ROTHAMSTED RESEARCH

Report for 1952

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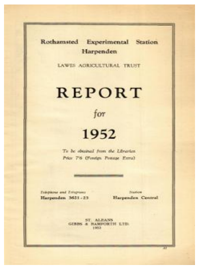
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Physics Department

R. K. Schofield

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PHYSICS DEPARTMENT

R. K. Schofield

R. K. Schofield was on leave of absence during the first half of the year while completing the tenure of a six months' appointment as Visiting Professor in Soil Physics in the Department of Agronomy at Cornell University. With the help of a travel grant from the Agricultural Research Council he also visited 22 other research centres in the United States and 3 in Canada. During these visits he had stimulating discussions on the extent to which meteorological data can serve as a practical basis for the control of irrigation, and on physico-chemical equilibria in soil. He wishes to record his sincere thanks to Dr. Richard Bradfield and many others who helped to make his time in America so profitable and enjoyable.

H. L. Penman returned in May from his six months' visit to Australia where about two-thirds of his time was spent at the Waite Agricultural Research Institute and the remainder in visits. These included an expedition to Lake Eyre in the " Dead Heart of Australia," a visit to a large sheep station in one of the semi-arid regions, many visits to research farms and orchards in intermediate rainfall regions, and inspection of engineering works in progress in the construction of reservoirs in the wet Victorian mountain regions. A tour of the Murray and Murrumbidgee irrigation areas was based on two- and three-day periods spent at the Commonwealth Scientific and Industrial Research Organization irrigation research stations at Merbein, Griffith and Deniliquin. From all these experiences, supplemented by formal talks and informal discussions a broad picture, detailed in parts, was obtained of the water problem in a range of climates all more extreme than that of the British Isles. On fundamentals most was abstracted from extended visits to the Commonwealth Scientific and Industrial Research Organization Division of Meteorological Physics where fine work is being done on the physics of the evaporation process, and from the Plant Physiology Department at the Waite Institute where an important school in the study of plant transpiration is being built up.

While away he was awarded a Darton Prize by the Royal Meteorological Society for his paper on " Evaporation over the British Isles." Since his return he has served on the Hydrology Research Group of the Institution of Water Engineers, the Working Party on Irrigation of the Ministry of Agriculture and attended the London Meetings of U.N.E.S.C.O. Arid Zone Research Committee as honorary consultant.

G. H. Cashen acted as Head of Department during the absence of R. K. Schofield and H. L. Penman. A. W. Taylor, who had been in receipt of a Research Grant from the Agricultural Research Council, was appointed in October, 1952 to fill the vacancy caused by the resignation of W. C. A. Hutchinson. J. P. Quirk received the Ph.D. degree of London University, and returned to resume his duties with the Division of Soils of the Australian Commonwealth Scientific and Industrial Research Organization. R. L. Closs spent three months studying temperature gradients immediately above and below the ground surface before returning to New Zealand; G. M. F. Grundy spent six months studying soil structure and physical chemistry before taking up an appointment in Malaya. I. R. Cowan has joined the department for one year in preparation for work in Jamaica on the irrigation of sugar cane; T. E. Tomlinson is studying soil physical chemistry for some months before taking up a research appointment in Sierra Leone.

Soil Cultivation

Deep ploughing

A full account of the results of the deep ploughing experiment at Rothamsted will be prepared when the second rotation is completed in 1955. Meanwhile only brief accounts will be given in these reports. In a season when potato yields were depressed by dry weather in June and July, the yields on all deep-ploughed plots were more than a ton per acre less than on the shallow ploughed plots. This result is very like that of 1951 in rather similar weather conditions. The marked depressions of these two years largely offset the small but consistent benefits reported for the first seven years. As usual deep ploughing has not affected the yields of cereals or the one-year grass ley. The results for sugar beet are not yet to hand owing to delay in lifting.

