen, dass der Wirnen Landern sehr verschieden gezeigt hat. In einer rezenten Arbeit (*Plant and Soil*, **4**, 97, 1952) habe ich die Ergebnisse der 27000 deutschen Feldversuchen, auf welche MITSCHERLICH sich stützt, nachgerechnet, und habe dabei gefunden, dass die c-Werten für die verschiedenen Gewëchse ziemlich verschieden sind. Demzufolge fanden wir auch stärker variierende

*v. BOGUSLAWSKI, E. Zur Methodik des Gefässversuches bei Wasserhaushaltsuntersuchungen. *Zeitschr. f. Bodenkunde u. Pflanzenernhrg.* **17**, 236–252 (1940).

b-Werte (1.11-1.83 gegen 1.01-1.31 bei konstanten c-Werte). Ich kann also Herrn VON BOGUSLAWSKI nicht ganz beifallen, wenn er sagt, dass der Variation der c-Werte nur geringe Bedeutung zukommt. Ebenso ist es mir nicht ohne Weiteres klar, dass die MITSCHERLICH sche Methode quantitativ bestimmte Resultate ergibt, welche denen der chemischen Methoden überlegen sein sollen.

E. VON BOGUSLAWSKI: Im Anschluss an meine Ausführungen und im Zusammenhang mit den sehr interessanten Untersuchungen des Herrn VAN DER PAAUW erlaube ich mir, folgende Bemerkungen zu machen:

(1) Aus neueren Untersuchungen in meinem Institut, welche noch nicht publiziert sind, ergibt sich für den Höchstertrag folgendes: Die in der Pflanze wirksamen " inneren Wachstumsfaktoren " einerseits und das beschränkte Selektionsvermögen der Pflanze bei der Nährstoffaufnahme andererseits bewirken, dass es schwierig ist, für den Höchstertrag ein determiniertes Nährstoffverhältnis anzugeben. Dabei ist zu berücksichtigen, dass der Höchstertrag in der Ertragskurve nicht durch einen Punkt, sondern durch einen mehr oder weniger grossen Kurvenabschnitt repräsentiert wird. Um ein Beispiel zu nennen, erhalten wir den gleichen A-Wert mit folgenden Nährstoffverhältnissen:

$$N : K_2O : P_2O_5 = 1{,}0 : 1{,}5 : 0{,}75 = 1{,}0 : 2{,}0 : 0{,}5 = 1{,}0 : 1{,}2 : 1{,}0.$$

Wenn diese Nährstoffverhältnisse zur Erzielung des Höchstertrages bei einer bestimmten Grunddüngung von N_1 festgestellt werden, so können wiederum Verschiebungen für das Höchstertragsgebiet festgestellt werden, welches mit der Grunddüngung N_2 erreicht wird.

Solche Verschiebungen im Verhältnis der Wachstumsfaktoren können auch in der Relation von Wasserversorgung bzw. Niederschlag zu Stickstoffdüngung, von Klima im allgemeinen zu Düngung, von Klima zu Pflanzenbestand nachgewiesen werden. Die angegebenen Nährstoffverhältnisse beziehen sich auf reinen Sand, nehmen also auf Festlegungen keine Rücksicht. Ausserdem gelten sie nicht für den Anstiegsteil der Ertragskurve.

(2) In den meisten Untersuchungen werden die Nährstoffaufnahmen in Prozent der Trockensubstanz angegeben. Unsere Ergebnisse zeigen, dass nicht nur die Aufnahme, sondern auch die " physiologische Verwertung " in der Pflanze von anderen Wachstumsfaktoren beeinflusst wird. Es erscheint deshalb zweckmässig, neben der *absoluten Menge an aufgenommenen Nährstoffen* ihre *Verwertung zur Substanzbildung* zu berücksichtigen und damit das Verhältnis der aufgenommenen Nährstoffe zum Ertrag anzugeben. Die alleinige Berücksichtigung des Nährstoffgehaltes in Prozent kann die Zusammenhänge nicht aufklaren. (Siehe auch die in meinem Referat mitgeteilten Ergebnisse).

(3) Die statistische Methode zur Auswertung von Feldversuchen, welche von Herrn VAN DER PAAUW vorgetragen und von Herrn FERRARI veröffentlicht wurde, erlaubt bei einer grossen Zahl von Experimenten die Feststellung von Korrelationen, welche in einem grösseren Anbaugebiet oder im Verlauf mehrerer Jahre auftreten. In erster Linie handelt es sich um qualitative Feststellungen. Ferner bestehen zwischen solchen Korrelationen nicht ohne weiteres ursächliche Zusammenhänge. Ein Beispiel hierfür scheint mir das von Herrn

VAN DER PAAUW veröffentlichte Ergebnis über die periodischen Schwankungen von pH-Werten und Ertragswerten zu sein. Die Ursache für letztere liegt offenbar nicht in den pH-Werten, sondern in den klimatischen Faktoren, welche beide Faktoren beeinflussen. Dieses müsste jedoch nachgeprüft werden.

Die der statistischen Methode zu Grunde liegenden Zentralwerte sind nicht repräsentativ für einzelne Standorte oder einzelne Versuche. Die in diesen jeweils vorliegenden ursächlichen Zusammenhänge können bei einer Mittelung einer grossen Zahl von Versuchen gegenseitig aufheben, so dass sie auch bei der Errechnung der Korrelationen nicht mehr erfasst werden. Dies wäre im Interesse des einzelnen Standortes und der hier zu treffenden Massnahmen jedoch erforderlich. Ausserdem wären quantitative Angaben oder Schlussfolgerungen erwünscht. Da die statistische Methode an viel Material und mehrere Jahre gebunden ist, ist es sehr schwierig, für den Einzelstandort jeweils die sofortige Prognose für die Wirkung von Düngung oder Bodenbearbeitung zu stellen.

Die statistische Methode kann für eine allgemeine Orientierung bei Vorliegen zahlreicher Versuche zweifellos wertvolle Hinweise geben. Sie kann jedoch nicht für den Einzelstandort quantitative Angaben machen, die eine eingehende Schlussfolgerung über die zu treffenden Massnahmen zulassen.

(4) Zu der Bemerkung, welche Herr VAN DER PAAUW über den c-Wert nach MITSCHERLICH und die Anwendung des Ertragsgesetzes gemacht hat, nehme ich wie folgt Stellung :

Es ist an dieser Stelle nicht erforderlich, das Problem der Konstanz des c-Wertes zu behandeln. Der Gefässversuch zur Bestimmung des Düngerbedürfnisses wendet das MITSCHERLICH sche Ertragsgesetz unter so kontrollierbaren Bedingungen an, dass er als empirische Methode bezeichnet werden kann und reproduzierbare Werte liefert. Infolge der starken Verdünnung des Bodens mit Sand erhalten wir einen Aufschluss über den Vorrat an Bodennährstoffen. Dabei ist der Gefässversuch zum Unterschied vom Feldversuch die erste, pflanzenphysiologische Methode, welche weitgehend unabhängig von klimatischen Wachstumsfaktoren wie insbesondere dem Faktor Wasser arbeitet. Durch die Anwendung des Ertragsgesetzes kommen wir dabei zu *quantitativen Angaben*, während alle chemischen Untersuchungsmethoden nur qualitative Vergleichswerte liefern. In diesen Feststellungen liegt, worauf ich bereits früher hinwies, die Bedeutung dieses Verfahrens.

Es gestattet im intensiven Ackerbau eine Prognose für die im Boden wirksamen Nährstoffe und das tatsächliche Düngebedürfnis. Es its selbstverständlich, dass auch der Gefässversuch trotz seiner Unabhängigkeit vom Wasserhaushalt des Bodens seine Brauchbarkeit durch den Vergleich mit dem Feldversuch erweisen muss. Deshalb erscheint es mir zweckmässig bzw. unbedingt erforderlich, bei der innerhalb der IV. Kommission vorgeschlagenen Gemeinschaftsarbeit den Gefässversuch mit in Vergleich zu stellen.

F. VAN DER PAAUW : Ich kann mich ganz bei der Antwort des Herrn VON BOGUSLAWSKI anschliessen. Dasselbe gibt jedoch nach meiner Meinung genau so für die chemischen Methoden, und ich

schliesse hieraus, dass die MITSCHERLICH sche Gefässmethode den letzteren in quantitativer Hinsicht *im Prinzip* nicht überlegen ist.

F. C. GERRETSEN pointed out that sterile cultures are necessary to ascertain what role micro organisms eventually play in transforming the substances added in pot cultures. He described a method of making sterile cultures for higher plants and indicated a method of watering these cultures so that infection would be reduced to a minimum. He also described a cheap device for keeping the temperature of the sand in pot cultures constant, showing how this is all important when pot cultures are started early in the Spring and especially when experiments are undertaken with phyto-pathological micro organisms, etc. He described a new type of pot which has been developed by one of the Dutch glass factories and in which the water content of the inner pot can be kept fairly constant.

E. M. CROWTHER, in closing the session, said that pressure of time would not allow a discussion to be started on the old questions relating to Mitscherlich's "c" factors. He, personally had attended, over the last twenty-five years, many congresses and conferences at which these matters had been vigorously discussed. During the last few months, he had been pleased to find that Professor MITSCHERLICH had at last agreed to increase his factor for nitrogen, if, as they all trusted, Professor MITSCHERLICH would continue to work actively for many more years, there might be further increases in the nitrogen factor to bring it more closely into line with the results of field experiments on many crops in many countries.

THE EXPERIMENTAL DESIGN WITH SINGLE PLOTS AND THE GRAPHICAL METHOD OF STATISTICAL ANALYSIS OF DATA

TH. J. FERRARI

Agricultural Experiment Station and the Institute for Soil Research
T.N.O., Groningen, Netherlands

In natural science the research worker often tries to overtake the relations between dependent and independent factors by introducing into the research a variation of one or more factors *artificially*. He concentrates particularly on the question whether a *supposed* influence of a factor really exists. The investigation is limited to some most important factors.

As agricultural science is a practical science many factors have to be considered for a right prediction. It will be clear that the usual experimental fields are too small for this purpose. Moreover, it is difficult and expensive to investigate the influence of factors which cannot be changed or are very hard to change, such as groundwater level, structure, clay content. No experimental results are, therefore, obtained for many interesting combinations of factor values.

VISSER projected a way of research, quitting the usual experimental fields and using single plots distributed over a wide area. A graphical method of statistical analysis, the *polyfactor analysis*, has been worked out to unravel the influence of all these growth factors. The analysis tries mostly to give an answer to the problem of which factors can be indicated as causing an influence; one concentrates on the problem of *describing* the data. Besides, this description is used to obtain the best (in a certain sense) estimate of the influence of a factor. There is also investigation into whether the experiment reasonably can be described omitting some influences.

In the analysis one starts from the hypothesis that there is a *functional* relation between the growth factors and the yield, i.e., to any combination of values of the growth factors belongs a particular value of the yield. In practice one will find yields which do not coincide with this yield, because the actual yield forms a sample of a probability distribution.

The *expectation value* of the yield (the probability distribution) $E(y)$ is the mentioned function of the growth factors: $E(y) = \hat{y} = f(x_1, x_2, \ldots . x_n)$. The purpose of the research will be to estimate this function with the aid of the data.

A second hypothesis is that this function is of the particular form (a *joint* function of EZEKIEL, 1947):

$$y = f_1(x_1) + \ldots . f_n(x_n) + f_{1\cdot 2}(x_1 x_2) + f_{1\cdot 3}(x_1 x_3) + f_{1\cdot 2} \ldots . \; n(x_1 x_2 \ldots . x_n) + C$$

The functions $f_i(x_i)$ indicate that to, e.g., 2 values of a certain factor x_i yields of a different amount belong. This difference in yield depends furthermore on the values of other factors (*interaction*). The interactions are absent if the functions with more than one argument in this formula are zero. The interactions found in practice could be satisfactorily described with this formula.

The purpose of the research is to draw up a regression equation of the above-mentioned type, which describes the experiments satisfactorily. It is, therefore, necessary that the *mathematical* form of this regression equation be known or reasonably assumed, after which the parameters in this equation with the aid of the experiments can be determined. The assumption of the form of the equation is essentially not a mathematical but an agricultural question. The data obtained by the experiment may give a *suggestion* about the possible form.

The theoretical knowledge of the influence of the growth factors is very small and consequently the form of the regression function is mostly unknown. Moreover, if a form is given, the process of the determination of the parameters is mostly very difficult and takes much time. A graphical method of statistical taking together is here used: a fluent line is drawn by hand, joining as well as possible the averages of the columns. Consequently the suggestion given by the data is fully used.

The figures 1, 2a, 2b, 3a, 3b and 4 show schematically the relation between the yield and respectively 1, 2 and 3 growth factors. These relations are represented mathematically by the equations

$y=f(x_1)$, $y=f(x_1, x_2)$ and $y=f(x_1, x_2, x_3)$.

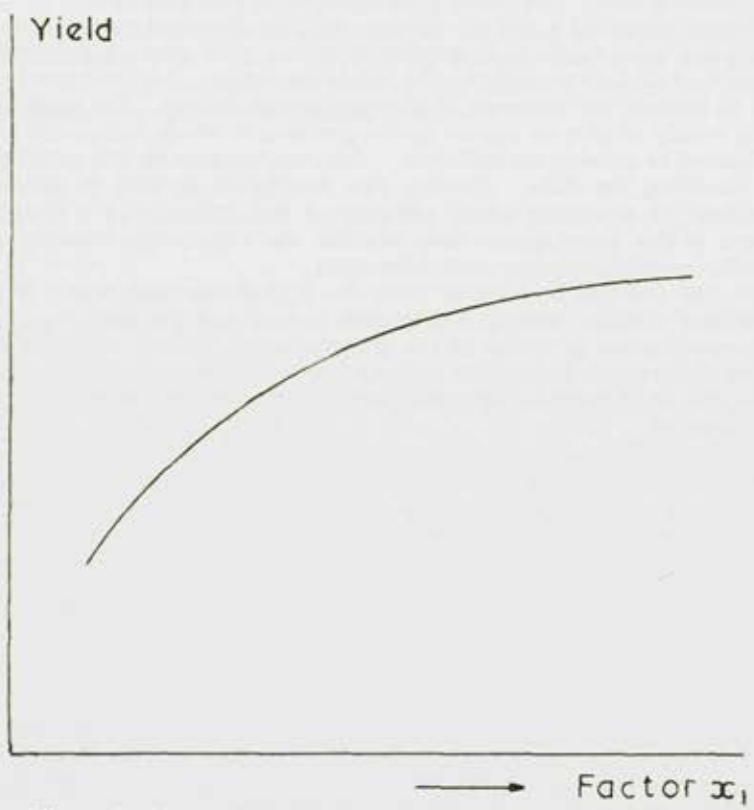


Fig. 1—Graph of the influence of the variation of a factor x on the yield.

The relation e.g., $y=f(x_1, x_2)$ is visualized in the three-dimensional diagram of the figures 2a and 3a. In the analysis a two-dimensional representation is used (figures 2b and 3b): a graph of the function $y=f(x_1, x_2)$ (x_2 constant) is given at different values of x_2.

The relation $y=f(x_1, x_2)$ in the figures 2a and 2b is supposed to be $y=f_1(x_1)+f_2(x_2)$, in which $f(x_1, b^i)-f(x_1, b^k)$ is constant. The relation $y=f(x_1, x_2)$ in the figures 3a and 3b, however, is supposed to be $y=f_1(x_1)+f_2(x_2)+f_{1\cdot2}(x_1\ x_2)$, in which $f(x_1, b^i)-f(x_1, b^k)$ is not constant (interaction).

In an analogous way it is possible to show the influences of n factors by using geometrical terms, which, when bounded by a three-dimensional space, can be represented geometrically. In the analysis one determines each time the influence of a growth factor on the yield, the other factors being held (approximately) constant at different values.

The more factors are studied at the same time, the more data are necessary, so that in complicated multi-dimensional problems the supposition must be made that interactions of higher degrees are absent. This supposition is probably permissible from the agricultural viewpoint as the frequency of the parcels, which are in an extreme situation for several factors at the same time, is relatively low.

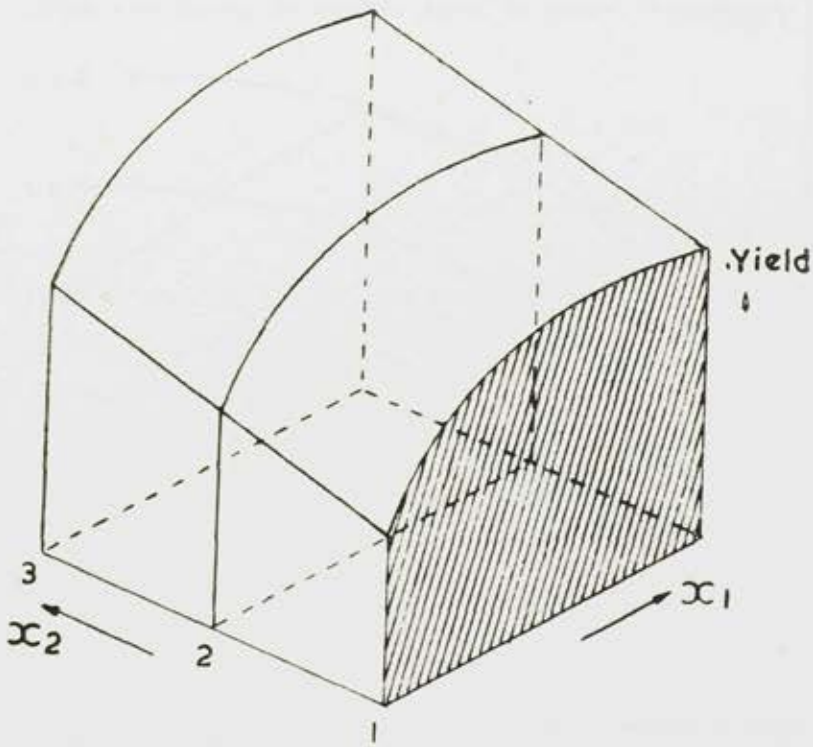


Fig. 2a—Graph of the influence of the variation of a factor x_1 on the yield, at different values of a factor x_2, without interactions. Fig. a—3-dimensional, fig. b—2-dimensional.

In the literature on the subject three adjustment lines are known : (*a*) and (*b*), the two regression lines, one of the coordinates is supposed to be errorless, (*c*) the line obtained by an adjustment perpendicular to this line, which has to be taken if both coordinates are equally inaccurate. VISSER pointed out that regression lines may be of no use ; usually the error of the first coordinate is not small with respect of the error of the second coordinate. He, therefore, introduced a so-called direction of averaging, which takes into account the error of all coordinates and which is based on the relation between the gradients of two conjugate diameters of an ellipse.

Once a relation $y=f(x)$ is found, it is possible to eliminate this influence (*correction*), by which the variance of the yield data is decreased. The correction value is the amount equal to the difference between the correction level and the expectation value of the yield corresponding to the values of the growth factor(s) on every plot. That yield is taken as the correction level for which $\Sigma(f(x^k) - y$ correction level) is zero.

More or less high correlations between the growth factors are introduced into the research, because they are not avoided in this method. It is necessary to eliminate the error in the conclusions, caused by these correlations. This may be done in the same way

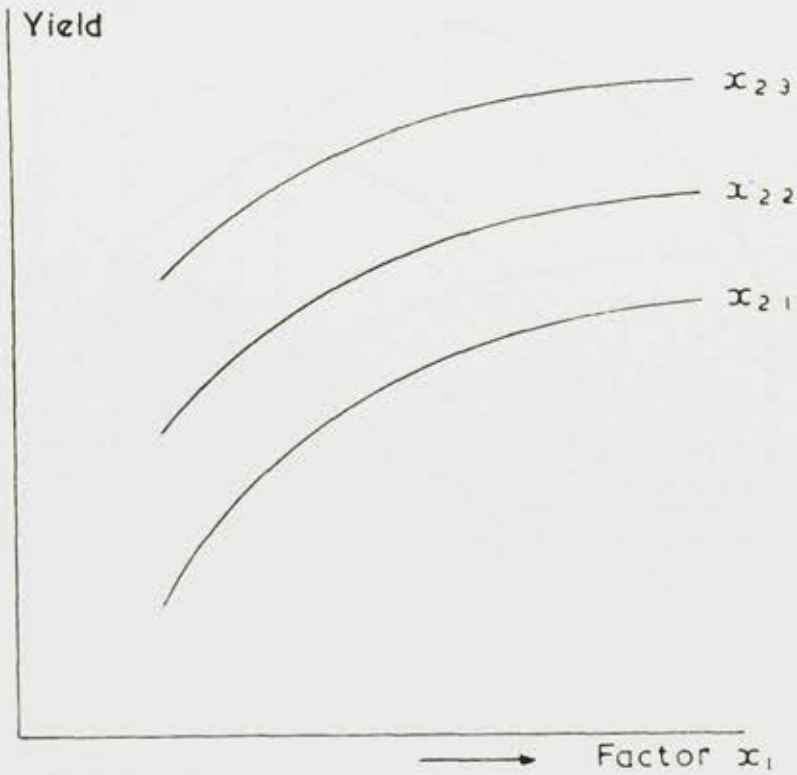


Fig. 2b

as has already been described showing the existence of the interactions ; the number of constant values (groups) depends on the highness of the correlations. In our research each time three groups were used.

If the number of growth factors is n and if the number of groups, in which the extent of variation of a factor is divided, is s, the number of necessary data is proportional with $c/n \times s^{n-1}$; here is $c<1$. Obviously a complete more-dimensional treatment demands a very large number of data. Generally the available number of data is not sufficient for a complete more-dimensional treatment. In such cases a process of *iteration* can be applied.

This process may be demonstrated by the following example. The influence of e.g., 2 factors is assumed to be expressible in the form $y=f(x_1, x_2)=f_1(x_1)+f_2(x_2)$; in the analysis $\Sigma(y-f(x_1, x_2))^2$ must be a minimum. In the process of iteration the function $y=f_1{}^1(x_1)$ is first determined in such a way that $\Sigma(y-f_1{}^1(x_1))^2$ is a minimum. After the correction for $y=f_1{}^1(x_1)$ the function $f_2{}^1(x_2)$ is determined ; this postulates that $\Sigma(y-f_1{}^1(x_1)-f_2{}^1(x_2))^2$ is a minimum. In the second tour the function $y=f_1{}^2$ is determined ; now $\Sigma(y-f_1{}^2(x_1)-f_2{}^1(x_2))^2$ must be a minimum. And so on. The functions $f_1{}^r(x_1)$ and $f_2{}^r(x_2)$ are the best preliminary estimates of the influences, if in the $(r+1)$-th tour the estimate of $f_1(x_1)$ shows no change. It is possible to get an ultimate best estimate by choosing the best one out of all the function $a_1.f_1(x_1)+a_2.f_2(x_2)$ (see further).

With what factors the analysis should be started, depends on :

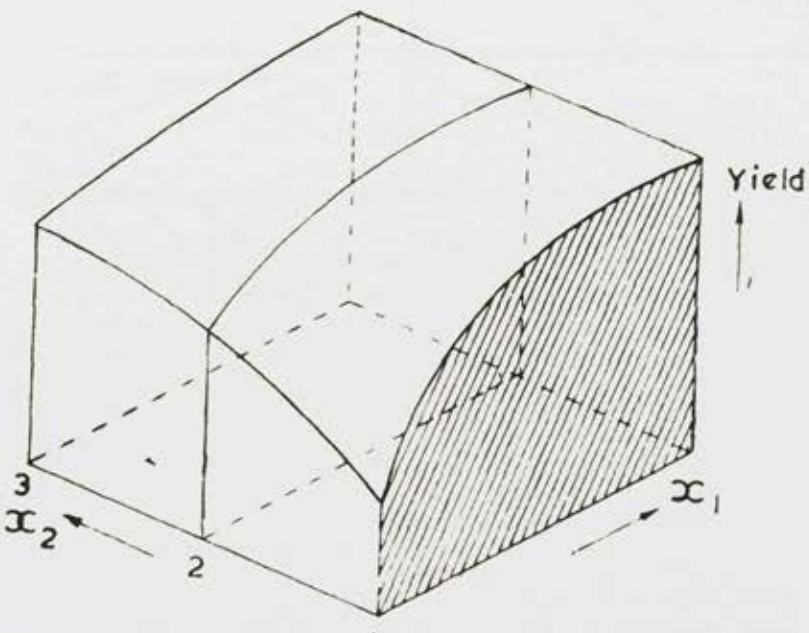


Fig. 3a—Graph of the influence of the variation of a factor x_1 on the yield, at different values of a factor x_2, with interactions. Fig. a—3-dimensional, fig. b—2-dimensional.

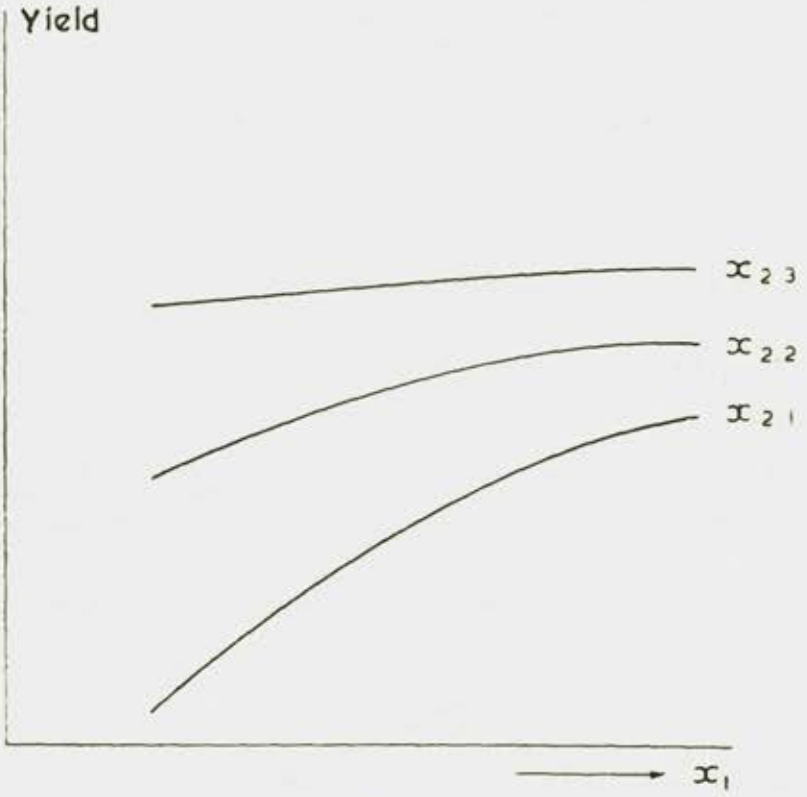


Fig. 3b

(*a*) the degree of the correlation between the several growth factors;

(*b*) the degree of the influence of each separate factor;

(*c*) the degree of the interaction.

It is possible to investigate whether the results obtained by this graphical method are reliable in a mathematical-statistical respect and whether all important growth factors have been really found.

An analysis of variance can be made for the sake of an investigation into the statistical reliability; this done, the ratio of the variances of the corrections and of the rest could be calculated. The theoretical expectation value of this ratio in a *O*-hypothesis is equal to 1; the F-table gives the probability of the ratio $\geq$the ratio found.

A second method of investigating the reliability of the results is to choose with the aid of the experimental data the best one out of all the regression equations $y=a_1.f_1(x_1)+a_2.f_2(x_2)+....+a_n.f_n(x_n)$. In these equations a_1, a_2, ... a_n are constants the best estimates of which must be calculated and $f_1(x_1)$, $f_2(x_2)$, ... $f_n(x_n)$ are the functions found graphically. The number of plots being m there

are m equations $y^k = a_1.f_1(x^k_1) + a_2.f_2(x^k_2) + \ldots + a_n.f_n(x^k_n)$. The normal equations give the best estimates $\bar{a}_1, \bar{a}_2, \ldots \bar{a}_n$. The following table gives the results of such a calculation (FERRARI, 1952).

Growth factor	$\bar{a}_1$	$s\bar{a}_1$	$\bar{a}_i'$	a''_i	$p(a''_i = o)$
Potash content and acidity	1,089	0,04	1,009	1,169	0
Potash dressing	0,964	0,11	0,744	1,184	0
Clay content of topsoil ...	1,153	0,18	0,793	1,513	0
Distance to farmstead ..	0,965	0,18	0,605	1,325	0
Data of planting	0,807	0,25	0,307	1,307	0,001
Organic matter content ...	1,263	0,31	0,043	1,883	0
Groundwater level ...	1,779	0,38	1,019	2,539	0
Depth of reduction ...	0,703	0,29	0,183	1,343	0,005
Structure	0,525	0,49	−0,455	1,505	0,130
Distribution of water-stable aggregates ...	0,137	0,68	−1,223	1,497	0,421
Groundwater fluctuation	1,508	0,95	−0,392	3,408	0,065
Clay content of subsoil ...	0,492	0,40	−0,308	1,292	0,115

The best estimate of a_i and the standard error $s\bar{a}_1$ are calculated from the equations $y^k = a_1.f_1(x_1^k) + a_2.f_2(x_2^k) + \ldots\ldots + a_{12}f_{12}(x_{12}^k$, in which $k = 1, 2, \ldots 222$. In these equations, y^k represents the yield on plot k and $f_i(x_i^k)$ the effect of a growth factor or of a combination of growth factors (=correction value) on a plot k. Furthermore

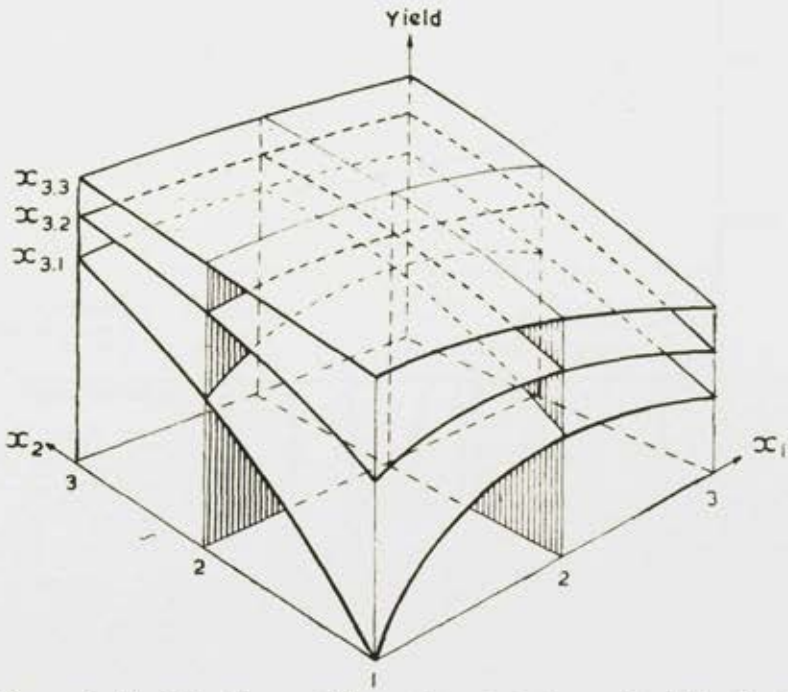


Fig. 4—Graph of the influence of the variation of 3 factors on the yield, with all interactions.

a'_i and a''_i are limits beyond which a_i is lying with a probability $p=0{,}05$. Also with the aid of the data the probability p can be calculated if $a'_i=0$ and $a''_i=\sim$ *is*. This coefficient p being $>0{,}05$ then $f_i(x_i)\equiv 0$ may be an acceptable estimate and the influence of the factor, found graphically, is not reliable. We expect a value $\bar{a}_i$ *is* about 1. If $\bar{a}_i>1$ *is*, the influence is underestimated; if $\bar{a}_i<1$, the influence is overestimated; the graph of the ultimately best estimate of the influence may be found by changing the yield ordinate with a factor $1/\bar{a}_i$.

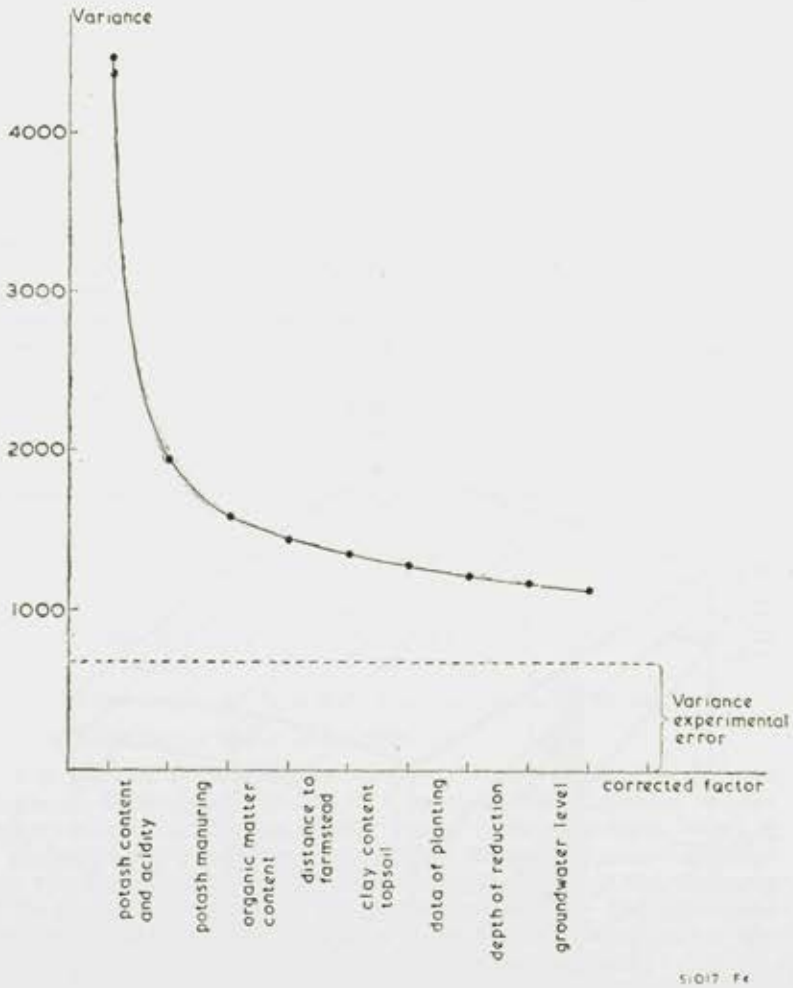


Fig. 5—Size of each variance after successive corrections.

Figure 5 gives an answer to the question whether all important factors have been really found. It appears from the figure that about 75% of the variance in the above-mentioned research can be explained

from the nine significant factors. If the variance caused by the experimental error and amounting to 676 is taken into account, it appears moreover that 88% of the explicable variance has been explained. This makes it plausible that important factors have not been neglected.

LITERATURE

EZEKIEL, M.: Methods of correlations. New York, 1947.
FERRARI, Th. J.: An agronomic research with potatoes on the river ridge soils of the Bommelerwaard. *Versl. Landbouwk. Onderz.*, **58**, 1 (1952).

THE USE OF SAND CULTURES FOR THE STUDY OF MINERAL DISORDERS, ESPECIALLY MICRONUTRIENT DEFICIENCIES

E. J. HEWITT

Long Ashton Research Station, University of Bristol, England

A technique has been developed during the last 10 years (1) to enable mineral disorders of plants to be reproduced and studied in sand culture on a large scale. An important feature is the applicability of the methods for all the known micronutrient elements, viz.: Fe, Mn, B, Cu, Zn, Mo.

Choice of techniques

Sand culture was chosen as it was thought that if a suitable means of purifying sand could be devised, the advantages of sand culture over water culture would justify the extra work involved. The relative merits of the two types of technique are briefly as follows.

Sand cultures are suited without special experience or adaptations to vigorous growth of all crops, including trees, so far tested. There is freedom from chlorosis due to precipitation of iron compounds and aeration is automatically provided at approximately optimal amounts in freely drained cultures. Frequent renewal of solution is also provided. Plants are supported naturally. Greater latitude to toxic effects is obtained in sand culture.

Water cultures on the other hand do not require the purification of the additional medium, and rapid change of treatment is more readily achieved but is possible for most purposes also in sand culture. Covers to exclude dust are more easily devised for water cultures but support of some plants is a difficult problem when species which develop from small seedlings to heavy adult specimens are used.

Culture materials

The basic materials used are the containers, sand, water, reagents and seed.

Containers are of two main types. New 10-inch horticultural clay pots lined with several coats of pure bitumen are satisfactory for all micronutrient problems and toxicity tests, and for deficiencies of iron, manganese or boron. Used pots are retained for the same type of test in subsequent experiments.

Pyrex containers holding from 1 to 6 gallons are used for deficiencies of copper, zinc or molybdenum. They are cleaned before use by detergent and steaming after an acid dip. Alkathene linings can be used for the micronutrient deficiencies and would be useful for lining large permanent tank cultures. Paraffin wax is quite unsatisfactory owing to biological breakdown.

Sand is natural silica, obtained from Leighton Buzzard greensand beds and is 99·85% SO_2. The microelement impurities comprise 100-300 p.p.m. Fe, ·1–3·0 p.p.m. B, Mn, Cu and Zn and ·002–·01 p.p.m. Mo as acid-soluble fractions. The available Mo determined by *A. niger* assay is about 0·001 p.p.m. initially and must be reduced to less than 0·00002 p.p.m. before acute deficiency is obtained. The sand is purified in an apparatus made of " Keebush." Steam is used

to heat and circulate automatically the sand in contact with 16–18% hydrochloric and 1% oxalic acids. After treatment for from 1–4 days the sand is leached extensively with water and also with a suitable purified calcium nitrate solution to remove free and exchangeable acid and the impurities dissolved by acid from the sand.

Water is obtained either by distillation of town hard tap water first in tinned copper stills with pyrex or silver condensers, and finally in all pyrex glass stills, or by treatment of rain water with ion exchange resins, after collection from the glass roof of the greenhouse and storage in bitumen lined tanks.

Once-glass distilled water is relatively free of iron, manganese and boron, but the second distillation is necessary before effects of copper, zinc and molybdenum deficiencies can be seen.

The resin-treated rain water is also entirely satisfactory for use in all macronutrient experiments and for deficiencies of all the micronutrients. When required for the latter type of test, the water which has been passed through Zeocarb 215 and Deacidite E is passed through a mixed bed resin Biodeminrolit FF. Comparative quantitative tests with higher plants and *A. niger* have shown beyond doubt that such water is entirely comparable with glass-distilled water, and a large scale supply has thus been provided for the work with a minimum of supervision. An example of purity is given by the low level of not above 0·000008 p.p.m. Mo regularly attained in the treated rain water.

Reagents. For micronutrient experiments reagents are a major source of contamination. They must, therefore, be purified by means that are effective for removing minute concentrations of unwanted elements from large volumes of relatively concentrated stock solutions, without leaving toxic or other undesirable residues.

The methods used include recrystallisation with alcohol to remove boron, alkaline phosphate co-precipitation, for iron and manganese and an additional dithizone extraction for zinc and copper. Molybdenum is eliminated either by co-precipitation with copper or lead sulphide or by co-precipitation with iron or aluminium and 8 hydroxyquinoline. These methods are all highly efficient and the removal may be 99·9% of the contamination present.

Seed. The fractions of plant material required to propagate the plants must contain a proportion of all elements essential for the species. In most instances seed reserves are not significant but the production of molybdenum deficiency in peas and beans and the severity of copper and zinc deficiencies in these species and in cereals depends greatly on seed reserves. Growth of plants under deficiency conditions yields seed markedly poorer in the element omitted and this is clearly reflected in the growth of the next generation.

Application

The value of culture methods needs little emphasis. An outstanding example is perhaps the elucidation of complex soil acidity factors by biological means described in Volume I (page 107), and culminating so far in the reproduction of Whiptail as a molybdenum deficiency effect.

The interpretation of results obtained in culture experiments may require caution as environmental factors of light, intensity, day

length, temperature and drought and humidity all exert a modifying influence on the growth of plants at deficient or toxic levels of the elements. A knowledge of these interactions and comparison of field and culture specimens, however, has permitted the development of a method (2) of diagnosis based on visual symptoms that is efficient and often specific for a wide range of crops and mineral disorders.

LITERATURE

(1) HEWITT, E. J.: "The use of sand and water cultures in the study of plant nutrition." Technical Communication No. 22, Commonwealth Bureau of Horticulture, East Malling, Kent (1952).

(2) WALLACE, T.: "The diagnosis of mineral deficiencies in plants by visual symptoms." A Colour Atlas and Guide, 2nd Edition, H. M. Stationery Office, London (1951).

SEASONAL VARIATIONS IN COTTON YIELDS IN THE SUDAN GEZIRA AND SOIL FERTILITY

T. N. JEWITT

Research Division, Ministry of Agriculture, Sudan

The Gezira is the principal cotton growing area of the Sudan. It is irrigated with water from the Blue Nile. The total area is about one million acres and about a quarter of this grows cotton each year. A general account of agricultural research has been given by CROWTHER, F. (1) and MACKINNON (2) has given a general description of the agriculture of the area. The soil is a deep, heavy, alkaline clay with a considerable salt content, particularly in the deeper parts of the profile. The soil has been described by GREENE (3) and by JOSEPH (4).

The irrigated Gezira cotton crop shows very large variations in annual yield. The following figures give the commercial yields for the last 10 years—4·81, 3·08, 4·92, 3·36, 3·94, 3·39, 4·26, 4·58, 6·78, 3·10 kantars per feddan of seed cotton. (1 k.p.f.=300 lb. p. acre). This variation is the principal problem of the irrigated cotton growing industry in the Sudan. Undoubtedly a considerable amount of the variation can be accounted for by variations in the damage done by pests and diseases. There is, however, powerful evidence that not all of it can be accounted for in this way. It is the purpose of this paper to give an account of the principal investigations which have been made into the subject and to describe some established features of the nutrition of the crop.

The response of the crop to nitrogenous manures is always considerable, regardless of the form in which it is applied. The response is relatively insensitive to the time when the manure is applied. The largest crop increases have been obtained in years of good yield. The general level of increase is of the order of 1 k.p.f. for the application of 50 lb. of nitrogen, though much larger increases have been measured (CROWTHER, F.) (5). In an extensive series of experiments, potassium and phosphate fertilizers have given very small and erratic increases, both when applied alone and in combination with each other and nitrogen (CROWTHER, F.) (6).

This regular response to nitrogen accords with the fact that in rotation experiments the yields are closely related to the levels of soil nitrate in the upper soil. The following results illustrate this. They show the mean yields for 5 rotations and the mean nitrate nitrogen (p.p.m.) in the top foot during the months August to November. The means are for 14 seasons.

TABLE 1

Cotton yields and nitrate levels from August to November

Rotation	Mean yield $\frac{1}{16}$ acre	Mean nitrate nitrogen (p.p.m.)
I Cotton—Fallow—Fallow	1499	8·1
II Cotton—Sorghum—Fallow	1418	10·1
III Cotton—Sorghum—Sorghum	990	4·9
IV Cotton—*Dolichos lablab*—Sorghum ...	1703	13·7
V Cotton—Sorghum—*Dolichos*	1496	10·8

CROWTHER, F. (7) has shown that for large areas of the commercial crop the yield of seed cotton is related to the rainfall in two ways. The yield is positively correlated with the rainfall which falls in the six weeks before the crop is sown. It is negatively correlated with the total rainfall which falls in the previous year—when the land is resting. It is thus possible at sowing time to make an estimate of the yield which will be obtained. This has been done for a number of years, on the whole with remarkable success. The first correlation, that with the rainfall immediately preceding sowing is the more important one. The mechanism is not known. The correlation with the previous year's rainfall is most likely due to the influence of those rains on the weed growth on the resting land which grows cotton in the following year. Considerable increases in yield can be obtained by keeping the resting land free from weeds (CROWTHER, F.) (8).

The relation with the presowing rains might be due to the effect on nitrification, leading to nitrate accumulation. The point has been tested and using the data from rotation experiments it has been shown that in years of heavy presowing rains, the top foot nitrates are low at sowing time—not high. Hence in the years of potentially good crops the land has low surface nitrate during the time of early growth. The correlation coefficients between surface nitrate and presowing rainfall for the rotation referred to above are :

TABLE 2

Correlation between top foot nitrates and 1 July to 15 August rainfall

Rotation	Correlation coefficient
I Cotton—Fallow—Fallow	—0·83
II Cotton—Sorghum—Fallow	—0·53
III Cotton—Sorghum—Sorghum	+0·47
IV Cotton—*Dolichos lablab*—Fallow	—0·59
V Cotton—Sorghum—*Dolichos*	—0·18

The levels for P=0·05 and P=0·01 are 0·53 and 0·66 respectively.

The differences in the correlations are believed to be due to differing physical states of the soils, and the reason for the correlation where it is negative is the washing down of nitrates by the rain. It is, of course, possible that the distribution of nitrate with depth as influenced by the presowing rainfall is a part of the mechanism of the annual yield fluctuations. There is no direct evidence supporting this view, and in spite of the widely varying correlation coefficients of top foot nitrate levels with presowing rains, the yields of the different rotations vary from year to year in a closely related manner.

The physical condition of Gezira soil deteriorates on wetting, and it is generally considered that this is an important reason for the benefit obtained from the wide rotation, with a large proportion of resting land, which is used in the Gezira (GREENE) (9).

Heavy rainfall before sowing should, therefore, cause a deterioration in physical structure before the irrigation begins to do so. In a season of light presowing rains the deterioration due to wetting should be

delayed, and the crop will be sown on land in better physical condition than in a year when presowing rainfall is heavy. The effect on the crop of this is not what would normally be expected ; the crop is predisposed to give a *poor* yield.

It appears, therefore, that in years of heavy presowing rainfall there are two factors operating which might be expected to cause poor yield. These are low nitrates in the top foot of soil, and a deteriorated physical condition. In fact it is in the presence of these that the crop gives a good yield.

There is some evidence to show that the *early* growth of the cotton plants responds to low surface nitrates and poor physical state in the manner which would be expected. Work done on the experimental plots which have been mentioned previously has shown that, during the last three years, growth and uptake of nutrients have varied with the presowing rain in a manner consistent with the known variation of surface nitrates and with the hypothesis of the dependence of physical condition upon this presowing rain. The experiment includes five rotations, the yields of each have responded to the presowing rainfall in accordance with the established positive correlation between these two quantities. For each of the three years the table below gives the nitrogen and calcium contents of the green leaves, six weeks after sowing. The figures are the average of the 5 rotations. The table gives the weight of the leaves (oven-dry) and the final yields of seed cotton.

TABLE 3

Weight of 100 leaves and their content of N and CaO in grams, and the final yield (k.p.f.)

Year	Leaf weight	N	CaO	Final yield
1949/50	80	2·7	4·4	3·6
1950/51	65	2·0	3·3	5·7
1951/52	135	5·4	8·6	3·6

The presowing rainfall (1 July to 15 August) in the seasons 1949/50, 1950/51 and 1951/52 were 68, 180 and 49 mm. respectively. The yields varied as would be expected—the crop in the first two seasons was not sprayed against jassids (*Empoasca libyca*, de Berg), but in the third season it was sprayed, and this must have improved the yield.

It will be seen that the uptake of N and CaO and the leaf weights were inversely related to the presowing rainfall. That is the early growth responded to heavy presowing rainfall as if nitrates were low and as if physical condition was poor. The soil nitrates were measured and were in agreement with this explanation. It may be added that K_2O and P_2O_5 uptake also varied in the same sense as that of N and CaO.

Some of the rotations on this experiment include the grain crop sorghum, and it is interesting that this crop, which is sown about 20 July, gives yields negatively correlated with the rainfall between 1 July and 15 August. It matures in October, much earlier than cotton

does. For the second rotation CSF, over a period of 19 years the correlation coefficient of cotton and sorghum yields with rainfall 1 July to 15 August are

$$\text{r. cotton} = +0{\cdot}50$$
$$\text{r. sorghum} = -0{\cdot}53$$

Both are significant at the $P = 0{\cdot}05$ level. Although the relationship between sorghum yields and the rainfall is in accord with the postulated soil conditions it is also true that the sorghum yields can be adversely affected by the water-logging which is associated with heavy rainfall in the period 1 July to 15 August. If the sorghum rainfall correlation is not solely explicable as caused by water-logging the response of irrigated sorghum to rainfall is similar to that of cotton in its early stages.

Table 3 shows that calcium uptake during early growth varies as widely as does nitrogen uptake, this is an unexpected result, for Gezira soil contains large amounts of exchangeable calcium and also large quantities as carbonate.

In this connection two other facts are of interest. Applications of gypsum have given considerable increases in yield, but have shown very little residual effects on later crops. The gypsum was applied in the expectation that it would improve the physical condition of the soil, and this it did. The improvement was not, however, like the increased yields, transitory; in field inspection it seemed to last for many years. There is, therefore, some question as to whether the calcium may not have had a specific effect in the nutrition of the plants (GREENE and SNOW) (10).

The second fact of interest is that calcium nitrate is a superior fertilizer to ammonium sulphate when the two are applied as equal dressings of nitrogen. It is known that ammonia is lost in considerable quantities when ammonium salts are applied to Gezira soil, but this does not appear to explain entirely the differences between the two fertilizers. If the difference lay in differences of availability of the ammonium and nitrate forms it would be expected that their relative effectiveness would depend largely on the date of application. This is not the case. The possibility that calcium plays a part in the nutrition of the plant cannot be ruled out (CROWTHER) (5).

In comparison of different rotations over a number of years the percentage of CaO in the young leaves has been related directly with the final yields of the rotations. For four years the cotton of the CSS rotation has had the lowest percentage of CaO in its leaves when young. In each of the four years this rotation has given the lowest yield. This rotation, being cropped and irrigated annually is in the worst physical state of the five. With some irregularities the calcium percentages for the other rotations have been related directly to their final yields. In alkaline soils containing considerable amounts of exchangeable sodium it has been suggested by several workers that difficulties in calcium supply may arise. It seems possible that this may be the case with Gezira soil and it is an aspect of plant nutrition which requires further investigation.

Although during the early stages of growth the cotton plant seems to have a low uptake of nitrogen in years which give a good yield, there is no question that they later obtain much larger quantities than in

a bad year. In the young plants we have discussed in this paper only a very small fraction of the final uptake has been absorbed. A hypothesis we have not been able to test is that in a good year the plant obtains nitrogen with ease from the lower layers of the soil. The experimental investigation of soil nitrate at depth in the growing crop is hindered by the difficulty of deep sampling, and by the occurrence of accumulations of nitrate at depths which vary greatly over short distances.

