ROTHAMSTED RESEARCH

Guide to the Work of the Departments 1984

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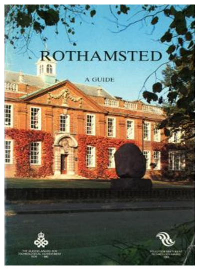


Soils Division

Rothamsted Research

Rothamsted Research (1985) *Soils Division ;* Guide To The Work Of The Departments 1984, pp 33 - 40

clones of certain of the proteins will be used for studies on gene transformation in higher plants (see Plant cell biology).

SOILS DIVISION

The Division includes the Soils and Plant Nutrition Department (which incorporates the Soil Physics section of the previous Physics Department) and the Soil Microbiology Department. Within this Division we aim to combine the study of the processes of soil behaviour and development, with their practical use for the growth of crops. Thus leaching affects profile development – and the loss of fertilizer nitrogen; clay behaviour affects structure formation – and the best method of cultivation; organic matter turnover is an essential part of soil microbiology – and also vital for the nitrogen nutrition of crops. An important aspect of our work is on soil-root relationships and plant nutrition. The dynamic relation between the root system and the soil requires that they be treated as a single system, and the activities of microorganisms are essential components of this. Our aim, on the basis of scientific principles, is to control plant growth and composition accurately, rather to rely on empirical tests. The broad scope of the Division's work is exemplified by the fact that it is heavily involved in computer simulation and advisory systems, and also in biotechnology, with the work on genetic engineering of symbiotic bacteria and fungi. With these interests, the Division must necessarily collaborate closely with others, expecially Agronomy and Crop Physiology and Molecular Sciences, and with the Soil Survey of England and Wales.

SOIL MICROBIOLOGY DEPARTMENT

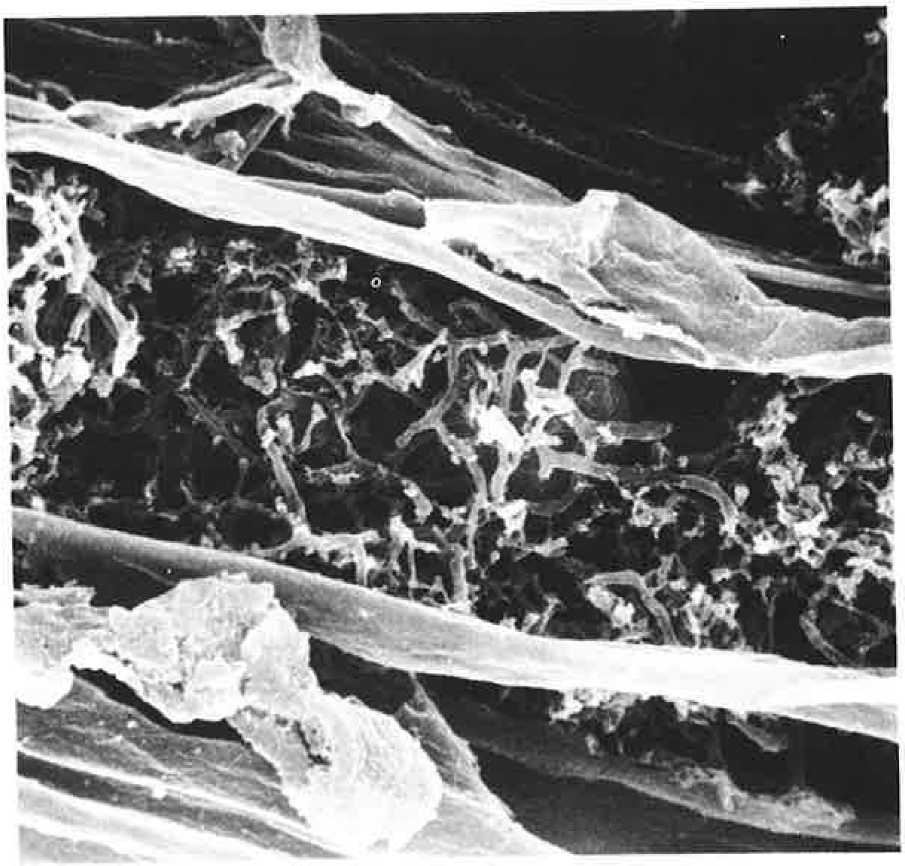
General soil microbiology

Soil contains very many different kinds of microorganisms in vast numbers, including bacteria, viruses, actinomycetes, fungi, protozoa and algae. They break down and transform organic and inorganic materials of the soil, so making nutrients available to crop plants. Some are beneficial, as those promoting good soil structures and fixing nitrogen from the air, and others are harmful, such as those causing disease. Methods of identifying and counting soil microorganisms still require much improvement, and work on this is in progress. It is particularly important for the study of the population in the 'rhizosphere' next to the root.