Agricultural Meteorology

Irrigation

The account of the sugar beet experiments has been published.

The Woburn experiment on grass, sugar beet, early potatoes followed by cabbage and barley has been kept going in spite of a shortage of assistance, but only at the level of a primary field experiment. It has not yet been possible to start the study of the physical and biological effects of irrigation on the soil and on plant growth as was planned.

The season was wet up to mid-May, then dry up to the end of July and wet thereafter. During the dry period water could not be put on frequently enough so most of the soil moisture deficits grew larger than was planned. For the rotation crops the four treatments were simplified: O, no irrigation; C, irrigation throughout the season to try and maintain the deficit near one inch; A, irrigation in the first half of the season equal to C and then no more; B, no irrigation in the first half of the season and then irrigation as in C. For grass, increasing amounts of irrigation were given in the order A, B, C. Brief notes on each crop follow.

Grass. Yields increased with water applied. Between mid-June and mid-August the O plots were brown and gave no yield. By mid-September all plots were even in colour and about equal in yield.

Sugar beet. Early watering appeared to be slightly harmful.

Barley. Total water was limited by lodging. Late watering was better than early; early and late was better than either.

Potatoes. Early watering was much better than late: early and late better than either.

The following table shows the yields for the watering extremes at two levels of nitrogen dressing.

Woburn Irrigation 1952

Crop	Period	Rain (in.)	Irrigation (inches)	Plot		Yield
Grass ..	Apr. 28–Sept. 29	9.6	—	ON_1	68·1	cwt. per acre (hay, 7 cuts)
				ON_2	66·2	
		9·6	5·1	CN_1	97·8	
				CN_2	103·5	
Sugar Beet	Apr. 28–Sept. 29	9·6	—	ON_1	47·1	cwt. per acre (sugar)
				ON_2	55·5	
		9·6	5·6	CN_1	57·7	
				CN_2	59·6	
Barley ..	Apr. 28–Aug. 18	7·0	—	ON_1	21·6	cwt. per acre (grain)
				ON_2	23·0	
		7·0	2·9	CN_1	22·8	
				CN_2	27·3	
Potatoes	Apr. 28–July 7	4·0	—	ON_1	6·0	tons per acre
				ON_2	6·2	
		4·0	2·7	CN_1	9·7	
				CN_2	10·9	

Evaporation and transpiration

Hitherto all our theoretical estimates of transpiration have been based on an empirical conversion factor expressing the ratio of potential transpiration to open water evaporation. The theory has now been extended so that potential transpiration can be estimated directly from weather data. Tests, mainly on Australian data, have been encouraging, but their success depends upon a correct value for a new empirical factor—the diffusive conductance of the leaf stomata. Geographical, seasonal and climatic factors are eliminated and only this plant constant remains, and in a few years' time this, too, should be known when techniques, now in development, are perfected for measuring it directly. At the same time, an attempt has been made to deal with the complex but important case of orchard irrigation, again with promising results.

For the present these new developments are primarily of benefit in clearing up ideas on the fundamentals of the problem: in our own work of the immediate future we shall continue to use the empirical conversion factor. In one application, a Working Party of the Ministry of Agriculture is drawing up a Technical Bulletin setting out the need for irrigation in Great Britain: in a second it has been used as the basis for a contribution on Evaporation in a symposium on Hydrology organized by the Institution of Water Engineers.

Micro-climatology

Throughout the summer I. F. Long has built and maintained thermistor equipment giving continuous records of dry bulb and wet bulb temperatures at six heights within and above a potato crop. Some of the records have been analyzed in detail to give half-hourly values of water vapour pressure gradients from the ground up to 160 cm. during days when a dew balance, set up by J. M. Hirst (Plant Pathology Department) was in use. On nights of dew, there were three phases on the records: formation, a steady period, and then re-evaporation. These are represented in the humidity profiles by a vapour pressure increasing from *c.* 40 cm. upward, no gradient, and vapour pressure decreasing upward.