A factor of great importance in deciding cotton yields in the Gezira is pronounced shedding of buds, young bolls and leaves during October and November. The incidence of this damage varies considerably, and it has not, however, been clearly related to the weather in October and November. If it is generally true that in a potentially good year the young plants are small at the end of September, the degree of shedding in October and November may be reduced compared with that in a potentially poor year, in which the plants enter this period at a more developed state and more susceptible to water strain. This hypothesis will receive closer examination.

It is evident from this discussion that only a little progress has so far been made in the study of this most important problem. Some of the basic facts have been described, and some of the lines of attack have been outlined. The problem is certainly not one of soil fertility alone since the pest factor is known to be important and weather has an important influence on the crop.

REFERENCES

(1) CROWTHER, F.: Agriculture in the Sudan, p. 439 (Ed. by J. D. TOTHILL) Oxford University Press (1948).
(2) MACKINNON, E.: Agriculture in the Sudan, p. 762 (Ed. by J. D. TOTHILL) Oxford University Press (1948).
(3) GREENE, H.: *J. Agric. Sc.*, **18**, 518 (1928).
(4) JOSEPH, A. F.: *J. Agric. Sc.*, **15**, 407 (1925).
(5) CROWTHER, F.: *Emp. J. of Exp. Agric.*, **9**, 125 (1941).
(6) CROWTHER, F.: Report of Plant Physiology Section, Res. Division, Min. of Agric., Sudan Government (1945).
(7) CROWTHER, F.: Report of Plant Physiology Section Res. Division Min. of Agric. Sudan Government (1944).
(8) CROWTHER, F.: *Emp. J. of Expt. Agric.*, **11**, 1 (1943).
(9) GREENE, H.: *Ann. Report Agric. Res. Sew.*, Sudan Government, III, (1937).
(10) GREENE, H. and SNOW, O. W.: *J. of Agric. Sc.*, **29**, 1 (1939).

OBSERVATIONS SUR LA SOLUTION DU SOL DITE D'ÉTÉ, EN CASES LYSIMÉTRIQUES

H. ROSEAU ET J. BATS
Laboratoire des Sols, École Nationale d'Agriculture d'Alger

Nous nous sommes proposé de suivre la nitrification de l'azote ammoniacal apporté sous forme d'engrais au sol de nos cases lysimétriques, en dosant périodiquement dans les solutions du sol, l'azote nitrique élaboré et le calcium entrainé éventuellement.

Nous avions remarqué en effet que le taux de Ca dans ces solutions du sol était d'autant plus élevé que ce sol avait reçu de l'azote ammoniacal et nous avons pu établir que ce n'était pas dû uniquement à l'anion NO^3 ainsi élaboré au dépens de l'ammonium, mais aussi pour une bonne part au cation ammonium lui-même.

Nous basant sur les travaux de SCHLOESING sur les solutions du sol, nous avons établi que le premier litre d'eau de drainage recueilli sous nos cases lysimétriques après une longue période de non-drainage, correspondait à la solution du sol de la période considérée. Ainsi après la période d'été au cours de laquelle tout drainage a cessé, les pluies d'automne dès qu'elles sont suffisantes déplacent ces solutions du sol qui peuvent être collectées sous chaque case. Pour cette raison nous appelons ces solutions " solutions d'été." Elles nous permettent de fixer les phénomènes chimiques et biologiques dont le sol est le siège au cours de l'été.

De même sous notre climat, au cours de certains hivers ou de certains printemps, nous avons de longues périodes sans pluies qui se traduisent par un arrêt du drainage de nos cases lysimétriques. Survienne une période de pluies, le premier litre d'eau drainé traduira donc la solution du sol au cours de cette période—solution du sol également intéressante à analyser.

Nos cases lysimétriques édifiées en 1935 ont 1 m^3 environ de capacité, plus exactement le sol de ces cases présente 1 m^2 de surface sur Om, 90 de hauteur. Elles sont constituées par trois types de sols de la région, dont les caractéristiques sont les suivantes :

Pour Cent de Terre Fine a 105°	Sol B	Sol G	Sol M
Analyse physique :			
Sables gros siliceux	9,5	1,4	28,0
Sables fins siliceux	51,0	7,3	33,7
Limon	12,0	28,0	16,3
Argile	23,0	32,0	20,0
Calcaire total	3,3	30,6	1,6
Humus (Sol. dans NaOH concentré)	1,2	1,0	1,8
Analyse chimique :			
Azote total	0,07	0,09	0,12
Ac. Phosph. assim. (en P_2O_5	0,002	0,016	0,018
Potasse assim. (en K_2O)	0,013	0,009	0,025
Calcium échangeable (en Ca)	0,025	0,180	0,080

Chaque case reçoit depuis 1935 le même type d'engrais et au même taux, soit ramené à l'hectare :

Azote .. .. 40 Kgr.

Sous forme de :
sulfate d'ammoniaque (N_1)
nitrate de soude (N_2)

Acide phosphorique .. .. 64 Kgr.
Sous forme de :
superphosphate de chaux (P_1)
phosphate bicalcique (P_2)

Potasse (K) .. .. 98 Kgr.
Sous forme de chlorure de potassium.

De plus, ainsi que nous l'avons établi dans nos cases lysimétriques, sous notre climat méditerranéen l'azote ammoniacal nitrifie en hiver et, par suite de la pluviosité importante au cours de cette période, cet azote nitrique est lessivé.

Pour cette raison nous avons complété depuis 1944 la fertilisation de certaines de nos cases qui ne recevaient jusque là qu'un apport d'acide phosphorique à l'automne, par un apport complémentaire N_1 K (sulfate d'ammoniaque et chlorure de potassium aux taux indiqués), fin février, après les fortes pluies d'hiver. Ceci afin d'apprécier quelle est pour l'azote ammoniacal la meilleure époque d'épandage.

Solution d'été du sol

Nous avons recueilli le premier litre lessivé à l'automne 1950 au bas de chaque case en jachère pendant la campagne précédente 1949-50 et dosé dans cette eau (solution d'été 1950), l'azote nitrique et le calcium. Nous avons obtenu les chiffres suivants :

Taux d'azote nitrique et de calcium dans les solutions du sol (solution d'été 1950) de 10 cases en jachère en 1949-50

Nature du sol	No. de la case	Engrais épandus		Date de collecte de la solution du sol	Taux en milliéquiv. (par litre)		Taux en grammes/ha.	
		Nov. 1949	Févr. 1950		N nitrique	Ca	N nitr.	Ca
				1950				
	18	O	N_1	30 Oct.	3,43	3,2	480	640
B	19	P_1	N_1 K	..	2,67	5,1	374	1.020
	20	N_1 P_1 K	O	..	2,61	3,9	366	780
	16	O	N_2	9 Déc.	3,16	3,52	442	704
	17	N_1 P_1 K	O	..	1,99	5,7	279	1.140
	11	P_2	N_1 K	30 Oct.	4,63	6,48	648	1.296
	12	O	O	14 Déc.	5,06	5,28	709	1.056
M	13	N_1 P_1 K	O	30 Oct.	4,06	5,07	569	1.014
	14	O	N_2	30 Oct.	4,8	4,72	672	944
	15	P_1	N_1 K	9 Déc.	5,52	6,68	771	1.336

Ces chiffres nous conduisent aux remarques suivantes :

Sol B

En comparant les deux cases (No. 19 et 20) à N ammoniacal à la No 18 recevant uniquement N nitrique, on constate que :

—la quantité de N nitrique libérée est plus grande chez la No 18 que chez les deux autres ;

—la quantité de Ca libéré est par contre moins élevée chez cette case No 18 que chez ces deux autres.

En comparant d'autre part entre elles les deux cases 19 et 20 recevant N ammoniacal à deux époques différentes, on constate :

—un taux sensiblement identique de N nitrique dans les solutions du sol. Ce qui ne peut s'expliquer que par une nitrification entravée au cours de l'été, au dépens de l'azote ammoniacal apporté fin février, par suite vraisemblablement d'une insuffisance d'humidité, chez ce type de sol en été ;

—un taux de Ca différent par contre dans les solutions du sol de ces deux cases—plus élevé chez celle qui reçoit son N ammoniacal en février.

Sol G

La case à N nitrique libère dans la solution du sol plus d'azote nitrique et moins de Ca que celle à N ammoniacal, ce qui corrobore les observations sur le sol B.

Sol M

Les taux d'azote nitrique dans les solutions des différentes cases de ce type de sol sont à première vue moins significatifs.

Cela provient pour une part de la date de collecte de la solution du sol qui n'est pas la même pour ces 5 cases :

30 Octobre, cases No. 11, 13 et 14 ;
9 Décembre, case No. 15 ;
14 Décembre, case No. 12.

On conçoit qu'au cours de la période, 30 octobre—9 décembre, le sol bénéficiant grâce aux pluies d'automne d'un taux d'humidité favorable, la nitrification ait été plus active dans les cases No. 12 et 15, d'où taux plus élevés de N nitrique dans les solutions de ces deux cases qu'ils auraient été le 30 octobre.

Pour être donc plus précis, nous ne comparerons entre elles que les cases où la collecte de la solution a été faite à la même date.

Nous pouvons ainsi comparer entre elles :

—les 3 cases du sol B et les cases No. 11, 13 et 14 du sol M ;

—les 2 cases du sol G et les cases No. 12 et 15 du sol M,

mais ici la nature de l'apport d'azote n'est pas la même dans ces 4 cases.

Cases recevant N nitrique au printemps (N_2) : le sol M en a davantage dans sa solution d'été que le sol B.

De même pour les cases des sols M et B recevant N ammoniacal à l'automne ou au printemps, c'est encore le sol M qui présente dans sa solution un taux de N nitrique supérieur.

Ce taux plus élevé de N nitrique dans les solutions du sol M ne peut s'expliquer que par la composition de ce sol M, mieux équilibré dans ses éléments physiques et mieux pourvu en humus que le sol B, aussi les phénomènes biologiques y sont-ils plus actifs. On a dans ce sol M également un gain supplémentaire de N nitrique au dépens de l'azote du sol lui-même.

Ceci est d'ailleurs confirmé par les récoltes chaque année. Les cases témoines ne recevant aucune trace d'azote minéral depuis 1935 du

sol M présentent toujours des récoltes plus substantielles que les cases témoins des sols B ou G.

Quant an calcium entraîné dans ce sol M en retenant les trois cases No 11, 13 et 14 dont la solution du sol a été collectée à la même date (30 octobre)—nous constatons ici encore l'influence prépondérante de N ammoniacal sur N nitrique —et également l'influence de l'époque d'épandage de cet N ammoniacal, l'épandage de février provoquant un entraînement de Ca plus important dans la solution d'été que l'épandage d'automne.

Ces observations corroborent donc celles faites sur le sol B.

Nous pensons devoir expliquer de la manière suivante ce phénomène de décalcification.

La décalcification du sol n'est pas seulement le fait de l'anion nitrique apporté sous forme de nitrate de soude ou résultant de la nitrification de N ammoniacal, elle est due aussi au cation ammonium qui se substitue au Ca du complexe absorbant du sol et ceci confirme certaines de nos conclusions précédentes (1).

Dans les deux types de sol B et M, où nous avons pu l'établir, cette décalcification au cours de l'été exprimée par le taux de Ca dans la solution d'été est plus importante lorsque N ammoniacal est épandu au printemps que lorsqu'il est épandu à l'automne précédent, ce qui signifie :

—soit que le N ammoniacal de l'automne a à peu près disparu du sol qui en avait bénéficié ;

—soit que sa substitution au Ca dans le complexe absorbant s'est opérée immédiatement après son épandage, le Ca ainsi libéré, ayant disparu dans les eaux de drainage de l'hiver et du printemps.

Le taux de Ca entraîné dépend aussi du sol. En comparant entre eux les trois sols, nous constatons que l'azote ammoniacal apporté en automne 1949 ou au printemps 1950 provoque une décalcification plus poussée dans les sols G et M que dans le sol B.

Cela résulte vraisemblablement du taux de calcium échangeable, différent chez ces trois sols ainsi que l'exprime le tableau suivant :

Sol	Ca échang. mgr. p. 100 gr. sol	Ca dans la sol d'été en gr./ha.	
		N. ammoniacal épandu : en Nov. 1949	en Févr. 1950
B	25	780	1·020
G	180	1·140	
M	80	1·014	1·296(2) 1·336(3)

(2) P_2O_5 fourni sous forme de superphosphate.
(3) P_2O_5 fourni sous forme de phosphate bicalcique.

A ce phénomène d'échange de bases qui se présente ainsi avec une certaine soudaineté, il convient de comparer le phénomène biologique de nitrification qui se poursuit au cours des mois, et ce phénomène

(1) Pouvoir décalcarisant de certains sels dans le sol H. ROSEAU. (C.R. de la Conférence de Pédologie Méditerranéenne 1947).

étendu dans le temps se traduit par des taux d'azote nitrique non négligeables même chez les cases ayant reçu leur azote ammoniacal à l'automne, azote maintenu en réserve dans le sol sous forme ammoniacal par le pouvoir absorbant du sol et mis à la disposition de la plante sous forme nitrique par les phénomènes biologiques. Ceci réfute ainsi la première hypothèse que nous avions envisagée : disparition totale du N ammoniacal épandu à l'automne.

En résumé ces observations sur ces solutions d'été 1950 de nos cases en jachère en 1949-50 nous permettent de saisir l'ensemble des phénomènes suivants :

Le mécanisme des actions subies dans le sol par l'azote ammoniacal peut se schématiser ainsi :

L'azote ammoniacal provoque :

1°) un phénomène physico-chimique, d'échange de bases qui suit immédiatement son épandage. Ce phénomène se traduit par un enrichissement en Ca de la solution du sol, et par conséquent par une élimination du Ca dans l'eau de drainage ;

2°) un phénomène biologique, plus lent, au dépens de cet azote ammoniacal mis en réserve dans le complexe absorbant, de telle sorte que dans la solution du sol, le maximum d'azote nitrique n'est pas synchrone du maximum de calcium.

Enfin la décalcification du sol (lato sensu) est l'ensemble de deux phénomènes :

—un phénomène de décalcification proprement dit,

—un phénomène de décalcarisation.

La décalcification (stricto sensu) du sol est le fait du phénomène physico-chimique d'échange de bases : substitution de NH_4 au Ca du complexe absorbant, ce phénomène ayant un caractère de soudaineté.

Le phénomène de décalcarisation résulte de phénomènes biologiques, concourent en effet à ce phénomène de décalcarisation :

—le NO_3 élaboré au cours du phénomène de nitrification ;

—le CO_2 résultant de l'activité des microorganismes sur le carbone, des débris végétaux.

Summary

The observations made upon soil solutions of summer in lysimetric boxes on the climate of Algiers prove the very clear influence on the rate of N nitric and Ca contained in soil solutions, of the nature of N given to the soil : N nitric or N ammoniacal and in that last situation (case) of time of spread : autumn or end of winter. The N nitric brought occasions a least decalcification of soils than the N ammoniac. Besides, the spreading of N ammoniac at the end of winter is translated in spring and in summer by a more important decalcification than the spreading of N ammoniac in autumn.

PHOSPHATE MANURING OF LEGUMES AND ITS ROLE IN THE BUILDING UP OF THE FERTILITY OF INDIAN SOILS

S. P. RAYCHAUDHURI AND B. V. SUBBIAH

Indian Agricultural Research Institute, New Delhi, India

The soils of India have reached a low level of fertility due to continuous cropping for centuries and due to very inadequate returns of plant nutrients lost annually by cropping, leaching and erosion. Nitrogen deficiency is extremely widespread, most of the soils containing not more than 0.03 to 0.05%; phosphate deficiency is comparatively less, the maximum percentage content being not more than 0.1%, while the potassium deficiency is, as yet, not apparent.

The main soil types in India are broadly (1) alluvial, (2) red soils, (3) laterites and (4) black soils. Alluvial soils cover large areas the whole of the north and deltaic areas of the south of the country. These soils are naturally of high inherent productivity and respond well to the applications of both N and P fertilisers, a combination of these giving generally higher response than either of them singly. Red soils occur extensively in many parts of India, particularly in the northern and southern portions of the country and are relatively low in lime and phosphate. In these soils, also, a combination of N and P has been found to be superior to either of them singly for the main crops wheat and paddy. Lateritic soils occur in the Deccan, Mysore, Travancore, the Eastern Ghats, regions of Orissa, South Bombay, Malabar and parts of Assam. These soils tend to be deficient in the common nutrients and generally organic manures have given better results. Black soils extend over a great part of the Bombay Province, Kathiawar, Berar, the Western part of C.P., Central India, Hyderabad, and some parts of the Madras province. These soils are potentially rich and productive and a combination of N and P have generally given the best increases in the yield. (Final Report of All India Soil Survey Scheme, 1947.) In Indian soils, response to phosphatic fertilizers will not be appreciable unless the nitrogen status of the soils is built up.

Thus phosphatic manuring of legumes which fix their own nitrogen and some of which have the capacity to enrich the soil as well, offers a great promise as being the most suitable method of improving the soil fertility.

Effect of phosphate manuring on the yields of leguminous crops

Among the leguminous crops, Sannhemp (*Crotolaria juncea*), Dhaincha (*Sesbania aculeata*), Pillipesara (*Phaseolus trilobus*), wild indigo (*Indigofera tinctoria*), cowpeas (*Vigna sinensis*), Guar (*Syamopsis psoralioides*), are commonly grown for green manuring purposes, Arhar (*Cajanus Indicus*), Moong (*Phaseolus radiatus*), Gram (*Cicer arictinum*), and peas (*Pisum Arbense*) as pulse crops while ground nut (*Arachis Hypogaea*), mustard (*Brassica juncea*), and Sesamum (*Sesamum Indicum*) are the chief oil-seed crops. In addition, Berseem (*Trifolium alexandrium*), Pillipesara (*Phaseolus trilobus*) etc. are also used for fodder purposes.

The application of mineral plant food, especially phosphatic fertilisers to the green manure crops for increasing the crop productivity has generally shown good results. As early as 1921, the efficiency of organic phosphates over the inorganic form has been stressed. (Anonymous, 1921). At Pusa (Bihar) which has a calcareous soil, sannhemp (*Crotolaria juncea*) supplemented with 50 lb. P_2O_5 per acre gave 100 per cent. increase in the yields of oats (VAIDYANATHAN, 1933). In Bihar, generally a dressing of superphosphate to the green manure at the rate of 50 to 100 lb. per acre has been found beneficial to paddy (Anonymous, 1947). In Mysore, application of phosphate to the green manures like Sannhemp (*Crotolaria juncea*), Dhaincha (*Sesbania aculeata*) and even ground nut (*Arachis Hypogaea*) grown in neutral and alkaline soils have given large increases (GOVINDA RAJAN, 1952). In one of the recent experiments at the Indian Agricultural Research Institute when phosphates were applied to a number of legumes, marked increases were noticed in the yields.

TABLE 1

Name of legume	Yields of the green matter in lb. per acre		% Increase over control
	Without P	With P at 80 lb. per acre	
Lentil (*Lens esculenta*)	3251	5390	64
Peas (*Pisum Arbense*)	5605	10470	87
Senji (*Melilotus parviflora*)	7053	13310	89
Methra (*Trigonella fœnum Graecum*) ...	5933	9630	66
Gram (*Cicer arictinum*)	3333	4469	36
Khesari (*Lathyrus sativa*)	5514	6741	22

Thus increases ranging from 20 to 90% could be obtained in different legumes.

Some of the striking results in the yields of berseem (*Trifolium alexandrium*) due to phosphate manuring have been reported by PARR and BOSE (1944 and 1945). Their results indicate that berseem crop responds very well to the phosphatic manures, the increases ranging from 100 to 150 per cent. Phosphatic manuring of other leguminous crops like pulses and oil seeds has also resulted in considerable improvement in yields.

Phosphatic manuring of legumes in crop rotations and their residual effects

It is now more or less clearly established that a sound crop rotation with a suitable legume is essential for the maintenance of soil fertility. Scientific manuring of crops consists in the application of fertilisers to the most responsive crops with the capacity to produce a residual effect of high soil fertility for the subsequent crops. Phosphate manuring of legumes particularly those of Rabi (winter) have been found to have good residual effect on the succeeding crops. The results of PARR and BOSE (1944 and 1945) given below are very

illustrative. The rotation followed by them was berseem-cowpeas for three years of which only berseem was fertilised every year with phosphate and later on the residual effect on wheat was studied.

TABLE 2

Average yields of berseem and cowpeas-green fodder and wheat grain yields

Treatments	Yields as percentages of control plots		
	Berseem (average for 3 years)	Cowpeas	Wheat grain
1. Control	100	100	100
2. Superphosphate at 132 lb.	209	113	163
3. Superphosphate at 198 lb.	235	118	176
4. Superphosphate at 264 lb.	229	124	171

The yields of wheat clearly show that the residual fertility is built up in the above rotation due to phosphatic manuring of berseem.

In general, the residual effect of applications of phosphate to winter legumes has been found to be considerable on the succeeding grain crop. Kharif (summer) legumes showed no such consistent effect. Thus in Bombay State (Anonymous, 1952), Paddy after dolichas (*Dolichas lablab*) and Bajra (*Pennisetum Typhoideum*) after gram (*Cicer arictinum*), both gave higher yields because of the application of phosphatic manure on pulses. When a leguminous crop like ground nut (*Arachis Hypogæa*) or china mung was grown in the kharif and followed by a cereal like wheat or jowar (*Sorghum vulgare*) in the succeeding Rabi, no beneficial effect was found (Anonymous, 1952). In Bihar, the application of phosphatic fertilisers has been reported to be profitable for the gram and the succeeding wheat crop (MUKHERJEE *et al.*, 1951). In U.P. in the sugarcane wheat rotation MUKHERJEE (1952) recommended the application of phosphates only to the sannhemp (*Crotolaria juncea*) in order to obtain the maximum yields of both wheat and sugarcane which by themselves failed to respond to direct applications of phosphates.

The residual effects of all legumes are not alike. Cluster beans (*Cyamopsis psoraloides*) have been found to be most beneficial in the case of irrigated cholam (*Sorghum vulgare*) while lablab (*Dolichos lablab*) and cowpeas (*Vigna sinensis*) seem to do good to rain fed cholam (*Sorghum vulgare*), Soyabeans (*Glycine soja*), green gram (*Phasedus Radiatus*) and cowpeas (*Vigna sinensis*) do more harm than good when they precede Combodia cotton (*Madras Agri. Jour.*, 1941). Thus it will be necessary to choose a leguminous crop which is most responsive and which is beneficial to the succeeding crop.

Effect of phosphatic manuring of legumes on crop composition

The work of PARR and SEN (*loc. cit.*) at the Indian Agricultural Research Institute shows that apart from the improvement in the yields, the berseem crop as well as the succeeding cowpea and wheat crops were markedly improved both in the phosphate and lime contents

which are from the nutrition point of view most important for fodder crops.

Their results are given below:

Treatment	Berseem (dry basis)		Cowpeas (dry basis)		Wheat grain and straw P_2O_5% in	
	P_2O_5 %	CaO %	P_2O_5 %	CaO %	Grain	Straw
Control	0·31	3·13	0·32	2·86	0·68	0·07
Super. at 132 lb. ...	0·73	3·84	0·83	3·47	1·00	0·16
Super. at 198 lb. ...	0·90	4·16	0·90	3·49	0·98	0·16
Super. at 264 lb. ...	1·00	4·08	0·83	3·41	1·10	0·14

Thus the percentage composition with respect to phosphate and lime contents in berseem as well as succeeding cowpeas crop was improved and the wheat after three years of berseem cowpea rotation with respect to its phosphate content, showed a similar effect. In another experiment (unpublished work) similar results were observed with berseem-guar rotation.

This improvement in percentage mineral composition is not confined to beerseem. In one of the experiments, the legumes named below showed the following increases in P content due to the application of 80 lb. P_2O_5 as super.

Name of the legume	P_2O_5% on dry basis	
	Untreated	Treated
Lentil (*Lens esculenta*)	0·51	0·69
Peas (*Pisum Arbense*)	0·49	0·69
Senji (*Melilotus parviflora*)	0·45	0·63
Berseem (*Trifolium alexandrium*)	0·50	0·79
Methra (*Trigonella foenum Graecum*)	0·79	0·79
Gram (*Cicer arictinum*)	0·57	0·76
Khesari (*Lathyrus*)	0·68	0·82

As can be seen from the above table, the increase in the percentage composition varied with the type of the legume. In Bombay State, phosphatic manuring of gram showed higher contents of phosphate in both the gram and bajra grains but the nitrogen content did not show any increase.

Legumes are better extractors of phosphates and contain both protein and mineral constituents more than other crops. Thus, both from the point of view of fodder and green manuring purposes, phosphatic manuring of the legumes will be beneficial.

Effect of phosphatic manuring on the soil nitrogen status

In a three-year rotation with berseem and guar (unpublished work) the phosphatic manuring has doubled the nitrogen increase in the soil nitrogen status compared to the effect of the rotation without the phosphatic manures.

Treatment	Percentage increase over the initial soil nitrogen after a period of 2 years of the Berseem-Guar rotation
Control	14
50 lb. Super.*	26
100 lb. Super.*	28

*Applied to berseem crop every year.

DESAI and PARR (1950) noticed that in permanent manurial experimental plots at Pusa, which have been in progress for nearly 30 years, the soil nitrogen content in plots receiving ammonium sulphate treatment every year for the 30 years, is about the same (approximately 31.5 mg. for 100 gm. of soil) as that of the unmanured plot. The plots to which phosphates alone were applied with or without a legume crop in rotation contained about 41.5 mg. per 100 gm. of soil, while the corresponding figure where phosphates has been added to a green manure legume crop is 47, which is the highest among these treatments.

Discussion

The choice of a legume for the purpose of fertilizing with phosphates in order to build up soil fertility, depends upon the local conditions of the soil, season, climate, cropping system and above all its responsiveness to the phosphates. There is a general evidence to show that rabi legumes particularly berseem, have good residual effect lasting for several years. Whenever irrigation water is available, rotation with rabi legumes treated with phosphatic fertilisers, requires to be encouraged. The available evidence also indicates that response to kharif (summer) legumes is dependent on soil type. Thus in Orissa dhaincha (*Sesbania aculeata*) was found to be better than others (VAIDYANATHAN, 1933) as green manure crop, while in Bihar with soils mostly of Indo-Gangetic alluvium, Sannhemp (*Crotolaria juncea*) has been recognised to be as efficient as dhaincha (*Sesbania aculeata*) for paddy (Anonymous, 1947). At Suri in Bengal with a sandy to medium lateritic loamy soil, cowpea was found to be the best (SETHI, 1940), while at Punjab with loamy to sandy loam soils, guar (*Syamopsis psoralioides*) proved to be the best (VAIDYANATHAN, 1933). In the alluvial soils of U.P. besides sannhemp (*Crotolaria juncea*), indigo, guar and cowpea were all found to be successful as green manure crops.

The practice of green manuring, in addition to its manurial value, has certain other beneficial effects. It has been found to promote the crumb structure in heavy clays and making also light soils cohesive and retentive. It has also been found helpful in opening up of hard soils, in prevention of excessive evaporation of moisture by shading the soil surface. Recently STRUTHERS *et al.* (1950) have shown that organic acids produced during the decomposition of the green manure increase the availability of phosphate for crop growth by combining with aluminium and iron. Green manures are also found useful in correcting alkalinity, salinity and such other soil deteriorations. Phosphatic manuring of green manures, by increasing the yields, is likely to enhance all the above-mentioned beneficial effects.

Systematic use of phosphate with the appropriate legumes either as fodder crops, green manures or pulse crops, promises a good hope of increasing and improving the quality of Indian crops.

Summary

The Indian soils are very much deficient in nitrogen and comparatively less with respect to phosphate while potassium deficiency is not yet apparent. Application of phosphates to legumes (especially winter legumes) resulted in the improvement not only of the yields and quality of the directly manured crop but the beneficial effect could be noticed on the succeeding crops in the rotation. The soil nitrogen status with respect to nitrogen showed remarkable improvement. Application of phosphate to green manures was found to be more beneficial than directly manuring the cereals with phosphate.

The extent of response to phosphatic manuring varies with different soil types. Inclusion of a suitable legume in the crop rotation and fertilizing it with phosphatic fertilizers offers a rapid method of improving the fertility of Indian soils which are in general very poor in nitrogen.

REFERENCES

(1) Anonymous: Review of Agricultural Operations in India. Govt. of India Press, Calcutta (1925).
(2) Anonymous: A note on the results achieved so far in Rice Research in Bihar. Supdt. Govt. Printing Press, Bihar, PATNA (1947).
(3) Anonymous: Scientific Manuring of Crops in a Rotation to build up Soil Fertility (Bombay State) (1952).*
(4) DESAI, S. V. and PARR, C. H.: A new outlook on the principles of manuring. *Proc. Ind. Soc. Soil Sci.*, 1945–49, 25–31 (1950).
(5) GOVINDA RAJAN, S. V.: Review of green manuring methods already adopted and further measures to popularize its use for increasing yield, particularly of food crops (1952).*
(6) MUKHERJEE, B. K.: Scientific manuring of crops in a rotation to build up soil fertility (U.P.) (1952).*
(7) MUKHERJEE, H. N., *et al.*: Best manure for increased production of wheat and gram, issued by Department of Agriculture, Bihar (in HINDI) (1951).
(8) PARR, C. H. and BOSE, R. D.: Phosphatic manuring of legumes—I. *Indian Farming*, **5**, No. 4 (1944).
(9) PARR, C. H. and BOSE, R. D.: Phosphatic manuring of legumes—II. *Indian Farming*, **6**, No. 5 (1945).
(10) SETHI, R. L.: Manuring of paddy in India. Imp. Council of Agri. Res. Miss. Bull. No. 38 (1940).
(11) STRUTHERS *et al.*: *Soil Sci.*, **69**, 3, 205–14. (1950).
(12) VAIDYANATHAN, M.: Analysis of manurial experiments in India. Vols. I, II, III Imp. Council of Agri. Research, India (1933).

*Papers presented for the Ninth Meeting of the Crops and Soils Wing held at Indore, 1952.

EFFECT OF FERTILIZER TREATMENT ON YIELD AND COMPOSITION OF SUGARCANE IN UPPER EGYPT

M. M. ELGABALY
Farouk I University, Alexandria, Egypt

Abstract

Fertilizer experiments on sugarcane variety Co 413 were carried out for three years at the Royal Khassa, Mataana, to study the effects of the three fertilizing elements, nitrogen, phosphorus and potassium given in different combinations at different levels on both yield and composition of juice, which are important factors in the sugar industry.

The following conclusions could be drawn from those experiments:

1. The yield of sugarcane varies slightly from year to year due to difference in climatic conditions.

2. The effect of fertilizer is very pronounced on increasing yields of sugarcane and may almost be doubled by using the right amount. Nitrogen seems to be the element most needed. The addition of nitrate up to 400 kgs./feddan seems justifiable. Potassium seems to be the second limiting element for sugarcane. The use of amounts up to 50 kgs. K_2O/feddan seems beneficial to the crop. If the dose is increased over this amount it may have a depressive effect. Phosphorus shows no significant effect on yield.

3. The effect of different fertilizer treatments on the composition of juice, including density, % sugar, % glucose, purity and richness, is not pronounced. However, the following differences were observed:

(*a*) The degree of purity was lower in the untreated than in the treated plots.

(*b*) Percentage of glucose was always higher in the untreated than in the treated plots.

(*c*) Percentage of sugar varied from 14·65 to 18·10.

The results are summarized in Tables 1 and 2.

TABLE 1

Effect of fertilizer treatment on yield of sugarcane (variety Co 413) (Mataana, Upper Egypt.)

Treatment	Yield (tons/feddan*)	
	1950	1951
$N_0P_0K_0$	30·450	27·730
$N_1P_1K_0$	58·548	40·278
$N_1P_0K_1$	61·095	42·252
$N_1P_1K_1$	62·985	43·924
$N_2P_1K_1$	72·883	52·206
$N_2P_1K_2$	71·064	53·088

N_1 = 300 kgs. nitrate of soda/feddan.
N_2 = 400 kgs. nitrate of soda/feddan.
P_1 = 100 kgs. superphosphate/feddan.
K_1 = 100 kgs. K Cl/feddan.
K_2 = 200 kgs. K Cl/feddan.

*1 feddan = 1·038 acres.

TABLE 2

Effect of fertilizer treatment on properties of sugarcane juice

Property	Year	TREATMENT					
		$N_0P_0K_0$	$N_1P_1K_0$	$N_1P_0K_1$	$N_1P_1K_1$	$N_2P_1K_1$	$N_2P_2K_2$
Density	1951	1.0805	1.0792	1.0784	1.0797	1.0797	1.0779
	1952	1.0743	1.0783	1.0756	—	1.0799	1.0765
% Sugar	1951	16·81	16·70	16·67	16·55	16·65	16·75
	1952	14·86	17·52	17·19	—	18·10	17·00
Purity	1951	87·03	87·80	88·43	88·26	89·73	89·06
	1952	82·40	86·30	86·30	—	87·40	85·70
Glucose % ...	1951	2·56	2·00	1·93	2·03	2·20	2·23
	1952	4·90	2·70	2·80	—	2·20	2·70
Richness	1951	13·78	13·70	13·77	13·90	13·66	13·74
	1952	12·25	13·49	13·19	—	13·91	13·10

EFFECT OF FERTILIZER TREATMENTS ON YIELD OF " MOUNUFI " COTTON IN THE NORTHERN PART OF THE DELTA

M. M. ELGABALY

Farouk I University, Alexandria, Egypt.

Abstract

The problem of cotton fertilization in Egypt has been and still is the subject of extensive studies and much controversy, particularly as regards nitrogen effects on yield. While some farmers claim that the use of nitrogenous fertilizers up to 600 kgs. of nitrate per feddan gives an economic return in certain localities, there are others who hold the opinion that even the use of 100 kgs. per feddan may be harmful to the crop. The discrepancies in results obtained may be due to the interaction of many factors on the yield of cotton which seems to be a very sensitive plant to changes in climate, management and soil conditions. Different varieties seem to respond differently to fertilizers depending upon sowing date, spacing, irrigation, and locality.

The fertilizer experiment carried out here on " Mounufi " cotton variety included different treatments of nitrogen, phosphorus, and potassium in different combinations and at different levels of these three nutrient elements in the hope of finding out the balanced fertilizer that gives the best yield under the specified conditions.

The following conclusions could be drawn from the results of two years' experiments :—

1. The absolute increase in yield due to N, P, and K is determined by the level of the yield of the untreated plots, the higher the yield, the greater will be the response to nitrogen.

2. The relative response to fertilizers varies from year to year due to difference in climatic conditions.

3. The increase in yield due to fertilizers is not proportional to the number of mature bolls which increases significantly with increase in nitrogen particularly.

4. The attack by pink boll worm was higher in the fertilized plots which may account for the slight difference in yield between different treatments. If methods of control are found, cotton yield may increase significantly with the use of the right fertilizer combination.

The results are summarized in Tables 1 and 2.

TABLE 1

Effect of festilizer treatment on yield and number of bolls of Mounufi Cotton (University farm, Alexandria, Egypt)

Treatment	Yield of seed cotton kentar†/feddan*		No. of mature bolls per plant
	1950	1951	1951
$N_0 P_0 K_0$	3·95	3·15	15·45
$N_1 P_1 K_0$	4·11	3·24	25·35
$N_1 P_0 K_1$	4·10	3·20	21·70
$N_0 P_1 K_1$	3·96	3·35	16·90
$N_1 P_1 K_1$	4·57	3·51	27·15

N_1 = 50 kgs. of sodium nitrate/feddan.
N_2 = 100 kgs. of sodium nitrate/feddan.
P_1 = 100 kgs. of superphosphate/feddan.
K_1 = 50 kgs. of potassium sulphate/feddan.
† 1 kentar = 315 lb. of seed cotton.
* 1 feddan = 1·038 acres.

TABLE 2

Effect of ratio between fertilizing elements on yield and number of bolls of Mounufi Cotton (University farm, Alexandria, Egypt) (1951)

Treatment	Yield of seed cotton kentar/feddan	No. of mature bolls per plant
$N_0 P_0 K_0$...	3·08	18·5
$N_1 P_1 K_1$	3·05	22·10
$N_2 P_1 K_1$	3·02	28·30
$N_2 P_2 K_1$	3·18	26·95
$N_2 P_2 K_2$	2·90	22·10
$N_1 P_2 K_2$	2·99	29·85
$N_2 P_3 K_1$	2·91	33·30

N_1 = 75 kgs. of sodium nitrate/feddan.
N_2 = 150 kgs. ,, ,, ,, ,,
N_3 = 200 kgs. ,, ,, ,, ,,
P_1 = 100 kgs. of superphosphate/feddan.
P_2 = 200 kgs. ,, ,, ,,
P_3 = 300 kgs. ,, ,, ,,
K_1 = 50 kgs. of potassium sulfate/feddan.
K_2 = 100 kgs. of potassium sulfate/feddan.

REFERENCES

(1) BALLS, W. L., GRACIE, D. S., and KHALIL, F. Min. Agric. Egypt. Bul., 249. (1948).
(2) GRACIE, D., and KHALIL, F. Min. Agric. Egypt. Bul. 251 (1948).
(3) CROWTHER, F., TOMFORDE, A., and MAHMOUD, A. Roy. Agric. Soc. Egypt, Bul. 8 (1937).

THE TECHNIQUE OF POT EXPERIMENTS

A. C. SCHUFFELEN, J. J. LEHR AND M. ROSANOW
Laboratory for Agricultural Chemistry, Agricultural University, and Plant Nutrition Research Laboratory, Netherlands, Wageningen.

As, according to our experience, the result of pot experiments on soils largely depends on the technique employed, we would contribute a description of the working methods adopted in our institutes.

Pure sand cultures, which are mostly used for physiological studies are left out of consideration. Good descriptions of this technique are given by REI ROBBINS (6).

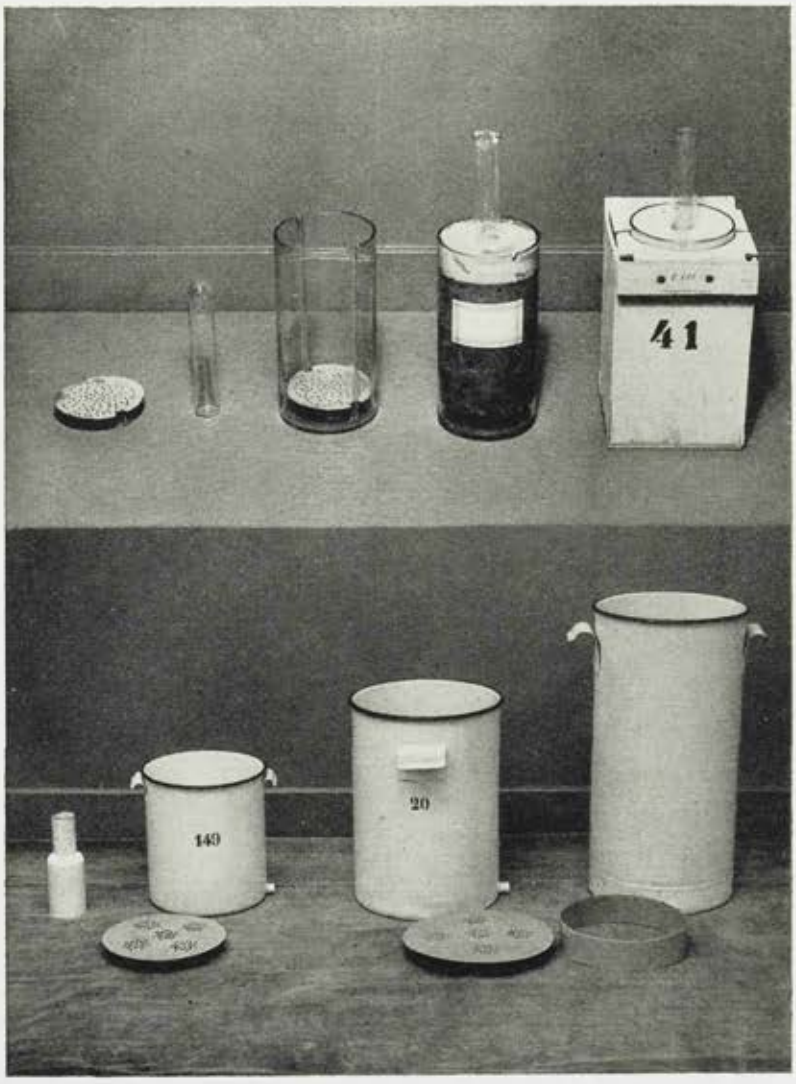
At our institutes pot experiments on soils are not intended to investigate individual soils (determination of fertility according to MITSCHERLICH) but to study general problems of plant nutrition.

The main subjects investigated by us by means of pot experiments, cover :—

(*a*) the influence of different fertilizers on soils and plants together with their interactions ; this has to be studied on natural soils ;

(*b*) the reaction of different plants to changes in the amounts and ratios of different nutrients present in exchangeable form. After several years of experiments on clays, saturated with a single cation, a simplified method was introduced in 1936 by HUDIG and SCHUFFELEN, replacing the clay with an activated coal, so-called dusarite (produced by Activit Company at Amsterdam), which is used as cation exchanger in the purifying process of water. This product consists of particles with a size between 200 and 20 μ and can easily be mixed with quartzsand without puddling or separating. It has an adsorptive capacity of about 2 m.e. per gram at pH 6·5.

At the moment, only Na dusarite is obtainable ; this is, however, heavily impurified with calcium and sulphate. For preparing H–dusarite the following procedure is followed :—the free sulphate is washed out by a pretreatment with water ; thereafter, Na is exchanged by H with hydrochloric acid until Na–free and the free acid is removed by washing out with tap water and demineralized water respectively. To substitute the adsorbed H, the H–dusarite is neutralized with the hydroxides of either Na, K (2N) or Ca (milk of lime) and washed out again. Mg–dusarite is prepared by percolation of the H–dusarite with Mg–acetate. As in alkaline media Na– and K–dusarite is slightly soluble, care should be taken not to exceed pH values of 6·5. After drying, the pH–values and cation contents are controlled. On mixing calculated amounts of dusarites, saturated with a single cation, artificial soils can be prepared with a definite composition of the exchangeable bases, wanted for investigation.



Above : Small cylinder with hopper.
Below : Big cylinders a, b and c with hopper and ring.

Types of pots used (Photograph)

The following types are in use :

1. MITSCHERLICH *pots.*
2. *Small cylinders* :
   d = 12·5 cm., h = 25 cm., total contents 2·5 L. (glass or enamelled).

An enamelled sieve resting on a triangular standard forms an air-space (h=2 cm.) at the bottom of the pot, which is ventilated by means of two bevel-edged glass tubes (d=1 cm.). After filling, the cylinders are packed in corrugated paper and placed in wooden boxes (16·5×16×24 cm.), which provide a good protection against daylight and high air temperatures.

These pots are mostly used for experiments mentioned under b; they are very suitable for growing oats and other cereals.

3. *Big cylinders*:

(*a*) d=20 cm., h=22 cm., total contents 6·9 L.
(*b*) d=25 cm., h=35 cm., total contents 17 L.
(*c*) d=25 cm., h=50 cm., total contents 24·5 L.

The cylinders b and c are specially used for the culture of fodder- and sugar-beets respectively. These pots were introduced after the experience gained with beets in smaller pots, which after a good initial development, mostly showed a check in growth as from the moment when the tap-root touches the bottom of the pot. The young leaves then manifest yellow patches and the older leaves die off prematurely. These symptoms are connected with a too limited volume of the pots which at the same time rendered it practically impossible to provide the plants with a regular supply of moisture.

Preparation of the soil

After drying, the soil is led through a sieve with 2 mm. mesh. The maximum waterholding capacity is determined in a sample of the prepared soil.

In the case of heavy clay soils, the pots are filled with an admixture of glass sand to ensure a more even filling and water-supply.

Filling of the pots

The required amounts of soil are weighed and thoroughly mixed with those fertilizers which are given in solid form (such as organics, lime and phosphates).

Other dressings are given in a soluble form together with a calculated amount of water corresponding to 40% of the waterholding capacity, and mixed by hand. When a homogenic mixture has been obtained the pot is filled with soil in layers of about one inch. Each layer is carefully pressed down and superficially loosened with a knife or spatula before being covered with the following layer. After filling, the total amount of water is gradually increased up to 60% of the maximum waterholding capacity. Our experience showed that this procedure warrants the best development of the plants with only small differences between the replication pot.

Germination layer

To prevent a retarding action of mineral salts on the germination of the seeds, the upper layer of the soil (1 in. thick) is not mixed with fertilizers but consists of the original soil mixed with water only.

Watering

In case of experiments with heavy soils, which have a slow water movement, a glass tube (d=37 cm.) is placed in the middle of the pot during the filling, at a height of 8 cm. below the surface. The soil is then filled round the tube. After filling, dry, coarse glass sand is poured into the glass tube and the tube removed. Thus the pots contain a sand column in the middle, going to a depth of 8 cm. On top of this sand column a watering hopper is put. Watering through this hopper prevents the puddling of the surface.

Dimensions of the watering hoppers :—

for use in small cylinders (2) :

height 17 cm., d=3 cm.

for use in MITSCHERLICH pots and big cylinders (3a) :

d (top)=6 cm.

d (bottom)=3·7 mm.

h=17 cm.

As beets are grown in the middle of the pots a ring of glass sand substitutes the sand column in the big cylinders 3b and 3c (3).

To assure a regular spread of water the hoppers are provided with 4 or 12 openings (for use in small cylinders and MITSCHERLICH pots respectively) in the lower sides of the tubes.

Water is supplied thrice a day, the pots are weighed every morning. The losses of weight are noted to be compared with an evaporation meter, which makes it possible to calculate the daily fluctuations due to the weather conditions.

Depending on the types of plants and their development the initial standard weights of the pots are increased 2 or 3 times during the growth period, in order to compensate the increase of fresh weight of the plants. All pots are watered with demineralized water (conductivity smaller than 60,000 mho's).

After thinning the seedlings, the soil surface is covered by a 1 cm. thick layer of " silex " to prevent extensive heating and evaporation of water. (" Silex " is ground gravel consisting of practically pure quartz.)

We consider the filling procedure and the watering of the plants to be important factors, with great influence on the result of the experiment. Filling of the pots by means of a spade, or water supply at the bottom of the pots proved to be less advantageous. Same experience is gained by several institutes (7).

Placing of the pots

The pots are placed on lorries, which stand in the open air, but are driven into the greenhouse by night and during rainy weather. Once or twice during the growing season, the plants are exposed to a soft summer rain for half an hour, to remove the dust from the leaves. Care is taken that this does not supply so much water as to cause drainage losses in the pots.

To prevent differences due to unequal exposure, all the pots are turned 180° after each weighing and circulated upon the lorries by moving two places in one and the same direction.

Fertilizer dressings

In the literature on the subject many prescriptions for pot-dressings are given without providing a logical derivation of the quantities used. Taking the practical field dressings as a starting point one must bear in mind that the growth conditions in pots differ greatly from those in the field. Here, the ratio between the nutrient uptake from the fertilizers and from the soil itself is lower than in pot experiments, due to the fact that in the field a much greater amount of soil is at the plant's disposal. The only real basis appears to be the comparison of the produced quantities of dry matter in the fields and in the pots.

Four methods of conversion can be used which are based on the ratio of :—

a) weight of the soil in the pot and the average weight of 1 ha. surface soil ;

b) area of the pot in relation to 1 ha. ;

c) number of plants ;

d) dry matter production.

Taking nitrogen as an example the next table shows a calculation according to the four points mentioned above.

Crop	Optimal N dose in a pot culture (g. per pot)	Contents of pot used	Corresponding N dressing in kg./ha. caculated on the basis of				Average normal field dressing kg./ha.
			area	†weight	number of *plants	prod. of dry matter	
Oats	0·4	2.5 L.	400	480	—	57	40-60
Sugar-beet ...	6·7	24·5 L.	1,365	773	469	207	120-180

*average number : 70,000/ha. (sugar-beet).

†average weight of cultivation layer of soil $\pm 3 \times 10^6$ kg./ha.

The optimal doses were found empirically by determining the optimal production of the crop with increasing amounts of fertilizers. Converting this dose to the corresponding dressing per ha. different amounts are obtained depending on the manner of calculation. (In the case of oats no calculation on the basis of the number of plants is practicable.) For calculation on the basis of production we used the average figures of production in the years 1931-1940 in Holland (5).

The table shows that the conversion of the optimal N dressing in a pot culture on the basis of production gives figures which are more in accordance with the average field-dressings. In the case of oats the agreement is quite satisfactory. Sugar-beets show a greater difference, which can, however, be explained as the beets grown in the field take up an amount of at least ± 50 kg. N/ha. from the soil, whereas the pot-experiment mentioned was carried out on a nitrogen-free dusarite-sand mixture.

LITERATURE

(1) SCHUFFELEN, A. C. "Is de plantengroei afhankelijk van de ionenverhouding in de grond." *Landbouwk. Tijdschr.*, **52**, No. 645 (1940).
(2) LEHR, J. J. "De invloed der kationenverhoudingen op de ontwikkeling van de suikerbiet." *Med. v. h. Inst. v. Rat. Suikerprod.*, **17**, No. 65 (1947).
(3) LEHR, J. J. "The importance of sodium for plant nutrition" II. *Soil Sci.*, **52**, No. 5 (1941).
(4) MAC INTIRE, W. H. and WINTERBERG, S. H. "Pot method for soil cultures." *Soil Sci.*, **62**, No. 1 (1946).
(5) Verslag over de Landbouw in Nederland over 1947. Vers. en Med. v.h. Min. v. Landb. Visserij en Voedselvoorz. No. 1 (1950).
(6) REI ROBBINS, W. "Growing Plants in Sand Cultures for Experimental Work." *Soil Sci.*, **62**, No. 1 (1946).
(7) ZAITSEWA, E. V. "Filling and Water supply of experimental pots." *Bull. of the U.S.S.R. Tobacco Exp. Station Witim, III*, No. 119, 44 (1935).
(8) PFEIFFER, TH. "Der Vegetationsversuch." Verl. Paul Parey, Berlin (1918).

SESSION 8

PLANT DIAGNOSTIC METHODS

25th July. Chairman : F. STEENBJERG (Denmark)

T. WALLACE. Plant Diagnostic Methods (Volume I, page 231)

W. A. ROACH. Preliminary Diagnosis of Mineral Deficiencies by Plant Analysis and Plant Injection (Volume I, page 240)

SESSIONAL DISCUSSION

S. HÉNIN : L'application d'éléments mineurs peut elle provoquer un accroissement de récolte en l'absence de symptomes de déficience ? Autrement dit, absente-y on une relation entre la récolte et l'apparition des symptomes ?

