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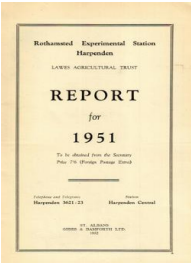
Rothamsted Report for 1951

Full Table of Content



Physics Department

R. K. Schofield

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DEPARTMENT OF PHYSICS

By R. K. Schofield

Dr. W. C. A. Hutchinson resigned in September and joined the research staff of Imperial Chemical Industries at Billingham. Mr. D. Pearce was awarded a National Certificate in Chemistry.

Mr. H. R. Samson of the Division of Industrial Chemistry (Ceramics Section) of the Australian Commonwealth Scientific and Industrial Research Organization and Mr. J. S. G. McCulloch of Edinburgh University joined the department for a two years' period.

Dr. Schofield has continued to serve on the Joint Committee on Soils appointed jointly by the Department of Scientific and Industrial Research and the Ministry of Supply. Dr. Penman has served on the Council of the Royal Meteorological Society and the Board of the Institute of Physics.

Dr. Schofield was granted leave of absence at the end of October to take up a six months' appointment as Visiting Professor of Soil Physics in the Department of Agronomy of Cornell University. For the same period, Dr. Penman was given a Nuffield Foundation Fellowship to enable him to spend six months in Australia, based on the Waite Institute, Adelaide, to study water loss from plants and irrigation research. Mr. G. H. Cashen was left in charge of the department during their absence.

Soil Cultivation

Deep ploughing

The weather has had a decisive influence on the effect of deep ploughing on the yield of potatoes. During the very wet winter the plots were usually waterlogged at plough bottom after rain, that is at 6-8 inches and at 12-14 inches on the shallow and deep ploughed plots respectively. As judged by tensiometer tests, movement of water was impeded on the dunged plots. Thus just before spring cultivation the plots in order of dryness were deep undunged, shallow undunged, deep dunged, shallow dunged. The disked plots would normally have the advantage of a better tilth, but this was completely outweighed by the long period without rain immediately after planting. The dry weather also accentuated the effect of fertilizer placement, the plants being unable to reach the ploughed-in fertilizer. Eye scores taken on July 3 on the general appearance of the plots gave highly significant differences in favour of fertilizer applied in the bouts, and the shallow ploughed plots as a whole were significantly better than the deep ploughed plots. The deep ploughed plots never attained the same growth as the shallow ploughed plots as the more backward plants were attacked by blight in August. This is borne out by the final yields of a poor crop (mean yield 4·8 tons per acre): the deep ploughed plots were significantly lower than the shallow ploughed plots whatever the method of applying the fertilizer; and the plots with fertilizer ploughed in were significantly lower than those with fertilizer applied in the bouts. In particular, the deep ploughed plots with 1 cwt. K_2O applied in the bouts yielded 1·7 tons per acre less than

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the corresponding shallow ploughed plots, in contrast to slight increases in the previous six years. There is as yet, therefore, no significant benefit from deep ploughing for potatoes.

This year the deep ploughed plots have yielded 34 cwt. per acre of sugar compared with 29½ cwt. per acre for the shallow ploughed plots so that in six out of the eight years the experiment has been running there has been a small increase in the yield of sugar, due to deep ploughing. The best effect from 0·6 cwt. P_2O_5 per acre as superphosphate was obtained by harrowing it into the seed-bed of the deep ploughed plots. This is in contrast to previous years and is probably again due to the very long dry spell immediately after disking preventing the young plants from reaching the fertilizer.

Of the crops in the rotation, considering the yields over the years there is no net gain to be derived from deep ploughing for wheat. There is no net residual effect on the following spring barley and undersown ryegrass-clover ley from deep ploughing for sugar beet. For the first time there has been a significant increase in the yield of spring oats after potatoes on the deep ploughed plots. However, taken in conjunction with the yields over the six years, there has been a small net loss.