This valuable piece of preliminary work offers possibilities of expansion to reveal more of the physical processes involved in condensation of water on potato leaves and its importance in the germination of potato blight spores. A similar set of equipment has been built for use at Woburn on the irrigation experiments.

Heat flow and water flow in the soil

J. S. G. McCulloch has worked on this problem at the soil cylinders in the meteorological enclosure and in the laboratory with small soil columns. Previously we had recorded rises in the water table (at about 24 in. below turf) early in the morning and attributed them to an increase in soil temperature. After failure of attempts to reproduce the effect by artificially applying heat to the soil surface, it was found that the main features of the earlier records were due to thermal expansions in the recording apparatus. Nevertheless, subsequent experiments in the laboratory have shown a small but real effect of temperature on the equilibrium distribution of water in a vertical column of soil. Experiments are now in progress to determine whether differential thermal expansions and the effect of temperature on surface tension provide a satisfactory explanation.

Soil Physics

Soil structure and grass roots

In an attempt to make use of last year's observation that the metaxylem vessels of severed grass roots conduct water, very shallow roto-tilling was compared with ploughing-out old grassland as an autumn seedbed preparation for spring wheat. Unfortunately, under the wet winter conditions, even repeated rototilling did not kill the grass which competed too strongly with the wheat. By comparing suctions developed in the surface soil both on thin plots and on de-turfed patches on grass plots it was shown that the roots do, in fact, conduct water upwards. It seems, however, that the effect of this on germination will be small except in a very dry spring.

Water entry into sand

Experiments on the rate of water movement into dry sand have shown the importance of the contact angle, sand-water. As a first step, work is being carried out on the simpler glass-water system.

Interaction of water and soil crumbs

It has been found that the moisture content and cohesion of soil crumbs vary continuously with their rate of wetting. At the higher rates the crumbs are disrupted by the escape of entrapped air. When repeated under vacuum, different rates of wetting had no effect on cohesion, indicating that uneven swelling is an unimportant factor. The work shows that at low suctions it is impossible to infer the suction of a soil sample from its moisture content unless the rate of wetting is known. Further, it brings out one of the uncontrolled variables in the Yoder wet sieving technique, which is frequently used as a criterion of good soil structure.

Equilibrium thickness of water films

Attention has again been given to the problem presented by the results of Deryagin and Kussakov who measured optically the thickness of films of liquids on solid surfaces. For pure water on mica and glass the results agree with those to be expected from Gouy's theory, but when dilute NaCl solutions were used the films were found to be much thicker than expected. G. H. Cashen has set up similar optical apparatus, and has broadly confirmed the earlier results using pure water. While he has not succeeded in obtaining satisfactory results with NaCl solutions, his attempts have led to an appreciation of the cause of the trouble. When a solution is used, concentration gradients develop in the initial stages of the experiment which are only slowly reduced by ionic diffusion. It is now clear that very elaborate apparatus would be required to ensure complete equilibrium of both salt and water as assumed in the theory.

A more promising line of approach has been opened up by J. P Quirk who observed that when orientated aggregates of Na-montmorillonite are placed in NaCl solutions of different strengths they spontaneously disperse when the concentration is less than N/100. From N/100 to N/3·16 the degree of swelling which K. Norrish, of the Pedology Department, measured by X-ray diffraction is inversely proportional to the square root of the salt concentration. Calculations, based on Gouy's theory, give repulsion pressures ranging from 10^5, dynes/cm.^{2}, in N/100 NaCl when the platelets are separated by 160 A to 3×10^6, dynes/cm. in N/3·16 when the separation is 28 A. The balancing attractive force thus appears to vary inversely as the square of the distance.