Mycorrhizas

Mycorrhizas are non-pathogenic fungal infections of plant roots. Those of the vesicular-arbuscular (VA mycorrhizal fungi) type are widespread in many crop plants. We are studying the biology of these fungi, and the effects of soil type, fertilizer and pesticide treatments and seasonal factors on them. Their influence on other soil microbes, including those fixing nitrogen or causing disease, may be considerable.

Their main importance is that, in soils containing little available phosphorus, mycorrhizal infection increases phosphate uptake and thereby improves plant growth, and the mechanisms whereby this occurs are being studied. Methods of exploiting mycorrhizas to improve productivity are being actively tested in upland grassland, vegetable production and horticulture.



Scanning electron micrograph of an onion root cell containing an arbuscule of the mycorrhizal fungus *Gigaspora* sp. × 2250. The root cell cytoplasm was removed chemically, showing this highly branched structure that the fungus develops within the vacuole of the cell. It is believed that phosphate is transferred from arbuscule to host, and carbon compounds in the reverse direction.

These fungi cannot as yet be grown as saprophytes in pure culture, but work is in progress to allow this to be done.

Root nodule bacteria of legumes (Rhizobium)

Leguminous plants, through the activity of their symbiotic bacteria, can use atmospheric nitrogen for their growth. This reduces the demands of these plants on soil or fertilizer nitrogen, and often provides nitrogen for the following crop.

Seeds of legumes are sometimes inoculated with nodule bacteria before sowing if the soil has only small numbers of the correct type of bacteria. White clover has an important role in the productivity of improved upland pastures, and its performance can be improved dramatically by inoculation with both *Rhizobium* and VA mycorrhizas. We are selecting improved strains of both organisms and developing novel inoculant formulations to improve and simplify clover establishment and performance in grass/clover mixtures.

Biotechnology

Both *Rhizobium* and mycorrhizal fungi have great potential for improving plant production. As part of our programme to understand their symbiotic relationships with plants, we aim to identify functions that can be exploited to produce better inoculants. Thus strains of *Rhizobium* are screened against a range of host plants to identify those combinations which are particularly efficient in their use of photosynthetic energy for N_2 fixation. Genes involved in these functions will then be moved between different strains to produce superior inoculants.

With both *Rhizobium* and mycorrhizal fungi we are looking for genes from other organisms which, when transferred to these microorganisms, could modify the way in which they interact with plants. We hope in this way to produce novel inoculants which modify plant growth or susceptibility to pathogens. An important aspect of this research is to develop the genetics of mycorrhizal fungi.

SOILS AND PLANT NUTRITION DEPARTMENT

Yield variation

As part of an AFRC priority programme we are studying the reasons why yields vary so much even when good husbandry is practised. Part of this results from inherent limitations of different soils, but also from problems of management. Field experiments test our ability to get high yields on different soils, and intensive monitoring attempts to explain why we fail in a few cases. The relative suitability of different soils is also studied from surveys, so that we can state whether a given soil series has inherent difficulties, and whether these can or cannot be overcome by the best management.

Crop modelling

Much of our work is now associated with computer modelling. One of the largest projects, in collaboration with other departments and institutes, is to construct a computer model of the growth of a wheat crop, including its use of water and nitrogen. This will allow us to understand which factors are vital for high yield, and so may be of value for advisory work in the future.

Root studies

The growth of crops, and the efficient exploitation of water and nutrients in the soil, depend on well-developed root systems. Roots of winter wheat are being studied in relation to soil compaction and to uptake of water and nutrients. Development of root length appears to be very closely tied to temperature and time. Up to 35 km of roots are found under each square metre of ground. Modelling of nutrient supply to root systems is now in progress.

Nutrient concentrations in crops

Crop composition is important both because it defines the nutritional state of a crop, and because it affects crop quality, e.g. protein content in grain. Nutrient concentrations in tissues as a percentage in dry matter have been used to define nutrient status, but these values vary. However, when these concentrations are expressed on the basis of tissue water they remain much more constant and the plant clearly has mechanisms to 'buffer' these values. This approach is being used to define sub-optimal levels of nutrients, and to investigate strategies that plants use to cope with potassium and nitrogen deficiency.

Soil variation and spatial analysis

Soil is not a homogeneous material: it varies both vertically and laterally at a wide range of scales. New methods of mathematical analysis are being applied to describe this variation. These enable us to estimate local values of soil properties from sample data with the minimum of error, to plan schemes for sampling soil in the most efficient way and to design field experiments effectively. By computer simulation we are also seeking to identify the causes of soil variation.

