ROTHAMSTED RESEARCH

# Report for 1934

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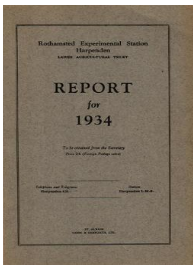


## The Chemistry of Soils and Fertilisers

### Rothamsted Research

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obtained with the ordinary implements. It is, however, much looser, and the methods for dealing with this new condition and turning it to advantage are still being worked out. In the early stages of growth a rotary cultivation tilth is superior to the normal type : germination and early growth are both better, and although the advantage is usually lost by harvest time, the final yields are usually as good as those given by normal cultivations. This result is obtained in spite of the extra weediness of rotary cultivated plots, which is probably a consequence of the action of the rotating tines. The weed seeds are distributed throughout the depth of cultivation whereas the normal methods encourage germination only in the thin surface layer, where hoeing can easily deal with them.

If these technical difficulties of rotary cultivation can be overcome, the way is clear for an appreciable reduction in the heavy costs of cultivations that the arable farmer must face. The field experiments are therefore being actively continued.

## THE CHEMISTRY OF SOILS AND FERTILISERS

E. M. Crowther

The general object of the work of the Chemistry Department under Mr. H. J. Page, from 1920 to 1927, and since then under the writer, has been the study of the chemical aspects of soil fertility and soil formation. In recent years most of the investigations have dealt with material provided by field experiments at Rothamsted, Woburn and commercial farms on which field experiments are conducted by the Rothamsted staff or local agricultural officers. Several soil investigations have also been carried out on overseas soils, especially from the tropics.

One of the most urgent problems is to devise better methods of obtaining precise agricultural information on soil fertility and crop nutrition. Much of the work of the Department is, therefore, devoted to improving the methods of field experimentation, especially on fertilisers, and to supplementing the crude yields by analyses of the crops. Soils from the experimental centres are analysed by a variety of chemical methods to ascertain how far the results of chemical analyses agree with the agricultural experience expressed in the results of the field trials. The soils of the long-continued experiments at Rothamsted and Woburn are studied to measure the cumulative secondary effects of fertilisers. Systematic samplings and analyses on these classical plots and on those of some of the complex replicated experiments are made for periods of a few years to follow the seasonal cycles in some of the main factors in soil fertility. Much of the laboratory work involves parallel investigations in the pot culture house.

### Soil Colloids and Ionic Exchange

It is now generally recognised that the amounts and composition of the soil colloids and the exchangeable ions associated with them are vital factors in determining the physical and chemical properties of soils and the availability of plant nutrients.(1) The first investigations on exchangeable bases were made on the soils of the Broadbalk

(1) H. J. Page—"The Nature of Soil Acidity." Trans. II Comm. Int. Soc. Soil Sci., Vol. A., Gron., 1926, pp. 232-244 ; C. E. Marshall—"Some Recent Researches on Soil Colloids. A Review." Journ. Agri. Sci., 1927, Vol. XVII, pp. 315-332.

continuous wheat plots and on some coastal soils which had been flooded by sea water.(2) The study of the soil colloids began with a series of investigations between 1921 and 1927, on the nature and origin of the humic material.(3) This was shown to be derived from the lignin constituents of plants by condensation with protein. Soils in which widely different carbon contents had been produced by cultural and manurial treatments had humic materials with closely similar compositions and properties.

Work on the composition of the inorganic soil colloids or clay fraction began with an examination of earlier American data.(4) It was shown that the ratio of silica to alumina in the clay fraction fell as the rainfall increased and rose as temperature increased ; the relative rates were such that for similar parent materials constant silica : alumina ratios are found when an increase in mean annual temperature of 1°C. is accompanied by an increase of 4 cm. in mean annual rainfall. For constant climatic conditions the silica : alumina ratio was greater on soils from parent materials which had been subjected to repeated reworking in water. A similar method of statistical analysis was also applied to problems of soil distribution in continental areas. More recently the chemical analysis of clays has been simplified by a method for the direct determination of aluminium.(5) Investigations of soils from Burma, Malay, Nyasaland and other countries have given ample additional evidence for the rule that hot wet regions tend to have clays rich in iron and aluminium, while those in arid regions are rich in silica. It has been found however, that although soils of the same type have similar clays, the ratio of silica to alumina or sesquioxides is not in itself a sufficient index of the composition and properties of the soil. Thus, a pair of contrasted but adjacent soils in a cotton experiment station in Nyasaland (an acid red loam and a neutral grey-brown soil with carbonate accumulations in the lower horizons) had clays with closely similar silica-sesquioxide ratios. Further fractionation and characterisation of clay fractions are required, and we are using a series of physicochemical, mineralogical and X-ray methods for these purposes.