Physical Chemistry

Physico-chemical determinations on soil samples

A. W. Taylor's work has again centred round the use of 0·01 M $CaCl_2$ solution in the physico-chemical testing of soil samples. Using the theoretical approach first introduced by Gouy it has been estimated that when a sample of almost any soil from the humid temperate zone is suspended in this solution the value of pH-$\frac{1}{2}$p (Ca+Mg), which we call the "lime potential," is less than 0·02 greater than the limiting value obtained at lower concentrations. Hence it can conveniently be determined in this way to a degree of accuracy which is ample for most practical purposes. It would be inconvenient to use a concentration much below 0·01 M, while the uncertainties introduced by the use of a solution much stronger than 0·01 M are greater and more variable from soil to soil.

In response to a suggestion received from the National Agricultural Advisory Service the method devised earlier by R. K. Schofield for measuring "lime requirement" has been modified so as to give the amount of alkali taken up by a soil sample to bring its "lime potential" up to 5. This potential is about one unit lower than that usually found in soils containing free calcium carbonate. In the modified method cacodylic acid is used in place of *p*-nitrophenol and the determination is speeded by using pH measurements in place of titrations. The method has given encouraging results with soil samples taken from liming trials laid out by the National Agricultural Advisory Service, but it must still be regarded as tentative.

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Distribution of positive and negative charges on crystals of kaolinite

The clay mineral kaolinite is a major constituent of many soils of the tropics and sub-tropics and china clay, which is almost pure kaolinite, is a material with many industrial uses. From the results of X-ray analysis a clear picture has been formed of the atomic arrangement within the crystal lattice, and from electron micrographs it is known that typical crystals have the form of thin hexagonal plates, but the location and origin of the electric charges carried by the crystals has not been established. Yet there can be little doubt that these charges influence the structure and the erodability of kaolinitic soils and the consistency of ceramic bodies and slips. Our understanding of the physical behaviour of kaolinite is incomplete so long as we lack precise knowledge about these charges.

Techniques devised earlier by R. K. Schofield have been successfully applied to this problem by H. R. Samson and, for the first time, a picture has emerged which appears to cover all the known facts. The electric charges arise from two quite distinct causes. One is the replacement within the body of the crystal of Al^{3+} for Si^{4+} and possibly Mg^{2+} or Fe^{2+} for Al^{3+}: each replacement of this kind gives rise to one unit of negative charge. Mild treatment with acid or alkali at room temperature does not alter these charges. The other cause is the exposure of oxygen atoms at the edge faces which, being bonded to fewer Si and Al atoms than oxygens in the body of the lattice can each form an additional bond with a hydrion. The extent to which these additional bonds are formed depends on the degree of acidity. If on an average only two-thirds of the possible bonds are formed the edge faces will be uncharged: if more than two-thirds are formed they will be positively charged; while if less than two-thirds are formed they will be negatively charged.

The condition brought about by washing kaolinite first with N. NaCl containing N./100 HCl and then with water is especially interesting, as typical samples remain strongly flocculated after all the salt has been washed out. In this condition the crystals retain exchangeable sodium ions, showing that they are on the whole negatively charged. Samson's discovery that these flocculated kaolinites absorb small amounts of chloride from very dilute salt solutions is readily explained if the edge faces are positively charged under these rather acid conditions. The flocculation in the absence of salt is also explicable as due to the attraction of the positively charged edge of one crystal to the overall negative charge of a neighbouring crystal.

The addition of more than a critical amount of NaOH brings about two changes: the kaolinite is deflocculated in the absence of salt, and it repels chloride when NaCl is added. Both effects are explained by the disappearance of positive charges from the edge faces. These positive charges can also be neutralized by the addition of oxalates, phosphates, alginates and even Na montmorillonite. When sufficient has been added to bring about deflocculation the kaolinite has no longer the power to attract chloride ions.

This work is of immediate value in opening up a very promising line of approach to the study of kaolinite and other clay minerals. In the long run it should yield information about the stability of kaolinitic soils. This may be particularly valuable in the tropics and sub-tropics.

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