Soil organic matter

The amount of organic matter in a soil depends on the history of the soil, its management, the soil and clay type and the climate. A change in soil management will ultimately alter the organic content of the soil and thus alter the size of the nitrogen, phosphorus and sulphur reserves; structural stability, water holding capacity and exchange capacity will also be affected. We are studying some of the factors governing the amount of organic matter in soil and hope to be able to predict the long-term effects of a given system of management on the amount in different soils.

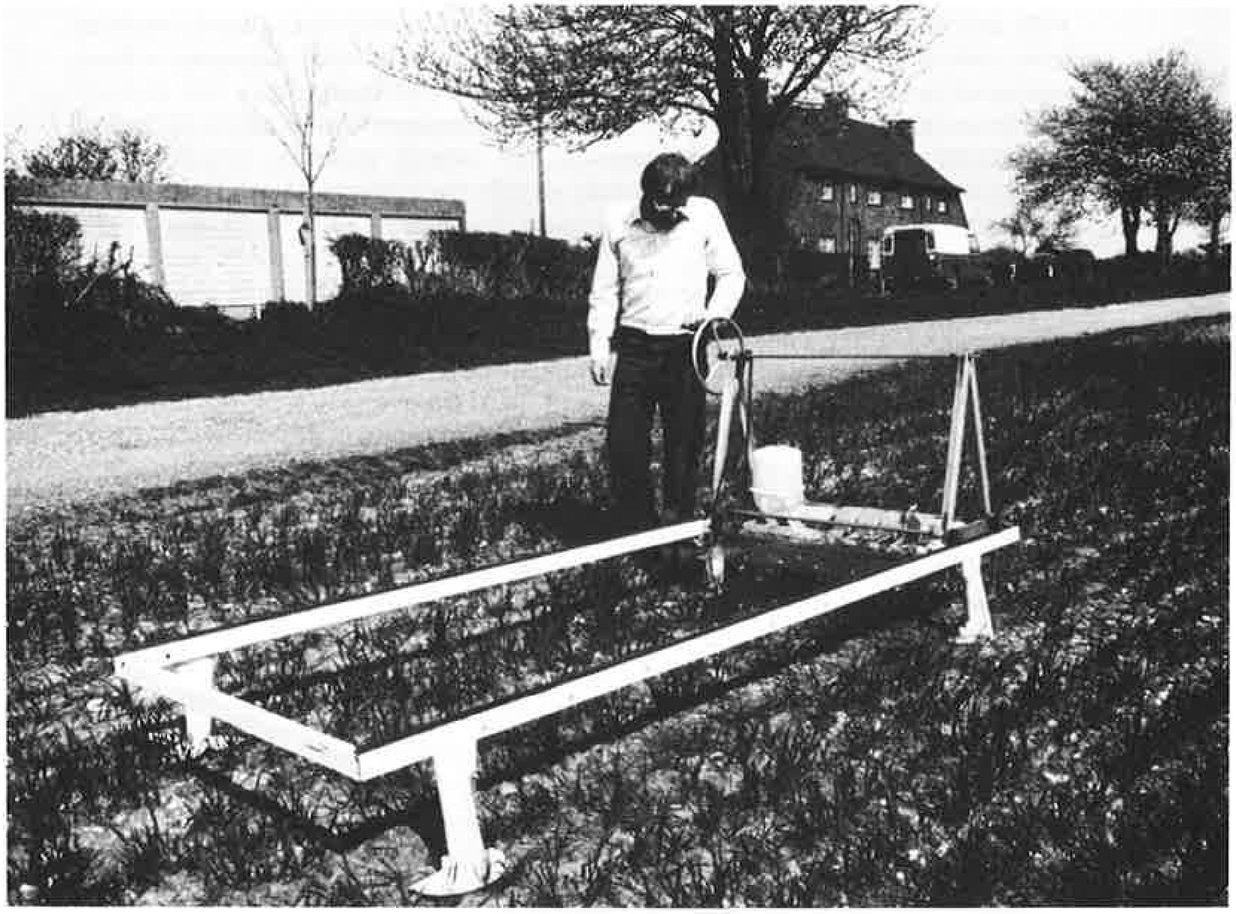
Soil organic matter is formed and decomposed by the soil biomass – the total of all the many sorts of microorganisms in the soil. We can now measure the size and activity of this biomass, and calculate the rate at which nitrogen and phosphorus are cycled through it.