P. BRUIN : In the Netherlands plant analysis is often carried out to get information on the influence of fertilizers and of different fertility levels in the soil on plant growth. Plant analysis may be very valuable for the evaluation of soil testing methods and is used to a considerable extent for this purpose in the Netherlands. Sometimes the results of plant analysis were used for practical advisory work, e.g., the K_2O content of potatoes (VAN ITALLIE). With regard to the lecture of Professor WALLACE, the question arises as to what value plant diagnostic methods may be used for advisory work in the case of rather high productivity level of the soil. Will it be possible to evaluate a more quantitative system on this basis in the same way as is being done by soil testing ?

A. C. SCHUFFELEN : Has Dr. ROACH any experience in using the injection method for producing symptoms of excesses ? There is some possibility that it may be a good tool for gaining information about these excess symptoms.

F. A. VAN BAREN : Can it be ascertained at what time of the growth period a deficiency affecting the yield of perennial crops may be expected ? Could any deficiency be cured before the period of fruit setting and cropping by applying normal fertiliser practices instead of injecting possibly thousands of trees ?

T. WALSH : In basing diagnosis on chemical methods a difficulty arises in establishing threshold values as, in some instances at least, it is more a matter of relative concentration than total concentration of nutrients in tissue. I have referred to this previously in connection with magnesium deficiency, while the same problem arises in connection with a number of other elements also. This has been shown by the work of THOMAS, and SHEAR and CRANE, in the U.S. It may possibly be that in the final analysis the presence or absence of some organic constituent in tissue may provide a sounder approach to the diagnosis of mineral deficiencies. Where diagnosing lime deficiency in soils is concerned, tissue tests for calcium have been found by us to be of but limited value.

M. M. ELGABALY : As regards Dr. WALSH's question on the importance of relative concentration more than the total concentration, I think for maximum growth you must have a given ratio and in addition an optimum concentration. At a given ratio you may have normal appearance but not necessarily maximum growth, unless the concentration is raised to a given level.

T. WALSH: I agree with Professor ELGABALY that these are two of the main considerations involved. It follows that the appearance of a symptom typical of some particular deficiency does not necessarily mean that a low level of that particular element is responsible for the symptom. It may mean that that element is low in relation to some other element and, therefore, cannot fulfil its normal metabolic functions. It also follows that to get a true picture of the nutrition status of a plant a complete analysis is necessary and that this analysis must be correlated with yield response and appearance of the plant. It is doubtful if with the present knowledge available any attempt can be made to set up specific standards for optimum nutritional conditions. Much more research in this field is needed. Complicating the picture also is the question of cation/anion interactions and this cannot be evaluated in terms of mineral analysis of leaves alone, as a number of other ions as well as complex organic ions resulting from the activities of mineral nutrients within the plant enter into cation/anion plant effects. There is urgent need for further study on mineral balance in relation to the organic constituents of plants if the picture of nutritional status of plants is to be completed.

R. F. INNES: Unlike most experiment stations, mine is connected wholly with a highly organised and integrated sugar industry so that I find my position the reverse of that in which Dr. WALLACE, and others like him, find themselves. Our facilities for controlled field experiments are relatively unlimited whilst our justification for extensive laboratory investigations are much more difficult to establish. Furthermore, being financed by a large business concern, our prime object is to enhance the *economic* production of recoverable sucrose. Our advice is continuously subject to critical appraisal, which evaluation can be fairly accurately checked from the detailed records of individual field performance, maintained by all plantations. It is not surprising, therefore, that in diagnosis techniques, we believe that the "end" justifies the "means" and the "means" in our opinion is any diagnostic technique which allows, not only of a highly significant condition being established with response, but such condition must have an error of a magnitude which allows the regression being used as a quantitative tool—some do not realise that the former is possible without the latter.

Preliminary examination of the relation between the presence or absence of response to potash dressings, and the potash content of the dry matter of an index tissue gave the following table, based upon the results of 126 experiments.

	No. of experiments in each group						
K_2O% dry matter	— 0·6	0·6 –0·8	0·8 –1·0	1·0 –1·2	1·2 –1·4	1·4 –1·6	1·6 —
Response +	11	19	24	20	1F	F	5
,, —	0	0	0	2	10	5	6
	All responses except 4, significant				All responses not significant		

The index tissue was an arbitrary one, namely the lamina of the first fully opened leaf, i.e., the first leaf to show an exposed ligule. The conclusion drawn from the above was that when the index fell below about 1·3 a response to potash dressings was highly probable. The definiteness expressed in the table encouraged us to look for a working relationship between index and response such that optimum economic dressings might be calculated from a knowledge of the index value. The data from 257 factorial experiments have gone into obtaining the relation, which was derived as follows.

In the first place, the response curve relating yield to applied potash was established. Several curves can be made to fit our data but the MITSCHERLICH curve was chosen simply because it has been widely used. Its acceptance by us as a law does not necessarily follow. The constant "C" fluctuates with the potash status of the soil but an average value of 0·44 gave a sufficiently good working relationship. Using field experiments as large pot tests, it is possible to derive

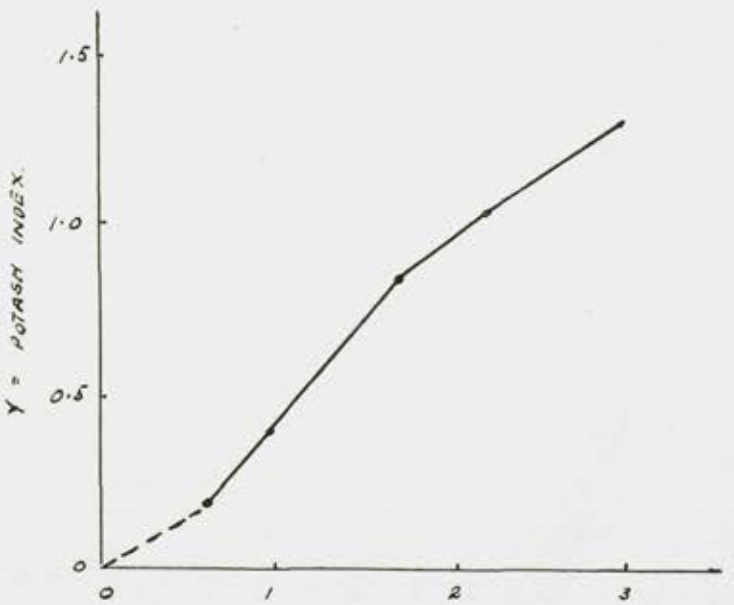
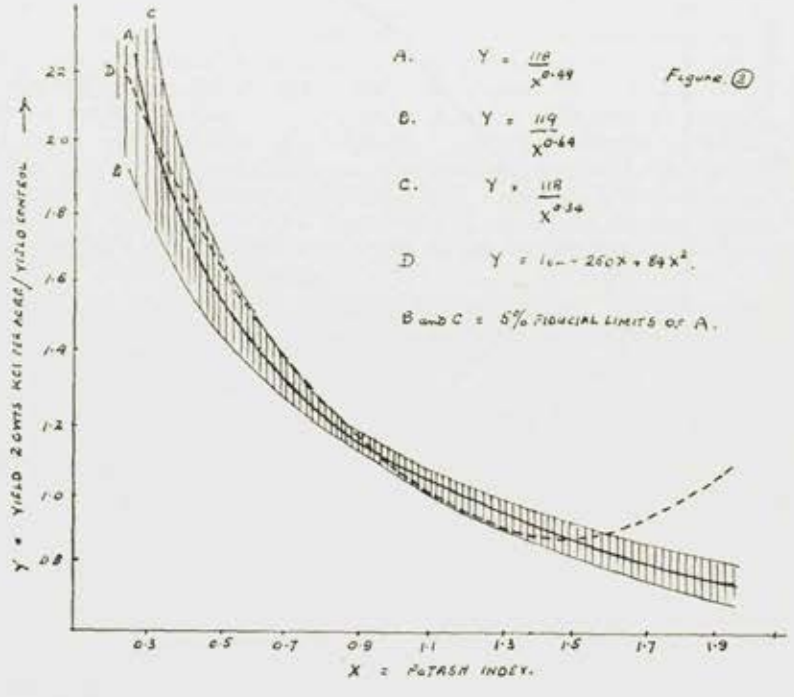


FIGURE (1).

values for soil available potash in terms of equivalent muriate of potash applied to the soil in the experiments. When this was done and the mean potash index of cane was plotted against the available soil potash the relation given in Figure 1 was obtained showing that potash index was a positive linear function of soil available potash.

Over an area where rainfall varies between 30" and 120" per annum, it becomes necessary to subject experiment data to a unifying process by considering relative yields and not absolute yields, before the data is in a form suitable for statistical examination. That this process has been undergone will need to be borne in mind later.

The data have been grouped into means of 5 groups in the diagram, because a reliable estimate of the soil available potash is only possible by using the mean response obtained from a large number of experiment responses. Since the relation was so definite it should be possible to relate potash index to the response obtained from a standard potash dressing. The success obtained is given in Figure 2. The band or shaded area represents the 1% fiducial limits within which the mean curve must be. Not only is the relationship highly significant, but the fiducial band is so narrow that the curve can be used in a quantitative manner. The relationship indicated is a hyperbole and in this respect agrees with LUNDEGARDH's work, but the curve need not be a hyperbole. A quadratic relationship fits the data just as well and when plotted, falls almost completely within the fiducial band of the hyperbole. Other curves could also be fitted.



By changing the response curve into a cost/return curve and differentiating return with respect to cost, as well as by taking into account the relationship between potash index and expected response, it is possible to construct a compound nomogram connecting the cost ratio of treatment to net unit value of crop produced by the treatment, with potash index (or response to a standard dressing of potash) provided the general yield level of the district (as determined mainly by rainfall) is known. The nomogram, Figure 3, does this such that the optimum level of available potash in the soil or the dressing of potash to be applied to attain this level, can be read off corresponding to any set of circumstances.

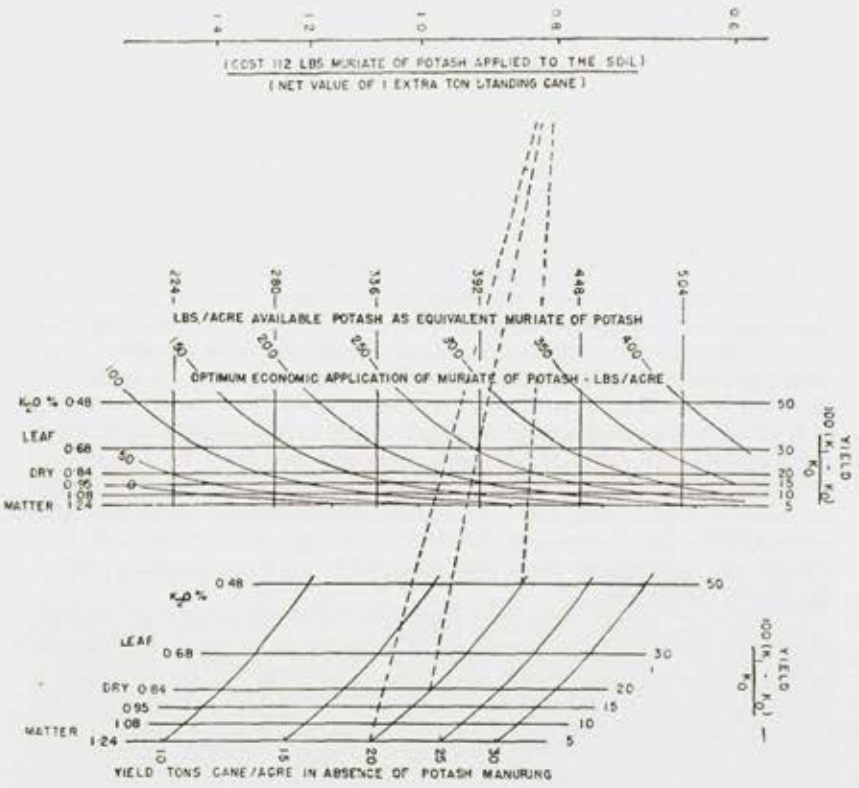


Fig. 3

These relationships, which are workable, have been obtained in spite of physiological interactions (if they existed). No NP or NK yield interactions were encountered. That physiological interactions occur is possible since a few experiments fell well outside the fiducial band in Figure 2. Their number, however, was small and their more detailed examination does not warrant priority at the present time.

The phosphate picture has not allowed of such extensive study because deficient areas are much smaller and of less economic

importance. We doubt whether similar methods would be as successful for phosphate because of its relatively great physiological immobility in plant tissues.

The nitrogen problem cannot be tackled in the same way as potassium since nitrogen levels in index tissues mean little. The nitrogen level in cane leaf depends upon sunlight, drought, temperature and the oxidation/reduction conditions in the rooting medium—the soil. We have shown, however, that when plots are given various levels of nitrogen dressings, the corresponding relative yields at harvest are linear functions of the relative total nitrogen status of leaf dry matter soon after the treatments are applied. Our system of nitrogen control, therefore, has resolved itself into placing a series of plots on each field, to which are applied different levels of nitrogen and of modifying the general field nitrogen treatment in accordance with the relative nitrogen status of the index leaf on the different plots. In this way, nitrogen dressings to cane fields can be controlled without much lapse of time, i.e., adjustments can be made to the growing crop. The method, of course, relies upon grouping the variance data in plots (or within blocks) into zones requiring similar treatment. Too much reliance cannot be placed upon the results obtained within one block, i.e., within the plots in one field as this would be statistically unsound. Basal dressings of P or K are given where these are required. In future we hope to reap most of the plots so as to obtain even more accurate data upon yield response and nitrogen requirement. The same general principles could be applied to potash control, but the method discussed earlier requires less labour and is preferable. The technique or a modification may, however, be necessary to solve the phosphate problem.

R. PIOT : Je demande à Mr. ROACH quel est le mode opératoire suivi pour pratiquer les injections dans les feuilles.

S. MCCONAGHY : Little has been said about varietal susceptibility to mineral deficiencies, e.g., oat varieties for example differ in their susceptibility to manganese deficiency, though susceptible varieties absorb less manganese than less susceptible varieties growing under the same conditions.

T. WALSH : In one case of manganese deficiency which we investigated the healthy variety gave practically twice as much manganese in the grain and three times as much manganese in the straw as a severely affected variety, growing on the same soil. From our investigations it appears that the manganese content of the grain is not sufficient to ensure freedom from the deficiency. In one case an oat variety when grown under acid conditions showed a manganese level of 100 p.p.m. in the seed, which seed when grown in a manganese soil gave, in turn, seed with 7 p.p.m. in the grain. It is obvious that in considering varietal susceptibility to manganese deficiency a number of factors, depending on the inherent manganese needs of different varieties, differences in feeding power and, to a less extent, the capabilities of seed of different varieties to store manganese, must be taken into account. We have now a number of aspects of this problem under investigation. From results so far to hand, it would appear that varieties bred under manganese-deficient conditions may be less susceptible to deficiency than those bred in soils of adequate manganese supply.

S. MCCONAGHY : Dr. WALSH remarks that there seems to be some connection between the varietal susceptibility of oats to manganese deficiency and the place where the variety is bred and gave an example of oat varieties grown at Glasnevin under conditions of mild manganese deficiency being less susceptible to manganese deficiency than varieties from elsewhere under conditions where this deficiency does not exist. This would seem to be at variance with the findings of the Long Ashton workers that a seed produced under a certain mineral deficiency is more likely to produce in the next season a plant which will show advanced symptoms of that deficiency if the particular element in question is still witheld.

A. M. SMITH : We have found varietal differences in oats with respect to manganese deficiency symptoms and in turnips with respect to boron.

S. TOVBORG JENSEN : The question was raised by Professor WALLACE whether the problem of micro-element deficiency should be attacked from a chemical or from a physiological point of view. The work done at Long Ashton in studying deficiency symptoms has been mainly on a physiological basis. From a chemical point of view it seems to be rational to cure deficiency diseases by injection or by spraying with the element in question. We know almost for certain that all these elements will be present in the soil in quantities large enough for a normal crop development. The disease occurs because the element in question has been inactivated and made unavailable. It should be possible by proper handling and treatment to keep the soil in such a condition that micro-elements are not inactivated. It is now up to the soil chemist to tell the farmer how to handle his soil in order to avoid micro-element deficiencies.

E. VON BOGUSLAWSKI : Schon früher (E. A. MITSCHERLICH, E. v. BOGUSLAWSKI, u. A. GUTMANN, *Schriften d. Königsberger Gelehrten Gesellschaft*, **12** Heft 2 (1935) (haben wir die Beziehungen zwischen "Düngung" und "Ertrag," "Nährstoffaufnahme" und "Verwertung" dargestellt. Die Skizze+) zeigt, dass die Ertrags-und Aufnahmekurven durch die von Herrn STEENBJERG gezeigten weitgehend bestätigt werden. Die "Verwertung" bringt zum Ausdruck, wieviel Trockensubstanz pro Einheit aufgenommenen Nährstoffes gebildet wurde.

Bei Erreichen des Höchstertrages können wir auf der x-Achse die erforderliche Düngung ablesen und ausserdem die dazu erforderliche "Aufnahme," ebenso wie die in der Pflanze erfolgte "optimale Verwertung." Die Schwierigkeit besteht nur darin, dass sich, worauf ich gestern schon hinweisen konnte, die Erträge innerhalb des Höchstertragsgebietes (siehe Skizze) nicht ändern, obwohl das Nährstoffverhältnis (insbesondere das Verhältnis der Faktoren zueinander) wechseln kann. Deshalb geht meine Meinung dahain, dass die Feststellung des Nährstoffverhältnisses in der Pflanze oder im Blatt nur im ansteigenden Teil der Ertragskurve brauchbare, und auch dann nur qualitative Ergebnisse liefern kann.

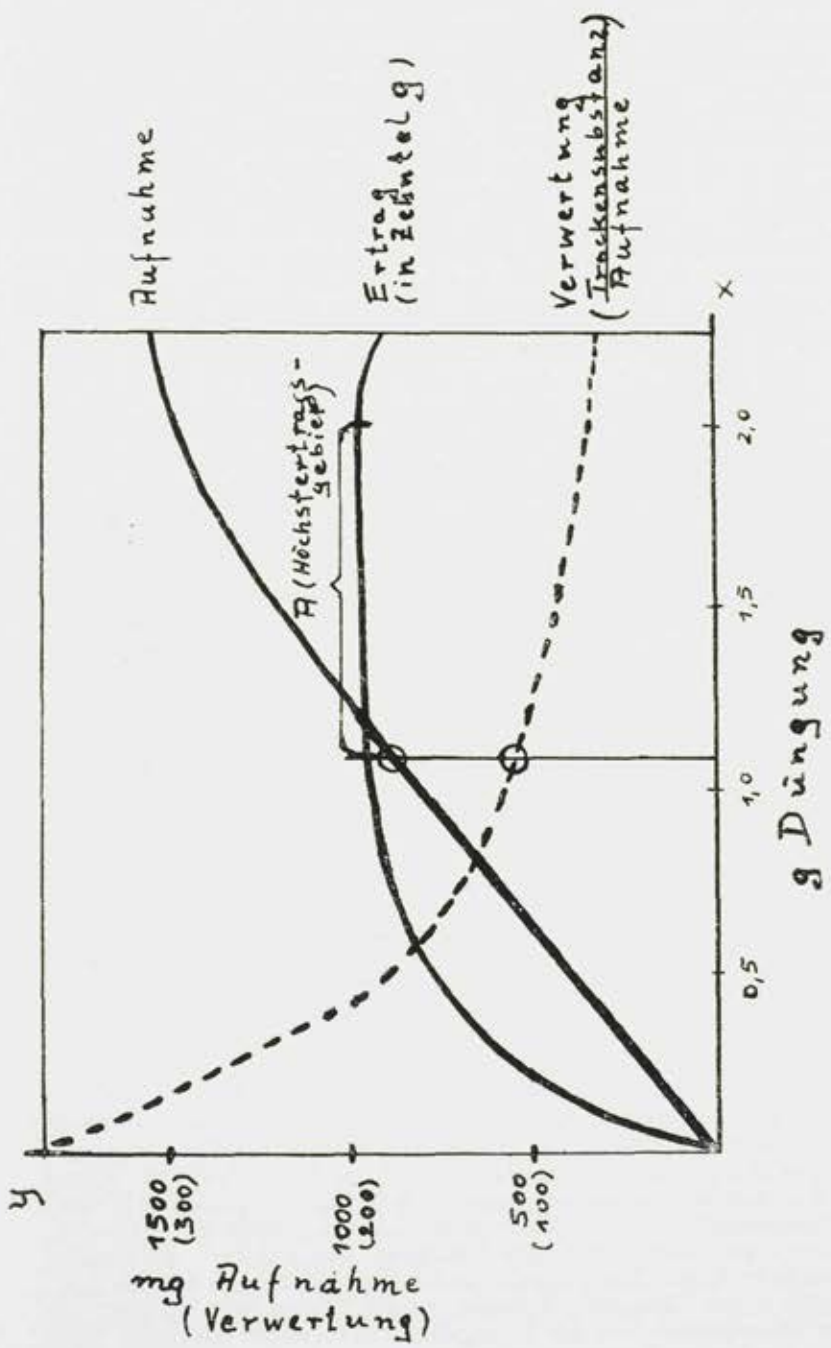

Aufnahme
Ertrag (in Zehntel g)
Verwertung (Trockensubstanz / Aufnahme)
A (Höchstertrags-gebiet)
y
1500 (300)
1000 (200)
500 (100)
mg Aufnahme (Verwertung)
x
0,5
1,0
1,5
2,0
g Düngung

Fig. 4

F. STEENBJERG: Before we close this session, I should like to summarize our discussions in the following way:

In diagnosing soil fertility several methods can be used, for instance, soil analyses, plant analyses, foliar diagnoses and visual symptoms, tissue tests, injection methods, NEUBAUER or MITSCHERLICH tests, etc., etc. Whether we use one method or another our final object is to correlate all these tests with one of our yield curves, for instance the yield curve giving the relationship between yield or increase in yield and the added nutrient (or nutrients) in minimum. To take an example. If we use visual symptoms we may have very strong and widespread symptoms, less strong symptoms or the symptoms may just have disappeared. ROACH and several others expressed as their experience that when the symptoms just disappear we may still have very great increases in yield by adding the nutrient in minimum. This, I think, is in accordance with general experience.

Furthermore, when diagnosing nutrient deficiency problems in the field, one ought to use more than one method because the methods we have discussed to-day are more or less independent of one another so when using several methods in diagnosing a soil fertility problem, our diagnosis wins in certainty.

Finally, I think it is important that we discriminate between the extreme physiological disorders (whether deficiency or excess of a nutrient) as determined in sand or water cultures and what we observe in the field. As stressed by WALLACE the highly analytical approach through water and sand cultures is valuable, but the importance of observing such physiological disorders by means of visual symptoms are perhaps sometimes overstressed by some persons who use the results in the field.

I would like to add that the work on the correlation of all these tests with field conditions must finally result in an estimation of the amount of fertilizers which must be added to obtain the largest net effect.

MINERAL STATUS OF CEREALS IN RELATION TO FINAL YIELDS

1. POTASSIUM STATUS OF BARLEY

2. MANGANESE STATUS OF OAT

D. J. D. NICHOLAS

Long Ashton Research Station, University of Bristol, England.

Field experiments described briefly in this paper were designed to study the relation between the mineral status of cereals and yields of grain. It is shown that crop plants may have suboptimal levels of nutrients without external symptoms being apparent.

1. *Potassium status of barley*

Barley was grown in factorial experiments in which graded amounts of potash fertilizer, e.g., 0, ½, 1 cwt. per acre were applied with the basal NP soil treatments, broadcast and placed respectively. The experiments were located at three centres differing in soil characters and incorporating soils which had a medium and normal K status.

The K, Mg, Ca, P and Mn status of the plant " tops " were determined twice during the season at flowering and at ear formation by ash analysis and tissue test methods. The mineral content of the young, mid-stem leaves and internode adjacent to the growing point were determined by rapid chemical tissue tests, using a diffusion method and a WARING blendor technique (1,2). An acetate buffer solution was used to extract the mineral nutrients. In this paper a statistical comparison is reported between the results of the various chemical methods. Minimum levels for K, determined by tissue tests and ash analysis, are given above which an increase in final yields as a result of applying further amounts of K would be unlikely to occur.

Comparison of results of chemical methods

Correlation coefficients 'r' values between the results of ash analysis and each of the rapid chemical methods for K, Mg, Ca, P and Mn are given in Table 1.

The important correlations are those for treatment and treatment x sites as the 'r' values for error are small and non-significant except for P. The tissue tests data are significantly correlated with those of ash analysis except for Mn in the young leaf by diffusion method. The choice of method for use instead of ash analysis should be based on the proximity of 'r' values to 1 and also on the speed with which the chemical method can be used. The WARING blendor method is advantageous in determining K, Mg, Ca and P as the procedure gives high 'r' values for the nutrients and the method is speedy and readily standardized in use. It does not, however, provide an estimate for Mn and in this respect the diffusion method (mid-stem leaf) can be used to supplement the blendor data.

TABLE 1

The correlation coefficients 'r' values between ash analysis and the rapid chemical methods for K, Mg, Ca, P and Mn in barley at three centres

Nutrient	Factors	Degrees of Freedom	WARING Blendor	Diffusion Method		
			'tops'	young leaf	mid-stem leaf	inter-node
K	Treatments (T) and Treatments (T) × Sites (S)	19	0·93‡	0·90‡	0·89‡	0·95‡
	Error (E)	19	0·24	−0·17	0·17	−0·05
	Total (T)	46	0·93‡	0·75‡	0·70‡	0·95‡
Mg	T and T×S	19	0·84‡	0·52*	0·89‡	0·70‡
	E	19	0·26	0·06	0·37	0·10
	T	46	0·72‡	0·64†	0·89‡	0·78‡
Ca	T and T×S	19	0·96‡	0·90‡	0·91‡	0·93
	E	19	0·07	0·26	0·05	−0·20
	T	46	0·94‡	0·86‡	0·83‡	0·90‡
P	T and T×S	19	0·92‡	0·82‡	0·93‡	0·92‡
	E	19	0·70‡	0·77‡	0·55†	0·84‡
	T	46	0·88‡	0·77‡	0·62‡	0·65‡
Mn	T×T×S	19	—	−0·11	0·83‡	0·83‡
	E	19	—	−0·27	0·25	−0·22
	T	46	—	0·04	0·63‡	0·78‡

P	*Treatments and treatments × sites and error* 't'	*Totals* 't'
*0·05	0·43	0·29
†0·01	0·55	0·37
‡0·001	0·67	0·46

Chemical status in relation to yields

Regression of yield response on K status of plants not receiving K were determined for the various chemical methods and plant portions. The minimum levels for K in the tissues above which a further increase in grain yields as a result of K treatment would be unlikely to occur at these centres, are given in Table 2.

The minimum values in relation to final yields are greater than those associated with the onset of visual symptoms of K deficiency. A reduction in final yields may, therefore, occur when there are no external symptoms, so that it is only by the use of chemical methods that suboptimum levels of nutrients in relation to yields can be satisfactorily determined. The minimum values vary with the plant portion tested and by the diffusion method is found to be highest in young leaves as K is readily translocated to the meristematic tissues. This emphasises the importance of standardizing the leaf samples used for chemical analysis. The position of the regression line for K (diffusion method, old leaves) shifts towards the ordinate as the season progresses. This is probably due to the movement of K to young parts as the deficiency develops.

TABLE 2

Minimum K values in various plant parts of barley associated with (1) visual symptoms of K deficiency ; (2) maximum grain yields

Minimum Values	μg extracted per gm. fresh weight				% K in dry matter
	Diffusion Method			WARING Blendor	Ash Analysis
	Young leaves	Mid-stem leaves	Internodes	'tops'	'tops'
Visual Symptoms	350	100	200	800	0·75
Grain Yields	700	500	600	2000	1·5

As the results of the WARING blendor or diffusion methods for mid-stem leaves were better correlated with ash analysis than other methods, these were further correlated with yields of grain.

The results are given in Table 3.

TABLE 3

The analysis of covariance ('r' values) for yields of grain and mineral status of barley determined by various chemical methods.

Nutrient	Factors	Degrees of Freedom	Ash Analysis 'tops'	WARING Blendor 'tops'	Diffusion Method mid-stem leaf
K	Treatments (T) and Treatments (T) × Sites (s)	14	0·75‡	0·69†	0·73†
	Error (E)	14	0·25	0·54	0·41
	Total (T)	34	0·80‡	0·77‡	0·62‡
Mg	T and T×S	14	−0·87‡	−0·83‡	−0·88‡
	E	14	−0·32	−0·096	−0·028
	T	34	−0·85‡	−0·79‡	−0·86‡
Ca	T and T×S	14	−0·72†	−0·80‡	−0·72†
	E	14	−0·14	−0·16	−0·39
	T	34	−0·78‡	−0·84‡	−0·78‡
P	T and T×S	14	−0·85‡	−0·78‡	−0·74‡
	E	14	−0·49	−0·37	−0·35
	T	34	−0·64‡	−0·40*	−0·13
Mn	T and T×S	14	−0·73†	—	−0·70†
	E	14	−0·034	—	−0·51
	T	34	−0·71	—	−0·37*

P	*Treatments and treatments × sites and error* 't'	*Total* 't'
*0·05	0·5	0·32
†0·01	0·62	0·42
‡0·001	0·74	0·52

The ash analysis method for K is better correlated with yield (P=0·001) than the blendor or diffusion methods (P=0·01). Nevertheless, there is a good correlation between either of the two rapid methods for K and yields of barley grain. Mg, Ca, P and Mn are significantly negatively correlated with yields.

2. Manganese status of oat

The study of Mn status of oat in relation to grain yields in field experiments is dependant on the use of appropriate methods to correct the deficiency. In factorial experiments, it has been shown that placing $MnSO_4$ with the seed even at the rate of 1 cwt. per acre, with or without sulphur at 2 cwt. per acre, did not fully correct the deficiency. Sulphur placed with the seed at 2, 4 and 8 cwt. per acre was ineffective. Foliage sprays at 0·1, 0·25 and 0·5% $MnSO_4$ respectively applied four times during the early season making total applications of only 10, 25, 50 lb. $MnSO_4$ per acre respectively were the most effective treatments which resulted in significant increases in grain yield.

In these experiments, the correlation between the Mn status of oat and final yields was complicated by the presence of residues of $MnSO_4$ on the leaf surfaces in the 0·25 and 0·5% spray treatments and by the relatively small increases in yields resulting from soil treatments. Moreover, even in the spray treatments which resulted in significant increases in grain, Mn contents of mid-stem leaves were low late in the season, when spraying had been discontinued.

In Table 4 are given '*r*' values for Mn status of mid-stem leaves of oat determined at ten-day intervals during the season, and final yields. The first samples were taken a month after seeding.

TABLE 4

Analysis of covariance ("r" values) for Mn status of mid-stem leaves of oat and final yields

(Sampling at 10-day intervals)

Sampling	Total	Treatment	Error
1st (month after seeding)	0·87‡	0·97†	0·60
2nd	0·75‡	0·83*	0·22
3rd	0·60	0·75	0·63
4th	0·41	0·76	0·17
5th	0·13	0·46	−0·68

‡P=0·001. †P=0·01. *P=0·05.

At the first and second samplings the Mn status of the mid-stem leaves is significantly correlated with final yields. At subsequent samplings, however, the '*r*' values decreased and became non-significant. At later samplings, when spraying had been discontinued, symptoms of Mn deficiency appeared in the mid-stem leaves of the sprayed plants. At this stage the Mn status was low, irrespective of treatment, thus confirming symptoms but not the changes in final yields.

A month after seeding, the regression of the final yield on Mn status of plants not receiving $MnSO_4$ treatment, showed that 40 μg per gm. dry matter was the minimum value above which a further increase in grain yield as a result of Mn treatment would not be expected. This value is greater than that associated with the onset of visual symptoms of the deficiency, viz., 10 to 20 μg per gm. dry matter, so that chemical methods only can be used to determine suboptimal levels of Mn in regard to final yields.

Conclusions

In a study of the mineral status of cereals grown in factorial experiments, it is shown that rapid chemical methods (diffusion and macerater methods) can be used as well as ash analysis for this purpose. The coefficients of variability and an analysis of covariance '*r*' values were determined for K, Mg, Ca, P and Mn determined by tissue tests and ash analysis. Moreover '*r*' values for the K content in barley and Mn status of oat determined in various plant portions by tissue test and ash methods were significantly correlated with yields.

The effect of using various (1) plant parts, (2) method of analysis, (3) sampling dates on the correlation coefficients of mineral status with final yields, has been studied. Minimum values, above which there is no further increase in yields as a result of increasing either element, have been suggested for K in barley and Mn in oat.

REFERENCES

(1) NICHOLAS, D. J. D. and FISHER, D. J.: The manganese content of cereal crops in relation to yield of grain and straw. 1. Field experiment with oats 1949 and 1950. *Rep. Agr. Hort. Res. Sta., Long Ashton*, 77 (1951).

(2) NICHOLAS, D J. D.: Potassium status of barley in relation to yields of final grain. *J. Agr. Sci.* (in the press) (1952).

THE USE OF MACERATERS FOR EXTRACTING MACRO- AND MICRO-NUTRIENTS FROM FRESH PLANT TISSUES

D. J. D. NICHOLAS

Long Ashton Research Station, University of Bristol, England

Ash analysis methods have been extensively used to determine the mineral status of crop plants. The main disadvantage of these methods continues to be the time involved, although this has been shortened to some extent by the use of the spectrograph, polarograph, spekker absorptiometer and flame photometer.

Rapid chemical tissue tests have been successfully used to determine the mineral status of crops (1 to 6). These methods are simple and quick in operation and need non-expensive apparatus. The results are less precise than those of ash analysis, but are sufficiently sensitive and quantitative to determine the mineral status of crops in relation to visual symptoms and final yields.

In this paper a brief account is given of the use of maceraters to extract macro- and micro-nutrients from fresh plant tissues. The WARING Blendor (American model) and NELCO or FOLLEY macerater (British model) have been used to extract K, Mg, Ca, P, nitrate N from leaf tissues of a range of crop plants grown in long-term manurial experiments (2,6). From 1946 to 1952 comparisons have been made between the two maceraters, using MORGAN'S acetic acid and water respectively as extractants. Several thousand analyses have been made and these have been statistically related to visual symptoms, ash analysis, and final yields.

Pyrex glass maceraters or micro-grinders have been devised for extracting micro-nutrient elements from fresh plant tissues by means of glass distilled water. This technique is of particular use when heavy metals are present in excess in plant tissues and for extracting 'active' iron from iron deficient leaves.

Methods

The sampling techniques for the maceration have been reported elsewhere and will only be mentioned briefly here.

Waring Blendor. 10 gm. of fresh leaf tissue, 100 ml. of extractant (usually MORGAN'S solution) 1 to 2 gm. Darco G60 carbon depending on type of material sampled, macerate for 2 minutes. Filter through tough bench filter paper into 200 ml. flask and make to volume with water.

Nelco Macerater. 3 gm. of fresh leaf tissue, 30 ml. extractant, 0·75 to 1 gm. carbon, macerate at full revolution for 3 minutes. Filter into 100 ml. grad. flask and make to volume with water.

Pyrex Glass Macerater or Micro-grinder. (3 sizes are available, 10 mm., 20 mm. and 30 mm. diameter tubes.) For the 30 mm. size, which is usually used, take 3 gm. fresh leaf tissue, 3 ml. glass distilled water, macerate for about 3 minutes until the tissues are completely comminuted. Add 10 ml. glass distilled water and transfer the homogenate to a centrifuge tube, heat to 80°C. for 15 minutes and spin at 3,500 revs. per minute. The supernatent is poured off and digested with

HNO_3 and $HClO_4$. The clear solution is made to volume and suitable aliquots used to test heavy metals, e.g., Co, Ni, Zn, Cu, Cd, Fe, etc. (3,4,5).

Results

It will be impossible to report the detailed results in this paper. The main comparison will be made between the results of the various macerater methods and those of ash analysis.

Waring Blendor and Nelco Macerators. The analysis of covariance 'r' values between the results of ash analysis and four macerater methods for mid-stem leaves of potato are given in Table 1.

TABLE 1

The analysis of covariance ('r' values) between ash analysis results for potato (mid-stem leaves) and those for macerater methods

3 *seasonal samplings combined*

Mineral Nutrient	Factors	Degrees of Freedom	Waring Blendor		Nelco Macerater		Yield
			Morgan's Solution	2% Acetic Acid	Morgan's Solution	2% Acetic Acid	
K	Treatment (Tr)	5	0·89†	0·64	0·92†	0·47	0·89†
	Error (E)	46	0·13	0·01	0·32*	0·17	0·01
	Totals (To)	53	0·78‡	0·42†	0·66‡	0·33*	0·61‡
Mg	Tr	5	0·89†	0·82*	0·92†	0·80*	−0·00
	E	46	0·02	0·32*	0·12	0·32*	−0·34
	To	53	0·74‡	0·78‡	0·70‡	0·73‡	−0·49‡
Ca	Tr	5	0·76*	0·34	0·89†	0·45	−0·81*
	E	46	0·30*	0·02	0·31*	0·01	−0·13
	To	53	0·50‡	0·28*	0·65‡	0·22	−0·43†
P	Tr	5	0·87†	0·80*	0·89†	0·76*	−0·88†
	E	46	0·27*	0·20	0·19	0·26	−0·24
	To	53	0·85‡	0·53‡	0·78‡	0·48‡	−0·62‡

P	*Totals*	*Treatment*	*Error*
‡0·001	0·44	0·95	0·46
†0·01	0·35	0·87	0·37
*0·05	0·27	0·75	0·27

The important 'r' values are those for treatment. The value of the correlation may be judged by the proximity of 'r' values to 1. The K, Mg, Ca and P Morgan's extraction in either macerater is highly correlated with that in the ash but these nutrients extracted by acetic acid are not so well correlated with the total amounts in the leaves. K status as determined by all methods is significantly correlated with the yield of tubers. Thus the Morgan's solution is a better extractant than the 2% acetic acid in either macerater. The Nelco (British macerater) has the following advantages over the Waring Blendor (*a*) it macerates smaller samples (*b*) it has a top drive

macerater rod so that the blendor cup can be cleaned easily (*c*) it has a rheostat to control the speed of maceration.

A further comparison was made between MORGAN'S and water extraction in the NELCO macerater for a range of crop plants. Moreover, the effect of prefreezing punched discs of leaf tissue in a deep freeze chest at − 12°C. for 12 hours prior to extraction was studied. The analysis of covariance '*r*' values between the results of ash analysis and extraction methods are given in Table 2.

TABLE 2

Analysis of covariance ('r' values) between ash analysis and the macerater methods

Element	Factors	D.F.	Water Extract		MORGAN'S Extract	
			Unfrozen tissue	Frozen tissue	Unfrozen tissue	Frozen tissue
K	Treatment (Tr)	5	0·98‡	0·97 ‡	0·98‡	0·88‡
	Error (E)	46	0·40*	0·32*	0·10	0·30*
	Totals (To)	53	0·61‡	0·57‡	0·78‡	0·78‡
Mg	Tr	5	0·48	0·63	0·98‡	0·97‡
	E	46	0·38†	0·39†	0·36*	0·35*
	To	53	0·52‡	0·49‡	0·67‡	0·57‡
Ca	Tr	5	0·98‡	0·96 ‡	0·75*	0·98‡
	E	46	0·35*	0·39†	0·29*	0·32
	To	53	0·64‡	0·65‡	0·64‡	0·89‡
P	Tr	5	0·77*	0·95‡	0·99‡	0·88‡
	E	46	0·27	0·14	0·29*	0·29*
	To	53	0·38†	0·52‡	0·62‡	0·61‡
N	Tr	5	0·92‡	0·92‡	0·96‡	0·81‡
	E	46	0·36*	0·32*	0·35*	0·29*
	To	53	0·47‡	0·40‡	0·45‡	0·50‡

P	*S.D.*		
	Treatments	*Error*	*Total*
‡0·001	0·95	0·46	0·44
†0·01	0·87	0·37	0·35
*0·05	0·75	0·29	0·27

All macerater methods for K compare favourably with one another and are all closely correlated with ash analysis. There is no advantage in freezing the tissues before extracting K. The MORGAN'S (unfrozen) extract is best correlated with ash analysis as the error term is not significant. The '*r*' values for Mg in water extracts are not significantly correlated with ash analysis for the element, whereas the MORGAN'S solution is well correlated. All methods for Ca and P are significantly correlated with ash analysis; for Ca the MORGAN'S extract (unfrozen) is the least significantly correlated and for P water (unfrozen) had the smallest '*r*' value for P. MORGAN'S extract of unfrozen tissue gave the best correlation for P and nitrate N respectively. The fact that nitrate N as determined by the four macerater methods is well

correlated with total N is of interest and confirms the practice of using this fraction to determine N status during early growth (1·2).

Pyrex glass micro-grinders. Tomato grown in large scale factorial experiments with soil was treated with Co, Ni and Zn singly and in combination at 0, 1 and 2 milliequivalent (m.eq.) per pot (2 kilo. of soil) for Co and Ni respectively and 0, 2 and 4 m.eq. respectively for Zn. The 27 metal combinations were applied to the soil in solution as sulphates. Co_2 or Ni_2 treatments produced Fe deficiency a week after application of the metals. A few days later necrotic patches appeared on the young leaves especially in the high Ni treatments. No well defined symptoms developed in the Zn treatment only, despite the higher m.eq. rates as compared with those of Co or Ni.

The values for Co, Ni and Zn respectively in water extracts of young leaves of tomato prepared in the glass maceraters are given in Table 3.

TABLE 3

Relation between metal treatment and Co, Ni and Zn contents of water extracts of young leaves of tomato

Metal applied per pot	Co_0	Co_1	Co_2	Ni_0	Ni_1	Ni_2	Zn_0	Zn_2	Zn_4
Mean of 36 values μg per gm. fresh weight	0	10	17	0	6	11	13	17	27
	$Co_2 > Co_1 > Co_0$ at P=0·001			$Ni_2 > Ni_1 > Ni_0$ at P=0·001			$Zn_4 > Zn_2$ at P=0·001 $Zn_2 > Zn_0$ at P=0·01		

The water extracts of young leaves reflected the metal treatments given. The results confirm the value of the rapid tissue test procedure to determine which of the heavy metals are present in excess in plant tissues as the visual symptoms in most instances are those of iron chlorosis followed by necrosis.

The total iron in plants seldom reflects iron chlorosis. In Table 4 it is shown that the water extractable iron of young leaves prepared in a glass macerater was significantly depressed in instances of Fe deficiency induced by heavy metals.

TABLE 4

The interaction of Co and Ni treatment on the water extractable Fe from young leaves of tomato

Metal applied m. eq. per pot	Effect on Fe extracted	P	Metal applied m. eq. per pot	Effect on Fe extracted	P
Co_0	$Ni_0 > Ni_1 > Ni_2$	0·001	Ni_0	$Co_1 > Co_2$ $Co_0 > Co_1$	0·001 0·01
Co_1	$Ni_0 > Ni_1$ Ni_2	0·001	Ni_1	$Co_0 > Co_1 > Co_2$	0·001
Co_2	$Ni_1 > Ni_2$ $Ni_0 > Ni_1$	0·01 0·01	Ni_2	$Co_0 > Co_2$	0·05

Increasing Ni at Co_0 depressed the Fe content of the water extracts, so did increasing Co at the Ni_0 level. An increase of Co at the high level of Ni or *vice versa* did not reduce the extractable Fe further.

The total Fe was not significantly changed by metal treatment in these experiments.

Thus the water extractable iron appears to reflect the " active " iron in plants given high levels of Co, Ni, and Zn.

Conclusions

In this paper a WARING blendor (American model) and NELCO or FOLLEY macerater (British model) have been successfully used to extract K, Mg, Ca, P and nitrate N from leaf tissues of crop plants grown in long-term factorial experiments. A comparison has been made, over a period of six years, between the results obtained by the two macerators using various extractants e.g.s. water, dilute acetic acid, and MORGAN'S solution. The effect of pretreating the tissues prior to extracting the nutrients, e.g., freezing, was also studied. The results were statistically compared with those of ash analysis.

Either macerater was equally effective in extracting the nutrients but the MORGAN'S solution gave '*r*' values for K, Mg, Ca, P and nitrate N that were consistently significantly correlated with the total nutrients in the ash. No advantage could be claimed for pretreatment of tissues prior to extracting the mineral elements. The correlation with final yields has been good so that it has been possible to determine minimum values for the nutrients above which an increase in yield as a result of applying the particular mineral element, would be unlikely to occur. It is suggested that the NELCO or FOLLEY macerater can be used as a quick method instead of the tedious ash analysis procedures to determine the mineral status of crops.

The value of pyrex glass microgrinders to extract heavy metals present in excess in plant tissues has been demonstrated. It is of particular use when a number of these are present together in the leaves.

The water extractable iron in the young leaves was correlated with the incidence of iron deficiency and chlorophyll content of tomato, whereas the total iron was not. Thus the glass microgrinders may be useful in fractionating Fe in fresh tissues.

REFERENCES

(1) NICHOLAS, D. J. D.: The application of rapid chemical tests in the diagnosis of mineral deficiencies in horticultural crops I and II. *J. Hort. Sci.*, **24**, 3, 72 (1948).

(2) ——. The relation between the WARING blendor method and other procedures for the diagnosis of the mineral status of crop plants. *Rep. Agric. Hort. Res. Sta., Bristol*, 98 (1948).

(3) NICHOLAS, D. J. D. and FORSTER, W. A.: Some effects of heavy metals in excess on crop plants grown in soil culture I and II. *Rep. Agric. Hort. Res. Sta. Bristol*, 96 (1950).

(4) NICHOLAS, D. J. D.: Chemical tissue tests for determining the mineral status of plants. Mimeographed publication. Long Ashton Research Station, Bristol (1951).

(5) NICHOLAS, D. J. D.: Some effects of heavy metals in excess on crop plants grown in soil culture III and IV. *Rep. Agric. Hort. Res. Sta., Bristol*, 87 (1951).

(6) NICHOLAS, D. J. D.: A survey of the use of chemical tissue tests for determining the mineral status of crop plants. *Soils and Fertilizers*, **14**, 3, 1 (1951).

THE DETERMINATION OF PLANT NUTRIENT REQUIREMENTS

MARCEL V. HOMÈS

University of Brussels, Belgium

When an agriculturist uses mineral fertilizers on a field, his purpose, whether he knows it or not, is to constitute in the soil a suitable nutrient medium for the plant he wants to grow. When, to do that, he relies on information given by soil scientists, he acknowledges implicitly the fact that the constitution of this nutrient medium results from two different causes: the requirements of the plant and the resources of the soil.

If this may seem too obvious to be said, let us point out the fact that disregarding one of these two causes has often led to important mistakes. In the face of the rapid and new achievements of soil science, disregarding the physiological component in the choice of a fertilizer is perhaps the greater of the two risks.

In the present paper, one aspect of this physiological component is laid out, and this does not imply that the writer underestimates the importance of the soil factor. On the contrary, it is perhaps because of its importance that he fears that the complexity of the soil problems makes the present information insufficient to enable the agriculturist to correct directly the imperfections of a soil by a simple complementary addition of a few chemicals. He thinks that it is better to add a complete fertilizer, as close as possible to the optimal requirements of the plants, and to modify quantitatively its formula on the basis of pedological information whenever possible. On the ground of experience too large and too complex to relate here, the writer thinks that there is no waste of chemicals in the use of a complete fertilizer. If this practice seems to neglect the supplying power of the soil, that is purely apparent and no economical loss may result from it, except maybe in very exceptional soils.

Thus, with the aim of using the pedological information in modifying the formula of the complete fertilizer, rather than using it for determining directly the requirements of the soil in order to make of it a suitable medium for plant culture, we have given our attention in the past years to the problem of determining the nutrient requirements of various plants.

The well-known difficulty lies in the complexity of this medium. Even if only major elements are concerned (and this is only a temporary simplification), six elements must be considered at once: N, S, P, K, Ca and Mg (placed by some among the minor elements).

The empirical determination of the best proportions of those elements to make a nutrient medium the best possible is of nearly infinite extension and has never been completely attempted. The partial determination of the suitable proportions has been empirically conducted by some scientists for various groups of chemical elements such as K–Ca, Ca–Mg and chiefly N–P–K. The experimentation device for this research is a factorial experiment. Here are given quite different lines of investigations from which good results have already been obtained and which seem to open a new field in the research of the plant nutrient requirements.

The following principles have been formulated and partly experimentally supported.

1. The optimum yield results of the absolute and the relative concentrations of all constituents of the nutrient medium. It means that only one medium can be the best from the relative point of view of its constitution, i.e., that the proportions of all elements must be correctly fixed. The absolute concentrations act by determining the total possibility of the yield, but no addition of a single nutrient might compensate for a deficiency in the relative composition of the complete medium.

2. In determining the best relative composition of a nutrient medium, it is possible to consider separately the elements of the anion-group and those of the cation-group. For each an optimum " equilibrium " exists, i.e., for each group, the correct proportions must be respected.

3. The greatest difficulty lies in the determination of those two equilibria. For each a complete empirical experimentation seems, at first, necessary. This, however, can be avoided on the following basis.

4. When, everything else being constant, the relative proportions of two constituents are varied, the curve expressing the yield is of the following type:

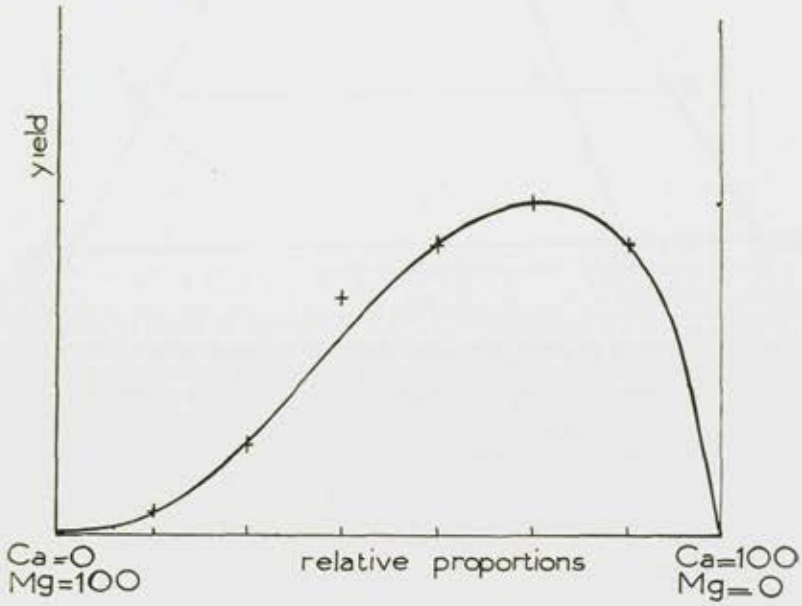


Fig. 1

Relationship between yield and proportions of Ca-Mg. in the nutrient medium. The position of the maximum depends only on those proportions.