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(2) H. J. Page and W. Williams—" Studies on Base Exchange in Rothamsted Soils." Trans. Faraday Soc., 1925, Vol. XX, pp. 573-585 ; H. J. Page and W. Williams—" The Effect of Flooding with Sea Water on the Fertility of the Soil." Journ. Agri. Sci., 1926, Vol. XVI, pp. 551-573.

(3) H. J. Page—" The Part Played by Organic Matter in the Soil System." Trans. Faraday Soc., 1922, Vol. XVII, pp. 272-287 ; E. M. Crowther—" Further Experiments on the Effect of Removing the Soluble Humus from a Soil on its Productiveness." Journ. Agri. Sci., 1925, Vol. XV, pp. 303-306 ; H. J. Page and C. E. Marshall.—" The Origin of Humic Matter." Nature, 1927, Vol. CXIX, p. 393 ; " Studies on the Carbon and Nitrogen Cycles in the Soil." I. H. J. Page—" Introductory." Journ. Agri. Sci., 1930, Vol. XX, pp. 455-459 ; II. C. W. D. Arnold and H. J. Page—" The Extraction of the Organic Matter of the Soil with Alkali." Journ. Agri. Sci., 1930, Vol. XX, pp. 460-477 ; III. M.S. du Toit and H. J. Page—" The Formation of Natural Humic Matter." Journ. Agri. Sci., 1930, Vol. XX, pp. 478-488 ; IV. M. M. S. du Toit and H. J. Page—" Natural and Artificial Humic Acids." Journ. Agri. Sci., 1932, Vol. XXII, pp. 115-125 ; V. H. J. Page—" The Origin of the Humic Matter of the Soil." Journ. Agri. Sci., 1932, Vol. XXII, pp. 291-296 ; VI. R. H. Hobson and H. J. Page—" The Extraction of the Organic Nitrogen of the Soil with Alkali." Journ. Agri. Sci., 1932 Vol. XXII pp. 297-299 ; VII. R. P. Hobson and H. J. Page—" The Nature of the Organic Nitrogen Compounds of the Soil ; ' Humic ' Nitrogen." Journ. Agri. Sci. 1932 Vol. XXII, pp. 497-515 ; VIII. R. P. Hobson and H. J. Page—" The Nature of the Organic Nitrogen Compounds of the Soil ; ' Non-Humic ' Nitrogen." Journ. Agri. Sci., 1932, Vol. XXII, pp. 516-526. H. L. Richardson—" The Use of Hydrogen Peroxide for Estimating Humification." Soil Sci., 1931, Vol. XXXII, pp. 167-171.

(4) E. M. Crowther—" The Relationship of Climatic and Geological Factors to the Composition of Soil Clay, and the Distribution of Soil Types." Proc. Roy. Soc. (B), 1930, Vol. CVII, pp. 1-30 ; E. M. Crowther—"Soils and Climate." Min. Agric., Rept. Agri. Meteorol. Conf., 1931, pp. 5-11; E. M. Crowther—" Climate, Clay Composition and Soil Type." Proc. 2nd. Intern. Cong. (1930) Soil Sci., Comm. V, 1932, pp. 15-23.

(5) S. P. Aiyer—Ph.D. Thesis, University of London, 1934.

A serious error was detected in the standard quinhydrone method for measuring soil reaction, and traced to the effects of readily reducible oxides of manganese.(6) This was followed up by a study of the amount and rate of solution of the exchangeable and readily reducible manganese in soils on which oats in this country and tea in Ceylon showed symptoms of deficiency diseases. The work suggested that soils with relatively large amounts of manganese oxides may yet contain very little readily soluble manganese.

Methods for the determination of the exchangeable bases and acidity (unsaturation) are being developed in suitable forms for combination with routine analyses for readily soluble plant nutrients.