Organic manures have traditionally been used on crops and there is currently a movement in favour of 'organic farming'. Work is being done on the comparison of organic and inorganic manures; usually these are equally good when compared in appropriate ways, but organic manures used regularly benefit soil structure and water holding capacity. Soil organic matter can also be increased by grass or grass/clover leys and short-term leys can be alternated with arable crops in ley-arable farming systems. Three-year leys increase the soil biomass but not soil organic matter. Longer leys may have a more lasting effect on soil structure. Nitrogen balances under various ley-arable farming systems are being studied using ^{15}N-labelled fertilizer.

Grass-clover leys with recently introduced clover cultivars can fix large amounts of N. Up to 450 kg N ha^{-1} has been harvested under favourable conditions.

Nitrogen

Nitrogen is vital to crop yields, and is the fertilizer element most difficult to use with precision and economy because of its complicated reactions in the soil. It is intimately associated with the organic matter, and the work on organic matter also contributes to our understanding of nitrogen behaviour. The very large sum spent annually on nitrogen fertilizer by British farmers, its frequently low efficiency of use, and the numerous different chemical forms and technical methods of application justify a large effort on this element. A major study of the nitrogen balance under wheat and grass using ^{15}N-labelled fertilizer is now being completed.



A machine designed and built at Rothamsted for applying isotopically-labelled nitrogen fertilizers to field experiments.

An important route for N loss is by leaching of nitrate, and this process is being followed in several fields with contrasting soils, crops and fertilizer regimes. The essential point is to ensure a continuous and sufficient concentration of nitrate ion in the rooting zone of the crops during their period of rapid growth. We are building up a system for predicting nitrogen fertilizer need, using our understanding of mineralization and nitrogen turnover in the soil, leaching processes, and denitrification. These processes are simulated in a computer model; so that from weather and soil data, soil nitrogen supply can be predicted; from crop growth, N demand can be determined; and any short fall between these two can be made good by a fertilizer dressing.

We are investigating methods of controlling the rate of nitrification of ammonium and the inhibition of urea hydrolysis in soil by various chemical additives for several crops.

Soil phosphate

Phosphorus is the only major fertilizer element for which there is no indigenous supply. Soil binds phosphate strongly, and many British agricultural soils now contain large reserves of added phosphate in addition to the natural supply. Our field and laboratory experiments measure the size of these residues in terms of crop yield. The rate of decline in soluble P under normal cropping is being measured to see how far residues can be used before yields decline.

We are also interested in those biological processes which affect phosphate availability. These include the amount and rate of turnover of phosphorus in the soil biomass to see if this could supply the P needs of arable crops and grass.

Soil potassium

The non-expanding layers in clay contain strongly bound potassium, and such clays, with feldspars and micas, are the main potassium bearing minerals in soil. The release rate of this potassium, and that from residues of K fertilizers, determines the long-term potassium supply to crops and hence current fertilizer need. Models of release processes allow us to predict the amount of potassium becoming available to crops over a growing season, and we are also interested in whether plant roots have any direct action on such release rates. We are now testing the ability of our methods to predict release rates of potassium to different crops on different soils.

Trace elements

The trace elements have an extremely complex soil chemistry. The availability of a given trace element to plants is only slightly related to its total concentration in the soil, and the various forms in which the trace metals are present are being studied. The processes which bring metals into solution are of special interest, since these determine how readily the metals move during soil development, and also their ability to move to plant roots prior to absorption. Complexes between the trace metals and organic chelating compounds, often produced by microbial action, are especially important, and their rates of formation, of transport and of decomposition are being studied.

Toxic heavy metals are often present in sewage sludge added to agricultural soils, and the behaviour of these metals determines whether they are a pollution hazard. Very similar chemical principles govern the behaviour of these and the plant nutrient trace elements, and sewage sludges have therefore been studied by similar methods, and in long-term field experiments.

'Available' and total contents of trace elements in different soil series and geological formations have been investigated. Recently a start has been made on the determination of trace elements in soil samples collected by the Soil Survey of England and Wales as part of the National Soil Inventory.

Soil acidity

The maintenance of correct pH or acidity is of fundamental importance for crops. Increasing acidity is associated with the appearance of aluminium ions in the soil solution, and the behaviour of these in solution and on soil surfaces is being studied. This is relevant to the processes taking place in soils where rainfall is acidic. The side effects of acidity on the availability of other elements are being studied on our long-term liming experiments.

Clay mineralogy

Clay is the most important inorganic soil constituent. Because of its colloidal nature, and consequent large surface area, and water, nutrient and soil relationships are largely determined by the surface properties of the clay colloids. The surface properties of clays are ultimately determined by their structures, and much of our work is devoted to studying the latter.