The position of its maximum is not influenced by the total concentration, thus by the absolute amount of any constituent alone. But it depends only on the proportions of the two constituents.

5. When three elements are considered at once, their relative concentration can be expressed in a triangular diagram.

In such a diagram, the previous statement (4) is expressed in the form that the best proportions of two elements, when the third varies also are on a straight line passing by one angle of the triangle. (Ceva lines.)

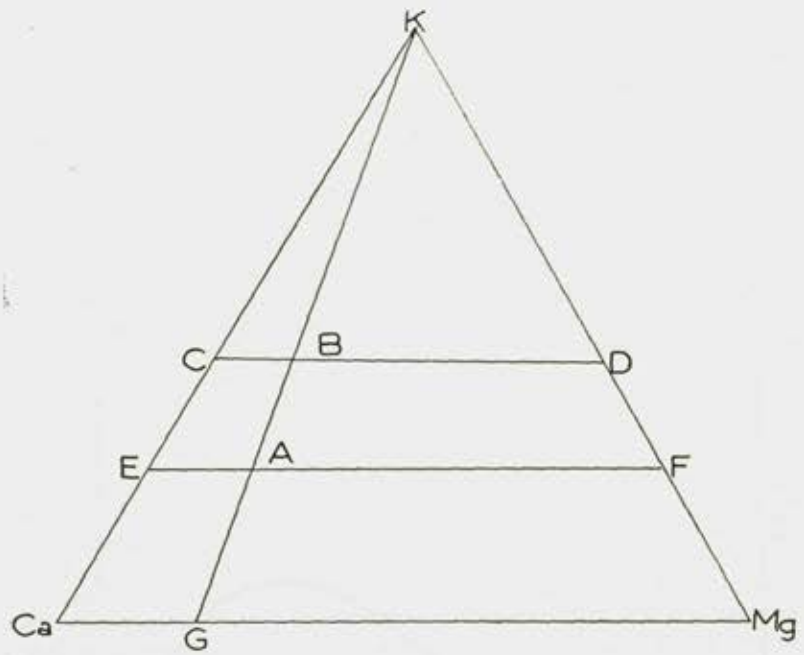


Fig. 2

Triangular diagram in which any point represents the composition of a nutrient medium so far as K, Ca and Mg are concerned. On CD are all the points where Ca and Mg vary for a given level of K concentrations. Of all the possible points, B represents the best solution. On EF are the points representing solutions in which Ca-Mg proportions vary at another level of K concentrations. Of these solutions A is the best. A and B are on a straight line with K (Ceva line).

6. Considering consecutively the relative proportions of two different couples of elements, it is possible to obtain two such lines. At the crossing (intersection) of those two lines is the point expressing the composition of the complex 3-element medium for which the yield is the best at a given level of total concentration.

7. Similar considerations for elements of cation- and anion-groups lead to the determination of the complete optimum nutrient medium so far as the plant requirements are considered.

8. An approximate determination of every Ceva line required for this reasoning is possible by comparison of the yield of a plant grown in two complete nutrient media of well chosen composition. This

point is not developed here, but it is emphasized that such an experiment is no longer a complete factorial one and that variability must anyway be considered and has different consequences.

9. The experimental design resulting from the foregoing principles is a simple one and can be used as well in water cultures as in pot experiments or in the field. In this last case, it enables the experimentator to integrate automatically in his results the soil factor as a whole.

A QUANTITATIVE FLAME SPECTROGRAPHIC METHOD FOR PLANT MATERIAL

F. H. VANSTONE

East Malling Research Station, Kent, England

A flame spectrographic method has been evolved for the analysis of plant material. The method is simple, rapid, requires no chemical treatment of the sample and the sensitivity is such that up to 10 elements can be determined on a sample of 50 mg. or less.

Twenty silica micro-crucibles containing the dry powdered samples are held in a silica crucible carrier 18cm. × 3½cm. so that a batch of 100 samples can be ashed in a quite small muffle furnace. The ashing is normally carried out overnight at a temperature of 420-440°C.

For reasons to be indicated later, 19 mg. cellulose powder, containing definite amounts of certain elements used as "internal standards," is added to the crucible containing the ash, which weighs only 2–4 mg. and the two are mixed thoroughly in the crucible with the aid of a small platinum spade.

With the aid of suitably designed apparatus, made of perspex, cellophane tubes 1 cm. long and 2½ mm. in diameter are made from 2 rolls of cellophane tape, one of which has an adhesive coating. The mixed powder is pressed into 4½ mm. length of the cellophane tube, housed in a perspex pressing mould, the remainder of the tube being filled with pure cellulose powder. During these operations neither the sample nor the cellophane tube is touched by hand. A perspex "magazine," which carries 10 filled tubes is placed in position in a "feeder mechanism" and the ten tubes are fed automatically, at intervals of 20 seconds into an oxy-acetylene flame. The light from the flame is taken into a medium spectrograph and an exposure, automatically controlled, of 7 seconds, is given for each sample. The operator only has to move the photographic plate between exposures.

Spectra so produced normally contain lines due to the elements Ca, Sr, Mg, Li, Na, K, Rb, Fe, Mn, and Cu in addition to those due to the internal standard powder.

A neutral stepped filter immediately in front of the spectrograph slit results in "stepped" spectrum lines. The densities of an element line and its internal standard line on suitable steps are compared and by reference to a standard graph the concentration of the element is determined.

Only the elements Ca, Mg, K, Fe, Mn and Cu have thus far been studies quantitatively. Pb has been used as the internal standard element for Mn, Fe and Mg; Cd for K and Cu and Ba for Ca.

Ba has been quite satisfactory for Ca; as has Cd for K and Cu; Pb has not been entirely satisfactory for Mn and Fe and has been even less satisfactory for Mg.

For Mg the accuracy has been of the order of ±15% and for the other elements better than ±5%.

Interference effects of Si and P have been the source of serious trouble in the past; but the only serious interference in this method at present is that of Si on Ca, Mg, Fe and Mn and it is in this connection that Pb has proved to be unsatisfactory. As SiO_2 is increased the above 4 elements are increasingly suppressed; now Ba and Ca are

similarly affected and so Ba is quite suitable as the comparison element for Ca ; but Pb is not suppressed as SIO_2 is increased and so cannot be said to be satisfactory as the comparison element for Mg, Fe and Mn.

Further work, with a view to using a smaller sample, and finding more suitable comparison elements, should make this interference effect negligible.

In spite of the above limitation the method has been used successfully for the analysis of a few thousand individual leaves of rooted apple shoots in their second year, grown under controlled nutrient conditions, with particular reference to K, Fe and Mn.

Samples have been taken at three weekly intervals throughout the growing season and the concentration of each of these 3 elements has been plotted for each leaf position from base to tip of the growing shoot.

From the graphs produced the following general points have emerged :—

1. The shape of the graph for a given element and given nutrient condition can vary considerably during the growing season, e.g., early in the season for trees growing with no Fe in the nutrient solution, the Mn *decreased* progressively from base to tip ; late in the season it *increased* from base to tip.

2. For a number of " trees " growing with one element completely withheld from the nutrient solution, the shape of the graph at any time for that element is similar for the different trees. The absolute values, however, at any given leaf position were smaller for small trees that made much growth and larger for large trees that made little growth.

3. These results raise the question as to whether the best diagnosis would not be obtained by considering the change of composition of comparable leaves with time or by a study of the relative composition of successive leaves on the shoot.

If the sensitivity of the method had been so low as to necessitate analysing together either similar leaves of different plants, or a number of leaves from one plant, most of the effects observed on single leaves would have been masked.

REFERENCES

VANSTONE, F. H. and PHILCOX, H. J. : A flame method of spectrographic analysis. *Rep. E. Malling Res. Sta.*, 105–10 (1949).

VANSTONE, F. H. and PHILCOX, H. J. : A quantitative method of flame spectrographic analysis. *Rep. E. Malling Res. Sta.*, 122–25 (1951).

Section C

SESSIONS 9 TO 11

SESSION 9

SURVEY METHODS EVALUATING FERTILITY LEVELS

25th July. Chairman : H. KURON (Federal Republic of Germany)

W. L. NELSON and C. D. WELCH. The Broad Utilization of Soil Test Information through Summaries (Volume I, page 245)

H. RIEHM. Bodenuntersuchungen in Deutschland und ihre Bedeutung für die praktische Landwirtschaft (Volume I, page 261)

L. DE LEENHEER, L. MAES, M. VAN RUYMBEKE. La Détermination de la Valeur relative de quelques Types de Sol d'une Même Région (Volume I, page 274)

SESSIONAL DISCUSSION

E. M. CROWTHER : Dr. NELSON has shown how a large number of rapid analyses can be grouped by districts, farming systems, past cropping, proposed cropping, etc., to bring out general rules for guiding farmers, advisory officers, research workers, and fertilizer manufacturers. As this kind of work is continued the generalisations may become so well established that it may be possible to reduce the number of analyses required (perhaps by charging more for them). I suppose that at the present time Dr. NELSON and his colleagues could already make good guesses about the analytical results from the descriptions sent with the samples. Does Dr. NELSON expect to be able in time to reduce the number of analyses needed each year ? A second question is " How far have the reliability and limits for various analytical methods been checked and adjusted to bring them into line with the findings from series of field experiments and various crops and soils series " ?

Where it is not at present possible to arrange an elaborate system of soil analyses to cover a whole country or regions it is well worth while supplementing existing knowledge from field experiments and soil analyses by making a survey of fertilizer practice on a small sample of the farms. This method gave very valuable results in England and Wales during the War when it was essential to use restricted supplies of fertilizers to best advantage. The essential step was to collect reliable factual data in great detail from a small random selection of farms and fields using modern theories and sample surveys. Reliable and representative data from random samples are more valuable than a very large number of opinions or guesses. Dr. RIEHM has shown from millions of analyses that pastures were generally less rich than arable land in readily soluble phosphates. The survey of fertilizer practice established the same point from a few thousand fields. The survey of fertilizer practice gave the information very cheaply and quickly and showed where and how educational efforts should be intensified. The survey would, of course, be improved by suitable analytical data for the soils but it was well worth while even where it was not possible to obtain analytical data for all the farms.

Does Dr. RIEHM make any change in the conditions of extractions by the EGNÉR method where the $CaCO_3$ content exceeds a prescribed figure ? If so, would it not be better to treat the results as if they had been obtained by two independent methods and not mix them together as being comparable ?

S. HÉNIN : Le procédé d'extension propagé par le Dr. BRUIN n'est utilisable que si l'on connait touts les propriétés du sol. En effet il est possible que les terres qui sont au dessous du rendement maximum ne reçoivent pas plus d'éléments fertilisants par suite du bas niveau d'autres facteurs du rendement tel qu'un mauvais état physique.

H. L. RICHARDSON : Could Professor NELSON give any information about the correlation of his chemical soil tests with field experimental results ? The results of large numbers of the chemical tests are very impressive but without such correlation one is uncertain about their actual practical value.

H. KURON : Bei vieljährigen Untersuchungen über die Auswirkung der Bodenerosion im gemässigten Klima Deutschlands konnte die Nährstoff-Bestimmung nach EGNER-RIEHM wertvolle Hinweise geben. Geeignet ist besonders die P_2O_5, die keine Auswaschung zeigt, aber mit den Bodenkolloiden bei der Abspülung an Hängen abwandert. Zur Kennzeichnung des Erosionszustandes wurde das Verhältnis $P_n : P_0$ in % verwendet, wobei P_0 den Phosphatgehalt den Ackerkrume und P_n denjenigen des I. Dezimeters des darunters folgenden Unterbodens bedeutet. Auf erodierten Flächen liegt dieser Wert in der Grössenordnung von 30%, bei nicht erodierten Böden um 60%, bei Senkenböden mit Auschwemmungen von Krume vom Hang her steigt er bis 80%. Diese Bezie'hungen sind von Bedeutung bei gut gedüngten Böden, die in der Krume durchgehend hohe Nährstoffgehalte aufweisen, bei denem jedoch in Hanglagen mit deutlicher Schichterosion eine schroffe Abnahme des Nährstoffgehalte unter der Krume vorliegt. Zu ähnlichen Ergebnissen führten Untersuchungen des physikalischen Zustandes und des Wasserhaushaltes von erodierten und nicht erodierten Böden. Ertragsmessungen haben diese Befunde bestätigt.

T. WALSH : At the present time soil surveys are proceeding in a number of countries but as yet there does not appear to be any really standardised system for obtaining productivity ratings in connection with such surveys. It is highly important that such surveys be of immediate value where agricultural production is concerned and in this connection it is urged that more attention to the development of these ratings is necessary. One of the most important uses of soil survey is to help advisory officers in their everyday work and soil tests should as far as possible be related to soil maps. In our country we have a number of very outstanding examples of soil type effects where nutrient absorption and release, micro-nutrient availability and inactivation are concerned but unfortunately we do not have sufficient data or information about the distribution of our different soil series. In this connection also we are proceeding with considerable work on different hydrologic associations but unfortunately with one or two outstanding exceptions the hydrologic association does not appear to get sufficient recognition in modern methods of soil survey.

H. GREENE: With reference to the place of productivity ratings in soil survey to which Dr. WALSH referred it may be well to note that if the soil survey is well done it will provide within a given climatic region estimates of the water-supplying power of the soil that are not otherwise readily obtained. In many parts of the world the water-supplying power of the soil is the most important factor in determining productivity. Secondly, if the soil survey is well done it will provide information that will remain valid for 100 years whereas productivity ratings will not. Within 10 or 20 years new crops may be grown or new varieties of crops; there may be new methods of cultivation and new methods of controlling disease and pests. It would seem, therefore, that the soil surveyor should not give too much attention to assessing productivity ratings in comparison with his major task of putting on maps the information that will remain true perhaps 100 years later.

T. WALSH: I agree entirely with Dr. GREENE as to the value of soil survey properly carried out but I fail to see how productivity ratings suitably developed could not be of a relative nature and not constitute or give much more long-term information than Dr. GREENE seems to think. Surely it would be a matter for agronomists closely associated with soil surveyors to develop such productivity ratings rather than making it necessary for the surveyor to do the whole job.

E. MARSDEN: With regard to the remarks of Dr. WALSH as to the economic value of soil surveys, the original soil maps of New Zealand were fortunately of districts where the farmer could see the immediate value of the maps so much so that the practice has grown among farmers of describing their farms in terms of soil type. The maps are mainly in terms of genetic soil types with special groups or series related more or less to maturity. The fertilizer response trials were laid out on the basis of soil types and farmers themselves co-operate by visual response trials. Maps have been prepared of phosphate and lime responses. Similarly maps showing deficiencies of minor elements which are studied in relation to the basic soil maps have been made. Naturally on our pastures, particularly in the North Island, the strain of grass or clover needs to be taken into account particularly also from the economic point of view since the best responses are obtained on the better grasses. Our farmers tend to work towards optimum yields rather than maximum particularly because labour is a most important factor. In general our soil and fertilizer advisory services aim at the provision of data on which the farmer can decide on useful practices rather than an attempt to dictate to him.

A number of other speakers also contributed. The Session was brought to a close by the Chairman, who summarized the discussions.

SESSION 10

METHODS USED IN SOILS ADVISORY SERVICES

25th *July*. Chairman : W. L. NELSON (United States of America).

K. A. BONDORFF. The Evaluation of Soil Analysis (Volume I, page 290)

G. BARBIER. Application pratique de l'Analyse chimique des Terres en France (Volume I, page 296)

SESSIONAL DISCUSSION

W. KUCZAROW : Les techniques d'analyse du sol admises par les divers laboratoires des pays européens ayant été discutées au cours de la session, il nous paraît utile de signaler quelques particularités des conditions de travail relatives à l'étude de la fertilité des sols de l'Afrique Equatoriale.

Il est indispensable de préciser tout d'abord la différence fondamentale entre la tâche principale des laboratoires de pédologie des vieux pays agricoles et les problèmes posés aux laboratoires des pays neufs comme l'est le Congo Belge.

Pour autant qu'en Europe la fertilité artificielle résultant de l'apport des éléments fertilisants déficients constitue, dans la plupart des cas, le but principal de l'analyse, notre problème numéro un reste (surtout en ce qui concerne la grande culture) la détermination de la réserve naturelle du sol, l'étude de sa variation au cours des cycles culturaux et des diverses techniques de jachères.

L'extrême pauvreté de la majorité des sols du Congo en réserve minérale rend notre tâche particulièrement complexe. Cette difficulté est accrue par le fait d'une dégradation accélérée (due à l'intensité des agents climatiques) que subit le sol après l'enlèvement de la couverture forestière naturelle.

Voici, pour représenter ce que nous venons de dire, quelques chiffres d'analyse se rapportant aux sols de plateau de la station de Yangambi.

	pH el. verre	B.E. tot. HCl N/20 ME/100g.	P_2O_5 H_2SO_4 N/20 mg/100g.	P_2O_5 H_2SO_4 N/20
Sol sous couvert forestier (surface)	4·0	2·4	1·1	
même sol après incineration mars 1949 ..	5·8	21·7	14·6	
même sol après une saison de pluies novembre 1949	5·0	11·8	5·3	

L'acidité et la pauvreté du sol sous couvert forestier naturel représentées par les chiffres de ce tableau sont typiques pour la Cuvette Centrale Congolaise. L'incinération (pratique courante de la préparation du sol pour certaines cultures) enrichit superficiellement le

sol, mais déjà quelques mois après, la grande part des éléments fertilisants se trouve en partie utilisée par la végétation qui reprend, et en partie lessivée. Au bout de 3 à 4 ans, ce sol perd toute la richesse résultant de l'apport des cendres, et l'analyse n'enregistre que des valeurs similaires à celles existantes avant l'incinération.

Les pertes des bases par lessivage sont considérables. Elles sont favorisées tant par la perméabilité excessive du sol (sols généralement à dominance de sable grossier) que par la nature même du complexe adsorbant (argile kaolinitique).

La fixation des phosphates par les composés de fer est intense.

La rétention des éléments biogènes et la constitution de la réserve pour les cultures sont conditionnées surtout par la matière organique qui maintient une fertilité essentiellement superficielle, typique pour les sols de la Cuvette Congolaise.

La difficulté de l'étude systématique de l'évolution de la fertilité est accrue par l'extrême hétérogénéité des champs. Cette hétérogénéité est due tant à la technique même de la préparation du sol pour cultures (exportation partielle et irrégulière des produits d'abattage, absence du travail mécanique du sol) qu'au relief des terrains très accidenté par suite de la présence de nombreuses termitières (qui occupent par endroit jusqu'à 30% de la superficie totale).

Les poches d'accumulation formées par les excavations et les espaces entre les termitières, les emplacements des troncs d'arbres et les anciennes racines pourries créent autant de taches de fertilité disparate.

L'échantillonnage correct devient un problème particulièrement délicat. Pour que les analyses conservent leur valeur significative, le nombre de prélèvements, même dans les parcelles réduites, doit être très élevé. La prise d'échantillons ne peut être confiée qu'à un élément expérimenté.

Les faibles valeurs absolues pouvant être enregistrées pour la plupart des facteurs chimiques dans ces sols pauvres et le fait que les différences analytiques entre les champs voisinent souvent avec l'erreur normale des déterminations nous obligent à pousser les soins de précision du travail à l'extrême. Toutes les déterminations sont effectuées en double et les écarts admis entre les déterminations parallèles sont réduits au minimum. Pour les déterminations principales, chaque série est complétée par un sol témoin de richesse connue.

Voici un bref aperçu des méthodes essentielles admises pour la caractérisation des sols par le laboratoire de pédologie de l'INEAC à Yangambi :

pH : Le pH est mesuré dans la suspension dans l'eau. L'avantage de l'emploi des diverses proportions eau : sol, de lapériode de contact et de l'agitation mécanique avant la mesure, a été étudié. La mesure admise dans la pratique courante se fait à l'aide de l'électrode de verre, proportion eau : sol 2,5/1.

C : Le dosage du carbone total par combustion ne présente, pour les sols du Congo, qu'un intérêt aléatoire par suite de la présence fréquente du carbone élémentaire (charbon de bois). La comparaison des méthodes par oxydation $KMnO_4$ et par $K_2Cr_2O_7$ a montré une étroite corrélation entre les résultats. La technique de WALKLEY et BLACK (sol passé par le tamis de 0,5mm. ; $K_2Cr_2O_7N$; $FeSO_4$ 0,5N), plus facile et hautement reproductible, a été retenue.

N : Pour le dosage de l'azote total, la méthode officielle de A.O.A.C. est admise. La détermination du taux de l'azote nitrique, par suite de son extrême variabilité, ne présente d'intérêt que dans des cas spéciaux.

Capacité totale d'échange : Diverses méthodes de la détermination de la valeur T ont été comparées (acétate de Ca, Ba, NH_4). Pour des raisons d'ordre pratique, le choix s'est porté sur l'emploi de l'acétate de Ca.

Hydrogène échangeable : L'application de la technique de A. MEHLICH aux sols du Congo Belge a fourni des résultats intéressants concernant les types des sols étudiés.

Acidité hydrolitique : Est déterminée suivant la technique de KAPPEN.

Bases totales : Le procédé rapide de GEDROÏZ-SCHOFIELD permet, malgré son caractère conventionnel, un triage des sols en catégories de richesse différente. Les résultats obtenus facilitent une première cartographie des sols et servent d'indication pour une étude plus détaillée de la composition cationique. L'extraction à l'HCl N/20 est réservée pour les sols pauvres ; pour les sols à réserve en bases élevées, l'NH_4ClN/10 est employé (KELLEY).

CaO, MgO, K_2O : Sont dosés séparément dans l'extrait d'acétate d'NH_4.

CaO, MgO, K_2O, MnO_2, Fe_2O_3, Al_2O_3 : La détermination dans l'extrait d'acétate de Na (pH 4,8) suivant les techniques de PEECH a été appliquée à des milliers d'échantillons des différentes régions du Congo Belge. Ces techniques rapides fournissent, dans de nombreux cas, des renseignements orientatifs intéressants.

P_2O_5 : Le phosphore est dosé dans l'extrait de H_2SO_4 N/20 (rapport sol/extr. 1 : 5, extraction 3 heures). La méthode de TRUOG H_2SO_4 0,002N (rapport sol/extr. 1 : 200, extraction 30 minutes) trouve l'application dans de nombreux cas, mais donne des résultats nuls dans certains types de sols à rétention de phosphore très forte.

Les méthodes signalées constituent les techniques essentielles appliquées sur une grande échelle pour l'analyse courante des sols. Le groupe de recherches pédologiques de l'Institut (sections de microbiologie, de physico-chimie et de minéralogie) complète l'analyse par des déterminations spéciales (cations par la voie microbiologique, fer mobile, sels solubles, etc. . . .).

Notons que, vu l'importance particulière des facteurs d'ordre physique pour les sols tropicaux (rétention d'eau, structure), l'analyse chimique doit être précédée, dans la plupart des cas, par la détermination de la texture, de la porosité et de la rétention d'eau.

Le laboratoire de l'INEAC à Yangambi analyse annuellement environ 5.000 échantillons de sols, tant pour la cartographie que pour les études agronomiques diverses.

Le laboratoire de la station de Mulungu (Kivu) est chargé de l'étude des sols de l'Est de la Colonie.

Summary

The systematic study of the fertility of most of the soils in the Belgian Congo is particularly difficult owing to their poor condition.

The extraordinary heterogeneity of the fields renders soil sampling very complicated.

The text presented gives some indications concerning the chemical analyses tried and accepted at the Pedologic Laboratories of INEAC at Yangambi.

H. ROSEAU: En Afrique du Nord, il existe deux types de cultures:—

(*a*) les cultures irriguées, dans lesquelles les techniques de fertilisation mises au point dans les régions tempérées humides peuvent être transposées.

(*b*) les cultures dites en terre sèche qui ne bénéficient que de l'eau de pluie.

Notre climat est très capricieux au point de vue pluie. Il suffit de quelques millimètres d'eau au moment opportun pour provoquer une belle récolte céréalière.

De telle sorte que l'élément essentiel sous notre climat est le facteur humidité du sol. Il vient en tête, bien avant les éléments azote, acide phosphorique, potasse, etc. Aussi a-t-on tendance à s'intéresser beaucoup moins à la fertilisation. On se préoccupe surtout par des travaux du sol à emmagasiner le plus d'humidité pour la plante qui viendra ensuite.

De telle sorte que le problème de la fertilisation du sol sous notre climat est un problème très délicat. Il doit retenir l'attention de nos Commissions II et IV. Aussi je me permets d'appuyer fortement la motion présentée aujourd'-hui de réunions ultérieures de ces Commissions dans les trois zones climatiques :—

I Atlantique
II Méditerranéenne
III Tropicale et Subtropicale

SOIL FERTILITY EVALUATION IN BELGIUM

A. VAN DEN HENDE AND A. COTTENIE

State Agricultural University, Ghent, Belgium

The routine soil fertility evaluation with advisory purposes in Belgium has been centralised for fifteen years under the Belgian Pedological Service. Besides this service some private laboratories also effectuate chemical soil analyses while another is doing more theoretical research on soil testing methods and their interpretation.

I. *Activity of the Belgian Pedologic Service*

The soil samples sent to this service are taken by a number of recognised samplers all over the country, who are at the same time the propagandists and the links between the laboratory and the farmers. The methods used in the Belgian official soil testing service have been studied by J. BAEYENS (1) and are based upon the soil extraction with Ca-Lactate as proposed by EGNÉR.

The complete soil analysis consists in the determination of:

—pH (measured in water)
—available phosphate
—available potash
—humus content
—nitrogen content
—ratio C/N

The basic work of this laboratory during the first years of its activity was to find reliable fertility norms for each important soil type. These critical norms are, in fact, empirical values, based upon a large number of analyses and field experiments, which should make it possible in each region, to distinguish the status low, medium and high.

The soil sample addressed to the laboratory is accompanied by an information bulletin, in which the farmer has to answer a number of 15 questions concerning his soil and the preceding and following crops on the sampled parcels.

As a result the farmer receives the analytical figures, accompanied by an appreciation and an advice for manuring. This indicates an approximate quantity of lime, P_2O_5 and K_2O units required per ha. This form also contains often a general conclusion giving directions for the following years. In order to make the analysis as profitable as possible, the farmer is invited to consult also the local agricultural advisors if necessary.

II. *Activity of private soil testing services*

During the first years after the second world war, some private organisations, following the practice of "quick soil testing" as used in a large extent in America, tried to apply this technique also in Belgium. Different factors have caused the failure of this tendancy: the existing of a central service, the non-reliability of the quick methods when executed by non-qualified persons, etc.

—A private soil testing service was organised by the Sucrerie Tirlemontoise, aiming at the analysis of the soils of farms cultivating sugar-beets. The determinations effectuated by its laboratory are:

—pH in water
—lime requirement: determined by titration with NaOH of the hydrolitic acidity
—phosphate requirement: determined by the Ca-Lactate method of EGNÉR
—potassium requirement: determined by the quick method of MORGAN-BARBIER: Nephelometric determination of K_2O
—organic matter content determined as per TIURIN-ANNE (wet oxydation with $K_2Cr_2O_7$)
—microscopic control of the infection-rate with beet-nematode.

—Another example of a local soil testing organisation is the activity of the Agricultural School of Ath, doing soil analyses for the benefit of the farmers of the environment.

III. *Research work on soil testing methods*

With regard to the diversity existing between the classical and more modern chemical soil testing methods available, it has been felt as a necessity to determine the most interesting methods of analysis for Belgian soils.

In July, 1950, the 8th International Congress of Agricultural Industries in Brussels adopted the following amendment: " that a progressive unification of analytical methods for the chemical determination of nutrient elements in soils should be aimed at " and also that the fertilizer need should be determined in function of the specific soil types.

The Agricultural Centre for Applied Physical Chemistry created by the I.R.S.I.A. has undertaken to work out a basis for realising this aim in Belgium. Some results of this study have already been published (2), (3), (4). Its working programme consists in the following points:

(1) the judicious choice of an appropriate extracting solution

(2) the standardisation of the extracting technique

(3) the description of analytical methods, both quick and exact, of a sufficient number of nutritive elements in the extracts

(4) the evaluation of a key to the interpretation of the analytical data obtained on different soil types.

Its general working technique has been exposed in another communication (4) and reckons with the following facts:

(1) the chemical determination of a sufficient number of nutritive elements in a single soil extract must be possible. This means that the extracting solution should realise the analytical possibility required for an accurate analysis. In this way the choice of Ca-Lactate, as applied in Belgium, seems less favourable, because it excludes an eventual determination of Ca;

(2) the extracting solution should also be satisfactory from an agricultural point of view. This means that it should make it possible to find the highest possible differences between soils, being from the same type, rich or poor in a certain element;

(3) the extracting solution should finally respond to some biological criteria: it must make it possible to find an undoubted correlation between the determined soil-status and the production.

As many research workers formerly have tried, without any result, to determine the "available quantity of plant nutrients," there is need to establish the parallelism between the extracted quantity of nutrients and those which will be delivered during the growth.

We mean that the chemical analysis being done at the laboratory, the interpretation of the analytical results and the elaboration of a manuring formula should be committed to local agricultural advisors, especially prepared and selected for this charge.

Summary

—In Belgium, routine chemical soil analysis with diagnostic purpose is effectuated by the central laboratory of the Belgian Pedological Service, at Louvain. The method in use is the Ca-Lactate method of EGNÉR.

—Besides this service some private laboratories, such as the Agricultural Service of the Sucrerie Tirlemontoise and the Agricultural School of Ath, also effectuate chemical soil analyses for the benefit of the farmers of the environment.

—Research on chemical methods is done by the Agricultural Centre for Applied Physical Chemistry, in Ghent. Its aim is to find the most appropriate technique for Belgian soils and to work out a basis for more unification between the methods in use in the country.

LITERATURE

(1) BAEYENS, J. La signification des normes chimiques du besoin en engrais des sols agricoles. VIIIe Congrès Int. des Industr. Agric. (Bruxelles 1950) **I**.

(2) VAN DEN HENDE, A. La valeur des méthodes chimiques pour la recherche du besoin en acide phosphorique des sols belges. Fourth Int. Congr. Soil Sci. (Amsterdam, 1950), Trans. **I**.

(3) VAN DEN HENDE, A. Onderzoek over nieuwe methoden voor de bepaling van de deficientie aan voedende elementen in de bouwlaag. VIIIe Congrès Int. des Industr. Agric. (Bruxelles, 1950), **II**.

(4) VAN DEN HENDE, A. and COTTENIE, A. Les équilibres nutritifs dans le sol et leur rapport avec l'analyse chimique de la plante et du sol. *Revue de l'Agriculture*, **5**, 1 (1952).

(5) VAN DEN HENDE, A., COTTENIE, A. and DE JONGHE, P. The value of some methods for chemical soil analysis applied to different Belgian soil types. Int. Soil Fertility Meeting (Dublin, 1952), Trans. **II**.

THE VALUE OF SOME METHODS FOR CHEMICAL SOIL ANALYSIS APPLIED TO DIFFERENT BELGIAN SOIL TYPES

A. VAN DEN HENDE, A. COTTENIE, P. DE JONGHE

State Agricultural University, Ghent, Belgium

In 1949 the Belgian Institute for Scientific Research in Industry and Agriculture (I.R.S.I.A.) created an Agricultural Centre for Applied Physical Chemistry, entrusted with the study of an appropriate method to determine the nutritive elements in the Belgian soils. The working out of a chemical method for soil analysis consists in the following points :

(1) the judicious choice of an appropriate extracting solution,

(2) the standardisation of the extracting technique,

(3) the description of analytical methods, both quick and exact, of a sufficient number of nutritive elements in the extracts,

(4) the evaluation of a key to the interpretation of the analytical data obtained on different soil types.

In a general way our research method is as follows : a limited number of experimental fields is systematically followed by the determination of the mineral equilibria in the soil as well as the quantitative and qualitative production of crops. These fields are situated on representative soil types and consist of different parcels submitted to one-sided treatments, repeated for several years, such as : no fertilizers, N-treatment, NP, NK, NPK, etc., eventually repeated on limed parcels. In this way we obtain different artificial deficiencies or non-equilibrated nutrient conditions. After one or more years the different parcels are bought into a nutritional status more or less stabilised in the known sense, and which can be characterized by crop growth and soil analysis. It is to be expected that a great number of soils of the same soil type, submitted to a chemical analysis for diagnostic purpose, will correspond with one of the artificially created situations. Our method makes it possible to study the following facts :

(1) The period after which a non-equilibrated nutrient application will be reflected by quantitative crop production, and the intensity of the influence on the production.

As the parcels are grown in a normal rotation, this will be known for each crop normally cultivated on the same soil type.

(2) The period after which a non-equilibrated nutrient application will be reflected in crop quality, characterised by chemical analysis. This has already enabled us to distinguish plants, of which the chemical composition was less influenced than others : we called them more rigid and more flexible varieties.

(3) The period after which a non-equilibrated nutrient application will be detected by chemical soil analysis and the intensity with which different methods show the different nutritional conditions.

In this way we can easily compare the sensibility, the reproducibility and the reliability of different methods for soil analysis.

(4) The correlation existing between fertilizer application, plant quality and production, and chemical soil characterization by different methods.

In this communication we will only expose a few results obtained in application of our general method, on some representative Belgian sandy, loamy and clay-soils: the fields were treated in the indicated way, respectively since 1951 (Lokeren), 1939 (Melle), 1950 (Proven) and 1923 (Stabroek).

Extracting solution

Table 1 shows the results obtained in 1950 by extracting the soil samples of 2 long-term experimental fields with the following extracting solutions:

not buffered { HCl 1 : 1 ; 1% Citric acid ; H_2O

buffered { Ca-Lactate ; Na-Acetate ; Am-Acetate

This comparison shows that strong acids are of no interest for diagnostic purposes and that citric acid and water also are unsatisfactory. The buffered solutions seem to be preferable: both Ca Lactate and the buffered acetates reflected truly the phosphate status of the soil, while only the buffered acetates enabled at the same time satisfactory determinations of a larger range of elements.

Considering these results we mean that the most ideal extracting liquid should realise the following conditions:

(1) be buffered at a pH between 4 and 4·8,

(2) permit a quick determination of a large number of nutrient elements,

(3) not contain any element for which determination in the soil sample is required. For this reason a buffered Na-Acetate solution would be preferable upon the Ca-Lactate extraction, because the Ca determination may be useful in some cases, and is undoubtedly more important than the determination of Na.

It is to be expected that the most satisfying liquid should contain an ion able to replace the adsorbed nutritive elements as quantitatively as possible, in order to give at the same time an indication about the total quantity of adsorbed elements.

The extractions with buffered Na-and Ammonium Acetates have given very interesting results. But we mean that a solution of buffered Ba-Acetate would realise the given conditions most completely. In fact, Ba is not to be determined in soils and has a strong replacing power, while the determination of the remaining Ba concentration, after extraction, could eventually give some indications concerning the total adsorption capacity of the soil. Our experience, however, has shown that the presence of a relatively large quantity of Ba-ions in the extracts is an unfavourable condition to the analytical determination of the nutrient elements; till now we found that the elimination of Ba, necessitating time-taking chemical manipulations, proved to be necessary.

In 1951 we continued the comparison of the soil extraction with buffered solutions on two fields existing for more than 12 years (M and S) and on two new fields (L and P) existing one year.

Table I

Soil analysis on long-time fertilizer experiments M and S

Soil	Treatment	Probable deficiency	mg. P_2O_5 per 100 g. soil extracted by						mg. K_2O per 100 g. soil extracted by			mg. CaO per 100 g. soil extracted	
			HCl 1 : 1	1% H_3Ci	H_2O	Ca-Lact.	Na Ac N/1	NH_4Ac N/1	HCl 1 : 1	NaAc N/1	NH_4Ac N/1	NaAc N/1	NH_4AcN
Loam (Melle) 1949	T	NPKCa	114†	25·3†	0·5*	20*	0·22*	1·52*		3·1†	6·3†	172	202
	NPKCa	—	122	29·3	3·3	27	0·96	2·76		4·6	8·5	189	256
	PKCa	N	109	32·6	4·6	24·7	0·92	4·04		4·8	8·7	190	218
	NKCa	P	96	25·3*	1·8*	18*	0·26*	1·64*		4·6	8·4	166	—
	NPCa	K	119	38·5	3·5	25·5	1·54	4·52		2·1†	5·1†	200	262
	NPK	Ca	110	31·0	3·7	24·5	1·21	4·16		4·4	8·0	188	228
	NPKCaMg	—	119	27·5	2·3	31·5	0·91	4·50		3·7	7·4	172	218
Clay (Stabroek) 1950	T	NPK	75·70*	33·67*	1·17*	39·50*	2·67*	1·60*	250†	1·50†	7·63†	355	473
	NK	P	103·70*	33·67*	1·17*	45·50*	2·50*	2·00*	285	1·63	10·43	381	511
	NP	K	112·40	44·83	1·33	44·83	4·50	3·50	250†	1·23†	6·70†	323	424
	PK	N	100·00	55·17	1·57	46·50	5·07	4·77	287	2·40	11·67	342	464
	NPK	—	86·60	57·58	2·15	47·67	4·35	4·12	281	2·02	9·48	344	463

*Indices corresponding with phosphate deficient parcels.

†Indices corresponding with potassium deficient parcels.

TABLE 2

Chemical soil analysis

A. Fields existing since:

—1939—Sand-loam (M) (Grass association) { pH H_2O = 6·37 / pH KCl = 4·93

	Mean quantity found in parcels	Extracting solutions						Relative production in 1951
		Ca-Lact.		Na-Acet.		NH_4-Acet.		
		mg./100g. soil	%	mg./100g. soil	%	mg./100g. soil	%	
P_2O_5	treated	7·05	100	2·06	100	2·43	100	100%
	not treated	2·16	30·64	0·38	18·45	0·35	14·40	72·6
K_2O	treated			2·87	100	5·55	100	100%
	not treated			2·20	76·65	4·06	73·15	52·3
CaO	treated			220·90	100	231·70	100	100%
	not treated			175·8	79·58	184·80	79·76	83·6
MgO	treated			26·76	100	29·06	100	100
	not treated			4·51	16·85	3·95	13·59	82·2
N	treated							100
	not treated							53·3

—1923—Clay (S) (Oats) { pH H_2O = 7·53 / pH KCl = 6·48

P_2O_5	treated	35·71	100	2,99	100	3·43	100	100
	not treated	24·15	67·63	1·49	49·83	2·34	68·22	103·4
K_2O	treated			3·79	100	9·78	100	100
	not treated			2·30	60·69	6·56	67·07	85·1
N	treated							100
	not treated							52·7

Table 2b

Chemical soil analysis

B. Fields existing since:

—1951—Sand (L) (Grass) { pH H_2O = 4·45 / pH KCl = 3·71

	Mean quantity found in parcels	Extracting solutions						Relative production in 1951
		Ca-Lact.		Na-Acet.		NH_4-Acet.		
		mg./100 g. soil	%	mg./100 g. soil	%	mg./100 g. soil	%	
P_2O_5 ..	treated			2·49	100	3·78	100	100%
	not treated			2·22	89·16	3·53	93·39	88·2
K_2O	treated			4·90	100	6·49	100	100%
	not treated			3·55	72·45	5·04	77·66	80·3
CaO	treated			78·87	100	66·37	100	100%
	not treated			25·58	32·43	18·00	27·12	77·9

—1950—Loam (P) (Barley) { pH H_2O = 6·72 / pH KCl = 6·12

P_2O_5	treated			7·27	100	9·92	100	100%
	not treated			5·57	76·62	8·51	85·79	90
K_2O	treated			12·28	100	20·71	100	100%
	not treated			8·47	68·97	15·17	73·25	86
CaO	treated			358·50	100	368·00	100	100%
	not treated			287·00	80·05	302·80	82·28	96
MgO	treated			9·12	100	9·16	100	100%
	not treated			7·51	82·35	7·31	79·80	84

The results are brought into Table 2 and permit the following conclusions:

—the chemical analysis by means of the three buffered solutions has permitted the revelation of a pronounced difference between the non-deficient and deficient parcels;

—the chemical indices concerning the phosphate status reveal a much greater impoverishment after a long-term one-sided treatment than after only one year of non-equilibrated fertilization;

—the chemical indices concerning the potash status indicate a very similar degree of deficiency in both long-term and

short-term experiences. Nevertheless, in the studied cases, the production has been influenced more by the K_2O-deficiency than by the P_2O_5-deficiency;

—the sensibility of soil extraction by buffered acetates was such that a significant difference was found even after one year of different one-sided treatments.

Extracting technique

As the use of a buffered solution of Na-Acetate was introduced by M. F. MORGAN (1) and M. PEECH (2) using different proportions soil : solution and different contact times, we have compared the following extractions with Na-Acetate (pH 4·8) and Amm-Acetate (pH 4·5) :

—relation soil/solution = 1/10 and 1/2

—contact soil/solution = 5 minutes hand shaking
30 minutes mechanical shaking

1. *Influence of ratio soil/solution*

The samples from the long-term fertilizer experiment M (sand-loam) were extracted with both Na- and Am-Acetate, using two extreme quantity ratios 1 : 2 and 1 : 10. The extracts were prepared by a 30 minutes mechanical shaking of the suspension. The analytical results are represented in Figures 1 and 2. As we see, both extracting ratios show a relatively large difference between the deficient and non-deficient parcels. The phosphate quantities extracted by both Acetates were nearly equal; Am-Acetate extracted a considerably higher quantity of potassium than Na-Acetate, but the relative differences found between deficient and non-deficient parcels were similar. Using a soil/solution ratio 1 : 10 a higher absolute quantity of nutritive elements is extracted per 100 g. of soil than at the ratio 1 : 2. However, if we consider the real concentration in the extracts, they are found to be higher with a ratio 1 : 2.

Figure 1 shows also a P_2O_5 determination by the classical extraction with Ca-Lactate at a ratio 1 : 50. Although the quantity of P_2O_5 extracted from 100 g. soil by Ca-Lactate is much higher than after Acetate-extraction, the concentrations of phosphate to determine in the extracts are meanly 5 times lower with lactate.

Table 3 gives a summarised review of the mean quantities found in the deficient and non-deficient parcels.

These facts brought us to the conclusion :

—that it is preferable to make the extraction with a soil-solution ratio as high as possible, for instance 1 : 2, in view of the higher analytical accuracy in analysing solutions with higher concentrations;

—that the range of the quantity of nutrient elements extracted from 100 g. of soil is more influenced by the ratio soil : solution than by the contact time. Therefore, it may be recommended to give the results of chemical soil analysis in concentration figures in the extracts, rather than in quantities extracted from 100 g. soil.

FIG 1. P_2O_5 DETERMINATION.

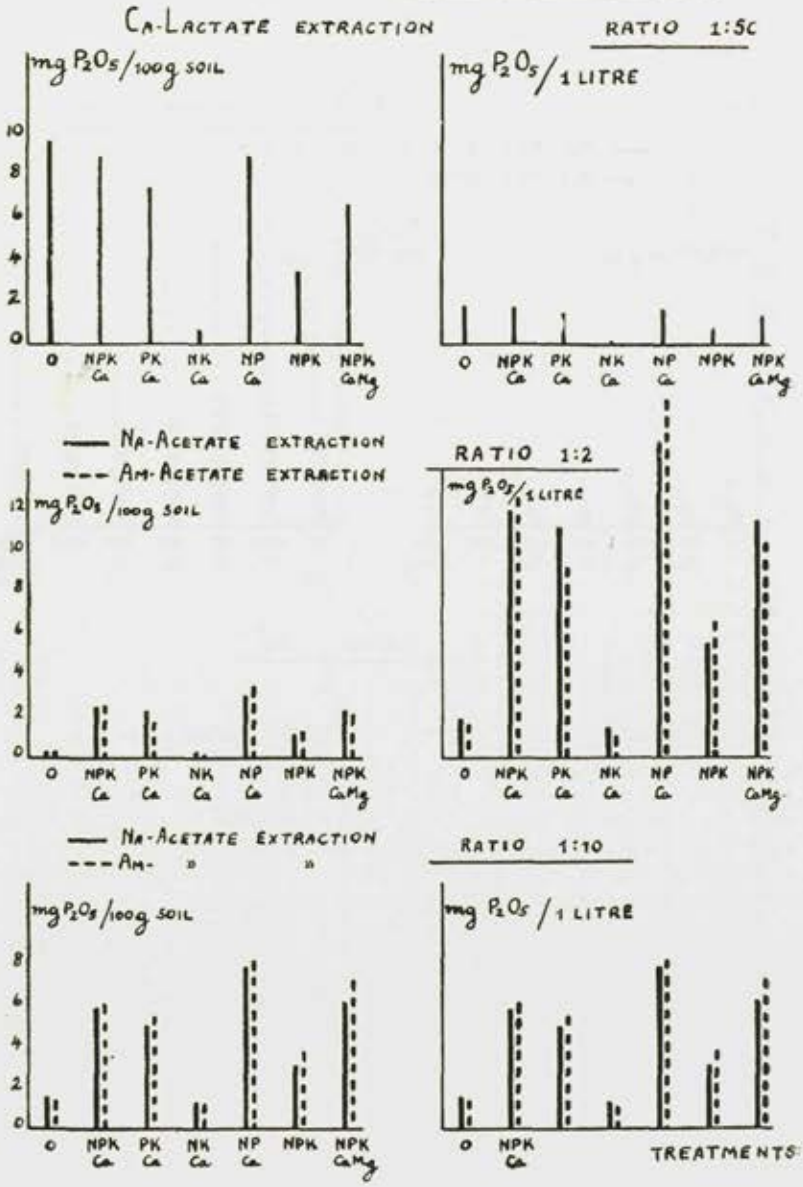


FIG 2. K_2O DETERMINATION.

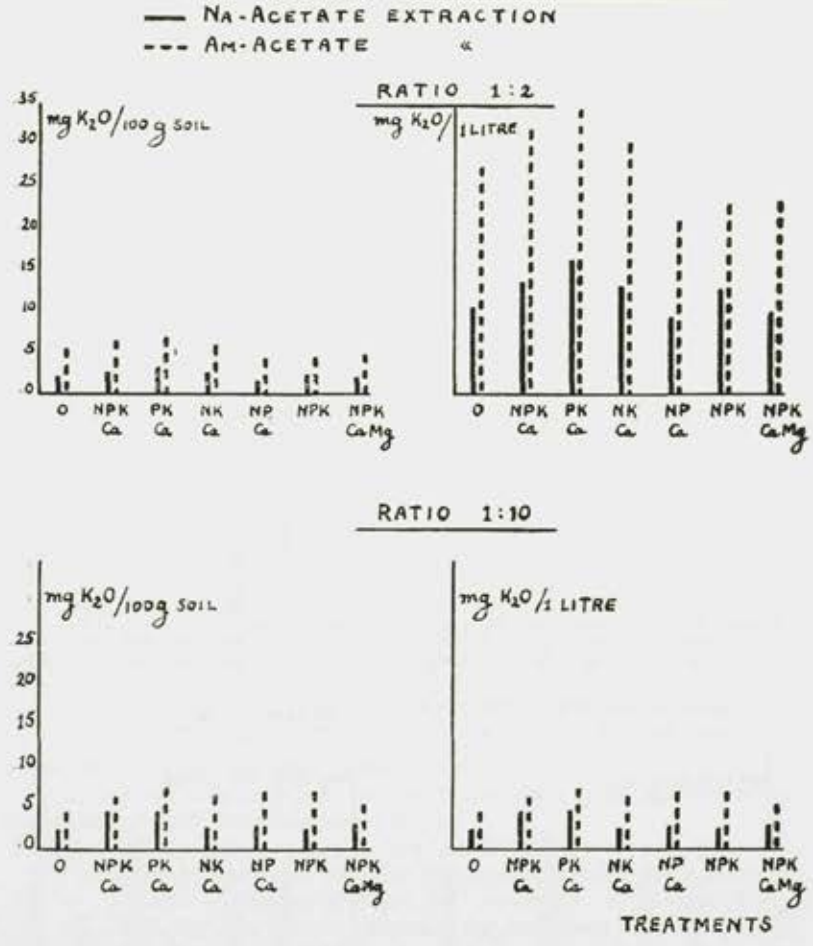


TABLE 3

	Mean quantity found in parcels	Extraction with: Ca-Lactate ratio 1/50		Na-Acetate				Am-Acetate			
		dpm	mg. extr. from 100 g. soil	ratio 1/2		ratio 1/10		ratio 1/2		ratio 1/10	
				dpm	mg. extr. from 100g. soil	dpm	mg. extr. from 100g. soil	dpm	mg. extr. from 100g. soil	dpm	mg. extr. from 100g. soil
P_2O_5	treated	1·43	7·15	11·15	2·23	5·63	5·63	11·25	2·25	6·18	6·18
	not treated	1·05	5·25	1·65	0·35	1·42	1·42	1·30	0·26	1·27	1·27
K_2O	treated			13·10	2·62	3·44	3·44	28·70	5·74	6·52	6·52
	not treated			9·9c	1·98	2·50	2·50	22·25	4·85	5·80	5·80
CaO	treated			1120	224	274	274	1215	243	274	274
	not treated			982·5	169·5	242·5	242·5	1100	220	250	250
MgO	treated			200	40	39·5	39·5	172·5	34·5	28·4	28·4
	not treated			35·10	7·02	5·72	5·72	29·85	5·97	4·38	4·38

TABLE 4

Extracting technique

Treatment	1. *Extraction with buffered Na-Acetate* (1 : 2)								2. *Extraction with buffered Am-Acetate*							
	30 minutes mechanical shaking				5 minutes hand shaking				30 minutes mechanical shaking				5 minutes hand shaking			
	mg. per 100 g. soil extracted				mg. per 100 g. soil extracted				mg. per 100 g. soil extracted				mg. per 100 g. soil extracted			
	P_2O_5	K_2O	CaO	MgO	P_2O_5	K_2O	CaO	MgO	P_2O_5	K_2O	CaO	MgO	P_2O_5	K_2O	CaO	MgO
none	0·38	2·12	209	10·5	0·26	1·48	155	6·52	0·32	5·5	235	9·7	0·29	4·6	212	8·8
NPKCa ...	2·41	2·76	249	6·9	1·53	2·16	188	4·6	2·52	6·4	264	6 0	2·48	4·3	202	2·6
PKCa ...	2·24	3·24	238	7·9	1·49	3·04	198	5·9	1·85	6·9	252	7·8	1·64	5·3	206	4·2
NKCa	0·29	2·60	193	5·7	0·22	2·12	113	3·4	0·21	6·1	219	4·2	0·22	4·8	175	3·2
NPCa ...	3·09	1·84	238	5·9	2·80	1·20	182	4·1	3·47	4·2	252	4·9	3·01	2·9	208	3·0
NPK ...	1·10	2·52	184	5·2	0·78	1·72	154	4·1	1·32	4·6	206	3·2	0·95	3·0	130	1·8
NPKCaMg ...	2·33	2·00	202	40·6	1·85	1·04	120	20·7	2·10	4·7	230	34·5	1·91	2·7	134	20·0
mean quantity found on :																
—deficient parcels ...	0·33	1·98	196·5	7·02	0·24	1·34	154·5	4·77	0·26	4·35	220	5·97	0·25	3·75	171	3·93
—non-def. parcels ...	2·23	2·62	224	40·00	1·69	2·02	160	20·7	2·52	5·74	243	34·50	2·00	4·02	185	20·0

2. Influence of the contact-time and method of shaking

Another comparison consisted in extracting soil samples during 5 minutes and 30 minutes shaking. Table 4 shows the results obtained in these conditions, with Na and Am-Acetates and with a relation soil : solution = 1 : 2. The samples were also taken from the parcels of the long-term fertilizer experiment M on sandy-loam. We can conclude that both techniques permit easily the making of a discrimination between the parcels having received no more Phosphate, Potassium, Calcium or Magnesium treatment and the others. Although there is generally a less quantity extracted in a 5-minutes contact, the mean difference found between the deficient and non-deficient parcels are in the same range. As we see, the quantities of elements extracted from 100 g. of soil, are greatly influenced by the extracting ratio, and much less by the time of contact between soil and solution.