Agricultural Meteorology

Irrigation

The results of the sugar beet experiments in 1948, 1949 and 1950 have been collated to see how far they can be unified in spite of differences of season, soil, and virus infestation. The result has been encouraging, for by plotting sugar yield as a fraction of an estimated maximum for the site and season against calculated soil moisture deficit coherent distributions of points have been obtained. From these diagrams it appears that mid-season deficit is probably more important than end of season deficit, i.e. early watering is probably better than late watering, and that yields are not appreciably reduced provided the mid-season deficit does not exceed about 2 inches, or if the end of season deficit does not exceed about 4 inches. The main value of this analysis lies in the clues it has provided for design of the more detailed experiments started this year at Woburn.

Four crops occupy the three acres being used at Woburn. Grass, to be cut frequently as though for grass drying, has been laid down for three years: the remainder of the area carries a three course rotation of a spring cereal (barley in 1951), sugar beet, and early potatoes with a brassica crop after (cabbages in 1951). During early 1951 an overhead spray system was installed, but contractors' delays were such that it was mid-June before even a low pressure water supply was available, and the end of July before pumping at the planned rate was possible. The effect has been that the full variety and intensity of desired watering treatments was not achieved. Results will not be given or discussed in detail until a few years' data are available, but as an indication of trends, yields and relevant waterings for the unirrigated plots (O) and the most watered plots (C) are given in the following table. All plots were given a basic fertilizer treatment including nitrogen (N_1), and half plots had an extra nitrogen dressing (N_2). The end of the

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period is arbitrary for the sugar beet, but for the other crops it is approximate harvesting date (third cut for grass).

May, June and July were dry and once irrigation could be started all crops except barley showed obvious benefit from extra water. These visual impressions were confirmed by the final yields:—

Woburn Irrigation 1951

Crop	Period	Rain	Irrigation (inches)	Plot		Yield
Grass ..	May 1–Sept. 4	8·8	—	ON_1	6·7	tons per acre (green)
				ON_2	9·5	
		8·8	3·6	CN_1	12·1	
				CN_2	13·5	
Sugar Beet	May 1–Sept. 17	9·9	—	ON_1	43·5	cwt. per acre (sugar)
				ON_2	56·8	
		9·9	3·4	CN_1	46·0	
				CN_2	62·5	
Barley ..	May 1–Sept. 3	8·8	—	ON_1	21·7	cwt. per acre
				ON_2	30·1	
		8·8	3·2	CN_1	29·0	
				CN_2	33·0	
Potatoes ..	May 1–July 30	3·9	—	ON_1	3·85	tons per acre
				ON_2	3·75	
		3·9	2·2	CN_1	7·65	
				CN_2	8·55	

Heat balance of the soil

Dr. Hutchinson continued his recording of soil temperatures and had begun to analyse some of the records when, unfortunately for the department, he took up a new post elsewhere. During the year, with the assistance of Mr. Long, he set up a continuously recording system of wet and dry bulb thermometers (thermistors) at six heights up to 6 feet; and, on the tower, set up resistance thermometers at 20 feet (dry), 40 feet (wet and dry) and 80 feet (dry). Mr. Long built another double recording anemometer, so that continuous wind speed readings are now being taken at 3, 6, 40 and 80 feet above ground.

On selected days, Dr. Hutchinson has used Robinson's technique (from Kew Observatory) for measuring radiant energy fluxes to and from the ground: analysis of these results will be very much delayed.

Mr. McCulloch has started a study of the interrelations of flow of heat and flow of water (as liquid or vapour) in the soil.

Evaporation and transpiration

The chief new extension of previous work has been in the working out of the water balance of the Thames catchment area, month by month from 1930 to 1949. Making reasonable assumptions about unmeasurable unknown quantities good agreement has been obtained between estimated changes in storage and observed changes in well level.

Miscellany

Application of the standard theory of atmospheric turbulence has shown that Dr. Johnson's records of changes of aphid density with altitude lead to a reasonable value for the clearance rate under calm evening conditions.