## Changes in the Soils of Long Continued Field Trials

The plots of Stackyard Field at Woburn were sampled fully in 1927 on the completion of fifty years of continuous experimentation with fertilisers and crop rotations. The sampling was repeated in 1932, and samples were available for a number of other years, including a few of the earlier ones. Soil samples from these plots were analysed for (1) carbon, (2) nitrogen, (3) exchangeable bases, (4) soil reaction, (5) composition of clay fractions, to study the changes on this light and poorly buffered soil under a wide variety of treatments.(7)

Under continuous wheat and barley without farmyard manure, one-third of the soil organic matter was lost in fifty years ; farmyard manure at the rate of about 7 tons per acre per annum merely sufficed to maintain the original organic matter content. Superphosphate had no appreciable effect on the soil reaction or base status, even after fifty annual applications. From plots which had been rendered almost infertile by sulphate of ammonia and then subdivided for varying dressings of lime, it was possible to show that the rate of loss of lime fell off rapidly as the soil became progressively more acid. An attempt was made to assess the effects of nitrate of soda and sulphate of ammonia on the lime status of the soil, and it was concluded that, if lime were to be added periodically to keep the composition of the soil and the crops with sulphate of ammonia similar to those with nitrate of soda, the amount of lime needed would be equivalent to both the nitric and the sulphuric acids produced by the oxidation of the sulphate of ammonia. The comparison is complicated, however, by the circumstance, which is well illustrated in recent pot experiments at Woburn, that nitrate of soda has a much more potent effect on plants grown in very acid soil than can be accounted for by the mere reduction of loss of calcium by leaching. These Woburn data and similar ones on the reaction, nitrogen and phosphoric acid contents of Rothamsted

(6) S. G. Heintze and E. M. Crowther—" An Error in Soil Reaction Determination by the Quinhydrone Method." Trans. Sec. Comm. Inter. Soc. Soil Sci., Budapest, 1929. Pt. A., pp. 102-111; E. M. Crowther and S. G. Heintze—In " Report of the Soil Reaction Committee of the International Society of Soil Science. I. Results of Comparative Investigations on the Quinhydrone Method II. Conclusions and Recommendations." Soil Res. 1930. Vol. II, pp. 28-139, 141-152 ; S. G. Heintze—" The Use of the Glass Electrode in Soil Reaction and Oxidation-Reduction Potential Measurements." Journ. Agri. Sci., 1934, Vol. XXIV, pp. 28-41.

(7) E. M. Crowther and J. K. Basu—" Studies on Soil Reaction VIII. The Influence of Fertilisers and Lime on the Replaceable Bases of a Light Acid Soil after Fifty Years of Continuous Cropping with Barley and Wheat." Journ. Agric. Sci., 1931. Vol. XXI, pp. 689-715 ; E. M. Crowther—" The Loss of Lime from Light Soils (an Examination of the Woburn Barley and Wheat Soils)." Journ. Roy. Agri. Soc. Eng., 1932, Vol. XCIII, pp. 199-214 ; A. Walkley. Ph.D. Thesis, University of London, 1933.

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classical fields show wide irregularities between comparable plots, and emphasise the danger of basing conclusions on differences between unreplicated plots. The main differences in the carbon contents of the Woburn plots proved to be due to coal fragments and not to normal soil organic matter.