Summary

Working out an appropriate method for the determination of the nutritive elements in Belgian soils, the authors have compared different extracting solutions and techniques.

As a result the buffered solutions of Sodium- and Ammonium-Acetate are found to be most adequate, whereas strong acids and non-buffered solutions were not satisfactory.

Concerning the extracting technique it has been found that the contact-time and the method of shaking do not seem to be of great importance for making a discrimination between deficient and non-deficient soils. However, the quantity of elements extracted from the soil, depends in a certain extent upon these factors.

They recommend that the ratio soil : solution should be as high as possible. When applying a lower ratio, greater quantities of nutrient elements are extracted per 100 g. of soil, but the concentration of these elements in the extract remains lower.

LITERATURE

(1) MORGAN, M. F. Chemical Soil Diagnosis by the Universal Soil Testing System. Connect. Agric. Exp. Sta. Bull. 450 (1941).

(2) PEECH M. and ENGLISH, L. Rapid Microchemical Soil Tests. *Soil Sci.*, **57.** 167 (1944).

(3) LEMMERMAN, O. Methoden für die Untersuchung des Bodens. Teil I, Verl. Chemie, 58 (1932).

LABORATORY METHODS FOR DETERMINING SOIL FERTILITY

S. TOVBORG JENSEN

The Royal Agricultural and Veterinary College, Copenhagen, Denmark

Chemical soil analyses are now widely used in advisory work for agriculture. The purpose of such advice is, from the analytical data, to tell the farmer how, and to what extent, crops will respond to fertilizers when applied to the soil in question, at the same time telling him whether such an application will be economically feasible.

Information of that kind is usually obtained from field experiments, which, when correctly planned and carried through, give the increase in crop yield per weight unit of fertilizer under the given conditions. Thus the farmer receives a direct answer to his question and the field experiments to that extent answer their purpose.

Such experiments, however, are of long duration, tedious and by no means cheap. Therefore, it is only natural that new and easier methods have been sought, methods that are less expensive and require less work. Among such methods, chemical analyses of soil samples are by far the most common.

By the analyses an attempt is made to find some sort of a figure supposed to express the soil's ability to furnish crops with the necessary quantities of mineral nutrients during the growth period, particularly such nutrients containing nitrogen, potash and phosphorus, in some cases also trace elements, such as manganese, copper, boron, zinc and others.

In the literature on the subject, a great number of such methods have been described, methods which in a more or less perfect way fulfil the above-named requirements. They are all dissolving methods of one kind or another, recognizing the fact that plants take up their supply of minerals in a liquid state dissolved in the soil solution. This is not the place to give a detailed description of all the different analytical methods. We shall only try to make a few principal statements and discuss the possibilities for their application in practical agriculture.

Important for deriving benefit from chemical soil analyses are the following points: (1) The analytical method used must be reliable and give reproducible results when applied to the same soil. (2) Soil samples must be drawn in sufficient number and so distributed that they are representative for the area to be investigated. (3) There must always be kept in mind what the analytical data really express, what conclusions they will and what conclusions they will not justify. The latter, so far, in many cases, seem to have been overlooked.

In this account we shall only consider the three "main nutrients," nitrogen, potassium and phosphorus, the trace elements being discussed elsewhere at this conference.

Nitrogen

Most of the nitrogen in soil is present in organic compounds as a constituent of humus and plant residues. In a cool temperate climate, mineral soils usually contain 2–3 per cent. organic matter and 0·10–0·15 per cent. N.

This, in the upper 20 cm. (plough share), corresponds to 2–3 tons N per ha., enough to satisfy the crops normal requirements for a great many years. From practical experience and from numerous field experiments, it is well known that application of only 100 kg. $Ca(NO_3)_2$ per ha., with less than 1 per cent. of the soil's nitrogen content, in nearly all cases stimulates crop development very considerably.

This, as we all know, is because the soil itself, in spite of its large nitrogen content, is not able, during the growth period, to release available nitrogen, i.e., ammonium salts or nitrates, in the q uantities necessary for full crop production.

Ammonium salts and nitrates are steadily produced in soils by mineralization of nitrogenous organic compounds from humus and plant residues. If the rate of this mineralization during the growing period is slower than the normal rate of uptake by crops, the supply of available nitrogen will be insufficient and the common indications of nitrogen starvation will appear.

The rate of mineralization for well decomposed humus is usually rather slow. By analysing an uncropped soil over 30 years, it was found that release of nitrogen from humus amounted to about 30 kg. annually per ha. (Rothamsted). This is normally not enough to meet the requirements of ordinary crops. (Nitrates produced in the autumn when the crops have been removed will leach out before the following spring and be useless to summer crops.)

Plant residues, green manure and stable manure will decompose much more rapidly than humus. If the organic material in the decomposing substance contains enough nitrogen (about 2 per cent.), ammonia and nitrate formation occurs and the materials act in soils as a nitrogenous fertilizer.

From these facts, we may conclude that any laboratory method for determination of " available nitrogen " in soils must, in some way or another, express the rate of ammonia and nitrate formation. This seems not to be obtainable by a single chemical analysis.

It is easy enough to determine the (always small) ammonia and nitrate content in a soil sample fairly accurately, but the analytical data do not tell the chemist how much nitrogen will be available to crops within a certain period of time and that is what he and the farmer particularly want to know.

Ammonia and nitrate, as already mentioned, are produced and removed simultaneously. Even if ammonium ions are kept in place by adsorption, the nitrates formed from them are very mobile. In dry periods they tend to accumulate near the surface, whereas in rainy they will be distributed in a much larger soil volume. These are the main reasons why safe conclusions about nitrogen deficiency may not be drawn from ammonia and nitrate determinations in soils at a given moment.

It seems, therefore, unlikely that simple soil tests for nitrogen deficiency can be of any great value to farmers. However, they seem to be less wanted than similar tests for potash and phosphate deficiency, because most crops in agriculture commonly respond to the application of nitrogenous fertilizers.

In horticulture, ammonia and nitrate determinations, particularly in soils from hothouses, are frequently used for diagnosing nitrogen deficiency and seem to serve very well indeed. It must be remembered,

however, that here we are facing a problem entirely different from that in farming. In horticulture, the cost of fertilizers will always be of minor importance, due to the high crop value. The horticulturist only has to furnish his crop with an ample supply of nitrogen during growth—and to make sure it will not be injured from an excessive application. The latter is by no means uncommon.

Keeping the content of ammonia and nitrate in ordinary field soil on the same level as that usually found in garden soil, will probably not be economically feasible in a moist climate, due to nitrate losses by leaching.

Potassium and available potash

Like nitrogen, the element potassium is absolutely necessary for the growth of all crops. Plants obtain their supply of potash by taking up potassium ions K^+ from the soil in the root zone. In many soils, however, the content of such ions is so low, or they are so firmly held in crystal lattices, that potash starvation will limit crop production.

Symptoms of potash starvation are in many cases easily recognizable. It would, nevertheless, be of great advantage if potash deficiency could be predicted from a soil analysis before it is visible on crops. The possibilities here seem more promising than for nitrogen.

The element K is a constituent of the minerals felspar (orthoclase) and micas (muscovite and biotite) which are commonly found in rocks and their weathering products, the parent material for most soils. The crystal lattice of felspar is extremely stable and by the normal weathering process, breaks down so slowly, that potash occurring in that mineral is practically unavailable.

The micas, especially the biotite, decompose more easily by weathering, releasing K^+. Normally, however, they are hardly of great importance as a direct potash source.

Potassium also occurs in soils as a constituent of clay minerals formed by weathering, and adsorbed to clay and humus colloids. Here it is less firmly bound and those materials are generally supposed to deliver the main part of potash to crops. Adsorbed potash may be released from the colloidal surface by exchange with other cations, for instance H^+ from acids, produced by living organisms in the soil.

Thereby potash passes into the liquid phase and becomes available to plants. The process may roughly be pictured by the following scheme

$$\left[\begin{matrix}\\ \\ \end{matrix}\right]\begin{matrix}K\\K\\K\end{matrix} + H^+ + HCO^-_3 \longrightarrow \quad \left[\begin{matrix}\\ \\ \end{matrix}\right]\begin{matrix}K\\K\\H\end{matrix} + K^+ + HCO^-_3$$

(Here it must be remembered that a soil's content of exchangeable K ordinarily is only a small fraction of its total content of "exchangeable bases," in most cases less than 10 per cent., the rest being chiefly calcium and magnesium.)

Using this as a working hypothesis, it seems very reasonable to determine the soil's content of exchangeable K and take this as an expression for its content of "available potash." This may be done by leaching soil samples on a filter with a neutral salt solution, for instance 2 N NaCl until all the exchangeable K has been removed from

the colloids and passed into solution, where it may be determined quantitatively.

By this, or by some modified method based on the same principle, the sample's content of exchangeable potash may be determined fairly accurately. This content, expressed in milli-equivalents exchangeable K per weight unit of dry soil, is often called T_K. From the value of T_K and from the soil's volume weight, we may calculate approximately the quantity of exchangeable K present in the soil per area unit to a certain depth, usually 20 cm. (the plough share) and thereby obtain instructive and convenient figures for comparison.

In doing so, we always find that a soil's content of exchangeable K is only a very small fraction of its total K content, which, again, is much larger than the quantity dissolved by such a drastic treatment as boiling with concentrated strong acids.

The following figures, which are typical for a series of Danish soils show that:

Soil type	kg K per ha. in the soil's upper 20 cm.		
	Total	Soluble in HCl	Exchangeable
Clay loam ...	30,500	4,150	387
Sand ...	22,750	1,214	235

Most of the potash present in mineral soils is non-soluble in strong acids. From 5 to 15 per cent. of the total quantity dissolves in such acids, while only 1 per cent. is exchangeable and contributes to the T_K-value.

This figure tells us how much exchangeable K the soil contained at the moment it was analyzed, nothing more. It seems, however, justifiable to assume that all the exchangeable potash is available to plants.

How far and to what extent, crops will respond to an application of potash fertilizers, may not be learned for certain from the analysis figures. Growth and development each year depend upon several factors which are independent of potash supply, among which is the varying ability of different crops to extract K from the soil constituents.

Soils with high T_K-values are doubtless for the moment not deficient in potash while extremely low values would strongly indicate such a deficiency.

The analytical data tell nothing about how rapidly T_K-values will regenerate in soils to which no potash is supplied. That such regeneration occurs may be taken for granted. In most soils, the amount of exchangeable K is only large enough to supply a few crops with the necessary potash. Nevertheless, a large number of crops may often be grown in succession before the usual signs of potash starvation become clearly visible.

T_K-values do not tell to what extent soils will be able to supply crops with potash over a larger period. This must depend upon the

total K content and the velocity at which, by weathering it passes into the exchangeable state.

Attempts have been made to find some expression for the rate of that process by elektrodialysis of soil (1) and determination of dissolved K at different times while dialysis is going on. During that process the medium, in which K dissolves, turns acid so that in reality the soil is subjected to a leaching with an acid solution, similar to that taking place by weathering under natural conditions.

Results from the analysis are expressed by a so-called *weathering constant* which is supposed to be a measure of the rate of *solubility* for potash in soils and better suited than T_K-values to characterize their " potash condition."

Analyses based on this principle have not yet been used to any large extent, probably because they are not well suited for routine work. An easy, practicable method of that kind is still wanted. Such a method would be valuable as a supplement to T_K determinations, and the two methods together would give a theoretically satisfactory characterization of the " potash condition " of soils.

Phosphorus and phosphate deficiency

Numerous methods are used in testing soils for phosphate deficiency. The practical value of such tests, even their justification, is stil heatedly discussed among farmers and soil men who do not seem to agree on this point. This is probably not accidental, but because soil phosphorus, in its compounds and behaviour, is much more intricate than soil potash and most other plant nutrients. Dealing with phosphorus, the soil chemist meets with very complicated systems, difficult to handle and clarify in detail.

It is generally assumed that plants take up phosphorus as the ion $H_2PO_4^-$. The element itself, is a constituent of several difficultly soluble calcium-, iron- and aluminium-phosphates occurring in soils, their chemical constitution and properties not in all cases being known in detail. Phosphate ions may also be present in an adsorbed condition, subject to anionic exchange.

From phosphate minerals, phosphorus is slowly released by hydrogen ions and passes into solution, for instance according to the scheme: $CaHPO_4 + H^+ \rightarrow H_2PO_4^- + Ca^{++}$. Reactions of that type are the main factors in rendering phosphates available to crops.

Phosphorus is also present in soils, in organic compounds (protein, phytin, etc.), in humus and other organic residues. Most of the phosphorus in such compounds is not directly available. By their microbial decomposition, phosphates are steadily produced in the soil. This process is, in its nature, quite similar to nitrate production, but its mechanism and importance is not nearly as well known.

It is not difficult to determine the total P content in soils. This may be done by oxidizing organic phosphorus by wet or dry combustion to phosphate, extracting with an acid and determining the phosphate content in the extract. By a similar extraction, without any foregoing oxidation, the soil's content of inorganic phosphorus is determined.

By this procedure soil phosphorus is divided into two fractions, one organic and one inorganic. In mineral soils, containing 2-3 per

cent. organic matter, it was found that in most cases both fractions were nearly of the same size, totalling about 0·1 per cent. P_2O_5 (2).

From such analyses we learn to know only the total phosphorus content, but hardly anything about its availability to plants, because in the analyses the soil has been subjected to chemically very drastic treatments. To avoid these, and come closer to natural soil conditions, soils are treated with some mild solvent, most frequently a weak acid or a diluted strong acid, selected in recognition of the major importance of H-ions in the dissolution of mineral phosphates in soil.

It seems most reasonable by such extractions to fix the H-ion concentration by means of an acid-reacting buffer solution, for instance an acetic acid-acetate or a lactic acid-lactate mixture. Many such methods are described in the literature on the subject. When the terms of procedure are strictly followed, they give fairly reproducible results. However, the quantity of phosphate found will differ from one method to another as applied to the same soil. All the methods, therefore, must be characterized as decidedly conventional.

The figures found in the analysis tell only how much phosphate will pass into solution, when, under strictly fixed conditions, a certain amount of soil is treated with an arbitrarily chosen solvent. Is it, then, reasonable to assume that this quantity is a reliable measure of the availability of phosphates to crops? Is it justifiable, as frequently done, from the amount of extracted phosphate, to calculate the amount of "available phosphates" per area unit (per acre or hectare)? Seen from a chemist's view point, the answer will be "Hardly." Effects from dissolving acids in the laboratory will, in most cases, be stronger than those in the soil. During the extraction process, the phosphate concentration in the extract increases, apparently approaching a limiting value. Whether this value represents a chemical equilibrium or a stationary condition in which slow solution and precipitation processes counterbalance each other, is uncertain.

By the natural extraction taking place in soils, the effective acid will chiefly be the weak H_2CO_3. The phosphate ions passing into solution will gradually be removed from the system by the root activity of plants, rendering the dissolution conditions totally different from those in glass vessels in the laboratory. Furthermore, none of the methods pay any attention to phosphate formation due to the gradual mineralization of organic compounds. This process may be of some importance, in some cases, even decisive, for phosphate availability in soils.

Calculating from laboratory figures the amount of available phosphate per unit of area seems hardly justifiable, and must be considered only a rough approximation.

The thickness of the soil layer from which plants extract phosphate is not known exactly and may be subject to wide variations in the different cases. (The same applies also to potash and nitrogen tests.)

If we ask further, is it possible, as sometimes claimed, from the analytical figures, to predict the increase in crop yield per weight unit of phosphate fertilizers, the answer is a decided "No." From the present methods it is not possible, nor will it be possible, even with an extended use of comparative statistical methods applied to results from field experiments and laboratory figures. The main reason for

this is that crop yield is not determined alone by the soil's content of available phosphate.

It is therefore unjustifiable to use analysis figures to predict yield increase per weight unit of applied phosphate fertilizer. It is preferable to use such figures only for dividing soils into 3 categories, namely (1) no phosphate deficiency, (2) doubtful, (3) phosphate deficiency. Such information is of practical value, even though a large number of soils belong in group (2).

At present there seems to be no method for determining phosphate deficiency in soils, which is both theoretically sound and of practical value. Therefore, it is only reasonable to discuss whether, under present conditions, it is justifiable to continue to use phosphate analyses as a basis for advice given to farmers. It *is* justifiable, no doubt. A long series of Danish field experiments running for many years (3) has shown that *on the average* there is good agreement between the response of crops to superphosphate on a soil and the soil's content of phosphates soluble by treating it with an excess of normal 0·2 H_2SO_4, i.e., nearly its total content of inorganic phosphates. From the average figure, however, deviations have been found, where crops from soil where the analysis had shown a high phosphate content reacted strongly for superphosphate—and *vice versa*. The analytical methods for detecting phosphate deficiency in soils have probably not yet attained complete development. There is no doubt but that the future will bring new and more reliable methods than those available to-day.

What main principles should be the basis for these new methods ? There is some indication that extraction with solutions showing a considerably lower pH value than the soil solution should be avoided. This means that the application of strong inorganic and certain organic acids must be abandoned in favour of weaker solvents, such as pure water, carbonated water or neutral salt solutions. The drawback in all such methods is that the extracts only contain very small quantities of phosphate and, therefore, the colorimetric phosphate determinations will be subject to rather large errors. In a rather unique and apparently promising method (4) the soil sample is suspended in water together with granulated sodium permutite and the mixture is kept in movement for some time. Sodium permutite reacts with the soil forming calcium permutite, while phosphate dissolves. The advantage of this method is that the reaction of the system is not changed appreciably. Its drawback is that sodium ions Na^+ disperse organic colloids forming darkish extracts ; further that the " solvent," in this case, is not a homogeneous liquid, but a solid material with unknown chemical constitution, therefore, difficult to produce with constant chemical properties.

It seems reasonable to supplement such analyses with a determination of total phosphorus in soil, perhaps also with a determination of the rate at which organic bound phosphorus is mineralized. This would give information on the present as well as the future " phosphate condition " in soils.

Finally, mention should be made of the fact that no laboratory method for determining soil fertility can stand alone, however theoretically well-founded it may appear. Its practical value may only be tested and proved by means of carefully planned field experiments

and by comparing their results with figures from soil analyses found in the laboratory.

LITERATURE

(1) ODÉN, S. and WIJKSTRÖM, T. Elektrodialysen, dess metodik och tillämpning på jordartsundersökningar. *Kungl. Lantbruksak. Handl. och Tidsskrift* (1931).

(2) DAMSGAARD SØRENSEN, P. Studier over jordens fosforsyreindhold IV. Det organisk bundne fosfor. *Tidsskrift for Planteavl.* (1946).

(3) BONDORFF, K. A. and associates. Studier over jordens fosforsyreindhold I —VI. *Tidsskrift for Planteavl.* (1932-1952).

(4) MØLLER, J. and MOGENSEN, TH. Metode til bestemmelse af den mobiliserbare fosforsyre i jordbunden. *Hedeselskabets Tidsskrift* (1951).

METHODS USED IN THE APPLICATION OF SOIL ANALYSIS TO THE MANURIAL PROBLEMS OF IRISH SOILS

T. WALSH, P. F. RYAN AND J. J. McDONNELL

Department of Agriculture, Ireland

In Ireland soil analysis is now widely used as a guide to the manuring of crops, a specialist service in this connection being operated by the Soils Advisory Service of the Department of Agriculture. An indication of the appreciation by farmers of the value of this approach to manurial problems is given in data presented in Table 1 which gives a record over the past four years of the number of samples received and tested at the soil analysis centre at Johnstown Castle Agricultural College.

TABLE 1

Year	No. of Samples
1948	5,000
1949	28,092
1950	50,905
1951	72,109

With the increase in the number of samples there has of necessity been an increase in facilities and equipment. These have been developed so as to ensure a high output of samples per worker but at the same time making certain of a satisfactory degree of accuracy in the determinations. All the operations have been mechanised as fully as possible. This paper presents a short account of the methods now used in this work under the main headings of soil sampling, methods of analysis and interpretation and application of test results to field conditions.

Soil sampling

As a number of agencies are serviced it has been especially necessary to ensure uniform soil sampling. From the literature on the subject, it would appear that in some countries the practice has developed of testing samples taken and submitted directly by farmers. This procedure has not been followed under our conditions as it is considered that under such a system it is impossible to obtain information of a sufficiently accurate nature in connection with soil type, to allow of the proper interpretation of soil test results, under conditions where soils are very variable. All samples are taken by technical officers specially trained in soil sampling methods. The main basis of soil sampling as carried out, is the selection of a number of samples of equal size at random, using a grid system, from a " sampling area " and compounding to make one representative sample. A " sampling area " is defined as one which is homogeneous with respect to soil type and previous cropping and manurial treatment. Even where there is a large area which might be regarded as a " sampling area " from the point of view of uniformity, the maximum size of area from

which any sample is taken is about 5 statute acres. On some small farms the adoption of this concept of sampling area as the basis for sampling means very intensive sampling but this has been found to be the only efficient approach. Each sample when submitted to the Laboratory, is accompanied by an accurate record setting out important soil type and treatment facts. A copy of the field sheet submitted to the Laboratory is given in Appendix I.

Where sampling with relation to depth is concerned soil profile characteristics are adopted as the basis of sampling. In ploughed land the plough layer is taken as the sampling depth while in pasture land the top organic horizon is divided in two regions, (*a*) the surface to a depth of approximately 2–3 inches and (*b*) the sub-surface. In old pasture soils where the development of a surface mat has resulted in the formation of a sub-horizon within the surface organic horizon, this technique has been especially necessary, as this surface zone is quite distinct in characteristics from the underlying sub-surface organic layer. In special cases such as where crop failures occur, in orchard soils, tomato house soils, etc., special sampling methods are adopted. It is again stressed that every effort is made to achieve uniform sampling.

Periodicity in the inflow of samples is not a serious problem as samples taken under the Land Reclamation Scheme of the Department of Agriculture are forwarded at a fairly uniform rate, and this scheme is one of the major sources of demand. The distribution of inflow of samples per month during the 1951 year is shown in Figure 1, April being the busiest month in this respect. There is, however, a very considerable periodic variation in the case of samples submitted by farm advisers.

Methods of analysis

Preparation of samples

On arrival at the Laboratory, samples are registered and subsequently dried on a specially designed air drier at a temperature not exceeding 35° C. Drying takes less than two days. In summer months artificial drying is not necessary as the samples dry on standing. When dry the soil is crushed and sieved on a special apparatus, at a rate of approximately 50 samples per hour. A note on the design of this apparatus is given in Appendix 2. After sieving, the samples are arranged in batches of 100 and are conveyed to the extraction room. When analyses are complete the soils are stored for one month before being discarded.

Extraction

Following the publication of MORGAN's paper describing his sodium acetate—acetic acid extractant (pH 4·8) this extractant has been the main one used in soil testing methods in this country. It was first used about 1935 by Dr. GALLAGHER in the laboratories of University College, Dublin, and the results obtained with the use of this extractant, and modifications made in MORGAN's method were described by

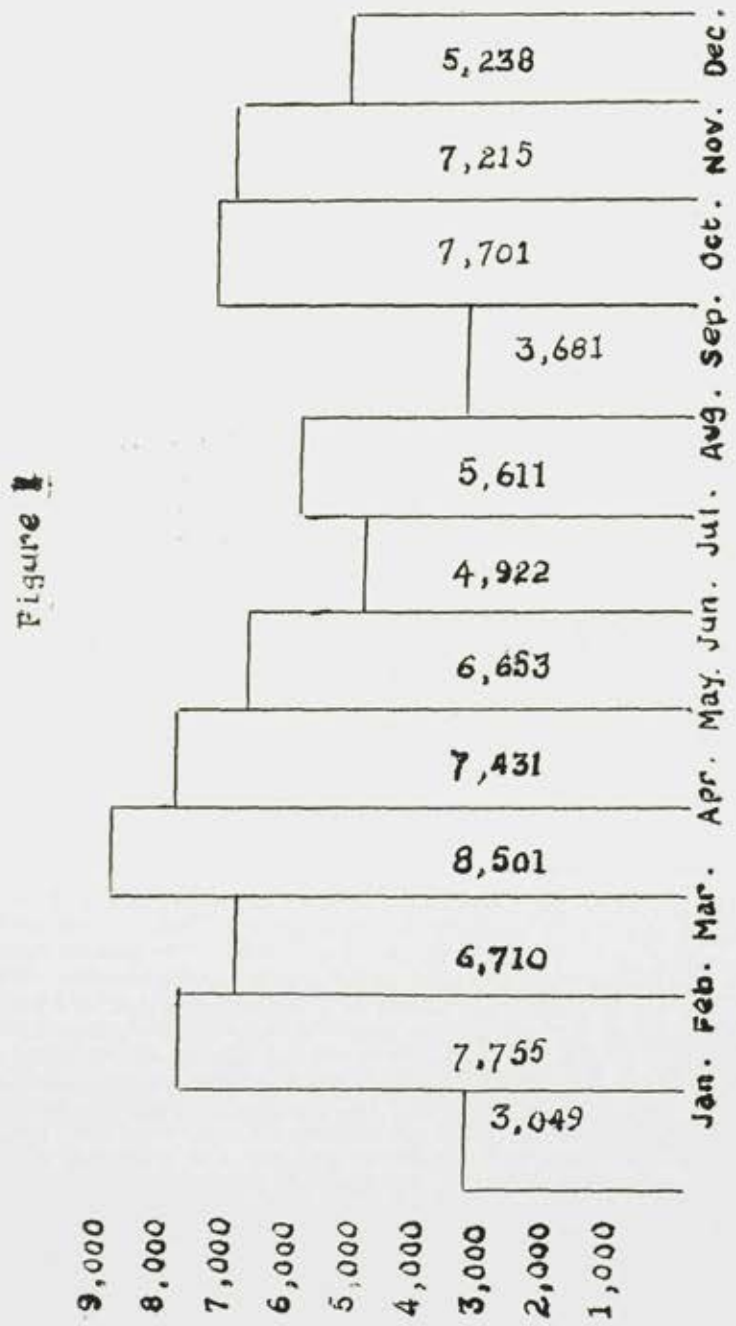

Jan.
Feb.
Mar.
Apr.
May.
Jun.
Jul.
Aug.
Sep.
Oct.
Nov.
Dec.
3,049
7,755
6,710
8,501
7,431
6,653
4,922
5,611
3,681
7,701
7,215
5,238
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000

Figure 1

WALSH (3). It is still the basis of extraction methods used in the Department's laboratories. This continuity in the use of one extractant has been of special importance where the interpretation of analytical results is concerned, a 1 : 5 soil-extractant ratio now, however, being used; the analytical methods at present in operation are derived mainly from PEECH and ENGLISH (2). Methods of mechanisation and organisation to facilitate the handling of a large number of samples are employed, many of these methods being adapted from those used in U.S. and European laboratories. Samples are divided into units or "sets" of 100 and handled in batches of 10. Shaking bottles, filter tubes and beakers for pH measurement are mounted permanently in racks of 10 and washed by inversion over a series of water jets. Hypodermic syringes and automatic pipettes are employed for addition of reagents, transfer of extract aliquots, etc.

In the extraction procedure, approximately 6 g. of soil (volume measurement) are extracted with 30 ml. of extracting solution. The soils are shaken in units of 100 (10 bottle racks) for 30 minutes. Stoppers are dispensed with during shaking by sealing the bottle mouths *en masse* with a board faced with "Dunlopillo" rubber sponge, which in turn, is covered by a plastic sheet. A shaking apparatus designed to take 400 samples has recently been installed.

Routine analytical procedure

All soil samples received are tested for pH, calcium, phosphate and potassium. Many samples, particularly horticultural soils, require more detailed analysis and this is carried out on request. pH is measured with glass electrode pH meters, on a 1 : 1 soil : water suspension, the electrodes are washed with an automatic device by which water is sprayed from a perforated brass pipe surrounding the electrodes when a foot or hand control is operated. *Calcium* is determined turbidimetrically using the stearate method of PEECH and ENGLISH. Preliminary work on a direct flame photometer method using the LANGE instrument indicates that this procedure can be substituted to advantage for the turbidimetric method.

Phosphate

In routine work the molybdate method of PEECH and ENGLISH has been adapted for colorimetric determination by using an E.E.L. colorimeter. In special cases the ammonium fluoride—hydrochloric acid extraction procedure of BRAY (1) has been adopted. Here also, the phosphate is estimated colorimetrically by the molybdate method.

Potassium

Is determined directly on the extract using a LANGE flame photometer, with a correction for calcium where the calcium content of the extract is above 500 p.p.m.

Methods used in special investigation

County Instructors and other advisory officials throughout the country frequently seek the aid of the laboratory in ascertaining the

cause of crop failures and livestock disorders arising from soil conditions. Such problems often require micronutrient analysis, or other non-routine analysis, on soil and plant tissue. At present, chemical and microbiological methods are used for micronutrient assay. A HILGER Large Quartz Spectrograph is now being installed and a BECKMAN Model Du Flamespectrophotometer has been used very successfully for a number of years.

Methods are at present in use or are in the course of preparation for the determination of nitrogen, carbon, magnesium, selenium, cobalt, copper molybdenum, manganese, boron, iron, zinc, cation exchange capacity, salt concentration (glasshouse soils), mechanical analysis, exchangeable hydrogen, drainage tile analysis and soil nutrient extraction by electrodialysis. Paper chromotographic methods for amino-acid and carbohydrate analysis are also under investigation.

Plant analysis

Analysis of plant material is carried out in connection with soil fertility experiments and as a diagnostic aid in crop and livestock problems. For total analysis, the wet ashing technique is usually employed with flamephotometric (BECKMAN) estimation of Ca, K and Na.

Interpretation of soil test results

As pointed out previously, the MORGAN extractant has been in use for Irish soils for a considerable length of time and as a result there has been a very considerable build up of information relative to the interpretation of test results based on the use of this extractant. Some of the information in this respect has been presented before (3, 4). In obtaining this information, systematic pot culture and field experiments on a wide variety of soil types have been applied in developing limit values while valuable information has also been obtained from the interpretation of farmer experience. For the purpose of adding to the information already available on the value of different extractants and methods of extraction in relation to soil types, an extensive scheme of field experiments is being actively operated.

In the early stages of this work when the number of samples tested was relatively limited it was possible for specialist advisory officers to furnish a specific recommendation to the general farm advisor, who, in turn, brought the recommendations and report to the farmer. With, however, the growth of the service it was impossible to continue this procedure and in order to meet the situation it was decided that the actual soil sampler should also make out the report. With this object in view, the officers concerned were given a short intensive training course in the interpretation of analytical results and a standard guide to the interpretation of soil test results was prepared and issued. The figures set out in this guide are based on the experience which had been accumulated to date in this field. It is of a relatively tentative nature and is being added to as experience indicates. This guide includes a chart showing the quantities of nutrients to be applied to a wide variety of crops at a particular limit value level, under what may be described as standard or modal soil conditions. For phosphate

this standard soil was fixed as a properly limed medium loam soil in a locality of average rainfall. For potash it is defined as a non-limestone or at most only partially limestone derived medium loam of medium organic matter content and having (or raised to) a calcium status of 3,000 to 4,000 lb. per acre of readily available calcium, while for liming recommendations a soil of medium loam texture of low organic matter content and medium base exchange capacity has been adopted as a standard.

As any soil varies from the standard conditions corrections are made depending on a number of factors associated with nutrient intake. Such factors as nutrient balance, soil texture, organic matter content, soil moisture conditions, soil parent material, soil structure, climate and so on, are taken into account. As examples of some of the corrections made the following are given.

In the case of a clay loam the phosphate level is increased by 12½% while in the case of a light loam it is decreased by 15%. Where the soil is derived from a non-calcareous parent material and where the pH is below 5·5 irrespective of whether or not liming is to be carried out, the dressing recommended for the standard soil at the particular nutrient level obtaining is increased by 12½%. In interpreting the phosphate result, considerable stress is laid on the base status of the soil, as it has been the experience that even at very low test results where the base status of the soil is satisfactory, response results from phosphatic fertilizers may not be so striking as might have been expected from the test value obtained. In all 14 different corrections are made for phosphate and when these have been applied the final figure is obtained.

For potash, considerable stress is laid on the level of lime and clay content. A correction of 10% for every 2,000 lb. in excess of 4,000 lb. of readily available calcium per acre level, is made to a maximum of 40%. If, for instance, a medium loam soil shows a potash requirement for potatoes at 2 cwts. of a potassic fertilizer per statute acre at a 4,000 lb./ac. calcium level, a soil of similar texture and origin showing a 12,000 lb./ac. level would at a similar potash test receive a dressing of 2·8 cwts./ac. of this fertilizer. In all some 17 corrections are made for potash, special attention being paid to the question of texture, potash fixation, organic matter content and unbalance effects especially where calcium and magnesium are concerned.

The making of lime requirement recommendations is based on a table which sets out the dressing of lime for the standard soil at a particular pH and readily available calcium level. Separate tables have been prepared for mineral and organic soils. Corrections are introduced for texture, organic matter content (in mineral soils), base exchange capacity, level of aluminium and manganese and other factors related to minor and secondary element availability. For instance, taking the standard soil as defined previously at a pH 5·2 and a readily available calcium level of 1,200 lb. per acre, a liming requirement of 3½ tons of ground limestone per statute acre is arrived at. If this soil were a clay loam some 4½ tons of ground limestone per acre would be recommended and for heavy loam, some 4 tons.

Nitrogenous manuring is based on the concept that optimum dressings of nitrogen can only be used effectively when phosphates

TABLE 1

Tentative limit values (lb./ac.)

Rating	Calcium	Phosphorus	Potash	Nitrate Nitrogen	Magnesium	Iron	Manganese	Aluminium
Extra low	0–400	0–1	0–25	0–5	0–10	0–5	0–25	0–10
Very low	400–800	1–2	25–50	5–10	10–25	5–10	25–50	10–25
Low	800–1200	2–4	50–100	10–15	25–50	10–15	50–75	25–50
Low-medium	1200–1600	4–9	100–150	15–20	20–10	15–20	75–100	50–100
Medium	1600–2000	9–14	150–200	20–30	100–150	20–30	100–150	100–150
Medium-high	2000–3000	14–25	200–250	30–40	150–200	30–40	150–200	150–200
High	3000–5000	25–50	250–300	40–60	200–250	40–50	200–250	200–250
Very high	5000–9000	50–75	300–500	60–100	250–500	50–100	250–350	250–500
Extra high	9000+	75+	500+	100+	500+	100+	350+	500+

and potash are at a satisfactory level. Under such conditions, a standard set of recommendations is arrived at in terms of different crops. The conditions influencing nitrogen availability in the soil are described and defined.

In the interpretation of results a set of tentative limit values for nutrient levels in the soil are given in Table 1 below. While ratings of " extra low," " very low," etc., are given in this table, such ratings are not now normally used as they can lead to considerable confusion where farmers and others are concerned. They have been replaced by a system of values, for instance, the " extra low " level of phosphorus at 0 to 1 lb. per acre is now defined as the P.1 value, " very low " level as the P.2 value and so on. In arriving at the limit values for potash, the use of the flamephotometer technique for the determination of potassium has been of considerable value. With the turbidmetric technique it was impossible previously to get, with any certainty, below a level of 50 lb. per acre. This was not sufficient in certain soils, for the proper diagnosis in connection with potassic manuring of pasture species. The K.1 value as given now is in the region where most pasture species will need and respond to potash, levels as low as 5 lb. per acre having been recorded for some old pastures. The tentative nature of these limit values must again be stressed and it remains for future work to arrive at a more precise definition of these values.

Except in certain circumstances, especially in connection with garden and glasshouse soils, routine estimation of minor element levels is not made. This aspect of the problem is, however, now receiving more attention and from investigations in hands it is hoped to be able to provide a considerably better service in this connection. In this sphere the main problem appears to lie in the determination of the effect of major elements on the availability of minor elements and in this connection an estimate of the minor element level and potential in soils is considered to be highly important. So far where molybdenum is concerned very good results have been obtained with the use of TAMM's oxalate extracting solution as applied by GRIGG, and estimation of aluminium on the MORGAN extract has also been of very considerable value.

Summary

An account is presented of the techniques applied in the operation of a large scale soil testing service. The various aspects of the subject are treated under the main headings of sampling, methods of analysis and interpretation of results.

LITERATURE

(1) BRAY, R. H. Univ. Ill. Agr. Exp. Sta. Pamphlet A.G. 1028 (1942).
(2) PEECH, M., and ENGLISH, L. *Soil Sci.*, **57**, 167 (1944).
(3) WALSH, T. *J. Dept. Agr., Ireland*, **39**, Nos. 1 and 2 (1942).
(4) WALSH, T., MANNION, L. and RYAN, P. F. Fourth International Congress of Soil Science (Amsterdam, 1950), Trans. **3**.

APPENDIX 1

AN ROINN TALMHAIOCHTA

SOIL SAMPLES FOR ANALYSIS: FIELD NOTES: County .....

Date sampled..... .....

Name and address of farmer.....

Name/No. of field..... Area sampled.....acres

Depth of sample ...	.....	.....	.....	.....	.....	.....
Identification No(s)...	.....	.....	.....	.....	.....	.....
Laboratory No(s). ...	.....	.....	.....	.....	.....	.....

Soil Description

Situation .....Geological origin.....

Texture .....Structure .....

Colour .....Drainage .....

Soil depth and root development.....

Other soil characteristics.....

.....

Previous treatment, Cropping data, etc.

Year	19.....	19.....	19.....
Crop ...	.....	.....	.....
Crop response	.....	.....	.....
Manurial treatment and liming	.....	.....	.....
	.....	.....	.....
	.....	.....	.....

Purpose of analysis.....

Other observations.....

.....

Signature of Instructor..... Date.....

APPENDIX 2

This machine was developed at the laboratory with two objects in view :—

(*a*) To speed up the work of sieving, which was initially done by hand, and was consequently a tedious, time-consuming job.

(*b*) To overcome the problem of dust during sieving operations.

The machine consists of a 12" square 2 mm. sieve sloped at an angle of 20° and mounted in the top of a sheet metal (copper) funnel which is suspended inside an angle iron framework. The combined funnel and sieve are given a reciprocating (1" stroke) motion by a camshaft driven by a $\frac{1}{4}$ h.p. motor mounted at one side of the machine. Over the sieve and resting on top of the framework is a rectangular sheet steel tray, on which the sample is crushed with a wooden, metal-covered, hand-operated, roller. After crushing, the sample is brushed by hand through a slot in the tray into the sieve.

Dust is carried out into the open air by a 9" ventilator fan mounted at the back of the machine, in a suitable window or wall opening. A plywood duct runs from the fan to the top of the machine, which it partly covers. Two operators are required ; one pours the sample on to the tray, hands the bag to the other operator, and crushes the sample. The other operator places the bag underneath the funnel, brushes the crushed soil into the sieve through the slot in the tray, and removes the bag when sieving has been completed. The coarse material runs off the sloped sieve into a canvas collecting bag attached to the rear. The machine has completely eliminated dust and enables sieving of soil samples to be carried out with the minimum of delay and labour.

Tests have shown that there is no contamination caused to samples from samples previously passed through the apparatus.

SOIL FERTILITY EVALUATION IN ITALY

G. PASSERINI

Ministry of Agriculture and Forestry, Italy

Soil fertility evaluation in Italy constitutes a task of the Agricultural and Agricultural Chemistry Experiment Stations, dependent on the Ministry of Agriculture and Forestry, and of the Agricultural Chemistry Institutes of some Universities.

Though most of the soil fertility analyses are based on chemical procedures, the Agricultural Experiment Station of Turin uses the pot-cultures method of MITSCHERLICH. This Experiment Station is well supplied with efficient and modern equipment for physiological soil analysis.

Essential features of the chemical methods for assessing soil nu trients availability are as follows:

1. *Organic matter and nitrogen*

Organic matter status of soil is assessed by dry or wet combustion methods; these latter are based on the original or modified procedures of ITSCHEREKOW, TIURIN, WALKLEY and BLACK. In some cases colorimetry is applied to humus extracts obtained by neutral or alkaline reagents. Soil nitrogen is determined by the KJELDAHL method. Nitrification tests are colorimetrically performed by the Agricultural Chemistry Experiment Station of Rome by following the TOMMASI method (16) based on the mineralisation of nitrogen in soil, maintained at the field capacity of 30° C. for 21 days. The same Experiment Station has recently applied the foliar diagnostic using the BRAY's reagent as test for the nitrate status of plant tissues.

2. *Phosphates*

Evaluation of the phosphate fertility level of soil is considered in Italy as one of the most important tasks of the Agricultural Chemistry Stations. For this purpose various routine methods are available, in relation to different concepts about soil phosphorus availability.

(*a*) WRANGELL successive-water extracts method, improved by MARIMPIETRI (11) is applied by the Agricultural Chemistry Experiment Station of Rome, by the Agricultural Experiment Station of Bari, by the Wheat Experiment Station of Catania, and by the Agricultural Chemistry Institute of the University of Perugia. This method appears a very suitable one for evaluating the practical phosphate need of soil, as the procedure adopted gives an account of the P_2O_5 both readily available and easily restored from soil.

For soil having a high P_2O_5 fixation, TOMMASI-MARIMPIETRI method (14) is employed, by which some increasing amounts of phosphate (as monocalcium salt) are added to soil, and by a diagram it is possible to calculate the phosphate requirement of the soil itself.

(*b*) The ANTONIANI method (2) used by the Agricultural Industry Institute of the University of Milano, requires both gravimetric determination of total P_2O_5 (by an original rapid procedure) and colorimetric determination of P_2O_5 soluble in CO_2–saturated water (ratio soil : water = 1 : 10). If CO_2 soluble P_2O_5 is 30 kg./ha., the soil needs phosphate dressings. The proper amount of fertilizer is computed

from a simple formula which contains an " utilisation coefficient " derived from the total P_2O_5/CO_2–soluble P_2O_5 ratio. The values of the above coefficient for different ratios as found in calcareous and non-calcareous soils are given in tables.

(*c*) With the ALINARI method (1) adopted at the Agricultural Chemistry Institute of the University of Florence, four acetate-acetic acid solutions, buffered at different pH ranges (from 3 to 6), are used for the extraction of soil phosphates. For each soil a diagram is drawn showing two well delimited areas, namely, of high and medium availability, and of low availability. Outside of these areas lies the zone of P_2O_5 difficultly available, from which depends the metabolic rhythm of soil phosphorus. From the ratio between the first two areas, it is possible to calculate the " availability factor," by which one can determine the P_2O_5 amount having both high and medium availability, that is, on an average, around 150 mg. per kg. of soil.

Soluble P_2O_5 is determined by molybdenum-blue reaction according to the procedure of FERRARI (7). Total P_2O_5 is determined by the ANTONIANI gravimetric rapid method (2).

(*d*) The Agricultural Chemistry Institute of the University of Bologna assesses soil phosphorus availability by the colorimetric determination of both P_2O_5 total and soluble at pH about 5. Recently there has been developed a new procedure by which the colorimetric determination of soil inorganic phosphates is carried out by producing the " phosphorated molybdenum blue " in presence of the soil itself (8, 13).

(*e*) The Agricultural Chemistry Experiment Station of Ufine has obtained good results by employing the MORGAN-BARBIER method for the analysis of available P_2O_5 in soil, except for high-calcareous soils.

(*f*) The Rice Experiment Station of Vercelli, uses for rice-soil the method of SCHLOESING–V. SIGMOND, as modified by BORASIO (3), by which the soil is treated with 1% nitric acid, and the P_2O_5 dissolved is determined by molybdenum-blue reaction.

3. *Potassium*

For routine analysis of available or exchangeable potassium in soil, the Agricultural Chemistry Experiment Station of Rome, the Agricultural Experiment Station of Bari, and the Agricultural Chemistry Institute of the University of Perugia use the RIEHM sedymetric method for soil extracts obtained with the KRAUS reagent (5).

The RIEHM method is also used by the Agricultural Chemistry Experiment Station of Udine for soil extracts obtained with the MORGAN-BARBIER reagent.

4. *Boron*

The Agricultural Chemistry Institute of the University of Milano, the Agricultural Chemistry Institute of the University of Perugia, and the Agricultural Chemistry Experiment Station of Rome, employ NAFTEL-curcumin method (10, 12) for the determination of available boron extracted from soil by the BERGER and TRUOG procedure.

At the Agricultural Chemistry Experiment Station of Turin, boron extraction is carried out by refluxing soil with ether in Soxhlet apparatus (4). Boron is successively determined by the curcumin method so performed that the excess of curcumin (ethers oluble) is separated from rosocyanine (acetone soluble).

5. *Manganese*

The Agricultural Chemistry Experiment Station of Rome determines the available manganese content of soil either as exchangeable Mn, by leaching soil with normal NH_4Ac, or as easily reducible Mn, by leaching the same soil aliquot with normal NH_4Ac, added of 0·2% hydroquinone (9).

6. *General soil fertility and fertilization*

(*a*) The Agricultural Experiment Station of Modena assesses soil fertility according to the concepts of DRAGHETTI (6) which considers the fertile soil status as a function of two factors, namely a physico-chemical factor (i) mostly related to the mineral soil colloids and a biochemical factor (ii) related to the organic matter in soil. The sum of these factors represents the agronomic soil fertility. While, for a definite soil, factor (i) is nearly constant against time, factor (ii) suffers indeed seasonal variations. Dressing of organic matter (as manure, compost, etc.) may be sufficient to ensure to a normal soil a good fertility level, especially if organic matter is previously enriched with phosphate fertilizers, necessary to integrate the P_2O_5 content which cannot return to soil with the organic substance itself.

Data concerning soil chemical analysis together with the field data concerning in particular crops rotation and manure production, permit the assessing of the soil agronomic fertility ; whose maintenance is assured by giving back nutrients to the soil itself, not directly, but by means of organic matter (humo-mineral fertilization).

(*b*) The Agricultural Chemistry Experiment Station of Rome performs soil fertility control on the basis of the " integral fertilization " concept of TOMMASI (15). According to TOMMASI, fertilizers application must be regulated by obtainable crop yields, which are related either to the crop nature or to the soil nutrients availability. This latter is ensured by both enrichment and maintenance dressings of fertilizer. Enrichment dressings provide to saturate the adsorbing or fixing soil complex, so that the mineral plant nutrient may keep its availability through the maintainance dressings.

On these bases, soil analysis, as being related to the more soluble forms of the soil nutrient, makes it possible to assess not only the soil fertility level, but even the fertilization status of the soil itself.

REFERENCES

(1) ALINARI, E., and CECCONI, C. A. In press.
(2) ANTONIANI, C. *et al.* *Ann. Facoltà Agraria Perugia*, **II** (1945).
(3) BORASIO, L. *Risicoltura*, **8**, 9 (1951).
(4) BOTTINI, E. *Ann. Staz. Chim. Agr. Torino*, **17** (1949-51).

(5) CAMPANILE, S. *Ann. Staz. Chim. Agr. Roma*, **III**, 37 (1950).
(6) DRAGHETTI, A. "Principi di fisiologia dell'azienda agraria." Ist. Ed. Agr. Milano e Bologna (1948).
(7) FERRARI, C. *Gazzetta*, **81**, 795 (1951).
(8) FERRARI, C. Manuscript paper for publication in Vol. II of the Trans., Joint Meet. Comm. II and IV of the I.S.S.S.
(9) GATTORTA, G. *Ann. Sper. Agraria*, N.S. **4**, 789 (1950).
(10) MALQUORI, A. *Ann. Sper. Agraria*, N.S. **6**, No. 3 (1952).
(11) MARIMPIETRI, L., MORANI, V. e GISONDI, A. *Ann. Staz. Chim. Agr. Roma*, S. **3**, No. 24 (1952).
(12) SALTO, L. *Rend. 1st. Lomb. Sci. Lett.*, **73** (1940).
(13) SANDRI, G. Manuscript paper for publication in Vol. **II** of the Trans Joint Meet. Comm. II and IV of the I.S.S.S.
(14) TOMMASI, G. and MARIMPIETRI, L. *Ann. Staz. Chim. Agr. Roma*, S. **2** No. 322 (1936).
(15) TOMMASI, G. *Ann. Staz. Chim. Agr. Roma*, S. **2**. No. 329 (1937).
(16) TOMMASI, G. *Ann. Staz. Chim. Agr. Roma*, S. **2**, No. 352 (1939).

THE NEW ZEALAND SOIL ADVISORY SERVICE

E. B. DAVIES

Rukuhia Soil Research Station, New Zealand

(Read by Mr. W. M. H. SAUNDERS)

It should be stated at the outset that the Advisory Service to be described is designed primarily for determining the requirements of phosphate, potash and lime of land under pasture, for such land constitutes three-quarters of the occupied area of New Zealand.