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Soil Physics

Soil structure and grass roots

From his last year's work Mr. W. W. Emerson concluded that the favourable structure induced by a period under grass could not be explained in terms of improved water stable aggregation. Accordingly a study was made of various Rothamsted fields during the winter 1950-51 in relation to their cropping history, in particular comparing Barnfield, continuous mangolds, and Highfield, just ploughed out of permanent grass. Water movement was followed by means of tensiometers placed at intervals from the soil surface into the subsoil. With the extremely wet weather Barnfield soon became waterlogged at plough depth, the tensiometers merely recording their height above the furrow bottom. Highfield, on the other hand, although saturated in the turf where it had been inverted, always showed a tension at the surface of over 30 cm. of water. The difference, too, in the general appearance of the two fields was remarkable. The surface soil of Barnfield was very compacted and extremely sticky, while the surface of Highfield was relatively dry and had preserved its crumb structure intact.

The difference could be accounted for by the ability of grass roots to conduct water under tension ; that is, sucking the water from the surface into the turf. Cross-sections of *Lolium perenne* showed one or two central metaxylem vessels of the order of $3{\cdot}0 \times 10^{-3}$ cm. diameter. Experiments on the rate of water conduction through severed *Lolium* roots corresponded to a hydraulic diameter slightly less than that given by hand sections. Microtome sectioning, carried out by Mr. Carolin (a temporary worker in the Botany Department), confirmed that the metaxylem vessels are continuous except for occasional very slight constrictions. Several other grasses were investigated, and all behaved similarly. In *Dactylis glomeratus* the metaxylem vessels are less than 1×10^{-3} cm. diameter, so that as water conduction depends on the fourth power of the diameter this grass will conduct a negligible quantity of water compared with other grasses.

To obtain the maximum benefit from these roots it would be better not to invert the turf, but to sever the roots immediately under the stolons. Then the root tip, being the newest tissue, would rapidly decay and a natural drainage system would be left for conducting water into the subsoil. Experiments will be made to compare shallow rototilling with ploughing.

The above type of continuous metaxylem cavity is confined to monocotyledons and may explain why Broadbalk continuous wheat has still a good structure compared with Barnfield continuous mangolds.

The possibility of simulating the action of dead grass roots by incorporating straw more or less vertically will also be tried. It has already been shown in the laboratory that the metaxylem cavities in the periphery of the straw are continuous through the nodes into the leaf sheaths.

Unsaturated flow of water in soil

Starting with very loosely packed sieved aggregates Mr. Emerson has found that the distribution of water at a given pressure deficiency

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can be treated as arising from a re-packing for which the pore space is similar to that occupied by water in the unsaturated case. Thus Kozeny's equation for the absolute variation of saturated flow with packing should apply to the variation of unsaturated flow with moisture content, where the moisture content per unit volume is substituted for the degree of packing. This was confirmed by the results of Childs and George on sieved sands, and values for the surface area derived are in very good agreement with other methods. Plotting permeability against pressure deficiency showed that the permeability decreased by a factor of 10^4, due to air entry into the intergranular pores—a quantitative explanation of the well known phenomenon of field capacity.

The method used by Childs and George for sands breaks down at very low permeabilities. It has been found possible, however, to compute unsaturated permeabilities from the rate of attainment of equilibrium in the normal method of determining moisture characteristics. This has been used to determine the permeabilities of 1-½ mm. sand at very low moisture contents up to the limit of liquid flow. The method is quite general and is being applied to 6 inch diameter field samples.

Soil/water relationships

Mr. G. H. Cashen, besides taking over the administration of the department during the absence of Dr. Schofield and Dr. Penman has rounded off and written up his work on the vapour pressure of aqueous solutions, the results of which have been given in previous reports. The work on the thickness of water films on mica and clays, which had been temporarily suspended, has been taken up again.