## "Available" Nutrients; Phosphate and Potash

In spite of a vast output from many countries of papers on methods for the estimation of fertiliser requirements by chemical analysis of soils, comparatively little real progress has yet been made, mainly because it has rarely been possible to conduct a sufficient number of precise field experiments to standardise the methods[8]. The factors involved are necessarily so complex that the most that can be expected is to establish analytical limits for given types of farming and soil conditions. Proposed methods must constantly be subjected to critical trials and, up to the present, the problem of organising the necessary trials has not been seriously attacked. At Rothamsted, our main contribution to the subject has been an attempt to develop and, at the same time, to simplify the technique of field experimentation. Our current scheme of a 27 plot test embodying all combinations of zero, single and double dressings of nitrogenous, phosphatic and potassic fertilisers promises to meet the general requirements. It provides a general survey of the nutrient requirements of a given crop and soil ; it shows how the response varies with the rate of dressing, tests the magnitude of interactions between fertilisers, and provides valid estimates of the errors of all of the points tested. The crop responses required to establish statistical significance are of about the same order as those which would be profitable to the grower. We have used this technique for a number of potato experiments, especially in fenland soils, and for sugar beet experiments in 1934 and 1935. We have also arranged a series of such experiments on over 1,000 acres of commercial rubber trees in Malaya. The results so far available in this country have not merely provided useful material for soil investigations, but, in addition, have brought out some unexpected results of practical importance. Thus on some black fenland soils, commonly believed only to require superphosphate, we have had large responses to both nitrogen and potash. On the other hand, in a series of experiments on sugar beet on farms normally receiving relatively heavy dressings of fertilisers, we have obtained very few responses to phosphate or potash. In selecting sites for such experiments, it has been our common experience that soils, chosen by farmers and beet factory agriculturists as poor, very frequently prove to be acid and not necessarily deficient in nutrients by chemical tests. The few experiments already conducted suggest that there is room for considerable improvements in fertiliser practice, by economy on some soils, and by more liberal manuring on others.

The sugar beet series of experiments has so far failed to provide good correlations between field responses and analytical data, because there were very few responses in the field. During the last two dry summers, the success of sugar beet, wheat and other deeply

(8) E. M. Crowther—" The Present Position of the Use of Fertilisers." Journn. Roy. Soc. Eng. 1931, Vol. XCII, pp. 16-18.

rooting crops emphasised the importance of the deep subsoil, and suggested that these crops obtain nutrients as well as water from the deeper soil horizons. Unfortunately, comparatively little is known about the effective root range of our cultivated crops. During the summer drought of 1934, we sampled the soils of our sugar beet experiments to four feet, and were able to divide them into groups with and without subsoil water supplies, by comparing the field moisture contents with those obtained when all soils were brought artificially to comparable degrees of moistness in the laboratory. The beets grown on moist subsoils gave much higher weights of tops per unit of roots and less pure juices ; they also appeared to show more response to superphosphate than those grown on drier subsoils. At Woburn, during 1934, the rate and depth of penetration of beet roots were followed by automatic soil moisture manometers. The roots descended from about 12 inches to 42 inches during July. Towards the end of the season, Dr. Mann excavated and washed out beet roots to a depth of five feet in the soil.

### Soil Organic Matter and Crop Rotation

The decomposition of crop residues, organic manures and soil organic matter has been followed in several series of field experiments with the object of trying to relate the availability of soil nitrogen to the nature of the readily oxidisable organic matter, and to the general soil conditions during the interval between the formation and the utilisation of the inorganic nitrogen.(9) The first problem was the paradox of the Woburn green manure plots on which wheat grown repeatedly after summer green manures deteriorated rapidly, especially after tares.(10) It was shown that the conditions in this light soil favoured rapid decomposition of the crop residues and loss of nitrate by leaching before it could be utilised by the wheat plants in the following spring. Subsequent work by Dr. Mann showed that there are other, as yet unexplained, losses of nitrogen whenever green manures are added to the soil long before the crop can utilise the nitrate produced. Efficient green manuring requires the careful timing of operations so that the absorption of available nitrogen occurs soon after the incorporation of green manure material.

In a ley and fallow experiment at Rothamsted, the changes in readily oxidisable organic matter were followed by measuring the end products of oxidation—$CO_2$, $NH_3$, $NO_3$—on incubating soil samples under optimal conditions in the laboratory.(11) Fallow caused rapid losses of oxidisable carbon, and clover ley increased nitrifiable nitrogen. Nitrates accumulated in the field during fallow in summer and autumn, but were lost from the surface soil during winter. In spite of this, the following wheat crops showed wide yield differences (wheat after fallow being twice that after ryegrass). These differences were correlated with the nitrate contents of the

(9) E. M. Crowther—" Soil Organic Matter and Crop Rotation." Second Conference on Cotton Growing Problems, Empire Cotton Growing Corporation, 1934, pp. 319-329.

(10) T. J. Mirchandani—" The Effect of Summer Green Manures on the Ammonia and Nitrate Contents of Soil Cropped for Winter Wheat." Journ. Agri. Sci., 1931, Vol. XXI, pp. 458-468 ; E. M. Crowther and T. J. Mirchandani—" Winter Leaching and the Manurial Value of Green Manures and Crop Residues for Winter Wheat." Journ. Agri. Sci., 1931, Vol. XXI, pp. 493-525. E. M. Crowther and H. H. Mann—" Green Manuring and Sheep Folding on Light Land "—An Account of the Green Manuring Experiments at the Woburn Experimental Station, 1893-1933. Journ. Roy. Agri. Soc. Eng., 1933, Vol. XCIV, pp. 128-151.