All farm advisory work, apart from that concerning animal disease, is carried out by field officers of the Extension Division of the Department of Agriculture. These officers have first-hand knowledge of local pastures and from observations of top-dressing trials and other experience know in general how they react to fertilizer additions. The definition of soil types by the New Zealand Soil Survey and the determination of their boundaries has made possible a logical assembling and wider application of such field observations. The classification, too, of a soil type gives information as to its nature and probable fertility. This background of information, together with a knowledge of the fertilizer and liming history of the farm concerned, is of great assistance to the field man in judging manurial requirements. It is not, however, enough. A soil advisory service based on chemical tests has been found to fill a real need.

In the past, chemical methods of determining fertilizer requirements have been used, but on a small scale only. The first chief chemist of the Department of Agriculture introduced DYER'S 1% citric acid method in 1900, but soil analyses of some type were recorded as early as 1867. It in time became obvious that the citric acid method was not generally applicable for determination of available phosphate. As an example, the yellow-brown loams of Taranaki are naturally well supplied with phosphate according to this method, yet the high productivity of the district has been built up and maintained only through heavy phosphatic manuring. In 1938, EGNÉR'S lactate method was introduced for phosphate determination. With the establishment, in 1945, of the Rukuhia Soil Research Station, attached to the Extension Division, a variety of methods of assessing available phosphate and potash were checked against results of MITSCHERLICH pot experiments run on a range of soil types.

Phosphate

The "available" phosphate in eighteen soils, examined by the MITSCHERLICH pot experimental technique, was determined by the following methods:—

(1) 1% citric acid extraction after DYER (1).

(2) Methods of BRAY and KURTZ (2)

1A. Adsorbed phosphorus

2A. Acid soluble and adsorbed phosphorus

3A. Total adsorbed phosphorus. (Extractant neutral N/2 NH_4F).

Methods 1A and 2A are rapid tests, the extractants being 0·03N respect to NH_4F.

(3) EGNÉR'S lactate method (3).

TABLE I

	1% Citric acid	Bray and Kurtz			Egnér	Truog	Exchangeable	C.B.P. HCII
		1A	2A	3				
Mitscherlich ...	0·844†	0·843†	0·888†	0·261 N.S.	0·914†	0·934†	0·442 N.S.	0·490*
1% Citric acid ...		0·761†	0·836†	0·548*	0·715†	0·827†	0·647†	0·601†
Bray and Kurtz, 1A			0·945†	0·156 N.S.	0·765†	0·964†	0·364†	0·378 N.S.
2A				0·211 N.S.	0·837†	0·955†	0·339 N.S.	0·336 N.S.
3A					0·079 N.S.	0·189 N.S.	0·901†	0·895†
Egnér						0·837†	0·235 N.S.	0·241 N.S.
Truog							0·393 N.S.	0·406*
"Exchangeable" ...								0·982†

*Significant at 5% level
†Significant at 1% level
N.S. Not significant

(4) TRUOG's method (4).
(5) The " Purdue " test (5).

In addition, total phosphate soluble in boiling C.B.P. HCl was determined and exchangeable phosphate as described in PIPER's. " Soil Analysis " by extraction with boiling caustic soda (6). The latter treatment would extract considerable organic phosphate.

In method (5) qualitative results only were obtained by visual comparison against colour standards.

The correlations between results of the various methods are supplied in Table 1.

A high degree of correlation between the MITSCHERLICH results, accepted in this case as a standard, and results from a chemical test, do not necessarily point to the latter's being generally applicable. A whole group may be represented by a single soil in the series selected, yet a serious deviation of that one result need not appreciably affect the correlation co-efficient.

In Figure 1, eighteen soils are placed in order, according to the MITSCHERLICH figures, for available phosphate. The inset figure gives the highest result in mg. % P_2O_5. In succeeding figures, levels according to the TRUOG, citric acid, and BRAY and KURTZ (3) methods are shown in a like manner, the MITSCHERLICH order being retained. The TRUOG test is effective in differentiating those few soils well provided from those poorly provided. The citric acid is misleading in six instances, representing four distinct soil groups. The " adsorbed " phosphate determined by extraction with neutral N/2 ammonium fluoride is no guide to available phosphate in New Zealand soils. This last test correlated fairly closely with total phosphate (C.B.P. HCl) and " exchangeable " phosphate (PIPER).



Fig. 1

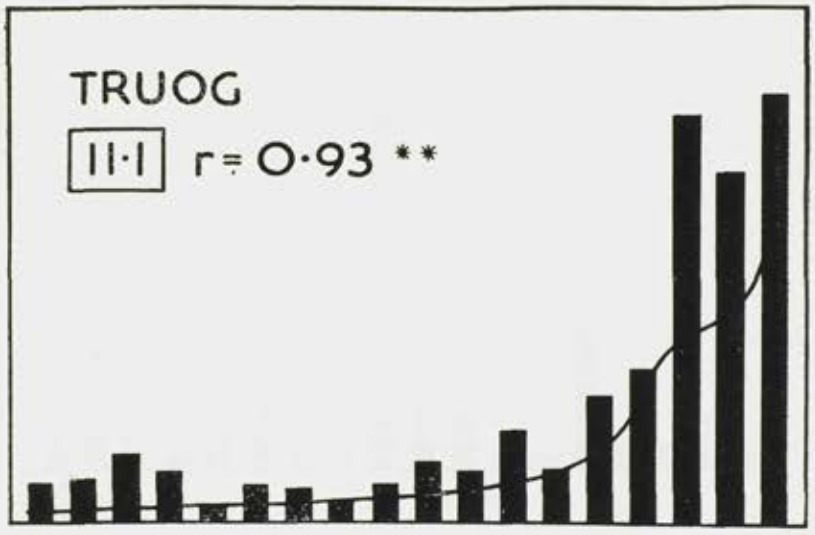


Fig. 2

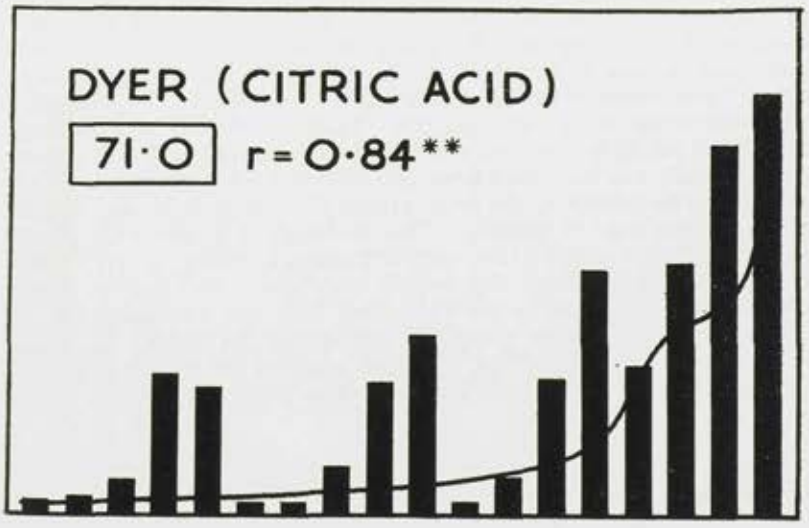


Fig. 3

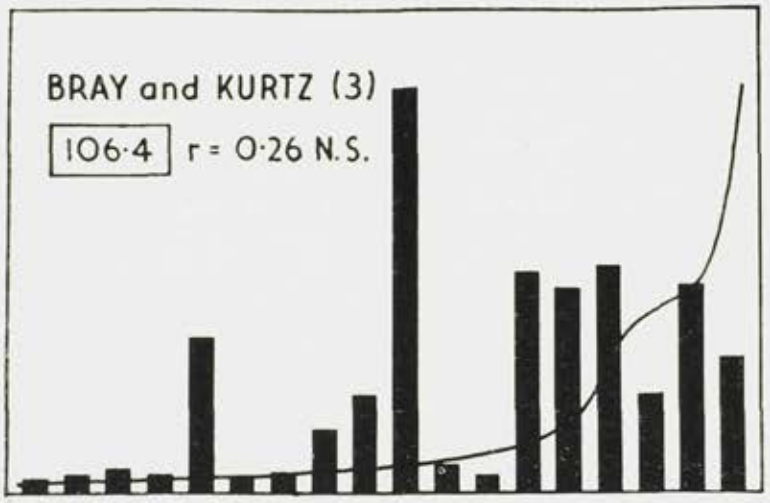


Fig. 4

The rapid methods of BRAY, using solutions 0·03N in respect to ammonium fluoride, gave results more in line with the MITSCHERLICH figures. The fluoride concentration was not high enough to affect results. EGNÉR results were somewhat similar.

The qualitative indications from the Purdue method are of interest, placing soils in much the same order as the " total adsorbed " phosphate test. The soil is shaken up with an acid solution containing ammonium molybdate and the filtered extract treated with stannous oxalate to produce the molybdenum blue colour. Actually the molybdate has been found to exchange with soil phosphate, which accounts for further molybdate having to be added to the extract for full colour development. A one-minute period of extraction is specified. The exchange with molybdate is a progressive one. Tests carried out with no final molybdate addition gave results diminishing to almost nil as the period of extraction was increased from one minute to five minutes. With addition of molybdate to the final extract, the reverse holds and results increase with time of shaking. This exchange is in line with observations of STOUT *et alia* (7) and with GOLDBERG's finding (8) that soluble phosphates can exchange with soluble molybdate. Soil tests in which molybdate is included in the extracting fluid are unsatisfactory on account of exchangeable phosphate influencing the result.

The TRUOG phosphate test has been adopted for routine advisory work, a tentative interpretation of results being as follows :—

Mg. % P_2O_5		
<1	Very low	responses probable
1–2·5	Low	
2·5–5	Medium	
5–10	High—responses possible but slight	
>10	Very high—responses improbable	

Occasionally duplicate tests are run in which dipotassium hydrogen phosphate corresponding to 15 mg. P_2O_5 per 100 grams of soil is added to the extracting reagent. The distribution of this phosphate between the soil and extractant is taken as an indication of the fixative power of the soil for phosphate. It is fairly consistent over each soil type. High-fixing soils absorb two thirds or over of the phosphate and in practice need phosphatic dressings of the order of 3 to 6 cwt. superphosphate per acre. Low-fixing soils absorb under one-third of the added phosphate and customarily receive 1–2 cwt. superphosphate per acre for good results. The test is indicative only and critical trials have not been carried out.

Potash

The following laboratory tests for available potash were checked against results of MITSCHERLICH pot experiments.

(1) NEUBAUER method using rye corn seedlings (9).
(2) DYER'S 1% citric acid method (1).
(3) Exchangeable potash (ammonium acetate leaching).
(4) Percentage potash saturation.
(5) Purdue rapid test (qualitative only) (5).

Correlation between the quantitative methods is given in Table II—

TABLE II

	NEUBAUER	Citric acid	Exchangeable potash	% Potash saturation
MITSCHERLICH ...	0·891	0·834	0·819	0·666
NEUBAUER ...		0·917	0·908	0·722
1% Citric acid ...			0·983	0·861
Exchangeable potash				0·866

All correlations were significant at the 1% level.

The NEUBAUER method showed up to best advantage but was not suitable for adoption as a routine test. The Purdue qualitative test was superior to any in that it divided the soils into three groups; those well supplied, those adequately supplied, and those likely to respond to potassic applications. The method was, therefore, adopted though differentiation within the last group was not particularly good. The soils are shaken with a cobaltinitrite reagent brought to pH 5 with acetic acid, the extract filtered off and potassium sodium cobaltinitrite thrown out by isopropyl alcohol addition. The turbidity is judged using a specially devised card against the light for high tests, against a white black lined back-ground for low tests.

The descriptive terms used correspond roughly to the following levels of exchangeable potash :—

	m.e. % *K*.
Very low (VL)	<0·15
Low (L)	0·15—0·25
Medium (M)	0·25—0·5
High (H)	0·5—1·0
Very High (VH)	>1·0

Very high potash levels such as may obtain in glasshouse soils cause potassium precipitation prior to filtering and give negative results. Half or third quantities of soil are taken in these cases.

Permanent pasture responds to potassic fertilizers when the soil test is below " high."

Lime requirement

Methods employing buffer curves or based on percentage base saturation of the soil are not rapid enough for advisory tests when large numbers of samples have to be handled. Lime requirement is, therefore, judged from a joint consideration of pH, determined by use of the glass electrode, soil texture and exchangeable calcium. The latter is extracted and precipitated as in MORGAN'S test (10) but the turbidities matched against standard glass dust suspensions in a glycerine water mixture. The viewing card used in the potash test assists. MORGAN'S procedure was found to give results more in line with exchangeable Ca determined by ammonium acetate leaching than did the procedures of PEECH and ENGLISH or WOLF and ICHISAKA (11).

Lime requirement recommendations are at present based on the following scheme :—

Normal soils of loamy texture	*Dressing of crushed limestone per acre*
pH under 5·5	1 ton
5·6–6·0	10 cwt.
Clay soils and soils high in organic matter	
pH under 5·5	1½ tons
5·5–6·0	15 cwt.
Sands	
pH under 5·5	10 cwt.
5·5–6·0	5 cwt.

Occasionally, light-textured soils have a pH 6·0 or over but exchangeable Ca below 7. In this case a limestone application sufficient to raise the Ca figure to 7 is suggested—roughly 3 (7—Ca figure) cwt./acre.

Peat soils are better not limed above pH 5. Soils of the yellow brown loam group do not as a rule respond to liming nor do Taupo pumice soils (rhyolitic), though the exchangeable Ca may be below 7 and pH about 5·5. The liming recommendations are in terms of high-grade, finely-crushed limestone, and need adjustment by the Extension Officer for coarse or low-grade products.

(Note : It is hoped shortly to use MORGAN'S universal extractant for both calcium and potassium and employ the flame photometer to obtain quantitative results. This should speed up operations and eliminate the personal factor.)

Check of suggested response levels

Tentative interpretations of results in terms of phosphate, potash and lime requirements have been mentioned. As a check on these, laboratory indications were compared with the results from observational top-dressing trials—a rough type of field trial, run on

permanent pasture. Soil samples were drawn either when the trial was laid down or later from control plots or headlands. These trials are scattered over most of New Zealand, but used to the largest extent in the Auckland Province.

Agreement between observational top-dressing trial indications and soil tests.

District	Treatment	No. of trials	Agreement %	Disagreement %	Inconclusive %
Auckland ...	Lime	88	70	17	13
	Phosphate	89	75	12½	12½
	Potash	79	77	15	8
Wellington ...	Lime	34	91	3	6
	Phosphate	38	90	10	—
	Potash	69	71	19	10
Christchurch ...	Lime	34	59	15	26
	Phosphate	32	72	12	16
	Potash	22	64	18	18
Dunedin ...	Lime	16	37	63	—
	Phosphate	14	71	29	—
	Potash	16	69	—	31
Dominion ...	Lime	172	69	18	13
	Phosphate	172	77	13	10
	Potash	186	73	15	12

It is evident from the Dominion totals that while results are generally in accord, in quite a number of cases, they cannot be reconciled. The most striking lack of agreement concerns the lime requirement of certain Otago and Southland soils. It was largely investigation of this anomaly that led to the discovery that parts of Otago and Southland were deficient in available molybdenum. Heavy liming, sufficient to bring the soil to near neutrality, is a general practice in the area and lime responses have been observed on soils of pH as high as 6·5. It is considered that the responses were due to soil molybdenum being made more available for plant uptake and the nitrogen fixing activities of Rhizobia. Unexpected lime responses in other parts of New Zealand may also be due to an effect on molybdenum availability.

Certain anomalous responses to superphosphate may be responses to the sulphate contained—a possibility under investigation. The marked capacity of some soils for "fixing" phosphate may account for small responses only on highly deficient soils. On the other hand, it is quite likely that certain soil types will require special consideration. A peculiarity regarding responses of pumice soils to lime has already been mentioned.

The phosphate test has been found to give unduly high figures where soils have had heavy treatments with ground phosphate rock.

No soil test is carried out for nitrate supplying power. In healthy balanced swards, the clover constituent supplies the nitrogen, though

in winter nitrogen applications might stimulate grass growth to advantage. On field crops and grasses sap tests afford a useful indication.

Soil tests in practice

The soil testing service has now been operating on a wide scale for some three years. The most dramatic results have been obtained through the revealing of unsuspected potash deficiencies. Changes in manurial practice recommended in certain affected dairy farms have led to increases in production of butter fat of the order of 20%.

Soil testing has proved useful:

(1) By showing where lime, phosphate or potash are needed.
(2) By showing where they are not needed, thus ensuring that limited supplies are not expended needlessly.
(3) By showing an adequacy of lime phosphate and potash in certain cases of low pasture production and thus drawing attention to other mineral deficiencies or poor pasture management.

At present, a staff of three in the laboratory is handling 8,000 samples a year supplied from all parts of New Zealand by Field Officers. Clerical and recording work has been reduced to the minimum through use of appropriate forms. Apparatus permitting numbers of samples to be treated as a unit has speeded up laboratory work. In the field more speedy and effective sampling has been achieved by the design of a suitable implement. The insistence that qualified Extension Officers take all samples is at present restricting the number dealt with. The precaution is considered to be warranted in the running of a sound advisory service.

REFERENCES

(1) DYER, B. *Trans. Chem. Soc.*, **65**, 115-165 (1894).
(2) BRAY, R. H. and KURTZ, L. T. *Soil Sci.*, **59**, 39-45 (1945).
(3) EGNÉR, H. Medd. Cent-Anst. Forsoksv. Jordbr. 425 (1932).
(4) TRUOG, E. *J. Amer. Soc. Agron.*, **22**, 874-882 (1930).
(5) THORNTON, S. F., CONNOR, S. D., and FRASER, R. R. Circular 204, Purdue Agric. Exptl. Stn., Indiana (1945).
(6) PIPER, C. S. "Soil and Plant Analysis," 195 (1944).
(7) STOUT, P. R., MEAGHER, W. R., PEARSON, G. A. and JOHNSON, C. M. *Plant and Soil*, **III**, 51-87 (1951).
(8) See above p. 65.
(9) See STEWART, R. Tech. Comm. 25, Imp. Bur. Soil Sci.
(10) MORGAN, M. F. Conn. Agric. Exptl. Stn., Bull., 450 (1941).
(11) HOGG, D. E. (unpublished data).

METHODS OF SOIL FERTILITY EVALUATION USED IN NORWAY

J. LÅG

The Agricultural College of Norway, Vollebekk Norway

The first laboratory method employed in Norway for soil fertility evaluation on a practical scale, was the determination of the nutrients after extraction of the soil sample with a cold solution of 10% hydrochloric acid for 48 hours. The method was developed by the Norwegian chemists V. A. DIRCKS and Fr. WERENSKIOLD in 1883–1884. Especially in the nineties, it seems that a few scientists regarded this method as very promising. Afterwards, however, no close correlation was found between the analytical figures and the excess of yield for the addition of the element in question to the mineral soils. Accordingly, the method was never widely used.

Determination of the total content of nutrients in peat and muck soils has to some extent been used for a long time in connection with fertility questions. By a comparison of figures from chemical analyses and field experiments, it has been found that it seldom pays to lime soils with a content of calcium exceeding 3,500 kg. CaO per hectare down to a depth of 20 cm. If the content is less than 2,500–3,000 kg., liming will, as a rule, be profitable (HOVD, 1932). Determination of total nitrogen in soils of organic origin has been used in a small measure for orientation concerning nitrogen fertilization, particularly with a view to reclamation for cultivation.

The studies on soil testing methods on a larger scale were first started in connection with lime problems. HEGGENHOUGEN (1923) published a new method for determination of the lime status. His idea was to find a measure of the so-called degree of base saturation. Only exchangeable calcium and release of hydrogen ions, effected by raising the pH to 7, were determined. The figure calculated by this method was named X-value. To the ordinary laboratory method HEGGENHOUGEN added a rapid field method, which was thought to give approximately the same figures. Even earlier, the determination of calcium soluble in 10% NH_4Cl—a part of HEGGENHOUGEN'S analysis—had been carried out for the estimation of the lime requirement. The analysis was done according to MEYER (1900) and is still employed in some degree. Later, also, 1 n. NH_4Cl and solutions of other neutral salts have come into use. pH-determinations have been used to some extent in the evaluation of the lime status and in a few cases attempts have been made to predict the required amount of lime on the basis of titration curves. The reaction determination, however, has been of relatively small importance in Norway. Much of the cultivated soils have a pH between 5·0 and 6·5 (LÅG, 1947), and it has been proved that in this interval a pH-determination alone cannot give complete information about the lime requirement. A new method used recently is EGNÉR'S (1948) determination of the so-called base number. Some other methods have also been tried in connection with research work.

The correlation between analytical figures and excess of yield has been studied in connection with some field experiments with lime. HASUND (1916) found very little relation between the *Azotobacter*-test

and the litmus-test on one side and the field experiments on the other. GLØMME (1920) has later drawn a similar conclusion. LØVØ (1934) has published results from lime experiments in the rural districts of Møre and Trøndelag. For nearly a hundred field experiments, averaging more than 4 years, he found the following values for the correlation coefficient, comparing the excess of yield with different chemical methods:

X-value	−0·493
NH_4Cl-soluble Ca, per cent. of loss on ignition ..	−0·467
NH_4Cl-soluble Ca, per cent. of dry matter ..	−0·198
pH	−0·383

SOLBERG (1937) has done similar investigations in experiments in Vestfold and Akershus. He found the following correlations between excess of yield and analytical figures for 35 field experiments, extending over an average of a little more than 5 years:

X-value	$-0{\cdot}67\pm0{\cdot}089$
NH_4Cl-soluble Ca, per cent. of the sample for analysis	$-0{\cdot}52\pm0{\cdot}115$
NH_4Cl-soluble Ca, per cent. of loss on ignition + clay	$-0{\cdot}42\pm0{\cdot}16$
pH	$-0{\cdot}35\pm0{\cdot}14$

When the X-value was determined by the field method, the correlation coefficient was − 0·41. Both in the series of LØVØ (1934) and SOLBERG (1937) 10% NH_4Cl was used for extraction. Comparison between base number and results of field experiments has not yet been published.

From the beginning of the thirties, interest in rapid methods for determination of the requirement of ordinary fertilizers increased. The Danish (BONDORFF and STEENBJERG, 1932, BONDORFF, 1935, and later publications), and especially the Swedish methods (EGNÉR, 1932, 1940, EGNÉR, KÖHLER and NYDAHL, 1938) received great attention. Electrodialysis was tried in comparison with a few field experiments (LØDDESØL, 1934, HOVDEN, 1937), but did not give a close correlation. Later, also, RIEHM'S (1943) modification of EGNÉR'S lactate method came into use in the determination of potassium. Measurement of the electrical conductivity in greenhouse soils has been frequently done. Besides, a few scattered determinations using other, especially rapid American methods, have been carried out. EGNÉR'S methods, however, are much more commonly used than the others.

So far only a few comparisons between analytical figures from such methods and field experiment results have been published. However, data from phosphorus and potassium fertilizer experiments in 400–500 fields, all of which were harvested more than once, are now investigated.

Attention has also been drawn to the problems pertaining to the analysis of micro-nutrients. Some analyses have been carried out with methods developed in Denmark, Sweden, and America. Moreover, at the State Agrochemical Testing Station at Trondheim, methods have been worked our for boron (BRAADLIE and MOEN, 1942), copper,

zinc, manganese, and iron (BRAADLIE and BERGH, 1942), and molybdenum (BRAADLIE and BERGH, 1945). For the determination of boron the extraction is made with monochloracetic acid—as EGNÉR's potassium method, for copper, zinc, manganese, and iron with magnesium sulphate, and for molybdenum with hydrochloric acid after oxidation of the organic matter. The methods have only on a very small scale been compared with investigations in the field.

Analyses of plant material for fertility problems in the agriculture have not been employed to any significant extent.

Soil testing has not yet been used much in Norway. Most of the analyses are being carried out at the laboratory of the State Soil Investigation, The Agricultural College of Norway. In the last year, this laboratory received more than 8,000 samples for determination of pH, and easily soluble phosphorus and potassium, according to EGNÉR. In addition, other determinations were carried out for some of the samples, e.g., base number, mechanical composition, humus content, and volume weight. This laboratory has not analysed micro-nutrients for the purpose of guidance in practical agriculture. The State Agrochemical Testing Station at Trondheim has, in recent years, analysed more than 1,000 soil samples. In distinction from the State Soil Investigation, the laboratory at Trondheim has determined potassium after RIEHM's modification of EGNÉR's lactate method. The latter institution has also received some samples for determination of micro-nutrients. The laboratory of the State Experimental Farm Holt near Tromsø has performed some analyses for the northernmost part of the country. In addition, analyses have been carried out at other state laboratories, but these samples are relatively few in number. The collecting of soil samples is mostly organized by the advisers in agriculture. A few horticulturists have made private arrangements for soil testing.

Field experiments are commonly used in order to settle soil fertility questions. In the literature up to 1940, I have found the following number of experiments:

	Fields	Number of yields harvested
On experimental farms	401	1,160
On agricultural schools	245	592
In other places	4,002	7,915
	4,648	9,667

More than two-thirds of these experiments were published in the years 1920–1940. As an average for this period, results have been printed yearly from one field experiment, harvested a little more than 2 years, for every 4,300 hectares of cultivated land.

The experimental fields can be divided into the following groups:

	Number	%
Experiments with only artificial fertilizers ...	3,154	68
,, ,, only farmyard manure ...	68	1
,, ,, artificial fertilizers and farmyard manure	490	15
,, ,, lime	435	9
,, ,, lime and fertilizers... ...	301	7
	4,648	100

Qualitative and quantitative experiments have been carried out on about two-thirds of the fields and comparative experiments were done on about one-third of the fields used for artificial fertilizers.

Most likely the number of published field experiments is a little higher than the figures in these tables show, as I have probably overlooked some. In addition, numerous unpublished trials have been carried out.

In order to facilitate a comparison of the above material with figures from other countries, it can be mentioned that the area of cultivated land in Norway in 1949 was only 0·81 million hectares.

LITERATURE

BONDORFF, K. A. Kationombytning i Jorden. I.—284. Beretn. fra Statens Forsøgsvirksomhed i Plantekultur. *Tidsskr. for Planteavl.*, **40**, 767-796 (1935).

BONDORFF, K. A. og STEENBJERG, F. Studier over Jordens Fosforsyreindhold. I. Jordfosforsyrens Opløselighed.–256. Beretn. fra Statens Forsøgsvirksomhed i Plantekultur. *Tidsskr. for Planteavl.*, **38**, 273-308 (1932).

BRAADLIE, O. Innhold av fosforsyre og kali i myrjord, bestemt ved Egnérs laktatmetode og Nydahls klorkalsiummetode. *Medd. fra Det. Norske Myrselskap.*, **33**, 23-30 og 53-61 (1935).

BRAADLIE, O. og MOEN, A. Kolorimetrisk borbestemmelse i jord. *Tidsskr. for kjemi, bergvesen og metallurgi*, **2**, 37-38 (1942).

BRAADLIE, O. og BERGH, H. Kolorimetrisk bestemmelse av bly, kopper, sink, mangan og jern i jord, plantedeler, nærings-midler osv. *Tidsskr. for kjemi, bergvesen og metallurgi*, **2**, 88-89 (1942).

BRAADLIE, O. og BERGH, H. Kolorimetrisk bestemmelse av molybden. *Tidsskr. for kjemi, bergvesen og metallurgi*, **5**, 48-49 (1945).

EGNÉR, H. Metod att bestämma lättlöslig fosforsyra i åkerjord. Medd. Nr. 425 fr. Centralanstalten för försöksväsendet på jordbruksområdet. Avdelningen för lantbrukskemi Nr. 51. 36 pp. (Stockholm, 1932). (Summary : A method to determine easily soluble phosphate in cultivated soils.)

EGNÉR, H. Bestimmung der Kalibedürftigkeit des Bodens auf chemischem Wege. *Bodenkunde und Pflanzenernährung*, **21-22**, 270-277 (1940).

EGNÉR, H. Jordanalyser och fältförsök. Några nya laboratorie-undersökningar. Beretn. om Nordiske Jordbrugsforskeres Forenings Syvende Kongres, Oslo, Juli, 1947, **3**, 765-770 (København, 1948).

EGNÉR, H., KÖHLER, G. und NYDAHL, F. Die Laktatmethode zur Bestimmung leichtlöslicher Phosphorsäure in Ackerböden. *Lantbrukshögskolans Annaler*, **6**, 253-298 (1938).

GLØMME, H. Om Kalkning. Jordbundsudvalgets smaaskr. nr. 10, 104 pp. (Kristiania, 1920).

HASUND, S. Forevisende forsøk med kalking og gjødsling på høivold. Beretn. om Norges Landbrukshøiskoles virksomhet 1914-1915, 15-22 (Kristiania, 1916).

HEGGENHOUGEN, S. Kalkens anvendelse i landbruket. Jordundersøkelsens småskr. nr. 12, 47 pp. (Kristiania, 1923). (English summary.)

HOVD, A. Kalking på myr. Resultater av eldre og nyare forsøk. Melding om det 22de og 23de arbeidsåret 1929 og 1930 ved Det Norske Myrselskaps forsøksstasjon, 56-80 (Oslo, 1932).

HOVDEN, A. A. Kjemiske undersøkninger av jord på langvarige gjødslingsfelter og noen andre jordprøver.—Meld. fra Statens forsøksgård pa Møistad for 1936. 103 pp. Tillegg H til Meld. . . . utg. av Landbruksdirektøren. (Oslo, 1937). (Summary : Chemical investigations in connection with permanent fertilization experiments.)

LØDDESØL, AA. Orienterende undersøkelser over sammenhengen mellem gjødsling og jordens innhold av lett tilgjengelige plantenæringsstoffer. *Meld. fra Norges Landbrukshøiskole*, **14**, 323-375 (1934). (Summary : Preliminary investigations of the connection between fertilization and the content of readily accessible plant nutrients in the soil.)

LØVØ, P. J. Resultater av forsøk med kalkning i Trøndelag og Møre. Meld fra Statens Forsøksgård på Voll 1932-33, 13-108 (Oslo, 1934). (Deutsche Zusammenfassung).

LÅG, J. Undersøkelser over innholdet av lettoppløselig fosfor og reaksjonen i jorda på en del gårder i østfold og Akershus. *Meld fra Norges Landbrukshøgskole*, **27**, 1-83 (1947). (Summary: Investigations on the acid lactate-soluble phosphorus and the reaction of the soils of some farms in østfold and Akershus in Norway.)

MEYER, D. Die Kalkverbindungen der Ackererden und die Bestimmung des assimilierbaren Kalkes im Boden. *Landwirtschaftliche Jahrbücher*, **29**, 913-1000 (1900).

RIEHM, H. Bestimmung der Kalibedürftigkeit des Bodens aus dem Kaligehalt des Laktatextraktes. *Bodenkunde und Pflanzenernährung*, **31**, 346-356 (1943).

SEMB, G. Undersøkelser over nøyaktigheten ved bestemmelse av lettoppløselig kalium og fosforsyre i jordprøver. *Meld. fra Norges Landbrukshøgskole*, **30**, 291-312 (1950). (Summary: Investigations of the analytical accuracy of soluble-potassium and phosphoric-acid determinations in soil samples.)

SOLBERG, P. Bidrag til karakterisering av kalktrangen innen Akershus og Vestfold ved hjelp av jordanalyser. *Meld. fra Norges Landbrukshøiskole*, **17**, 356-371 (1937). (Zusammenfassung: Beiträge zum Charakterisieren des Kalkbedürfnisses innerhalb Akershus und Vestfold durch Bodenanalysen.)

ØDELIEN, M. Gjødslingsforsøk på eng. *Meld. fra Norges Landbrukshøgskole*, **24**, 159-228 (1944). (Summary: Fertilization experiments on temporary hay land.)

THE EVALUATION OF THE AVAILABLE PHOSPHATE STATUS OF AGRICULTURAL SOILS IN NORTHERN IRELAND

S. McCONAGHY AND J. S. V. McALLISTER

The Queen's University, Belfast, and Ministry of Agriculture, Northern Ireland

The Soils Advisory Service of the Ministry of Agriculture, Northern Ireland, is available to all farmers who wish to have information and advice on the lime and manurial status of their soils. Among the rapid methods adopted in assessing the available phosphate status of these soils, that most commonly used is a modification of EGNÉR'S method. The extractant solution is 0·02 normal with respect to calcium lactate and 0·02 normal with respect to hydrochloric acid, i.e., twice the acid concentration of the original EGNÉR extractant. This increased acid concentration results in somewhat higher phosphate values, the normal range being from 0 to about 15 mgm. P_2O_5 per 100 g. soil, compared with 0 to about 10 mgm. per 100 g. soil with the EGNÉR extractant. An indication of the actual differences in amounts of phosphate which may be removed by the two extractants is given in Fig. 1 using data obtained with some Northern Ireland soils of different phosphate status. Normally the differences are appreciable only at higher phosphate levels.

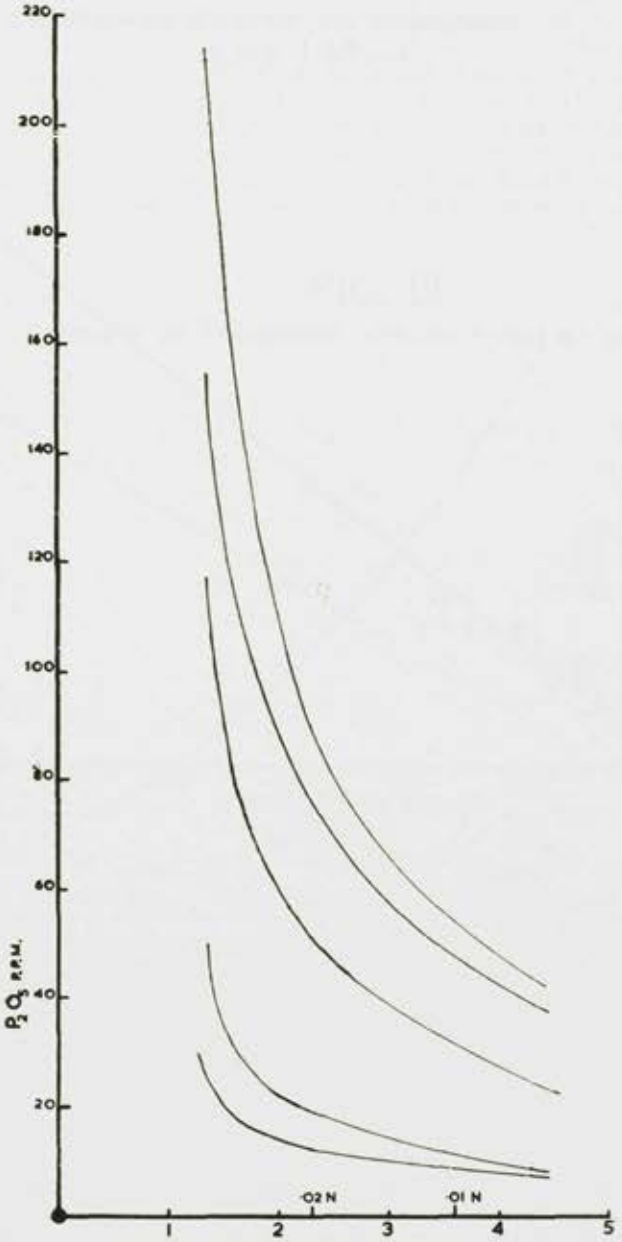
Comparison of results with different extractants

Under Northern Ireland conditions the results with the modified EGNÉR extractant have been found to agree fairly closely with those obtained using $\frac{N}{2}$ acetic acid. In Fig. II the modified EGNÉR phosphate values for a series of basaltic soils and for a series of acid schistose soils are compared with phosphate values as determined using $\frac{N}{2}$ acetic acid as extractant.

While there are differences in the amounts of phosphate extracted by the two methods, especially from phosphate deficient basaltic soils, the differences are of little significance in determining the phosphate grouping of particular soils and would not normally affect manurial recommendations.

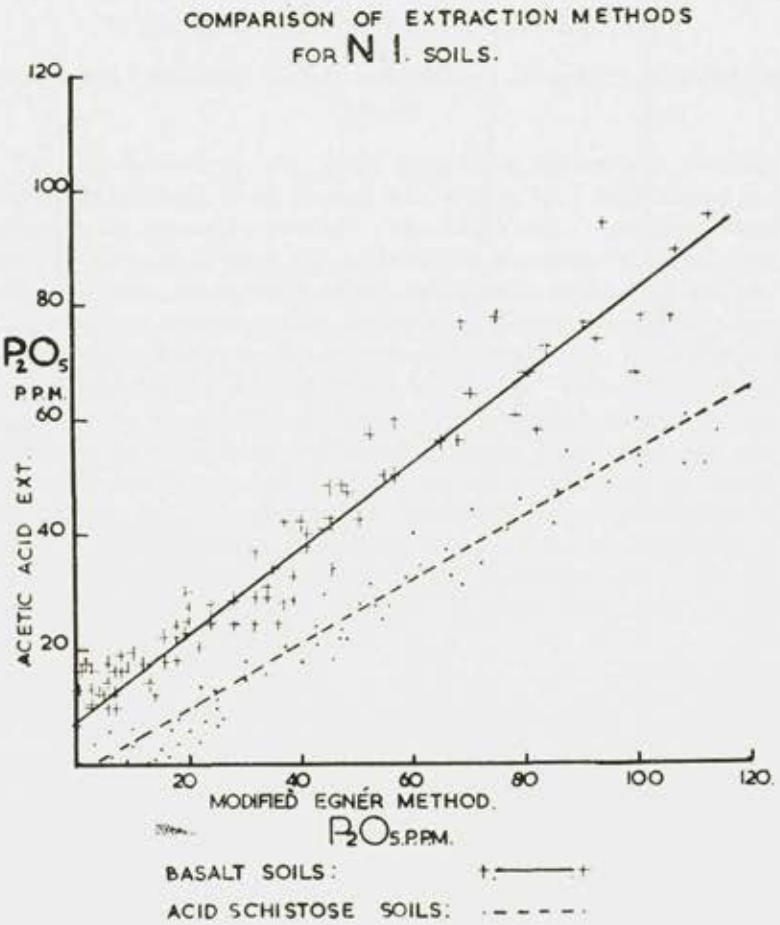
Citric acid has been found to be of relatively little value in assessing the available phosphate status of Northern Ireland soils though McALLISTER (1952) has found it useful in pot experiments with a well-limed soil, as a means of recovering applied phosphate in quantities which correlate well with phosphate recoveries by perennial ryegrass.

FIG. 1



EFFECT ON P_2O_5 REMOVAL OF ACID CONCENTRATION OF EXTRACTING SOLUTION

FIG. 11

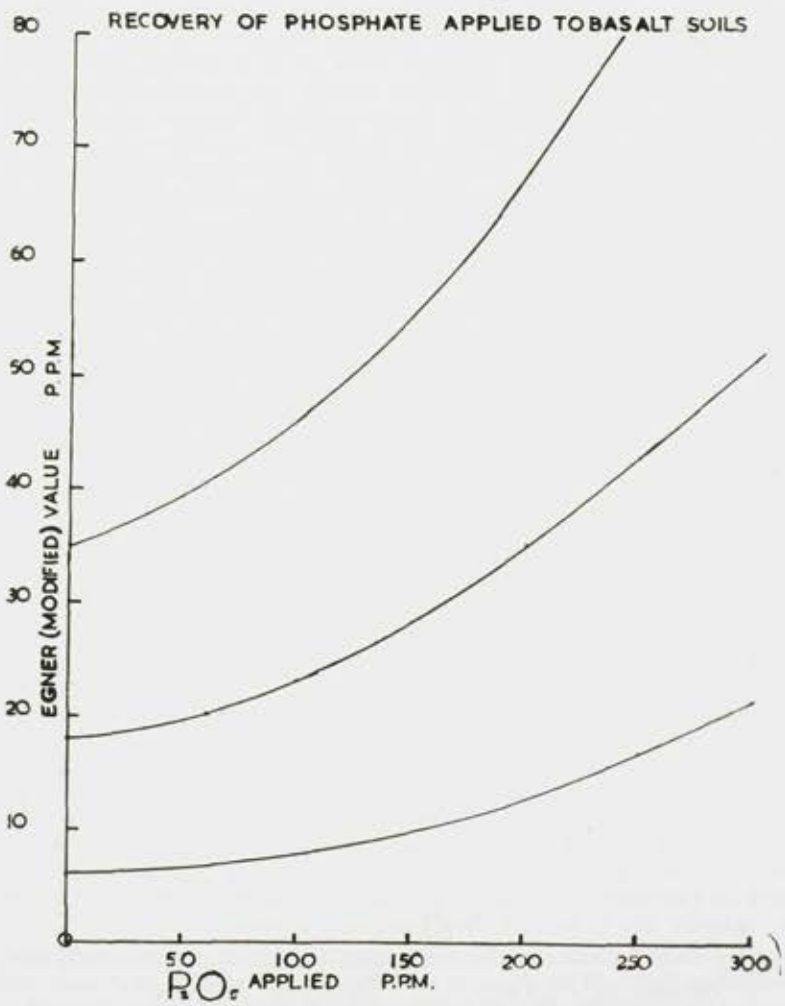


In general, however, there is a poor correlation between the citric soluble and modified EGNÉR soluble soil phosphate values, and the modified EGNÉR values usually agree more closely with the phosphate status as determined in the field. These results are in agreement with those of WILLIAMS and STEWART (1943), who found that EGNÉR extractable phosphate values agreed fairly closely with acetic soluble phosphate values for Scottish soils and that phosphate uptake by plants in pot and laboratory experiments correlated more closely with EGNÉR values than with soil phosphate values determined by other rapid methods. And as practically all the agricultural soils in Northern Ireland are acid in reaction—only 6% having pH values above 6·4—the results also agree with CROWTHER'S (1946) findings that acetic acid is a more suitable extractant for acid soils than citric acid which is the more satisfactory for well-limed soils.

Recovery of added phosphate

At low levels of phosphate applications such as those normally applied in the field the use of any of the dilute acid extractants is not an efficient means of indicating availability of added phosphates, especially on phosphate deficient soils. In pot experiments, where applied phosphates can be uniformly mixed throughout the soil, it may be possible by the modified EGNÉR technique to detect the addition of phosphate at levels of P_2O_5 of over 50 p.p.m., a figure equivalent to about 5 cwt. superphosphate per acre. But under field conditions, with such phosphate deficient soils the modified EGNÉR values may not show any appreciable increase even with dressings of phosphate

FIG. III



equivalent to 10 cwt. superphosphate per acre. An indication of the types of curves obtained for some Northern Ireland soils is given in Fig. III.

On soils with low phosphate status, successive small increments of phosphate show no significant increase in the EGNÉR (modified) values though crops show high responses to such small dressings. At levels when the EGNÉR (modified) values increase with further increases in applied phosphate, crops may no longer show any further response. On less deficient soils, however, crops usually do show a response to phosphate at levels which also show as increased EGNÉR values.

Plant analysis

Plant analysis is often considered to be superior to soil analysis as a means of diagnosis of soil fertility. There is no doubt that on phosphate deficient soils the phosphate content of young leaves or petioles of crops usually show low values though the actual values vary somewhat according to other nutrient levels. Furthermore, applications of phosphate to such deficient soils noticeably increase the phosphate contents of the foliage within limits, determined to some extent by actual phosphate levels and by nutrient interaction. The effects of such interaction of nutrients and of other factors, such as physiological state of growth, diseases and the variations of phosphate contents of different parts of a single plant, all combine to make necessary a very careful interpretation of results. The method, however, when properly used is extremely useful for work both on so-called " major " and " minor " elements and is especially successful within single experiments, from which plant material under different manurial levels can be obtained for analysis. In this respect, it has been found in Northern Ireland to be more sensitive than any of the rapid soil analysis techniques. This is illustrated in Fig. IV by the results from potato experiments in Northern Ireland on three different soils where the EGNÉR (modified) extractable phosphate values were not appreciably affected by the different levels of superphosphate applied. Fig. V also shows the increases in phosphate contents and in yields of Swedes by increasing dressings of superphosphate on a County Down soil, whose EGNÉR phosphate value was not increased by the treatment.

But the EGNÉR (modified) values obtained for these soils before the experiments were laid down indicated that two of the potato soils and the Swede soil were deficient in phosphate and likely to give good responses to applied phosphate while the results of plant analyses merely confirmed this. Plant analyses also confirmed merely what was already obvious by visual inspection of the growing crops. In some cases plant analysis may reveal deficiencies or abnormal nutrient levels which may not be easily recognisable in the growing crop, but by the time the foliage is available for analysis it is often too late to remedy the defect in that particular season.

And so the plant analysis technique, though it can be much more sensitive than soil analysis, is used mainly in experimental work and only to a limited extent for advisory purposes in Northern Ireland.

EGNÉR *values and crop yields*

Where a method of soil analysis is first introduced, the interpretation of results is based on crop growth data under relatively local conditions. The same method may only be of value elsewhere by using a somewhat different interpretation of results or it may be found to be of limited value under different soil, climatic, and crop conditions, no matter how the results may be interpreted. It is sometimes necessary, however, to adopt a method before exhaustive tests of its " local " value can be made, but such tests must be made sooner or later. When the modified EGNÉR method was adopted in Northern Ireland for routine use during the early part of the last war, no exhaustive local tests of the value of the method had been possible and the success of the method had to be assumed from knowledge of the use of a similar method elsewhere. But during the last ten or eleven years it has been possible to make a fairly clear assessment of the advantages and disadvantages of the technique as used in the province. Field and laboratory pot experiments have directly or indirectly given useful data in this respect, but though relatively large numbers of experiments have been conducted, no large number has been conducted on any one crop and most of the soils have been low or relatively low in " available " phosphate. In Fig. VI the results of some of these experiments on potato crops have been used to indicate the degree of correlation between results in the field and EGNÉR (modified) values. The soils concerned were mainly medium loams in texture but they

FIG. IV

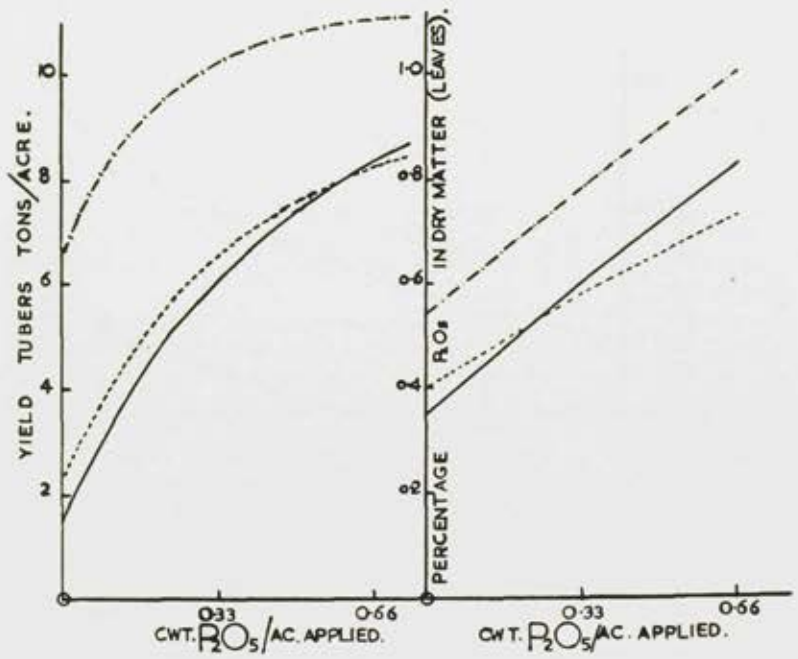


FIG. V.