Soil clays are often too poorly crystalline to be studied by normal methods, but many give an X-ray powder diffraction pattern similar to a layer silicate mineral with a known structure. These clays are complex mixtures, but special treatments allow the constituent minerals to be identified using computer techniques to simulate their complex diffraction patterns. In some clays expanding and non-expanding layers are stacked together in a random or in an ordered fashion. We are especially interested in their behaviour when they absorb water.

Soil structure

The arrangement of individual soil particles into aggregates and the network of pores within the soil constitute its structure. For agricultural crops the structure should be porous and stable. Our research aims to measure the effects of the pore network, its stability, and the physico-chemical reactions that affect aggregation. The formation of stable structure in soil depends ultimately on the aggregation of individual particles, which must be bound at their surfaces. The nature of these surfaces and the way in which they adsorb inorganic ions and organic molecules are most important in this binding.

In clayey soil the pore system arises largely as a result of swelling and shrinkage. We are studying the mechanics of these and the consequences for the flow of solute and water.

Agricultural practices often damage the soil structure by compacting the soil. Different soils have differing ability to recover and this may be just as important as the inherent stability of the structure. We are studying the susceptibility of soils to such damage and the processes by which their structure is regained.

Cultivations

The primary aim of cultivation in the preparation of seedbeds is to provide the best physical environment for seed germination and plant emergence. The conditions of the cultivated zone depend on many factors, including the soil structure created by the cultivation and its subsequent deterioration, the nature and soil-water condition of the subsoil, and the weather. Changes in soil water and soil temperature in the cultivated zone are being studied, using newly developed equipment in field experiments and physical theory in simulation models. Our aim is to be able to select the optimum cultivation in the preparation of the seedbed, given the physical boundary conditions.

Movement of soil water and solutes

The retention and movement of soil water is important for land drainage, irrigation, soil-water profile development and soil classification, soil mechanics, and the role of the soil as the environment for plant roots. Our research is concerned with the development of essential theory, and its application to practical soil-water and ground-water problems. Soil-water theory, which assumes that soils are completely uniform, is being extended to take into account soil heterogeneity, soil aggregation and soil swelling, that occur in most field situations and that create difficulties in the solution of soil physical problems. Our work is directed particularly towards understanding the physics of groundwater control by land drains, including that involved in the mole drainage of clay soils.

When water moves, it carries dissolved salts with it, and salts can also move by the process of diffusion. This is important in loss of plant nutrients, such as nitrate, and the distribution of fertilizers and agrochemicals. We aim to predict such movements in the field situation.

Analytical methods

All our work involves analyses of soils and plants, and we use modern equipment including emission and absorption flame spectrophotometry. The recent acquisition of an Inductively Coupled Plasma Emission Spectrometer (ICP) has made possible rapid analysis of plant and soil extracts for up to 28 elements.

SOIL SURVEY OF ENGLAND AND WALES

Land is our most important and most enduring natural resource and soil is a vital component of land. The nation needs to use and conserve its soils to obtain optimum productivity and to develop a rational approach to protecting and improving urban and natural environments. To implement these broad requirements reliable information is needed on the quantity and quality of our land resources. The Soil Survey of England and Wales was established in 1939 to systematize the production of this information. The work of the Survey involves development of a suitable classification system, production of soil maps at various scales and for various uses, interpretation of maps and soil experience for a variety of users and development of a soil information system.

Soil classification

The soil mantle over the landscape is continuous except where broken by water, bare rock or ice. Classification systems are needed to identify individual soil types within this continuum for soil mapping and to facilitate the transfer of information from one area to another. The basic unit of soil classification is the soil profile, in which vertical variation can be observed as a sequence of soil horizons parallel to the land surface. The Survey has developed a hierarchical classification system for England and Wales in which are defined 10 major groups, 43 groups, 107 sub-groups and some 700 soil series. The lowest category, the soil series, defined as collections of soil profiles showing the same successions of horizons and developed in lithologically similar materials, is the class used to identify map units at scales of 1 : 63 360 or larger. Soil series are often divided into phases on the basis of other internal or external features significant for land use, such as climatic characteristics, stoniness, slope. Soil series with similar phase characteristics are homogeneous for farming and advisory purposes.

Soil mapping

Field mapping is carried out by hand augering or digging to about 1·5 m depth to expose the soil profile. Soils are mapped at various scales depending on the level of detail required. Much of the early mapping was published at scales of 1 : 63 360 and 1 : 25 000, each covering about 10% of the land surface of England and Wales. These surveys were made on a field by field basis with