(11) E. R. Orchard—Ph.D. Thesis, University of London, 1933.

soil in the previous summer. It seems necessary to conclude that in the heavy Rothamsted soil the nitrate washed out of the surface in the autumn and early winter is stored in the structural units of the subsoil. Heavy rains drain away through the main cracks and channels, but the nitrate is lost much more slowly, and presumably much of it remains available to deeply rooting crops in the following spring. It seems possible that this hypothesis of the storage of nitrate, and possibly of other nutrients, in subsoils with well developed structures may serve to bridge the gulf between the pedologist's concern with the deeper horizons and the analyst's use of surface samples. It is almost impossible to determine by direct experiment the depth from which plants absorb nutrients, but it may be possible to interpret the effects of changes in surface nutrients in terms of the extent of subsoil storage.

Experiments on a synthetic humic acid prepared from coal by a patented process showed that the organic nitrogen present had little nutritive value for crops.[12] Parallel experiments, conducted on four soils in pot cultures on barley and also in incubators in the laboratory, gave closely concordant results, suggesting that the technique now employed to compare the rates of decomposition of organic manures is satisfactory.

Up to the present, we have found only inappreciable differences between the rates of nitrification of the slow-acting organic manures favoured by market gardeners, and it seems probable that their essential merit lies in their physical state. Lumps and granules allow only slow attack, diffusion, and leaching, and they may, therefore, maintain moderate nitrate concentrations throughout surface and subsoil with less loss by leaching than occurs from readily soluble and diffusible salts.

Short period experiments on repeatedly mown grass and systematic analyses on the Park Grass plots for three years showed that more nitrogen is present as ammonia than as nitrate in normal grassland soils.[13] Evidence was obtained to confirm an old—and sometimes forgotten—view that grasses assimilate ammonia directly and without prior nitrification. The rate of nitrification depends in part on the soil reaction, but some Park Grass soils which have received neither sulphate of ammonia nor lime have very feeble nitrifying powers. Low nitrification means that the available nitrogen and, presumably, the grass roots, tend to concentrate near the surface.

The decomposition of organic matter under the extreme conditions of waterlogging, as in rice soils, was investigated.[14] A deaminase was extracted which was capable of splitting off ammonia in waterlogged soils in the absence of living organisms.

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(12) E. M. Crowther and W. E. Brenchley—" The Fertilising Value and Nitrifiability of Humic Materials Prepared from Coal." Journ. Agri. Sci., 1934, Vol. XXIV, pp. 156-176 ; E. M. Crowther—" A Note on the Availability of Organic Nitrogen Compounds in Pot Experiments." Journn. Agri. Sci., 1925, Vol. XV, pp. 300-302.

(13) H. L. Richardson—" The Behaviour of Nitrogenous Fertilisers in Grassland Soils." Agric. Prog., 1933, Vol. X, p. 160-163.

(14) " Biochemistry of Water-logged Soils." I. V. Subrahmanyan—" The Effect of Waterogging on the Different forms of Nitrogen, on the Reaction, on the Gaseous Relationships, and on the Bacterial Flora." Journ. Agri. Sci., 1927, Vol. XVII, Pt. IV, pp. 429-448; II. V. Subrahmanyan—" The Presence of a Deaminase in Water-logged Soils and its Role in the Production of Ammonia." Journ. Agri. Sci., 1927, Vol. XVII, Pt. IV, pp. 449-467 ; III. V. Subrahmanyan—" Decomposition of Carbohydrates with Special Reference to Formation of Organic Acids." Journ. Agri. Sci., 1929. Vol. XIX, Pt. IV, pp. 627-648.