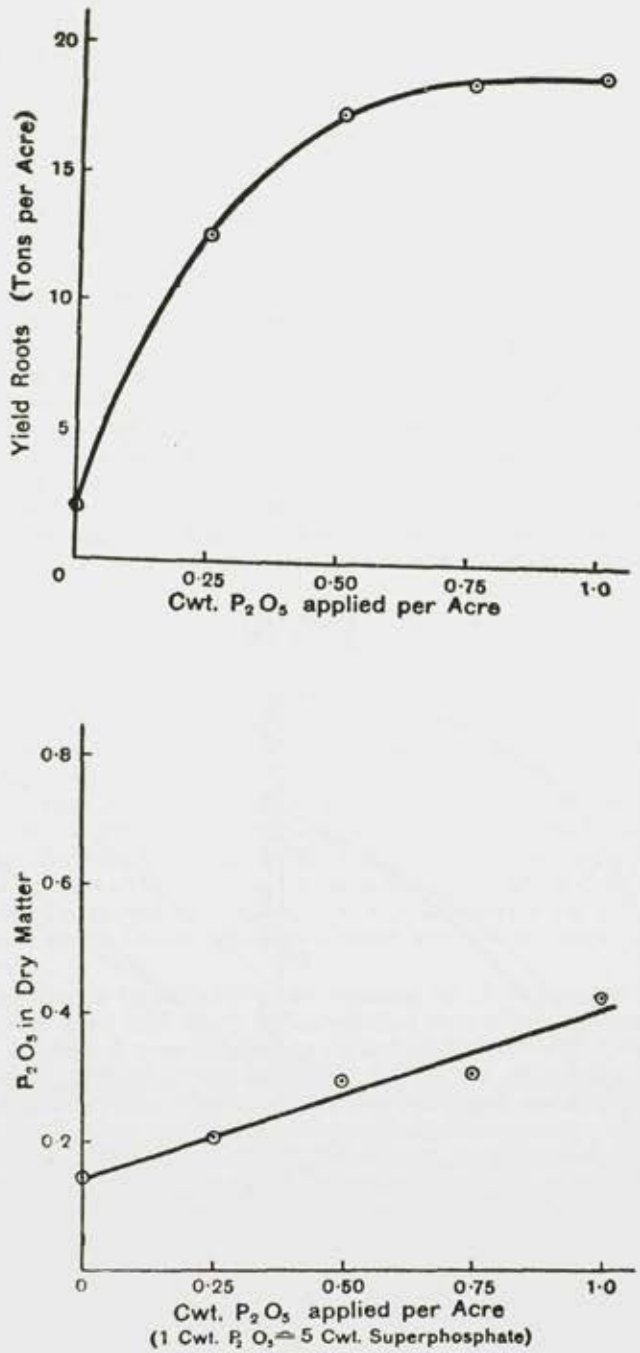
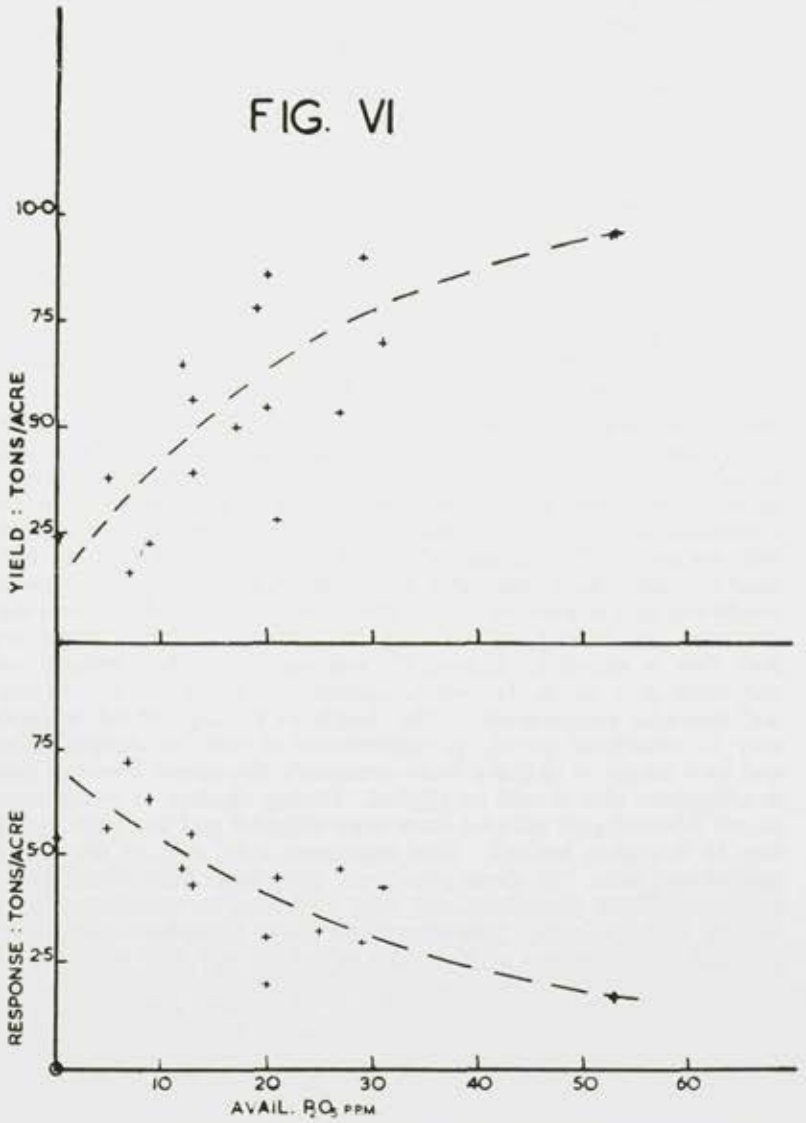

Yield Roots (Tons per Acre)
20
15
10
5
0
0·25
0·50
0·75
1·0
Cwt. P_2O_5 applied per Acre
P_2O_5 in Dry Matter
0·8
0·6
0·4
0·2
0
0·25
0·50
0·75
1·0
Cwt. P_2O_5 applied per Acre
(1 Cwt. P_2O_5 ≙ 5 Cwt. Superphosphate)

FIG. VI



RELATIONSHIP BETWEEN SOIL PHOSPHATE STATUS AND
(A) YIELD OF POTATOES WITH NO PHOSPHATE APPLIED
(B) RESPONSE TO APPLIED PHOSPHATE (0·66 CWT. P_2O_5/AC.)

differed considerably in lime status for which no correction factor has been made. The results were collected over a number of seasons, but many more experiments are desirable with each main crop over a wider range of soil phosphate status and over a longer period of years. The results recorded in Fig. VI support most of the general findings on the EGNÉR method as used in Northern Ireland:—

(1) that it is very satisfactory for indicating phosphate deficient soils;

(2) that it is satisfactory for grouping soils into the phosphate classes such as low, medium, high, and very high;

(3) that it is not sufficiently sensitive to warrant the use of a large number of phosphate classes or groups, i.e., to subdivide, for example, the "low" class into "very low," "low" and "medium low";

(4) that the EGNÉR values are not appreciably affected by the application of light annual applications of phosphate, especially on the more deficient soils.

The chances are small that this EGNÉR technique will wrongly classify an agricultural soil as regards phosphate status and the use of this method with the system adopted under the Soils Advisory Service in Northern Ireland makes it extremely unlikely for farmers to receive unsuitable advice or recommendations. All requests received for analysis are dealt with and all soil samples are collected by fully qualified agriculture graduates with considerable experience of local conditions and farming practice. They obtain full details of cropping, manurial and liming history over the previous rotation for every field that is sampled. Indeed the soil sampling officer usually can and often does advise farmers adequately on the spot on both lime and manurial requirements. The results of subsequent soil analysis may be considered mainly as confirmation of such recommendations and as a means of defining more accurately the actual levels of lime or phosphate that should be applied. During the last 11 years, some 52,000 advisory soil samples have been sampled and analysed in this way in Northern Ireland. This represents over 10% of the actual agricultural soils. Of these soils, over 55% have been found to be low in available phosphate and only 17% can be considered satisfactory in this respect. Soils considered low in phosphate status have modified EGNÉR values of less than 30 p.p.m. and field experiments in the province have repeatedly shown that on such soils a dressing of about 3½–4 cwt. superphosphate per acre in the absence of dung gives an average increase of about 15 tons per acre of Swedes and an increase of over 4 tons per acre of potatoes.

There is no doubt that in Northern Ireland the EGNÉR phosphate determinations have given a reliable indication of the phosphate status of the soils. The fact that only a very small proportion (17%) of the soils have a satisfactory phosphate status does raise the question as to whether there is a continued need for such determinations in making recommendations to farmers for individual crops. It has been proved fairly conclusively that standard recommendations of phosphate in all cases would be nearly right in 90% of the cases and in the other 10% the standard dressings would certainly do no harm.

The number of requests by farmers for soil analysis is at present considerable and shows every indication of continuing to increase, but we are hoping to economise gradually on the time and labour required for the analysis of advisory samples and so enable the staff and facilities to be used more on soil survey and fundamental work.

REFERENCES

CROWTHER, E. M. Rothamsted Experimental Station Report for the War Years, 1939-1945, 50-61 (1946).

WILLIAMS, E. G. and STEWART, A. B. Studies on phosphate fixation in Scottish soils. *J. Agr. Sci.*, **33**, Part 4, 179 (1943).

MCALLISTER, J. S. V. Unpublished data (1952).

EVALUATION OF SOIL ANALYSIS FOR ADVISORY PURPOSES

N. H. PIZER

National Agricultural Advisory Service, Ministry of Agriculture and Fisheries, Cambridge, England

The Soil Chemist in the National Agricultural Advisory Service is concerned with the broad field of crop nutrition and the influence of soil conditions on crop growth and productivity. Cropping changes over the country with changes in soil and climate and the level of farming. My experience has been in the drier eastern and south-eastern parts of Britain, in typical gently undulating country with large stretches of low upland, dissected by broad, gently sloping valleys, which widen out and open on to large areas of low-lying fertile land. There are no mountain or moorland areas in the region. These lie well to the west and north-west and have very different soil types and cropping problems of which I can say very little.

The soils in the east and south-east of Britain are mostly derived from superficial deposits of glacial or alluvial origin overlying a series of rocks which go back in geological history from the present to Jurassic times. Parts of the upland areas have been in cultivation for thousands of years and parts of the lowland areas bordering the sea have only recently been reclaimed and cultivated. The greater part of the region, however, was under broad-leaved forest until a few centuries ago and the soils show evidence of this, and, in places, of previous podsolization under pine and birch forest in the Boreal Period. In the last fifteen years, large areas of ancient heathland with sandy, podsolized soils have been cleared, limed and brought into cultivation. Extensive areas of Fen Peat have been in cultivation since the Fens were drained in the 17th, 18th and 19th centuries, and have been under intensive arable cropping during the last fifty years; remaining areas of Fen Peat under bushes and sedges or under carr vegetation are being cleared and have their own particular problems. There is thus variety and diversity in the soils in the region due to age, parent materials, the influence of topography, previous vegetative cover and length of time under cultivation. The soils of neighbouring fields often differ considerably, in fact, many of the old field boundaries mark big changes in soil type, and within field boundaries, important variations in the soil commonly occur.

The main differences in the soils are in amount and distribution of organic matter, in depth, drainage, consolidation, texture and structure —factors which influence root range and moisture supply—and in acidity, mineral nutrients and nitrogen. When soil and crop problems are examined, all these factors are taken into account, together with the condition of growing crops and the level of farming, and an endeavour is made to assess the potential cropping capacity of the land, what is needed to improve it and what is feasible to recommend.

Soil analysis is used to determine calcium carbonate, pH, lime-requirement, exchangeable bases—calcium, magnesium, potassium, sodium, ammonium, manganese and aluminium—sulphate, nitrate, nitrite, total nitrogen, organic matter, available phosphate, conductivity or pC, and sometimes borate, chlorate, zinc and other

substances, when they are thought to be present in toxic amounts.

Other diagnostic methods are also used—the visual symptoms shown by crops, application of solid nutrients or solutions of nutrients to the soil, injection of the crop plant with mineral nutrients; application of mineral nutrients in solution in water as foliage sprays; and petiole or leaf analysis.

The extent to which these methods are used depends on the problem. Visual examination of the soil profile by means of a soil auger, handling the soil, the symptoms of crops, and soil analysis are the chief ones, and they provide sufficient information in most instances. The other methods are used for unusual and difficult problems, but it is my belief that they would be used more frequently if greater facilities and staff were available, for they often give more positive evidence of the nutritional requirements of crops than the methods commonly used.

There are many inherent difficulties in the use of soil analysis which are absent from most of the other methods mentioned. There are the uncertainties as to what is actually being measured and whether a method of analysis is applicable to a wide range of soil types and conditions; the effects of seasonal changes in the soil; variations in the soil over a field; and changes in the soil with depth. There are the different nutritional requirements of a large number of crops; different rooting habits and relative ability to absorb nutrients under difficult conditions. The latter often shows up strikingly among varieties of the same crop as, for example, the ability of Du Puit lucerne to grow well on a soil on which Provence varieties fail from potassium deficiency.

Added to these difficulties are the problems in the laboratory of dealing rapidly with large numbers of soil samples. Methods of analysis must be simple and rapid in operation, require little space and be suitable for use on an open bench, so that the most effective arrangement and sequence of operations can be used. Methods virtually stand or fall by these requirements and much analytical skill and ingenuity has been put into simplifying promising, but difficult, methods of analysis and bringing them into general use. Perhaps the most outstanding example of this is the determination of soil potassium which, from being lengthy and subject to many errors, was simplified and made more accurate, but did not become rapid until the flame photometer was recently introduced. High accuracy is seldom necessary in advisory work, but consistency is essential. Methods such as the determination of organic matter by wet-digestion may not be very accurate, but if they give the same result consistently, they may be of value for comparing one soil with another. There is no place for methods which have been simplified by omitting essential steps until there is uncertainty whether the element being estimated is present in low or moderate amount or even present at all.

With slow or difficult methods of analysis, very few soils and crops can be examined in one season. Evaluation of the method must, therefore, take a very long time and very little information can be obtained on seasonal effects, particularly where both soils and crops are varied, for methods must eventually be proved suitable for each crop and each class of soil.

The advisory problems in which soil analysis has been found to provide useful information are :– (1) Failures of crops due to nutritional deficiencies ; failures due to acidity or alkalinity ; failures due to excessive amounts of a nutrient or of soluble salts : (2) suitability of new land for reclamation and cropping : (3) fertility levels over farms : (4) manuring of crops and changes in manurial programmes.

The crops grown in the eastern counties and elsewhere in the country are many and varied. There are more than thirty different farm crops, numerous varieties of soft fruit, tree fruits on different stocks, vegetable crops, crops grown for seed, bulbs and crops under glass. The difficulties and length of time needed to evaluate a method of analysis for so many crops and types of soil must be obvious to all.

Evaluation of a method of analysis is a slow, continuous process. It begins with the collection of results for a large number of soils on which crops have failed and crop symptoms show the likely cause of failure. The soil conditions affecting root development and moisture supply are also recorded and, in due course, the levels at which crops fail under different soil conditions are established. The next stage is comparison of results of analysis in poor and good areas of a crop, and recording of soil conditions. Eventually, the critical levels between poor and good cropping under different soil conditions are ascertained, but the method is not free from difficulties. If the soil conditions are much better in the good areas, the results of analysis may be lower than in the poor areas, simply because better crops year by year, remove more from the soil than poor crops. Examination of soil conditions is thus essential for the successful use of this method and allows doubtful results to be discarded. So far the differences between crops have been sufficiently great to be easily visible. In the next stages, which are assessment of the levels at which good crops are obtained and the levels above which crops do not respond to fertilizers, the differences are not always easily visible and field experiments are ultimately necessary to measure them. A first approximation to the levels at which good crops are obtained can be made by analysing soils in which good crops are being grown without application of the appropriate fertilizer. Some soils are naturally in this condition, but most soils will have had fertilizer for previous crops, and the crop being grown will be feeding on fertilizer residues as well as on nutrients that are derived from the soil. The difficulties of interpretation of analytical results are, therefore, greater, but if the two conditions are examined separately, information is obtained for dealing with them when they are met with in the field.

The stages in the evaluation of a method of soil analysis may be illustrated by the method for determining available potassium. As a measure of available potassium we are using the potassium in a given volume of soil which is readily replaceable by other bases. Volume is preferred to weight of soil, because the soil types of the region show a very wide range in specific volume. Many of our crops have a high demand for potassium which must be supplied to them in a relatively short time, and it is doubtful whether other forms than replaceable potassium are of much value to them.

The method of determining replaceable potassium had to be suitable for a wide range of acid and calcareous mineral soils and acid and calcareous heath and fen peats. A number of methods were examined,

including the effect of the cation and the anion in the extracting liquid. Eventually, it was found that the highest extraction of potassium from our soils was given by ammonium salts and that ammonium nitrate was the best salt to use. In order to obtain consistent results, the texture of close-textured soils, particularly silty loams, silt loams and silty clay loams had to be lightened and made open by the addition of silver sand. 8 ml. (the average volume of 10 gms. of loam) of air-dried soil passing the 2 mm. sieve are mixed with silver sand and leached with 50 ml. of N ammonium nitrate solution. For the majority of soils, 50 ml. of ammonium nitrate is sufficient to extract 90 per cent., or more, of the replaceable potassium. For glasshouse soils and other soils that are abnormally high in K, two or three successive extractions with 50 ml. of ammonium nitrate are usually necessary. The potassium in the extract is determined by the Flame Photometer and expressed on a standard basis as parts per million of K in the extract. The results are then classified according to the following scale:

Class	Very Low	Low	Medium	Medium High	High	Very High
p.p.m. K in extract	0–19	20–29	30–39	40–49	50–65	above 65

This scale has been established in the manner already described. Visual symptoms of potassium deficiency are common in cereal crops when the value of K is less than 20 and failure of cereals occur when the value of K is less than 15. The severity of symptoms is most marked in dry seasons and in soils which are shallow or poorly drained. When considering the likely effect of a very low level of K, it is essential, therefore, to take into account the soil conditions affecting root range and moisture supply. Uneven growth and heading of cereal crops may occur when the value of K lies between 20 and 25, but good even crops are common above 25. In manurial trials on cereals, the main response to K has been obtained with soil levels up to 20 and little or nothing above 25.

Linseed, peas, sainfoin, trifolium, vetches, sugar beet, mangolds, turnips and swedes appear to behave similarly to the cereals, but higher levels of K in the soil are needed by clovers, lucerne, beans, cabbages and kales. Failures of these crops occur when the K level in the soil is 20 or under and deficiency symptoms are common up to 25; uneven cropping occurs up to 30, but the level at which response to application of K fertilizers ceases has not been ascertained. The fruit crops—blackberries, blackcurrants, loganberries, strawberries, plums, pears and cherries—appear to behave similarly to the clovers, lucerne, etc., but apples, gooseberries, raspberries and red currants appear to need a K level in the soil of 30 to avoid marked deficiency symptoms and 35 to 40 to be free from deficiency symptoms. With the tree fruits, the distribution of K in the soil has a marked effect, more K being needed in the top 6 inches when low or very low amounts of K occur in the second 6 inches. For all the fruit crops, the level of K in the soil above which response to K fertilizers ceases is not known, but with many of them adverse effects, particularly induced magnesium deficiency, may occur when the K level is above 60.

It will be apparent that the scale of classification of soil K levels is mostly a scale of levels at which deficiency symptoms appear in a range of crops. Above 40, the divisions into medium high and high become arbitrary and the upper division of very high is one in which adverse effects may appear. No comparable scale exists for other cations. In the past two years, with the introduction of a reliable and moderately rapid method for magnesium, similar data has been collected for this element. Magnesium is determined by a modification of HUNTER'S Titan Yellow method (1) in the ammonium nitrate extract prepared for the determination of potassium. So far we have found that magnesium deficiency symptoms appear in cereals, sugar-beet and brassica crops when the Mg in the extract is 5 p.p.m. or less.

The determination of available phosphate in the soil has presented many more difficulties than the determination of available potassium. We have not yet found a method that is suitable for all our soil types, particularly the fen peats and calcareous soils. We are using a modification of MORGAN'S method, adding extra acetic acid, equivalent to the calcium carbonate present in the soil, when the calcium carbonate exceeds 2·5 per cent. 4 ml. of air-dried soil passing the 2 mm. sieve are shaken with 25 ml. of N/2 acetic acid + N/2 sodium acetate solution for 15 minutes. After filtering phosphate is determined as "molybdenum blue" and expressed as parts per million of P in the extract.

The results are classified according to the following scale:—

Class	Very Low	Low	Medium	Medium High	High	Very High
p.p.m. P in extract	0–0·8	0·9–1·5	1·6–2·5	2·6–4·5	4·6–8·0	above 8·0

This scale has been established in the manner already described for potassium, but we have evidence that it will need some adjustment for non-calcareous soils and it is doubtful whether it is applicable to fen peats and very calcareous soils.

With non-calcareous mineral soils equilibrium is reached within 15 minutes between the phosphate in the soil and the phosphate in the extracting liquid. The equilibrium has been examined by shaking soil with extracting liquid containing 0, 2, 4, 6, 8, 10, 20, 30, 40, and 50 p.p.m. P as sodium monohydrogen phosphate and determining the amount of phosphate in the extracting liquid after 15 minutes. With soils containing very low amounts of available phosphate, the removal of phosphate by the soil from the extracting liquid appears to be an adsorption, which is expressed exactly by FREUNDLICK'S equation for adsorption:—

$$\frac{x}{m} = a\ C^{\frac{1}{n}}$$

where x = amount of phosphate adsorbed from solution
m = weight of air-dried soil
C = concentration of phosphate in solution at equil brium and
a and $\frac{1}{n}$ are constants.

It is considered from this evidence that adsorbed phosphate is probably being measured by the method employed, and that the figures express level of availability of phosphate to crops rather than total available phosphate.

The effect on extraction of phosphate of adding extra acetic acid to neutralize calcium carbonate in the soil has been partly examined by correlating level of phosphate in the extract with per cent. $CaCO_3$. The level of phosphate in soils containing more than 5 per cent. $CaCO_3$ was found to be generally higher than in non-calcareous soils and to rise with increase in the percentage of $CaCO_3$. It seems, therefore, that in some calcareous soils large amounts of phosphate are brought into solution from chalk fragments which, in the soil, are largely unavailable to crops. These doubts and the evidence of field experiments are compelling us to seek an alternative method of determining available phosphate.

The methods for available potassium and phosphate find wide use for ascertaining whether soils are deficient in these plant nutrients and where the chief areas of deficiency occur. For example, in the county of Norfolk, potassium deficiency in crops is more common than in other counties of the Eastern Province. 76 per cent. of soil samples from arable fields fall in the very low class for potassium and a further 15 per cent. in the low class; by contrast, 10 per cent. of soil samples from arable fields in the county of Huntingdon fall in the very low class for potassium and a further 15 per cent. in the low class.

While the recognition of deficiencies and deficient areas is of considerable value in advisory work, the farmer wishes to know how a deficiency should be dealt with, and at what levels of available potassium and phosphate he may withold fertilizers without risk of incurring a large reduction in crop yield. This problem is being approached in two ways: (1) the average manurial requirements of crops and (2) the response of crops to P and K on soils with different levels of available phosphate and potassium, are being ascertained on the main soil types by means of field experiments. As far as possible, the two requirements are combined in the same experiment which usually takes the form of a factorial NPK $3\times3\times3$ design. The rates of application of P and K, which are suitable for the manurial trial are not always suitable, however, for measuring responses in relation to soil analysis. It happens that manurial trials commonly go down on soils that are very low, low or medium in P and K, because most soils in the Province are in this condition. For measuring responses at higher levels of available P and K in the soil, a careful selection of sites has to be made and the amounts of P and K commonly applied in manurial trials may be too high to measure responses well.

For example, a series of thirty-four experiments on the responses of sugar-beet to NP and K at different levels of available P and K in the soil has just been completed on Chalky Boulder Clay soils. It was relatively easy to find sites that were very low and low in K and very low, low, medium and medium high in P, and difficult to find sites at higher levels of K and P on farms where sugar-beet is normally grown. The response to K was greatest on sites with very low levels of K, much less on sites with low levels, nil at medium levels and negative at medium high and higher levels. The response to P was variable and very similar at levels of P in the soil up to medium high and fell

off at higher levels. This result clearly throws doubt on the suitability of the phosphate method for calcareous soils and as mentioned earlier has led to a search for a sounder method.

Field experiments, designed to ascertain the average manurial requirements of crops on different soil types and the responses of crops to P and K in relation to soil analysis, are essential to the effective use of soil analysis in advisory work and for checking the suitability of methods. The experimental design being used at present requires a considerable amount of time and labour, when the experiments are put down and when the plots are harvested. The result is that only a small number can be put down each year. A change of policy to simpler designs and more experiments is needed if rapid progress is to be made, and it is to be hoped that this will be possible.

It is usual in advisory work to take the average manurial requirements, as shown by field experiments, as the standard manuring for a crop when the soil contains low levels of available P and K, to increase or decrease the rate of application according to the potential cropping capacity of the soil and to add extra P and K if the levels of available P and K in the soil are very low. For example, if the standard fertilizer application for potatoes on dunged land were 8 cwts. per acre of an 8 : 6 : 10½ compound for an 8-ton yield, 12 cwt. might be recommended for a soil capable of producing 12 tons per acre and if the soil was very low in K, 1 to 2 cwt. per acre of muriate of potash would be recommended in addition.

Where manurial experiments have not yet been carried out on a given soil type, use is made of the regional summaries of field experiments by CROWTHER (2, 3) and YATES (2) for assessing the standard manuring of a crop. These summaries have been of great value and for many areas are the only information available on the manurial responses of crops.

One is often asked whether it is advisable to reduce applications of P and K when the soil contains medium high or high levels of available P and K. If the crops to be considered are potatoes and roots—which usually receive the bulk of the manuring of the rotation—any reduction for these crops might not only reduce their yield, but reduce subsequent crops in the rotation. Reduction or omission of P and K for cereals, beans and peas is permissible, especially when the soil is in good physical condition. When the levels of available P and K are very high, reduction in the application of P and K to potatoes may be desirable, for instances are known of reduction in yield from normal application of P and K under these conditions. Most instances of benefit from reduction in the use of P and K have, however, arisen in glasshouses and on market garden holdings where excessive amounts of fertilizer have been used for many years.

One of the chief difficulties arising in the application of soil analysis is lack of uniformity in the soil, for this affects soil sampling and subsequent recommendations. Investigations are in progress on variations in fields which are apparently uniform, and will be extended to fields where wide variability is known to exist. Liming recommendations are particularly affected by variability in the soil, for complete interaction between soil and calcium carbonate is required in dealing with acidity, whereas as little interaction as possible between soil and fertilizer is desirable in dealing with deficiencies of phosphate

and potassium. The laboratory method of determining lime requirement—which is an electrometric titration of the soil to pH 6·5 with lime water—appears to be sound. In field experiments, however, where finely ground chalk or limestone has been carefully applied to sites that are uniformly acid, from 1 to 2 times the laboratory lime requirement figure has been needed to raise the pH to 5·8 and from 2 to 3 times the laboratory figure has been needed to raise the pH to 6·5, after allowing a period of two years for the liming material to interact with the soil. There is, therefore, considerable uncertainty as to the amount of lime that should be recommended even where acidity is fairly uniform and methods of distribution are good. A more common case is where acidity varies considerably over the field and in some parts increases with depth and in other parts decreases with depth. Here pH values over the field and with depth in the soil are first of all needed. A lime requirement figure for the more acid areas multiplied by three, provides a useful estimate of the amount of finely ground chalk or limestone that is needed initially, but there is always considerable uncertainty, and invariably more lime is found to be needed within a year or two.

Little progress has been made in evaluating methods of analysis for organic matter, nitrogen and minor elements. Organic matter by wet oxidisation and total nitrogen by KJELDAHL are proving useful in parts of the eastern counties in recognising areas and fields where the amounts of organic matter are so low that providing crops with adequate nitrogen is a difficult problem. An arbitrary scale for organic matter has been adopted as follows :—

Class	Very Low	Low	Medium	Medium High	High	Very High	Abnormal
Organic Matter %	*less than* 1·0	1·0–1·9	2·0–2·9	3·0–3·9	4·0–4·9	5·0–5·9	6·0 *and over*

Troubles in crops due to nitrogen deficiency or poor soil structure commonly occur in the Very Low, Low and Medium classes. In other parts of the country, particularly in the wetter and cooler areas, such low levels of organic matter may seldom occur and a scale for organic matter may have little application.

Methods of analysis for the minor elements are at present limited to the detection of excessive amounts which are proving toxic or are likely to be toxic to crops. Excessive amounts of soluble manganese are frequently found in soils which have been sterilized for use as seed or potting composts, and toxic concentrations of zinc, borate and chlorate are found from time to time where these materials have been inadvertently added to the soil. Simple semi-quantitative tests are adequate for detecting them in the soil.

The problem of deficiencies of minor elements in the soil is too complex and obscure at present for deficiencies to be detected by chemical analysis of the soil. The only certain method of detection is to apply sprays containing minor elements to the foliage of crops,

and to observe and measure the response. This method is being used very effectively in advisory work and has revealed extensive areas of copper deficiency on peat soils in the Fenland. Many years of work will be needed before this technique will be replaced by analysis of the soils for copper.

It will be evident from the examples I have given that soil analysis is being most successfully applied to the recognition of mineral deficiencies and excesses. Very useful and valuable work is being done in this direction for deficiencies are a common problem. Methods of analysis are first of all tested on deficiency problems and rejected if they have no value. Less frequently methods are tried for detecting excesses. For example, in the past two years, conductivity measurements have been extensively made on glasshouse soils and pC values compared with crop growth, because this method appears to offer a simple rapid method of detecting harmful concentrations of salts in the soil arising from excessive use of fertilizers. It is too early to say how useful pC measurements will be, but I think it will be agreed already that they are of value. In all instances establishing a method of analysis is a slow lengthy process.

The correlation of soil analysis with crop requirements and responses requires extensive field experimentation on different crops on different soil types and this has only been attempted to a limited extent for lime requirement, potassium and phosphate. More field experiments of this kind are needed. We are a long way from being able to construct manurial tables for all the common crops, such as have appeared in a number of publications on soil analysis.

Lastly, I must stress again that soil analysis is not the only, nor always the most important, method of diagnosis used by the advisory soil chemist, and that a pre-requisite for its successful application is an examination of the soil profile to assess conditions affecting depth of rooting and root activity of crops, and to provide an intelligent basis for soil sampling and judging the potential cropping capacity of the land.

REFERENCES

(1) HUNTER, J. G. An Adsorptiometric Method for the Determination of Magnesium. *The Analyst*, **75**, 91-99 (1950).

(2) CROWTHER, E. M. and YATES, F. Fertilizer Policy in War-time. *The Empire Journal of Experimental Agriculture*, **9**, 77-97 (1941).

(3) CROWTHER, E. M. Fertilizers During the War and After. Bath and West and Southern Counties Society, Pamphlet No. 13 (1948).

THE ASSESSMENT OF SOIL FERTILITY FOR ADVISORY PURPOSES BY MEANS OF *ASPERGILLUS NIGER*

A. M. SMITH AND K. SIMPSON

Edinburgh and East of Scotland College of Agriculture, Edinburgh, Scotland

Introduction

The possibility of assessing the productiveness of soils by chemical analysis has attracted the attention of agricultural chemists for at least 150 years. At first the problem seemed to be a comparatively simple one limited only by imperfect analytical techniques, but the complexity of the soil soon became obvious and such fascinating observations as those of THOMSON and WAY on cation exchange, had perforce to lie undeveloped until the laws of mass action and the principles of colloidal behaviour were promulgated and studied. Meantime it had become apparent that so many interdependent factors were involved in plant growth that it was unlikely that a laboratory method could be devised to measure the fertility of the soil.

The field experiment is, of course, the only way of obtaining reliable information and there has been a remarkable advance in the development of experimental design to economise in labour and secure precision in the interpretation of the results; but the number of field experiments that can be laid down to deal with such variables as climate, soil and crop is limited and hence the study of laboratory methods has never ceased. Indeed, it has become more and more intense during the last 25 years with the urge to help in the advisory work directed towards greater crop production.

It has long been appreciated that any simple chemical extraction of plant nutrients from a prepared sample of soil can be only a guide to the nutrients absorbed by the plant during a growing season. This was probably responsible for investigators turning to the pot culture experiment as something more closely akin to natural conditions. The work of MITSCHERLICH and many others in this direction is too well known to need emphasis here but it is worth recalling that the co-operative studies on the evaluation of soils, which were organised by the International Society of Soil Science some 20 years ago and reported by MITSCHERLICH at the Oxford Congress in 1935 (1), were directed to finding what laboratory method agreed most closely with the pot method. Field results for the soils in question were not available and the pot culture result had to be accepted as the best standard. The pot experiment of course was designed to measure the fertilizer requirement of the soil whereas the usual extraction procedure measured the easily soluble nutrients in the soil.

Another technique that deserves mention was developed by NEUBAUER and consisted essentially in using a plant (usually rye) to extract all the available phosphate and potassium in a soil. This method, however, demanded a high degree of technical skill and rather special facilities and for those reasons never became popular for advisory purposes. But it no doubt encouraged the hope that simpler organisms whose growth depended, like the higher plants, upon a

supply of such elements as phosphorus and potassium, might be used to examine soils. At any rate, both the *Azotobacter* semi-quantitative test for calcium and phosphate and the *Aspergillus niger* quantitative method for phosphate and potassium received a good deal of attention. The former was at one time widely used in Denmark whilst the latter has been employed in several countries.

The Aspergillus method

The peculiar merit of the *Aspergillus* method lies in the fact that it does not require an accurate chemical determination. There is really no justification for the precise analytical results obtained in many methods when due consideration is given to errors associated with the sampling of soils and to the uncertainty in interpreting the results. The final step in the *Aspergillus niger* procedure simply involves the weighing of a mycelium to within 3 or 4 mg.—an operation that can be carried out quickly and does not demand much skill. The simplicity of the test coupled with the fact that it gave results closely parallel to the results obtained with acid extractions was instrumental in our deciding to adopt the method for routine advisory purposes and it has been used at Edinburgh for 20 years, exclusively for potassium and frequently for phosphate.

Technique. A study of the more important factors concerned in the laboratory technique has previously been published (2, 3) and details of the influence of source of nitrogen, size of vessel, acidity, strain of organism and inoculation on the growth of the fungus need not be repeated. For the extraction of potassium, 2·5 g. of soil are placed in a bottle (diameter 5·5 cm. and capacity 130 ml.) with 30 ml. of a nutrient solution containing 10% sucrose, 1% citric acid, 0·1% peptone, 0·075% P_2O_5 as $NH_4H_2PO_4$, 0·36% NH_4NO_3, 0·03% $MgSO_4.7H_2O$, 1·5 p.p.m. Cu and 1 p.p.m. each of Fe and Zn (as sulphates). A few drops of a suspension of conidia are then added and the bottle is incubated at 35° C. for 6 days. The mycelium is then removed from the surface of the liquid by means of forceps, washed in water, dried overnight at 50-60° C. and finally for an hour at 100° C., and then cooled and weighed. Under these experimental conditions the weight of mycelium from various classes of soils varies from about 0·2 to 1·0 g. and the standard error of an individual determination is about ±5%. The only changes made for the extraction of phosphate are that 5 g. of soil are taken while the nutrient solution contains 0·02% K_2O as K_2SO_4 and no phosphate.

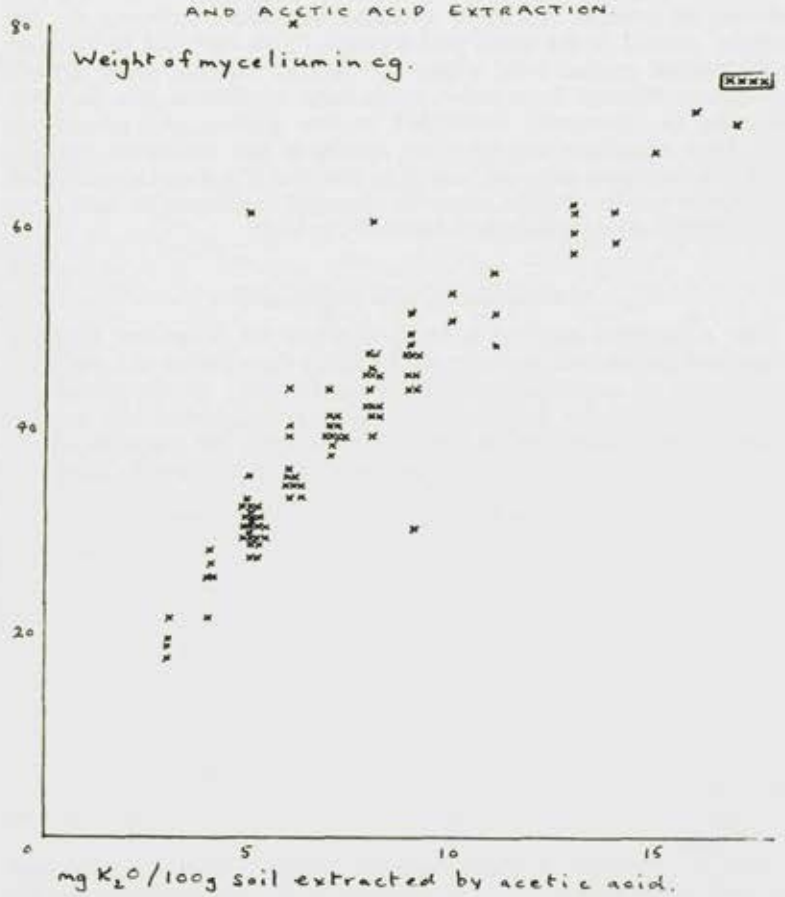
Comparison with chemical methods

The method is therefore closely related to a chemical extraction procedure inasmuch as the soil is in contact with a 1% citric acid solution for 6 days and the growth of the organism is determined by the amount of potassium or phosphate dissolved from the soil; all the other elements essential for growth are present in adequate amounts. The chemical composition of the mycelium is not constant, the percentages of potassium and phosphorus both increasing with increase in the weight of mycelium. Hence the amounts of these elements removed from the soil increase much more rapidly than the yield of mycelium. Nevertheless, it is not surprising that a good

agreement should be found between the mycelium weights and the amounts of potassium or phosphate dissolved from a series of soils by a dilute acid.

A single example is sufficient to show this close relationship between the results obtained by *Aspergillus niger* and by a purely chemical extraction. In a co-operative study a few years ago, 100 soils from various parts of Scotland were examined at Edinburgh by the *Aspergillus* method and at the Macaulay Institute by extraction with 0·5 N acetic acid. In the estimation of potassium, 50 of the samples gave mycelium weights between 0·3 and 0·45 g.—the range of values over which fertilizer may or may not be required. As will be seen from Fig. 1, the acetic acid values for these 50 samples lay between 5 and 9 mg. K_2O/100 g. soil. It is also clear from Fig. 1 that with 2 or 3 exceptions, all the soils yielding less than 0·3 g. mycelium contained less than 5 mg. acid-soluble K_2O and all the soils giving more than 0·45 g. mycelium contained more than 9 mg. acid-soluble

Fig 1. RELATIONSHIP BETWEEN ASPERGILLUS NIGER RESULTS AND ACETIC ACID EXTRACTION



K_2O. The group of encircled points represent soils that gave very high values by both methods. These results are quite typical of numerous comparisons that have been made from time to time of mycelium weight and acid-soluble potassium or phosphate.

Parallelism between two laboratory methods, however, does not mean that either is reliable in estimating a nutrient that may be easily soluble under field conditions, and we have endeavoured to check the *Aspergillus* test against field performance. There have not been enough field experiments with potassium fertilizer to provide evidence of a precise threshold value but all the experimental results and the general observations made in the course of many years advisory work indicate that a potato crop, for example, will respond to fertilizers if the soil yields less than 0·3 to 0·33 g. of mycelium. In other words we have had no reason to alter the lower limiting value originally chosen on the basis of comparison with MITSCHERLICH pot results (3). This we feel to be the most useful application of the method, namely, its value in deciding whether a soil is deficient in potassium. At the other end of the scale, we feel fairly confident that when the weight of mycelium exceeds about 0·4 or 0·45 g., the soil is able to provide an amount of readily available potassium sufficient for the healthy growth of the usual arable crops. This may not be the case with market garden soils where the factors limiting plant growth are rather different from those under farm conditions. In fact, the majority of intensively cultivated market garden and greenhouse soils give mycelium weights that approach the maximum possible with the technique adopted, and it is doubtful if a single examination of the soil can be used to prescribe manurial treatment in such cases when the uptake of nutrients is relatively so large.

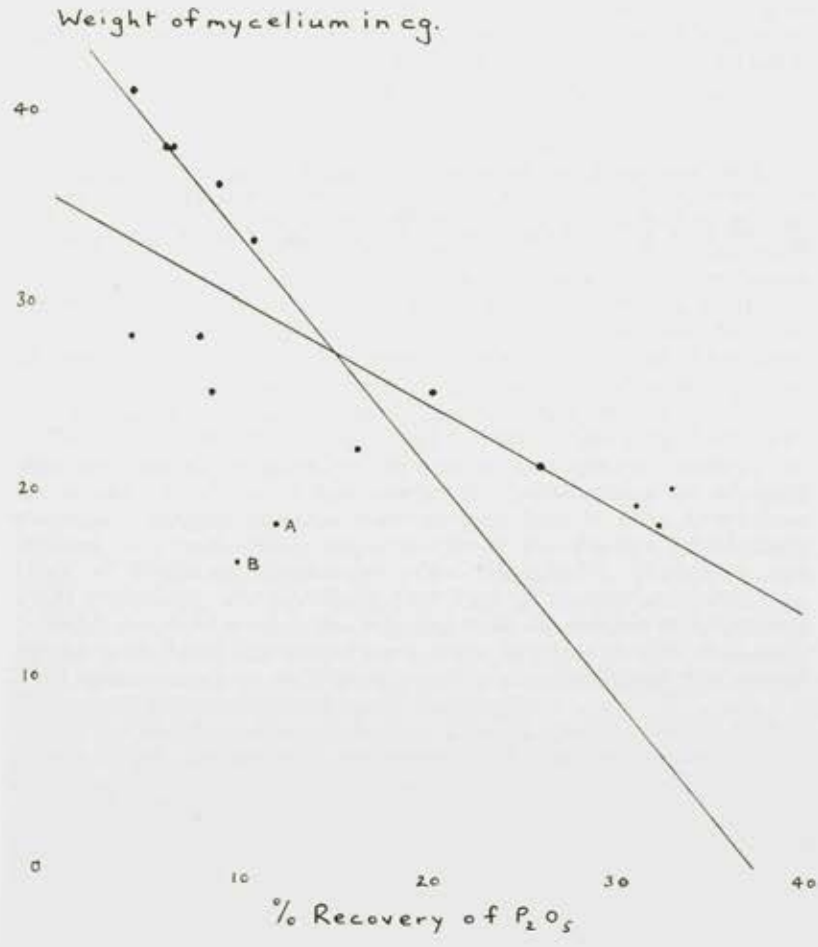
Comparison with field results

The *Aspergillus* method is more sensitive for potassium than for phosphate estimations and can readily detect the addition of a moderate application of a potassium fertilizer to the soil. In the laboratory the recovery by the fungus of potassium added to the soil may be almost quantitative but, as might be expected, the response of the fungus to small additions of phosphate to the soil is small. That this is caused by a reaction between soil and added phosphate is clear from the fact that the growth of the organism is determined by the amount of phosphate in solution. The agreement between the *Aspergillus* method and the usual straightforward acid extraction methods is at least as good for phosphate as for potassium and the mycelium weight is in general a good guide for advisory purposes. Again, it has been found that a figure below 0·3 g. almost invariably means that the soil is deficient in phosphate and that a substantial response in crop yield will follow an application of phosphatic fertilizer. The upper limit, above which there is unlikely to be a significant response to phosphate, is more difficult to define. This is partly because most of our field experiments have been carried out on phosphate-deficient soils and partly because the response in the field to phosphate is so much influenced by seasonal conditions.

One set of results obtained during a period of several seasons may be cited in this connection. The experiments were designed to compare

the effects of superphosphate and various other phosphatic fertilizers on the yield of crop (usually turnips) grown on acid soils at an elevation of 500 to 1,000′ O.D., in the East of Scotland. Details of all but three more recent experiments have been published (4) and show that the average yields per acre were 11·0 tons without phosphate, 14·6 tons with 0·33 cwt. P_2O_5 and 16·2 tons with 0·66 cwt. P_2O_5 as superphosphate. There were large differences among the soils in the crop yields and in their responses to fertilizer and for the purposes of comparison it was decided that the percentage recovery in the crop of the phosphorus added as fertilizer was the best measure of the fertilizer treatment.

Fig. 2 RELATIONSHIP BETWEEN ASPERGILLUS NIGER RESULTS AND RECOVERY OF PHOSPHATE ADDED TO THE SOIL



An examination of various factors demonstrated that there was a strong positive correlation between phosphorus recovery and the exchangeable calcium in the soil (a correlation which was raised by eliminating summer rainfall), and a negative correlation of the recovery and the citric-soluble phosphate in the soil. The agreement between citric-soluble phosphate and mycelium weight was very close the correlation coefficient being +0·94 for 17 pairs of values. Consequently there was also a good negative correlation of response and mycelium weight. These results are shown in Fig. 2, the regression lines being inserted for reference. Of the two exceptional points, *A* refers to a potato experiment in which the haulms had died down before harvest and were not analyzed so that the recovery of phosphorus refers only to that in the tubers. The other case, *B*, concerns a very acid peaty soil that behaved anomalously in many respects.

Including the values for *A* and *B*, the correlation coefficient of the recovery and mycelium weight is −0·67 for 17 pairs of values which is quite significant at the 1 per cent. level. Hence, for this class of soils the *Aspergillus* value, especially if supplemented by exchangeable calcium, provides a very good indication of the nature of the response to phosphatic fertilizer.

REFERENCES

(1) MITSCHERLICH, E. A. Third Int. Cong. Soil Sci., Trans. **2**, 95 (1935).
(2) SMITH, A. M. and DRYBURGH, A. *J. Soc. Chem. Indus.*, **53**, 250 T (1934).
(3) SMITH, A. M. *J. Soc. Chem. Indus.*, **55**, 217 T (1936).
(4) SMITH, A. M. and SIMPSON, K. *J. Sci. Food and Agric.*, **1**, 208 (1950).

THE METHODS EMPLOYED IN THE ROUTINE EXAMINATION OF SOILS AT THE WEST OF SCOTLAND AGRICULTURAL COLLEGE

C. L. WHITTLES

West of Scotland Agricultural College, Ayr, Scotland

Scotland, like Gaul, is divided into three parts, North, East and West, whose Agricultural Colleges are situated at Aberdeen, Edinburgh and Glasgow respectively. About twenty years ago the Soil Chemist was transferred from Glasgow to Auchincruive which is about three miles from the town of Ayr. The Analyst's Laboratory, which he shared, was formerly the stable in which were housed the coach horses as well as the hunters kept by the Squire of Auchincruive, an estate previously owned by the Oswald family. It will be readily understood that with no technical assistants, the number of samples examined annually was not large. On the other hand the demand was not great, for the County Advisory Officers had not then realised the extent to which soil analyses would help them in their work. As a matter of fact, the Soil Chemist was obliged to take a considerable number of samples in order to demonstrate that the work was of more than academic interest. Their interest was gradually aroused, and when the " Plough-up Campaign " was launched in September, 1937, the trickle of samples became a flood.

This resulted in the removal of the Soil Chemist, with his four assistants, to fresh quarters and the appointment of an Assistant Chemist. A large room was fitted with temporary benches (which are still in use), and a loft was utilised for the preliminary treatment and ultimate storage of samples. These rooms have since been re-conditioned, and additional equipment installed. In 1948 the number of assistants was increased and a daily output instituted in place of a weekly one. So much by way of historical introduction.

The College advisory area is served by eleven Agricultural Advisers, who are assisted by Advisory Officers in Horticulture, Poultry, etc. These officers now send soil samples to Auchincruive for advisory purposes. Samples are also received from time to time direct from growers and from other Departments of the College, particularly those of Grassland Husbandry, Crop Husbandry, Chemistry and Plant Pathology, who all supply field data on appropriate forms.

When a sample arrives, the relevant data are entered in a " sample receipt book " and the sample itself given its serial number on a small label which serves as its identity card and accompanies the sample throughout the remainder of its life as a sample.

The soil is then rubbed through a $\frac{1}{4}$" mesh garden sieve to remove stones. This also brings it into a fine tilth which facilitates drying. The material passing through the sieve is collected on an aluminium tray, which is placed in a drying cabinet. Warm air, driven by fans, passes over and under the trays with the result that even very wet samples are brought to an air-dry condition within 24 hours. Temperature is controlled thermostatically so that it does not exceed 40° C., a temperature frequently attained by the surface of soils in summer under natural conditions.

The dry soil is reduced to a fine meal by grinding in an end-runner mill of which the mortar is lined with rubber and the pestle is made of wood (1). Experience has proved that this treatment effectively breaks up soil crumbs but does not fracture stones or mineral fragments. Great credit is due to the Waite Institute for this valuable labour-saving device. The time taken to mill a sample weighing about 1 lb. varies from 2–4 minutes according to its texture.

The milled material is then passed through a sieve of stainless steel provided with holes having a diameter of 2 mm.; the residue failing to pass through the sieve is gently triturated in a wooden mortar with a wooden pestle, by hand, to ensure the breakdown of any hard crumbs which may have survived the milling process, and again sieved. The "fine earth" so obtained, together with its label, is transferred to a paper bag bearing the appropriate serial number. It has been found that automatic numbering stamps are of great help in numbering labels and bags, as well as in the preparation of laboratory sheets.

Aliquots of the samples have now to be weighed for the various determinations. It has been found that it is more expeditious and effective for this operation to be performed by the assistant who is to carry out the determination in question, and this has the advantage that the weight on the balance pan remains unchanged throughout a batch, unless a peat is encountered, when half quantities are taken.

A small aluminium scoop, provided with a counterpoise, is used, and the soil in the bag stirred with this. Careful training in avoiding any unnecessary motion, and the correct use of the spatula, though making progress very slow at first with the beginner, results eventually in astonishingly fast and accurate work. All balances are fitted with the Grainger attachment, so avoiding the use of loose weights smaller than 1 gram.

To pass now to the determinations:—

1. *Moisture and loss on ignition.* Vitreosil crucibles of the squat form having a capacity of 50 ml. have proved satisfactory. They are marked with a letter followed by a digit. This procedure enables one to deal with a larger number using only two cognomens, than is possible with figures alone, whose maximum is clearly 99. The black paint used for decorating china and porcelain has given satisfaction. The table of crucible weights, which requires to be checked at intervals, is written up in the form of "crucible weight+10 grams soil," and hence these values are copied on to the laboratory sheet after the weighing out has been completed.

Ten grams of soil are weighed out on to the counterpoised scoop and transferred to a crucible, whose designation is entered on the laboratory sheet opposite the serial number of the sample in question. The crucibles, on trays of perforated metal, are placed in an electrically heated oven which is thermostatically controlled at 105° C. After 24 hours they are transferred to a desiccator of the vacuum type. A guard tube, containing indicator silica gel as a drying agent, serves to prevent the entry of moist air, and at the same time prevents the formation of a partial vacuum as occurs when the ordinary solid lid is used. When cool, the crucibles and their contents are weighed; the loss in weight multiplied by 10 gives the moisture content as a percentage of the air-dry soil, and it is in this form that all results



FIGURE 1. Gibbsyard Auchincruive. In foreground is the Poultry School. The Chemistry Department occupies the block to the right of the clock tower.



FIGURE 2. Removal of stones, etc.

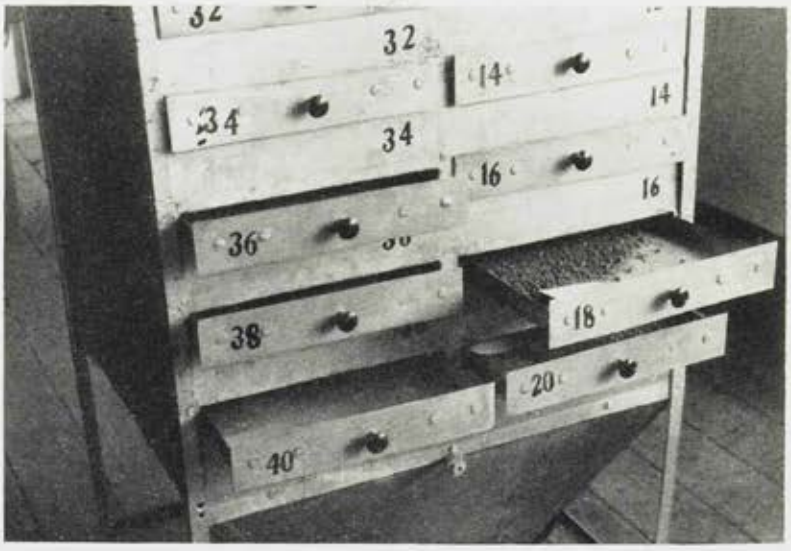


FIGURE 3. Soil Drier.