Physical Chemistry

Ions in soils

In view of the complex chemical behaviour of free aluminium ions in solutions in equilibrium with soils, Mr. A. W. Taylor has turned his attention to a more rigorous checking of the theoretical principles on which this study of the behaviour of ions in soil solutions is based. A series of experiments was carried out to examine in detail the changes in hydrogen ion activity in soil in equilibrium with sodium, potassium, calcium and aluminium salt solutions over wide ranges of concentration.

The results obtained were in close agreement with those predicted from the theoretical study based upon the Gouy theory of the electrical double layer, and indicate that this theoretical treatment may be used with confidence in the interpretation of the study of equilibrium conditions in soil solutions.

The experiment in which the changes in pH of the calcium saturated soil in equilibrium with calcium chloride solutions of various concentrations were measured has confirmed the view that M/100 $CaCl_2$ is the most satisfactory solution to use in the determination of soil pH values.

The standardization of the electrolyte concentration at this level has the great advantages that the result obtained using a normal pH meter is independent of the soil/solution ratio, and that

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erratic variations due to suspension effects present when the soil is dispersed in water are absent.

This reagent is now used as the standard reagent for the measurement of soil pH in this laboratory, and it has been found that the results obtained are more reproducible and reliable than water measurements.

In view of the importance of aluminium in soils, particularly in connection with the buffer capacity of clays, the study of the hydrolysis of aluminium chloride solutions has been extended so as to obtain more detailed information about the electric charges present on freshly precipitated aluminium hydroxide. It is already clear that, at the "end point" around pH 7 where the system is practically unbuffered, the precipitate still carries a few positive charges. A suggested structure for the colloidal precipitate places these charges at the end of chains of aluminium ions linked together by pairs of hydroxyl ions. If this interpretation can be substantiated it enables the average length of the chains to be determined. The work on this problem is being continued.

Critical salt concentrations for deflocculation of soils

The deflocculation of soil has been investigated by Mr. J. P. Quirk using a permeability method and single ion systems. At sufficiently high salt concentrations steady flow occurs through a soil pad (1 cm. thick and 5 cm. diameter), but when the electrolyte content of the percolating liquid is reduced beyond a critical level for each ion (deflocculation concentration) decreases in permeability are noted. The ions used were those practically important in soils, viz. Na, K, Mg and Ca.

Measurements have been made of the activity product [H] × [Cl] from which information is obtained about the drop of electrical potential across the diffuse component of the electric double layer. At the critical electrolyte concentration for deflocculation the potential drop is nearly the same for the four cations, and considerably greater than would be obtained from electrophoretic measurements using Smoluchowski's equation, which is evidently inaccurate under these conditions.

The work has been extended to mixed ions systems, particular attention being given to Na/Ca systems. It has been shown that the concentration of the equilibrium solution, which is critical for deflocculation, can easily be spotted visually. This concentration characterizes the tendency of the soil to deflocculate and is much easier to determine than the percentage of sodium amongst the exchangeable ions upon which this characterization has hitherto been based. For practical purposes this critical concentration can be obtained with sufficient accuracy by measurement of electrical conductivity, which is very rapid. If the chemical composition of the irrigation water is known, the degree of stability for the soil structure under irrigation can be predicted, and corrective measures devised when necessary. In this way control can be exercised at much lower cost than would be required to operate a system based on the estimation of exchangeable sodium by chemical analysis.

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Colloidal studies in kaolinite suspensions

Mr. H. R. Samson has undertaken a fundamental study of deflocculation with special reference to kaolinite. Viscometric measurements on kaolinite suspensions show that even in very low electrolyte concentrations and with Na^+ as the sole exchangeable cation, the suspensions remain flocculated.

In this respect, kaolinite differs from other clay minerals, which form colloidally stable dispersions under these conditions. It is found that the addition of a small amount of alkali, or a negatively charged polyelectrolyte, e.g. polymetaphosphate, sulphonate or alginate, is required to deflocculate the kaolinite.

In order to investigate the charge distribution on the kaolinite platelets, measurements of cation exchange capacity and of buffer properties over a wide pH range are being carried out.