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## The Availability of Fertilisers

Studies on the behaviour of fertilisers may have immediate practical value and, in addition, may reveal important factors in soil fertility. Among the nitrogenous fertilisers we have made detailed studies on the decomposition of calcium cyanamide, which undergoes a complex series of changes before its nitrogen becomes available to plants.[15] It is commonly said to act more slowly than sulphate of ammonia, but the delay, especially in nitrification, occurs after the cyanamide nitrogen has been converted into ammonia. This is not necessarily a disadvantage, for ammonia is less liable to loss by leaching, and, in addition, may be more rapidly available than nitrate. In some pot culture experiments with barley on a rich acid soil we invariably got better results from cyanamide, which stopped nitrification, than from sulphate of ammonia. The barley plants with cyanamide tillered more rapidly, and appeared to utilise ammonia nitrogen more rapidly than nitrate nitrogen. In field practice the differences between nitrates and ammonia are often masked by the more rapid diffusion of the nitrate through the soil. We have obtained some evidence that cyanamide or dicyanodiamide may be preferable to sulphate of ammonia for autumn dressings of winter wheat on heavy soil.

Basic slags have received detailed study in the Chemistry Department, partly because the English slag problem is unique in the low solubility of some of the materials, and partly because the proper evaluation of slags called for an improved experimental technique, especially on grassland.[16] Basic slags of less than 35 per cent.solubility by the conventional Wagner citric acid test were shown to be definitely less effective as sources of available phosphorus than those of more than 75 per cent. citric solubility. In a series of six hay trials and three repeated mowing trials at centres throughout England for four years, we measured the total yields of dry matter, protein and phosphoric acid in the herbage from four phosphatic fertilisers. All of the experiments gave consistent results for the recovery of the added phosphoric acid. High-soluble slags and superphosphate gave similar recoveries : low-soluble slags provided only about one-third as much phosphoric acid to the crops : on acid soils mineral phosphate was as good as high-soluble slag, and on neutral soils as bad as low soluble slag. In a limited number of trials, it is difficult to distinguish soil from climatic conditions.

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(15) "Studies on Calcium Cyanamide." I. E. M. Crowther and H. L. Richardson—"The Decomposition of Calcium Cyanamide in the Soil and its Effects on Germination, Nitrification and Soil Reaction." Journ. Agri. Sci., 1932, Vol. XXII, pp. 300-324 ; II. B. K. Mukerji—"Microbiological Aspects of Nitrification in Soils under Varied Environmental Conditions." Journ. Agri. Sci., 1932, Vol. XXII. pp. 335-347; III. H. L. Richardson, "Storage and Mixing with Superphosphate" Journ. Agri. Sci., 1932 Vol. XXI, pp. 348-357; IV. H. L. Richardson—"The Use of Calcium Cyanamide and Other Forms of Nitrogen on Grassland." J. Agri. Sci., 1934, Vol. XXIV. pp. 491-510 ; H. L. Richardson and E. M. Crowther—"The Utilisation of Calcium Cyanamide in Pot Culture Experiments." Journ. Agri. Sci., 1935, Vol. XXV, pp. 132-150; H. L. Richardson—"Field Experiments on the Action of Calcium Cyanamide on Germinating Seeds and on Charlock in Barley." Emp. Journ. Expt. Agri., Vol. III, No. 9, pp. 41-49, 1935. E. M. Crowther—"Comparative Field trials of Calcium Cyanamide and Other Nitrogenous Fertilisers on Arable Crops". Emp. Journ Expt. Agri., 1935, Vol, III, pp, 129-143.

(16) R. G. Warren, C. T. Gimingham and H. J. Page—"The Chemistry of Basic Slag I. The Determination of Fluorine in Basic Slag." Journ. Agri. Sci., 1925, Vol. XV, pp. 516-528 ; A. W.. Greenhill—"The Availability of Phosphatic Fertilisers as shown by an Examination of the Soil Solution and Plant Growth." Journ. Agri. Sci., 1930, Vol. XX, pp. 559-572 ; E. M. Crowther and R. G. Warren—"The Fertiliser Value of Basic Slags and Other Phosphates." Agric. Prog. 1934' Vol. XI, pp. 99-105 ; E. M. Crowther—"Basic Slags and Mineral Phosphates." Journ. Roy. Agri. Soc. Eng., 1934, Vol. XCV., pp. 34-53 ; E. M. Crowther and R. G. Warren—Appendices to Interim Reports of Permanent Committee on Basic Slag, Ministry of Agriculture, annually since 1927.