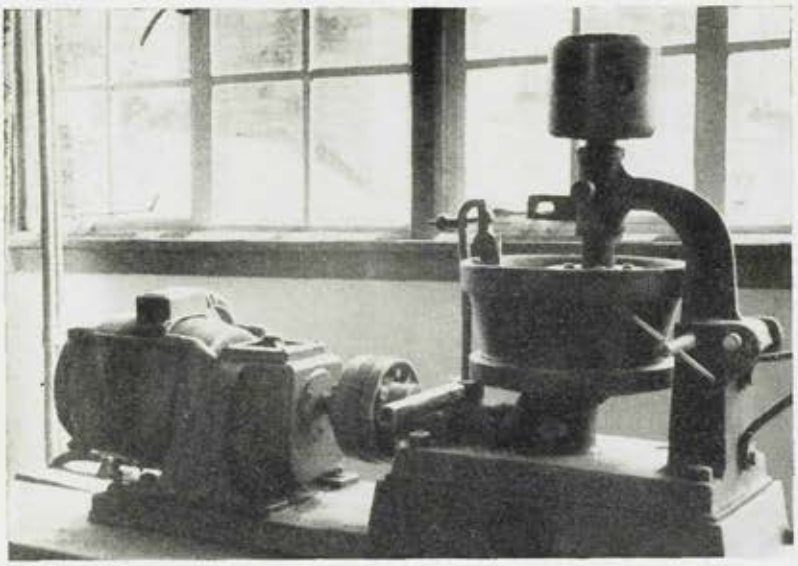


FIGURE 4. End-Runner Mill.

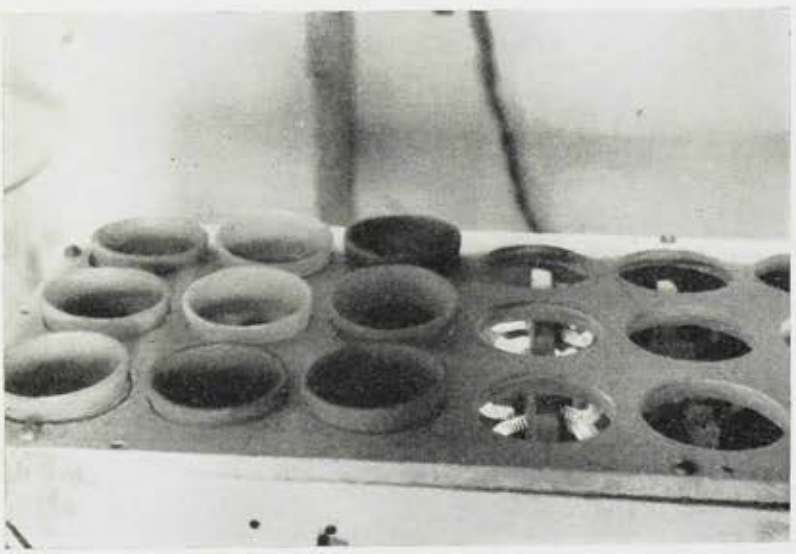


FIGURE 5. Crucible Furnace.

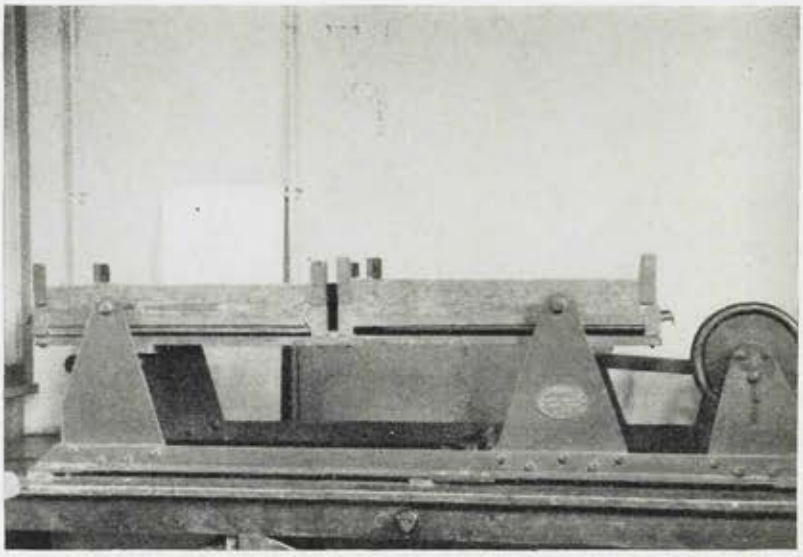


FIGURE 6. To-and-Fro Shaker

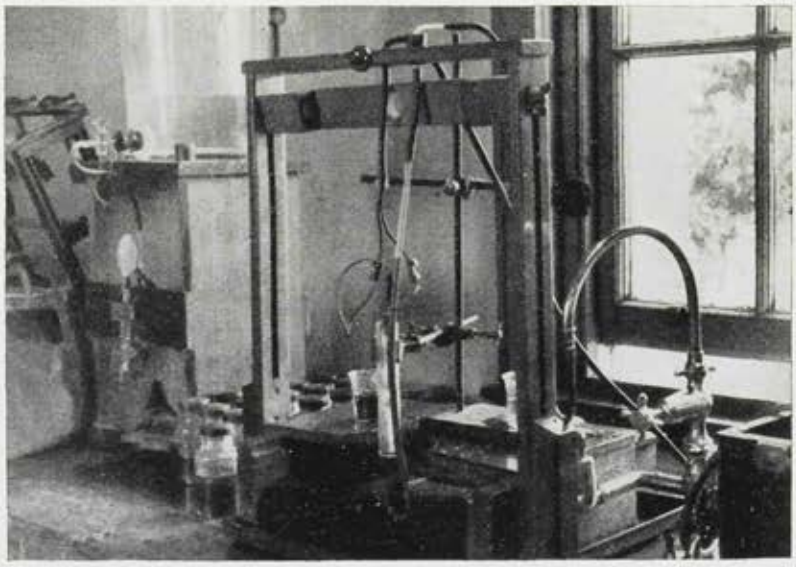


FIGURE 7. Electrode assembly for measurement of pH.



FIGURE 8. Automatic filtration of soil extracts

are expressed. Should any value be required on an oven-dry basis, it can be calculated.

The ignition of the soil is carried out in two stages. In the first stage the crucible is heated in the open on a specially constructed furnace so that those areas of the walls of the crucible with which the soil is in contact, are heated by a coil of an electric radiator element. The loading is at the rate of 1000 watts for each group of six crucibles. Occasional stirring with a copper wire prevents the formation of coke or charcoal, and this stage takes 30 to 45 minutes. The ignition is completed by heating in a muffle furnace at a dull red heat. The completeness is evidenced by the uniformity of the colour of the residue. After cooling in a desiccator, the further loss in weight $\times$ 10 gives the loss on ignition as a percentage of air-dry soil.

This value, the loss on ignition, is of service in two ways. Firstly, it gives a rough measure of the organic matter present; secondly, it serves as an indicator of the volume : weight relationship. Remembering that the weight of the top 9 inches of an acre of peat, with a loss on ignition of 50 per cent., or more, is about half of that of an acre of sand or loam with a loss on ignition of not more than 12 per cent., it is clear that we can make use of the loss on ignition value to correct our findings for lime requirements, and our standards for available phosphate and potash.

2. *pC*. The pC is the negative logarithm of the specific conductivity of the soil suspension with a soil : water ratio of 1 : 2·5, and is a useful value in revealing a high content of soluble salts, such as may have resulted, for example, from flooding by sea water, or from excessively heavy dressings of fertilizers, which is still only too frequently encountered in glasshouse soils (2).

30 grams of soil are weighed out and transferred to a numbered 6 oz. screw-top (fitted with rubber washer) wide mouthed sample bottle. 75 ml. of distilled water are added, and the bottle with its contents shaken for half an hour on a to-and-fro shaker running at 96 cycles per minute, the horizontal travel of the shaker being 3 inches. The bottles fit into trays, 30 bottles per tray, and the shaker can carry 8 or 10 trays, and this might be increased if necessary.

Having stood overnight, the resistance of the suspension is measured using a dip type conductivity cell with platinum black electrodes and a MULLARD meter. By means of a table the readings are expressed in terms of pC. It has been found most convenient with a limited staff to complete the measurement of the resistances of all the suspensions in the batch before proceeding to measure the pH, for the one suspension serves for both determinations. If another assistant were available it would probably be more efficient for both measurements to be in progress at the same time, the resistance always being measured first, to avoid contamination by KCl from the liquid junction.

3. *pH*. The pH is measured by means of a dip type electrode which is held in a clamp, the bottle being supported by a sliding shelf. The platinum electrode and calomel element are protected by a skirt tube, which has been found to prolong the working life of the platinum electrode. The quinhydrone electrode is still used, but it is anticipated that the glass electrode will be adopted in the near future.

4. *Lime requirement*. The method employed is that described by HARDY and LEWIS (3), and has been in use since 1929. A few minor modifications have been made which render the method more suitable for dealing with large numbers.

It has been found that soils dressed with ground limestone, when re-examined after an interval of six months, display the prophesied pH values, so confirming our belief that this is a satisfactory method.

5. *Available phosphate*. The method now employed is that described by WILLIAMS and STEWART (4), which has superseded that of KIRSANOV.

In preparing the ammonium molybdate reagent it is important that the procedure of TRUOG and MEYER (5), be adhered to closely :— A 12·5 N. solution of sulphuric acid is prepared by diluting the appropriate volume of pure acid and allowing it to cool. 25 grams of ammonium molybdate are dissolved in 200 ml. of water heated to 60° C., filtered and allowed to cool. When cold this solution is added to 800 ml. of the cold 12·5 N. acid, so giving the required reagent, viz., 10 N. sulphuric acid containing 2·5 grams ammonium molybdate per 100 ml. It is important that the dilute sulphuric acid be no stronger than 12·5 N., so that the least possible rise in temperature takes place when the ammonium molybdate solution is added to the acid.

6. *Available potash*. The method employed has been developed at Auchincruive and a full description was published about eighteen months ago (6).

In the foregoing description of the methods employed in the laboratory, reference has been made to laboratory sheets. Since a fresh batch of samples is started every day, it is not practicable to use note-books, as these would be required in different places at one and the same time ; hence the necessity for using the loose-leaf system.

The results obtained in the laboratory are entered in a Record Book and from this are prepared the reports, which, being our main

objective, must now be considered in greater detail. The field data are supplied by the Advisory Officers on folded forms, so providing duplicates. The analytical results are typed on these; one copy is returned to the Officer concerned, the other is retained. A verbal description is given, in addition to the value according to the following tables:—

TABLE I

Loss on ignition and organic matter

Loss on Ignition	Organic Matter	L.R. Factor
50·1 and over	Very High	$\frac{1}{2}$
20·1–50·0	High	$\frac{3}{4}$
16·1–20·0	Above Normal	$\frac{3}{4}$
12·1–16·0	Slightly Above Normal	$\frac{3}{4}$
6·1–12·0	Normal	
3·1–6·0	Low	1
3·0 or less	Very Low	

The acidity is a verbal description of the pH value, and is of great value in assessing the urgency of the need for liming, but gives no clue whatsoever as to the amount required.

TABLE II

pH and acidity

pH	Acidity
Below 4·5	Abnormal
4·5–5·0	Very Strong
5·0–5·5	Strong
5·5–5·75	Pronounced
5·75–6·0	Moderate
6·0–6·5	Slight
Over 6·5	Nil

TABLE III

Available phosphate

mg. P_2O_5/100 gm. soil	Available Phosphate
201 or over	Abnormally High
101–200	Very High
51–100	High
11–50	Satisfactory
5–10	Medium
1–4	Low
Less than 1	Very Low

TABLE IV

Available potash

mg K_2O/100 gm. soil	Available Potash
201 or over	Abnormally High
101–200	Very High
51–100	High
12–50	Satisfactory
6–11	Medium
1–5	Low
Less than 1	Very Low

TABLE V

pC and soluble salt content

pC	Soluble Salt Content
3·0 and over	Normal
2·75–2·99	High
2·50–2·74	Very High
Below 2·50	Abnormally High

The standards for horticultural soils (i.e., gardens, nurseries, etc.) are rather higher, and higher still for glasshouse soils.

The soluble salt content, which is reported as a matter of routine in the case of horticultural and glasshouse soils, is based on the pC value and for agricultural soils is only reported when the pC is below 3·0. The pH value of any soil suspension is changed by an alteration in the salt concentration, consequently the values pC and pH are inter-dependent. It also follows that a fuller description of the system is given by a statement of both values, than by either alone.

A second report, in which only the verbal descriptions are given, is also sent to the Advisory Officer. On this he enters his manurial recommendations and then passes it to the grower.

For our own convenience and use, an alphabetical card index of farms is maintained. These cards not only give the Serial Nos. of the samples, but also the parish, county, and the location of the farm on the National Grid. Similarly, horticultural and glasshouse soils are indexed under the name of the grower.

Prior to the introduction of the duplicate soil forms a few years ago, a record card was made out for every sample. On this was recorded the field data supplied by the sampler, as well as the results of the analyses. These cards were filed on a topographical basis as regards parish, and county, but alphabetically within each parish. This enables one at a glance to assess the density of sampling in different districts.

A closer examination of these accumulated records is now in progress, with the object of preparing a series of maps of the college area. As

a first step the means, etc., of the analytical data for each farm are being calculated, and from these in turn the corresponding values for the parish will be determined. It is thought that the latter will provide a suitable basis for generalised maps of the area.

As regards the value of the work done so far, there is no doubt that it is responsible for a reduction of the great acidity of some of the soils. Whereas ten years ago pH values of 6 and over were rarely encountered, these are now comparatively common; nevertheless, the majority of the samples still have a pH value of between 5 and 6. During the war years the amount of lime, chiefly in the form of ground limestone, applied in Ayrshire was considerably greater than that applied during the previous hundred years, and this alone shows that the work has been justified. The effect of this treatment is obvious to anyone who was familiar with the district before the war—much of the countryside is now more of an emerald green in colour instead of the yellowish-green which characterized it in the past. This is not to say that our task is completed. Much still remains to be done. The College Advisory Area comprises nearly 6½ million acres, and many farms still remain to be sampled. It will be a long time before every field is examined at least once in the rotation, and not more frequently than once in four years.

The phosphate status is generally low. This is often due to fixation, particularly on the acid soils. An exceptional instance is afforded by the early potato land on the Ayrshire coast, where heavy dressings of phosphatic fertilizers over a long period of time have resulted in soils which, while still acid, nevertheless have a very satisfactory phosphate content, often 20 to 40 mgm. P_2O_5 per 100 gms. soil.

It is, perhaps, worth noting that red clover grows here at pH levels at which it is very rarely found elsewhere. This may be due to the locking up of the toxic elements as insoluble phosphates, or may be associated with a higher sulphate content which one would expect to find on account of the heavy dressings of superphosphate which are still applied.

The available potash content is generally medium, higher values being associated with soils derived mainly from igneous rocks. On the whole, potash is not one of our major problems.

A Spectrographic Unit, which has been set up at Auchincruive, now investigates suspected cases of minor deficiencies, chiefly cobalt, magnesium and manganese.

In conclusion, the continuous increase in the number of samples is evidence of the increasing appreciation of our work by the farming community. The Agricultural Advisory Officers nearly always appear to have a waiting list, for requests for sampling now come from the farmers. This is vastly different from the state of affairs about 25 years ago, when an irate farmer shouted to a Soil Surveyor " Put it all back ! Put it all back ! I won't have you college men stealing my soil ! "

I have to thank Mr. JOHN MACFARLANE for the photograph of Auchincruive, and my colleague, Dr. DOVASTON, for taking the photographs of the apparatus.

REFERENCES

(1) PRESCOTT, J. A. and PIPER, C. S. Methods for the examination of soils: C.S.I.R. Pamphlet No. 8.

(2) WHITTLES, C. L. and SCHOFIELD-PALMER, E. K. On pC, pS and pN as Indicating Functions of Electrical Soil Conductivity. *J. Soil Sci.*, **2**, 243-245 (1951).

(3) HARDY, F. and LEWIS, A. H. Rapid electrometric method for measuring "Lime Requirements" of Soils. *J. Agric. Sci.*, **19**, 17-25 (1929).

(4) WILLIAMS, E. G. and STEWART, A. B. The Colorimetric Determination of readily soluble Phosphate in Soils. *J. Soc. Chem. Indust.*, **60**, 291-297 (1941).

5) TRUOG, E. and MEYER, A. H. Improvements in the Deniges Colorimetric method for phosphorus and arsenic. *Ind. Eng. Chem. (Anal.)*, **1**, 136-139 (1929).

6) WHITTLES, C. L. and LITTLE, R. C. A colorimetric method for the determination of potassium and its application to the analysis of soil extracts. *J. Sci. Food Agric.*, **1**, 323-326 (1950).

SESSION II

CORRELATION OF DATA

26th July. Chairman : P. H. GALLAGHER (Ireland)

P. BRUIN. The Development of Soil Fertility Research in the Netherlands (Volume I, page 300)

F. STEENBJERG. Verification of Chemical Soil and Plant Analyses : General Considerations (Volume I, page 309)

J. A. PRESCOTT. Some Basal Concepts in the Appreciation of Problems of Soil Fertility (Volume I, page 323)

SESSIONAL DISCUSSION

S. HÉNIN : Il est très difficile d'établir une relation entre l'état structural et le developpement des plants sauf en ce qui concerne la germination. Même dans les sols ayant une structure peu stable si la végétation peut s'établir on obtient une bonne récolte. Dans un tel sol l'état structural sous le couvert végétal parait bon. Je me demande si les interactions entre les engrais, le rendement et la structure ne traduisent pas simplement l'effet d'un développement plus ou moins bon du système racinaire dû aux engrais, sur la structure.

S. TOVBORG JENSEN : I should like to ask Dr. BRUIN the reason underlying the use of such large amounts of nitrogen as 60 kg. N annually per ha. on grassland. Would it not be more profitable to use more legumes, i.e., white clover, in the seed mixture ? By doing so you would probably get a more valuable crop richer in protein and you might perhaps save most of the nitrogen.

M. M. ELGABALY : I wish to ask Dr. BRUIN the following questions :

1. In the yield-structure relations, what is the structural measurement adopted ? This is not a single value property. Is the water table aggregate taken as an index of structure ? Very probably he is correlating yield with the physical condition and not the structure.

2. In the yield potash level curves can Dr. BRUIN account for differences in yield due to variation in potash level alone as other bases will be changing and not remaining constant ? I wonder if he is measuring a summation effect of other nutrient bases in addition to potash on yield.

F. A. VAN BAREN : Dr. LEHR has introduced the climatic factor into this discussion of soil fertility problems. I wholeheartedly support his point of view notably with regard to mediterranean and subtropical regions. I should like to ask, however, how evaporation has been determined, whether transpiration is taken into account as does THORNTHWAITE in the U.S. with his pE or evapo-transpiration factor.

F. VAN DER PAAUW : Is there really proof that leaching of nitrogen may be considered as a causal factor in connection with the correlation of rainfall in winter and the yields of rye ? At present there is some

evidence that rhythmical fluctuations of yields are connected to periodical climatic fluctuations (periods of 4 to 5 years) occurring in Spring (cf. VAN DER PAAUW, Trans. Int. Congr. Soil Sc., Amsterdam, Vol. **II**, 1950). There are some indications that different amounts of nitrogen are mobilised in this period. The fluctuations in yields may depend mainly on these differences in available nitrogen.

R. CHAMINADE : La quantité de K_2O renfermée dans l'Illite que l'on rencontre comme constituant des sols d'Australie est-elle suffisante pour assurer l'alimentation potassique des récoltes ?

F. C. GERRETSEN : According to what Professor STEENBJERG has told us he takes three samples on one and the same plot of plants standing very closely together, healthy, less healthy and bad plants. He analyses the plants and the soil on which the plants have grown and tries to correlate the results. It seems to me that this can never be a generally applicable method as it will seldom happen that one finds these three different stages of plant development so closely together. In most cases the whole field will show a rather uniform picture be it healthy or poor. Moreover, it may be that the one factor which caused a poor or better growth is not included in the analysis made or that the cause has already faded away at the moment the samples are taken. Will Professor STEENBJERG be so kind as to give his opinion on this problem and also tell us why he does not use differently treated plots on experimental fields known to show one or more deficiencies ?

H. L. RICHARDSON : In the discussion did Dr. BRUIN state that at a low soil potash status potash fertilizing gave a small response in yield as well as a low potash K_2O content of plant tissue ? Normally one would expect a large potash response on a soil of low potash status. Did the chemical test truly represent the potash status of the soil ?

L. AUDIDIER : Nous avons été tout à fait intéressé par le remarquable exposé de M. BRUIN ; il nous a fourni un magnifique exemple de travaux scientifiques ayant une application directe pour développer lés progrès de l'agriculture d'un pays.

De ce point de vue pratique, nous avons été un peu surpris de l'équilibre moyen des fumures des prairies aux Pays Bas :

60 N—40 P_2O_5—30 K_2O.

En France, les prairies les plus intensivement exploités reçoivent toujours une fumure de base phospho-potassique plus é'évée, du moins 80 P_2O_5 et 80 K_2O. Cela afin de maintenir un pourcentage suffisant des legumineuses dans les prairies.

Les legumineuses ont en effet l'avantage de fournir gratuitement des protéines d'une bonne composition et surtout d'avoir une plus grande richesse en éléments minéraux (phosphate de chaux en particulier) que les graminées et cela est très important pour la santé des animaux.

F. STEENBJERG : It was questioned by Dr. GERRETSEN whether it was possible to find patches with a normal growth of the crop, a smaller crop and a very small crop and where at the same time the distances between the places of sampling were small. It is, indeed, very easy to find such patches for sampling and it is important to

sample in that way because the samples whether plant or soil samples must not be too far removed in time and space by this type of verification. In this connection I would like to add with respect to Dr. BRUIN's paper that his curves showing the relationship between percentage potassium content in the leaves and the potassium content in the soil were convex. From a theoretical point of view this is quite impossible as I have pointed out in my lecture and the reason for such convex curves being observed may be that the samples were collected from field experiments too far removed in time and space, i.e., from different parts of Holland. In such a case one may from place to place work with yield curves which besides having a different shape may be very different placed in the coordinate system, i.e., different yield levels. This possibility corresponds to example IV in my lecture.

Dr. CROWTHER in his opening lecture made some very interesting observations of the fundamental nature with respect to yield curves. The question which CROWTHER touched upon is, indeed, so important that I would like to add a few remarks based on our experiences. We can, of course, only observe the yield curve in its whole course when we work with a soil or any other medium which is very deficient in a nutrient.

Now, do the consequences of such observed yield curves hold from case to case in the field, for instance, so that the laws we think to have observed in our rather special experiments with respect to the increase in yield is reproduced or reflected from case to case in the field ? My proposition is here, that the factors governing the slope and the position of the yield curve have the same value in the experiments where we are able to observe the whole yield curve, as from case to case *in the field* where we have to use our experimental evidence of the form and slope of the yield curve gained in the *special* experiments we have made.

I *could* also say this more summarily as follows : Do the nutrients found in the soil and the nutrients added to the soil *act* in the same way on the *slope* and the *position* in the coordinate system of the yield curve ?

I think they do approximately, when we work with potassium and quite often when we work with nitrogen ; for microelements and for phosphorus this may be true when we try to determine the average yield curves in experiments running for many years. In such long-term experiments the nutrients added are transformed—after different time periods—to compounds, which with respect to solubility, etc., may resemble the compounds already present in the soil.

What I have put forward here to-day are, of course, only facts and opinions which are common property, but I found it of some value to summarize it, when the organizing committee asked me to do so.

P. BRUIN : In reply to Professor JENSEN I wish to point out that it is true that the amount of clover in grassland is decreased by applying 60 kg. N per ha. The first cutting of grass, however, is promoted by this dressing in such a way that agriculturists of the Netherlands prefer this to a higher percentage of clover in the grass. Moreover, the total yearly amount of protein which can be got in

this way is increased, the loss of nitrogen fixed by the clover being a definite draw-back.

In reply to Dr. E. M. CROWTHER I wish to point out that the yield curves which were shown in relation to the pH content of the soil came from experimental fields. It is possible to get these also from different fields in a certain region. In this instance the results are treated in such a way that possible errors caused by correlations with other growth factors are prevented. The paper of Dr. VAN DER PAAUW is referred to in this connection. The variance of the error of the single plots is calculated out of the parallels of the dressing of the experimental fields. The K_2O content curves of the potato leaves are similar to those for the yields in so far as at a very low K_2O status of the soil optimum yields cannot be reached with heavy dressings. Comparing the results of FERRARI with the conclusions of Professor STEENBJERG, attention must be given to the general form of the curve, relating the amount of available K_2O in the soil with the K_2O content of the leaves.

In reply to Mr. AUDIDIER I should like to say that the average amount of artificial fertilizers applied to grassland in the Netherlands is for N P_2O_5 and K_2O respectively 60, 40 and 30 kg. per ha. Before any explanation can be given for differences between the use of fertilizer in the Netherlands and France, the soil fertility levels with respect to phosphate and potash must be known for both countries. It is possible that these are higher in the Netherlands. It is true that grassland in the Netherlands contains less clover than elsewhere. The P_2O_5 content of the grass mixture can as a consequence be less.

In reply to Dr. HÉNIN it may be pointed out that soil structure was determined before and after the growing season. For our graphs we took the figures first mentioned. Thus the crop did not have any influence. Generally, there is an interaction between the structure and crop growth. Very often it is a problem of the chicken and the egg. Nevertheless, besides differences in this respect, there are remarkable differences between different fields. The soil structure is determined visually and after the wet sieving method. In the curves shown, a visual method is used.

CLOSING SESSION

A closing session was held at which proposals were made relative to co-operative international work where field experiments are concerned. These proposals were as follows:—

INTERNATIONAL CO-OPERATION IN FIELD EXPERIMENTS ON SOIL FERTILITY

Proposal

The Fourth Commission of the international Society of Soil Science is asked to promote the setting up on an international basis of a series of field experiments in countries with temperate climates on the basis of which chemical, physical and biological research may be done in teamwork.

Argumentation

1. International congresses and committee meetings have had the inestimable value of establishing contacts between investigators from many countries and of facilitating an efficient exchange of scientific data. Joint research has, however, so far been mainly on laboratory methods of soil research. The present time with its many possibilities of communication and exchange of views may be suitable for undertaking detailed studies based on jointly organised field experiments.

2. Several research workers in different countries have come to the conclusion that field experiments form the backbone of soil fertility studies. Chemical, physical and biological studies, separately conducted, are, undoubtedly, of great importance for the development of soil fertility research, but, after a certain progress has been made, these studies need to be combined with suitable series of field experiments. The results of these series will give an impression of the fertility status of a region and at the same time give rise to further detailed studies in different directions.

3. International co-operation will bring research workers into contact with each other on the basis of the same project. Furthermore, in the co-operating countries interest will be focussed upon the common problems of soil fertility and their importance for practical farming and the national economy.

Procedure

A Working Committee is to be formed to study the possibilities of the proposal in both technical and financial aspects. Frequent international meetings between the actual co-workers will be necessary.

Final remark

The proposal will be commented on in the lecture of P. BRUIN—"The Development of Soil Fertility Research in The Netherlands" (Session II—Saturday, 26th July).

Netherlands : P. BRUIN
W. R. DOMINGO
A. C. SCHUFFELEN
Denmark : K. A. BONDORFF
F. STEENBJERG

LA COLLABORATION INTERNATIONALE DANS LE DOMAINE DES EXPÉRIENCES PRATIQUES RELATIVES À LA FERTILITÉ DU SOL

Proposition

Il est recommandé que la quatrième Commission de la Société Internationale de la Science du Sol favorise, sur le plan international, une série d'expériences pratiques qui auraient lieu dans des pays à climat modéré et qui permettraient de faire des recherches chimiques, physiques et biologiques dans le cadre d'une étroite collaboration.

Exposé des motifs

1. Des réunions internationales de congrès et de commissions ont eu le grand mérite de permettre une prise de contact entre chercheurs venant de différents pays et de faciliter un échange fort intéressant de données scientifiques. La recherche en commun, toutefois, s'est bornée, jusqu'ici, à la question des méthodes de laboratoire pour l'examen du sol. Étant donné les possibilités actuelles dans le domaine des communications qui permettent un large échange de vues, le moment semble opportun pour entreprendre des études detaillées fondées sur des expériences pratiques faites en commun.

2. Dans différents pays plusieurs chercheurs sont arrivés à la conclusion que l'expérience pratique constitue le pilier central des études relatives à la fertilité du sol. Des études chimiques, physiques et biologiques sont certainement d'une très grande importance pour les recherches relatives à la fertilité du sol, lorsqu'elles sont faites séparément, mais il est nécessaire de les combiner avec une série d'expériences pratiques. Ces expériences permettront une meilleure appréciation de la fertilité du sol dans une région déterminée et, en même temps, elles provoqueront d'autres études detaillées dans d'autres directions.

3. Une collaboration internationale permettra aux chercheurs de prendre contact avec leurs confrères dans le cadre du même travail. En outre, dans les pays participant à ces travaux, l'intérêt serait éveillé pour les problèmes communs concernant la fertilité du sol et l'on se rendrait mieux compte de leur importance pour l'agriculture et pour l'économie nationale.

Procedure

Il est recommandé qu'une groupe de travail soit chargé d'étudier les possibilités de cette proposition des points de vue techniques et financiers. Il serait nécessaire de prévoir des réunions fréquentes des participants.

Observation finale

La proposition sera présenté par M. P. BRUIN à l'occasion de sa conférence intitulée " Le developpement de la recherche relative à la fertilité du sol aux Pays-Bas " (11ème session, samedi 26 juillet).

Netherlands : P. BRUIN
W. R. DOMINGO
A. C. SCHUFFELEN
Denmark : K. A. BONDORFF
F. STEENBJERG

We are in agreement with the proposal of our colleagues from the Netherlands and Denmark concerning international co-operation in research into problems of soil fertility.

It appears to us to be desirable that an exchange of ideas should be established through the intermediary of Commission IV, which would take into account those principal climatic zones which correspond to the different trends of soil development.

Three principal climatic zones may be considered to be :—

I. Atlantic

II. Mediterranean

III. Tropical and Subtropical

Meetings and co-operative investigations should eventually be organised to cover the range of each of these climatic zones.

France : G. DROUINEAU
Italy : G. PASSERINI
Australia : J. A. PRESCOTT
Netherlands : F. A. VAN BAREN

Nous sommes d'accord avec la proposition Néerlandaise et Danoise sur la coopération internationale dans les recherches sur la fertilité.

Il nous semble nécessaire que des échanges de vues ultérieurs de la Commission IV en tenant compte des zones climatiques principales qui correspondent également à des modes differents d'évolution du sol.

Une division en trois zones climatiques principales pourrait alors être envisagée :—

I. Atlantique

II. Méditerranéene

III. Tropicale et Subtropicale.

Des réunions ou des travaux ultérieurs devraient être organisés dans le cadre de chacune de ces zones.

France : G. DROUINEAU
Italy : G. PASSERINI
Australia : J. A. PRESCOTT
Netherlands : F. A. VAN BAREN

Comme quelques régions arides ou semi-arides ont des problèmes résultant d'un excès du carbonate de calcium, nous proposons que de tels problèmes soient examinés sur une base internationale entre les nations ayant de tels problèmes, spécialements dans la région méditerranéenne.

Egypt : M. ELGABALY
Spain : V. HERNANDO

As some of the arid and semi-arid regions have problems of excess calcium carbonate, we propose that such problems be investigated on an international basis among nations having such problems particularly within the Mediterranean Area.

Egypt : M. ELGABALY
Spain : V. HERNANDO

CLOSING SPEECH BY THE PRESIDENT OF THE MEETING

LADIES AND GENTLEMEN,

On behalf of all the members of the meeting, I would like to say that we are very grateful to the Irish organizing committee and to all their co-workers who have contributed so much to the organisation of this conference. There has—as you all know—been some work to do both before and during the conference and I think we all agree that they have done good work, indeed.

The significance of a conference is, undoubtedly, determined by its results. We are many who have been able to follow very closely the work in most of the sessions, and as far as we can see it was most happy that we agreed to have principal speakers and supporting speakers so that some of the time of each session could be used for discussions. It is my impression that the success of our conference is founded to a very high degree on some of our interesting discussions. Personal discussions on as high a level as possible are very valuable, not only because they help the mind to set forth and clarify principles along which the details group themselves, but also because they mean quick exchange of thoughts between persons who ordinarily do not have the possibility to meet. Discussions save much valuable time. I think our chairmen have shown excellent leadership and taken much pain during each session.

Before trying to summarize the results of this conference, I would further like to express the gratitude of the organizing committee for all contributions.

But now as to the results. You may allow me shortly to remind you of the fact that the main object of this conference was to discuss chemical and biological methods for the improvement of yield. So we have discussed both the analytical methods as used in the laboratory *and* in the field, and besides, we have concentrated on the principles and details with respect to the interpreting or evaluating of the analytical results. There is no doubt that the analytical methods used whether for soil analyses, plant analyses, etc., can be refined so that a more and more precise dividing up of a plant nutrient in fractions of a different nutritional value to the plant will be possible. It may even be possible in the future to identify and determine with a certain degree of precision, some of the compounds of nutrition existing in the soil.

Several of the papers on the analytical methods have, naturally, contained much of importance with respect to the interpretation of the analytical results in field terms. We must admit that the verification of chemical plant and soil analyses, visual symptoms, etc., etc., rests on the even to-day rather slight knowledge of the shape of the yield curve and its position in the coordinate system as influenced —for a nutrient in minimum—by many different factors of production, the importance of which may differ in various regions. The problem which confronts us here rests upon the old saying: that agricultrue is an art, or as we would prefer to put it to-day in its most broad outlines: by what means will the chemist be able to agree with the plants in the field? I think that the discussions on the correlation of the analytical results with field growth have centred mainly around two methods: statistical grouping and spot or contrast investigation,

the last method is a rather special way of statistical grouping. At the present state of development, one may be most successful in solving actual occurring field problems by using a combination of two or more of the methods we have discussed at this meeting. The different methods have the advantage of being more or less independent of one another.

It has generally been agreed upon that at the statistical grouping of the experimental results, one must first and foremost work with the factors of production which experience has shown to have a great influence on the shape and the position of the yield curve provided they can be regulated and expressed numerically. The factors of production which are less important and which most often cannot be regulated, for instance, climate factors or determined mean and uncontrollable variation of the yield figures; this variation must enter into the final answer to the agriculturist and cause a varying error to be attached to this answer. I may add that solutions of these problems, which are of a summary nature, are often dangerous, because they may be seemingly efficient without giving much information to the farmer in the field; besides such solutions often hamper the true analytical approach to the verification.

A group of factors which we have discussed and which causes great variations in the production is the climate factors, and even though they ordinarily cannot be regulated and are difficult to express numerically, it is becoming more and more necessary that the research work is extended to cover this field as well. The question as to whether the spot or contrast investigation should be used at the verification or statistical grouping based on results from long- or short-term field experiments depends on several conditions, also on the quantity and quality of the results of field experiments available. It has been stressed that in countries and in fields of work, where results from field experiments are scarce, the method of contrast investigation may solve several problems in the field in a satisfactory way, whether using chemical soil or plant analyses, tissue tests, foliar diagnosis, etc., etc.

Ladies and gentlemen. This conference is nearly closed. Much work has yet to be done, and it will be done to the benefit of agriculture all over the world, because soil science is to-day as before a true international science.

Ladies and gentlemen. The conference here in Dublin is closed.

List of Delegates and Observers

ALGERIA
Durand, Jacques, Official delegate.
Roseau, Prof. Henri, Official delegate.

AUSTRALIA
Hutton, J. T., C.S.I.R.O. Division of Soils.
Jones, Dr. Lloyd H. P., School of Agriculture, Melbourne University.
Prescott, Prof. J. A., University of Adelaide.

BELGIUM
Cordier, Paul, Service Pédologique de Belgique.
Cottenie, André, State Agricultural University of Ghent.
Homès, Prof. M. V. L., Institut National pour l'Étude Agronomique du Congo Belge.
Kuczarow, W., Institut National pour l'Étude Agronomique du Congo Belge.
Molle, A. L. J., Institut National pour l'Étude Agronomique du Congo Belge.
Piot, Richard, Service Pédologique de Belgique.

BURMA
Zin, Kyaw, Private.

CHILE
Aguirre, Raúl, Official delegate.

DENMARK
Boken, Mrs. Else, Royal Veterinary and Agricultural College.
Steenbjerg, Prof. Dr. F., Royal Veterinary and Agricultural College.
Tovborg Jensen, Prof. S., Danish State Board of Plant Culture.

DOMINICAN REPUBLIC
Boyrie, Louis A. de, Official delegate.

EGYPT
Elgabaly, Prof. M. M., Farouk I University.

FINLAND
Vuorinen, Prof. Dr. Jouko Ensio, Official delegate.

FRANCE
Audidier, Lucien, Société Commerciale des Potasses d'Alsace.
Barbier, George, Station Centrale de l'Agronomie, Versailles.
Chaminade, Prof. Raymond, Official delegate.
Drouineau, Gustave, Official delegate.
Gouère, André, La Compagnie de Saint Gobain.
Henin, Dr. Stephane, Laboratoire des Sols, Versailles.
Morel, Prof. Robert, Official delegate.

FEDERAL REPUBLIC OF GERMANY
Alten, Prof. Dr. Fritz, Kalivertriebsstelle GmbH.
von Boguslawski, Prof. Eduard, Institut für Pflanzenbau und Pflanzenzüchtung der Justus-Liebig-Hochschule.
Flaig, Prof. Dr. Wolfgang, Institut für Biochemie des Bodens.
Jacob, Prof. Dr. Artur, Agrikulturchemische Laboratorium der Gewerkschaft Victor.
Kuron, Prof. Dr. Hans, Institut für Bodenkunde, Justus-Liebig-Hochschule.
Riehm, Dr. Hans, Fachgruppe Bodenuntersuchung im Verband Deutscher Landw. Untersuchungs- und Forschungsanstalten.
Schachtschabel, Prof. Paul, Institut für Geologie und Bodenkunde.
Scheffer, Prof. Dr. Fritz, Deutsche Bodenkundliche Gesellschaft.
Welte, Dr. Erwin, Agrikulturchemisches und Bodenkundliches Institut.

ICELAND
Johannesson, Dr. Bjorn, Official delegate.

ITALY
Ferrari, Prof. Carlo, Università di Bologna.
Passerini, Prof. Gino, Official delegate.
Rotini, Prof. Orfeo T., Università degli Studi, Pisa.

IRELAND
Bellew, J. K., Imperial Chemical Industries, Ltd.
Brickley, W. D., University College, Dublin.
Breathnach, T., Co. Mayo Committee of Agriculture.
Fleming, G., Department of Agriculture.
Gahan, W., Comhlucht Siúicre Éireann, Teoranta.
Golden, J. D., Department of Agriculture.
Kavanagh, T. J., Department of Agriculture.
Kilroy, J. J., Department of Agriculture.
Lamb, J. G. D., Department of Agriculture.
Lewis, B. M., Potash Ltd.
Mannion, L., Department of Agriculture.
Masterson, C., Department of Agriculture.
Mellon, D., Irish Fertilizer Manufacturers' Association.
Murphy, Miss C. M., Department of Agriculture.
McDonnell, J. J., Department of Agriculture.
McDonnell, P., Department of Agriculture.
Neenan, M., Department of Agriculture.
O'Donohoe, S., Co. Mayo Committee of Agriculture.
Parkes, J. W., Irish Fertilizer Manufacturers' Association.
Quinn, E., Department of Agriculture.
Ryan, Pierce, Department of Agriculture.
Ryan, P. F., Department of Agriculture.
Walsh, Dr. T., Department of Agriculture.

IRAN
Goodarzi, Karim, Official delegate.

JAMAICA
Innes, R. F., The Sugar Manufacturers' Association (of Jamaica) Ltd.
Thompson, H. A., West Indies Sugar Company, Ltd.

MALAYA
Coulter, J. K., Official delegate.

NETHERLANDS
Baren, Prof. Dr. F. A. van, Secretary-Treasurer, International Society of Soil Science.
Bruin, Dr. P., Agricultural Experimental Station and Institute for Soil Research, T.N.O., Wageningen.
Domingo, W. R., The Laboratory for Soil Testing and Plant Analysis.
Ferrari, Dr. Th. J., Agricultural Experimental Station and Institute for Soil Research, T.N.O., Wageningen.
Gerretsen, Dr. F. C., Agricultural Experimental Station and Institute for Soil Research, T.N.O., Wageningen.
Haasjes, K.H.S., Albatros Superfosfaatfabrieken N.V.
Kloes, L. J. J. van der, Horticultural Experimental Station of Fruit and Vegetables, Naaldwijk.
Kortleven, Jac., Agricultural Experimental Station and Institute for Soil Research, T.N.O., Wageningen.
Kuipers, Sjirk Frans, Official delegate.
Lehr, Dr. Jan J., Nitrate Corporation of Chile Ltd.
Middelburg, Dr. H. A., The Laboratory of Agricultural Chemistry of the Agricultural College.
Paauw, Dr. F. van der, Agricultural Experimental Station and Institute for Soil Research, T.N.O., Wageningen.
Poll, K., Co-operative Fertilizer Works, Vlaardingen.

NETHERLANDS—continued
Rosanow, M., Nitrate Corporation of Chile Ltd.
Schuffelen, Prof. Dr. A. C., Laboratory for Agricultural Chemistry, Agricultural University, Wageningen.

NEW ZEALAND
Marsden, Dr. E., Department of Scientific and Industrial Research.
Saunders, W. M. H., The Soil Bureau, Department of Scientific and Industrial Research.

NIGERIA
Greenwood, M., Official delegate.

PORTUGAL
Alves, José Almeida, Estacáo M. Plantas.

S. RHODESIA
Duguid, James F., Official delegate.

SPAIN
Hernando, Dr. Valentín, Instituto de Edafología y Fisiología Vegetal.
Tamés, Alarcon, C., Official delegate.

SWITZERLAND
Bach, Dr. Roman, Agriculturchemisches Institut, Eidgenössische Technische Hochschule.
Bovay, Dr. Ernest, Stations fédérales d'essais agricoles.
Hasler, Dr. Arthur, Official delegate.

TRINIDAD
Hardy, Prof. F., Imperial College of Tropical Agriculture.
Page, Harold J., Imperial College of Tropical Agriculture.
Rodrigues, G., Imperial College of Tropical Agriculture.

UNITED KINGDOM
Armitage, E. R., Jealott's Hill Research Station.
Arnott, G. E., Colonial Service Agricultural Probationer.
Bascomb, C. L., Rothamsted Experimental Station.
Blenkinsop, A., Official delegate.
Bould, Dr. Cyril, Long Ashton Research Station.
Bromfield, S. M., Rothamsted Experimental Station.
Crawford, D. V., Nottingham University School of Agriculture.
Crowther, Dr. E. M., Rothamsted Experimental Station.
Davies, R. I., University College of North Wales.
Dunn, J. H., Jealott's Hill Research Station.
Gasser, John K. R., Rothamsted Experimental Station.
Greene, Herbert, Rothamsted Experimental Station.
Hewitt, Dr. Eric J., Long Ashton Research Station.
Horton, C. E., Fisons Limited.
Jacks, Graham V., Commonwealth Agricultural Bureaux.
Jewitt, T. N., Private.
Jones, John D., Official delegate.
Lees, Dr. Howard, Aberdeen University.
Lloyd, Dr. Arthur J., Monsanto Chemicals Limited.
Mattingly, Dr. G. E. G., Rothamsted Experimental Station.
Morley Davies, W., Official delegate.
Nicholas, Dr. D. J. D., Long Ashton Research Station.
Nicholson, M. N., Official delegate.
McAleese, D., Private.
McAllister, J. S. V., Official delegate.
McArthur, Dr. D. N., Macaulay Institute for Soil Research.
McConaghy, S., Official delegate.
MacGregor Crooke, Wm., Macaulay Institute for Soil Research.
Patterson, J. B. E., Official delegate.
Pizer, Dr. Norman H., Official delegate.
Plant, Dr. William, Long Ashton Research Station.

UNITED KINGDOM—continued
Reith, Dr. J. W. S., Macaulay Institute for Soil Research.
Richardson, Dr. H. L., Imperial Chemical Industries, Ltd. (Central Agricultural Control).
Roach, Dr. Wm. A., East Malling Research Station.
Romney, D. H., Colonial Research Service.
Russell, Dr. E. W., Department of Agriculture, Oxford University.
Schofield, Dr. R. K., Rothamsted Experimental Station.
Semmens, P. W. B., Imperial Chemical Industries, Ltd.
Shaw, Kenneth, Rothamsted Experimental Station.
Simpson, D. E., Scottish Agricultural Industries, Ltd.
Smith, Dr. A. M., Edinburgh and East of Scotland College of Agriculture.
Taylor, A. W., Rothamsted Experimental Station.
Tinsley, Dr. Joseph, University of Reading.
Vanstone, Dr. F. H., East Malling Research Station.
Wallace, Prof. T., Long Ashton Research Station.
Wardell, E. V. M., Imperial Chemical Industries, Ltd.
Warren, R. G., Rothamsted Experimental Station.
Webber, Jack, Official delegate.
Whittles, Dr. Cyril L., West of Scotland Agricultural College.
Wild, Dr. Alan, Reading University.
Williams, Dr. E. G., Macaulay Institute for Soil Research.
Williams, Dr. Rice, official delegate.

U.S.A.
Dean, Lyman A., Official delegate.
Nelson, Prof. W. L., North Carolina State College.
Reitemeier, R. F., Official delegate.
Smith, Prof. G. E., University of Missouri.

HOLY SEE
Gallagher, Dr. P. H., Observer.
McElligott, S.D.B., The Rev. R., Observer.

F.A.O.
Dion, Henry G., Observer.

M.S.A.
Nelson, A. P., Observer.

O.E.E.C.
Rowan, B. L., Observer.

Index of Authors

PAGE

BARBIER, G., et TYSKIEWICZ, MLLE. E. 79
BARJAC, H. DE, et POCHON, J. 48
BATS, J., et ROSEAU, H. 248
BOGUSLAWSKI, E. VON 195
BOLLE-JONES, E. W. 186
BOULD, C., NICHOLAS, D. J. D., and THOMAS, W. D. E. 92
BOULD, C., NICHOLAS, D. J. D., and TOLHURST, J. 172
CARQUÉ, E. 95
COPPIER, O., et POCHON, J. 52, 71
CORADUCCI, P., SANDRI, G., and LUGO, P. 103
COTTENIE, A., and HENDE, A. VAN DEN 304
COTTENIE, A., HENDE, A. VAN DEN, and JONGHE, P. DE 307
COTTENIE, A., HENDE, A. VAN DEN, and VLIEGHERE, R. DE 37
CROWTHER, E. M. 14
DAVIES, E. B. 340

PAGE

ELGABALY, M. M. 259, 261
FERRARI, C. 99
FERRARI, TH. J. 231
FLEMING, G. A., and WALSH, T. 178
FRANC DE FERRIÈRE, P. J. J. 132
GARAUDEAUX, J., QUIDET, P., et MALICORNET, H. 126
GOLDEN, J. D., and WALSH, T.... 167
HENDE, A. VAN DEN, and COTTENIE, A. 304
HENDE, A. VAN DEN, COTTENIE, A., and JONGHE, P. DE 307
HENDE, A. VAN DEN, COTTENIE, A., and VLIEGHERE, R. DE 37
HERNANDO, V., and JIMENO, L. 107
HEWITT, E. J. 240
HOMÈS, M. V. 288
INKSON, R. H. E., WILLIAMS, E. G., and REITH, J. W. S. 84
JACOB, A. 56
JENSEN, H. L. 153
JEWITT, T. N. 243
JIMENO, L., and HERNANDO, V. 107
JONES, L. H. P. 164
JONGHE, P. DE, COTTENIE, A., and HENDE, A. VAN DEN 307
LÅG, J. 349
LEHR, J. J., and VEEN, B. 61
LEHR, J. J., SCUFFELEN, A. C., and ROSANOW, M. 263
LUGO, P., SANDRI, G., and CORADUCCI, P. 103
MCCONAGHY, S., and MCALLISTER, J. S. V. 354
MCALLISTER, J. S. V., and MCCONAGHY, S. 354
MCDONNELL, J. J., and MURPHY, Miss C. M. B. 74
MCDONNELL, J. J., WALSH, T., and RYAN, P. F. 326
MALICORNET, H., GARAUDEAUX, J., et QUIDET, P. 126
MATTINGLY, G. E. G. 68
MIDDELBURG, H. A. 116
MURPHY, Miss C. M. B., and MCDONNELL, J. J. 74
NICHOLAS, D. J. D. 158, 278, 283
NICHOLAS, D. J. D., BOULD, C., and THOMAS, W. D. E. 92
NICHOLAS, D. J. D., BOULD, C., and TOLHURST, J. 172
PASSERINI, G. 336
PIZER, N. H. 364
PLANT, W. 140, 176
POCHON, J., et BARJAC, H. DE 48
POCHON, J., et COPPIER, O. 52, 71
QUIDET, P., GARAUDEAUX, J., et MALICORNET, H. 126
RAYCHAUDHURI, S. P., and SUBBIAH, B. V. 253
REITH, J. W. S., WILLIAMS, E. G., and INKSON, R. H. E. 84
ROSANOW, M., LEHR, J. J., and SCHUFFELEN, A. C. 263
ROSEAU, H., et BATS, J. 248
RYAN, P. F., WALSH, T., and MCDONNELL, J. J. 326
SANDRI, G., CORADUCCI, P., and LUGO, P. 103
SCHEFFER, F., und WELTE, E. 29
SCHUFFELEN, A. C., LEHR, J. J., and ROSANOW, M. 263
SIMPSON, K., and SMITH, A. M.... 373
SMITH, A. M., and SIMPSON, K. 373
SUBBIAH, B. V., and RAYCHAUDHURI, S. P. 253
THOMAS, W. D. E., NICHOLAS, D. J. D., and BOULD, C. 92
TOLHURST, J., NICHOLAS, D. J. D., and BOULD, C. 172
TOVBORG JENSEN, S. 318
TYSKIEWICZ, MLLE. E., et BARBIER, G. 79
VANSTONE, F. H. 292
VEEN, B., and LEHR, J. J. 61
VLIEGHERE, R. DE, HENDE, A. VAN DEN, and COTTENIE, A. 37
WALSH, T., and FLEMING, G. A. 178
WALSH, T., and GOLDEN, J. D.... 167
WALSH, T., RYAN, P. F., and MCDONNELL, J. J. 326
WELTE, E., and SCHEFFER, F. 29
WHITTLES, C. L. 379
WILLIAMS, E. G., REITH, J. W. S., and INKSON, R. H. E. 84