There is evidence from practical experience and also from some of our recent pot experiments that mineral phosphate may give much better results in moist soils than in drier ones. Swede trials in Scotland in 1934 showed that low-soluble slags, though inferior to the more soluble ones, were capable of greatly increasing the yields. Pot experiments on perennial rye-grass grown in sand-calcium bentonite mixtures at constant moisture contents showed extraordinarily close agreement between the yields or the uptake of phosphoric acid, and the citric acid solubilities of a dozen basic slags.

Our experience of field and pot experiments on phosphatic fertilisers suggests that much of the conflict and confusion in the results of the older field experiments was due to the inevitable uncertainties from unreplicated experiments, reliance on yields alone and failure to group the experimental soils. In recent years, each new series of field or pot experiments has confirmed or extended the conclusions from earlier ones.

## The Composition of Crops

From the beginning of the Rothamsted experiments ninety years ago, it has been the rule to prepare and store samples of the produce from most of the experimental plots. Such samples are examined to determine the effect of soil, season and treatment on the composition of the crops. In many comparative experiments on fertilisers the total contents or percentage recoveries of a given nutrient give better measurements of availability than the yields alone. For many crops it is necessary to consider how far changes in composition affect the quality of the product as a food, feeding stuff or industrial raw material. Sometimes, as in sugar beet, the methods of analysis and valuation are either relatively simple or based on well recognised conventions. For other crops it has been necessary to carry out experiments or ambitious programmes of research in conjunction with the industry concerned.(17) Thus, in our work on the effect of soils and fertilisers on the composition of potatoes we had the collaboration of the research staff of Messrs. Lyons. For over ten years members of the staff of the Institute of Brewing Research Scheme worked in the Chemistry Department on the composition of barley. It was shown (18) that soil and season were the most important factors governing quality of barley for malting and brewing ; variety and fertilisers had much less effect. The most important soil factor appeared to be the presence or absence of nitrogenous organic matter. Nitrification late in the life of the barley plant tended to give grain with high nitrogen and low malting quality.

(17) E. M. Crowther—" Influence of Fertilisers on the Yield and Composition of Potatoes." Brit. Assoc., Rept. of Bristol Meeting, 1930, p. 420 ; E. M. Crowther—" Results of Recent Fertiliser Experiments." Problems of Potato Growing, Rothamsted Conferences, 1934, Vol. XVI, pp. 34-40.

(18) E. J. Russell and L. R. Bishop—" Investigations on Barley. Report on the Ten Years of Experiments under the Institute of Brewing Research Scheme. 1922-1931." Journ. Inst. Brew 1933, Vol. XXXIX, pp. 287-421 ; L. R. Bishop—" The Nitrogen Content and ' Quality ' of Barley.." Journ. Inst. Brew., 1930, Vol. XXXVI, pp. 352-364.

## General

Much time has necessarily been devoted to the improvement and standardisation of analytical methods.(19)

The Department has taken an active part in the cooperative investigations on soil analysis by Committees of the Agricultural Education Association(20), and of the International Society of Soil Science (Mechanical Analysis and Soil Reaction Committees for the Second Congress in Leningrad in 1930, and Organic Carbon and Soil Reaction Committees for the Third Congress in Oxford in 1935.)

Since 1921 the Head of the Chemistry Department has prepared an annual report on the progress of investigations on soils and fertilisers for the Society of Chemical Industry's "Reports on the Progress of Applied Chemistry."

# REVIEW OF WORK OF THE BACTERIOLOGY DEPARTMENT

H. G. Thornton

The work that has been carried out in this department can be divided into three sections :—

The quantitative study of the bacterial population of the soil; investigation of various specific bacterial activities that occur in soil; investigations concerning the nodule organism and its relation to leguminous crop plants.

## The Quantitative Study of the Bacterial Flora

The study of ecology of the soil micro-population at Rothamsted was initiated by the work of Russell and Hutchinson on partially sterilised soil, which led to the conclusion that an antagonism existed between certain groups of the population, particularly between soil bacteria and protozoa. Some results obtained by Russell and Appleyard at the same time indicated that the numbers of bacteria in soil were far from constant. It was therefore decided further to investigate these fluctuations in numbers, particularly to discover whether they were related in any way with the numbers of soil protozoa. Before this could be done, however, it was necessary to improve the existing technique of plate counting, which was clearly

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