Report for 1955

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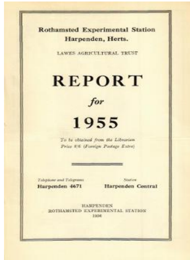
Rothamsted Experimental Station
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REPORT
for
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Physics Department

H. L. Penman

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PHYSICS DEPARTMENT

H. L. Penman

On his return from the University of Wisconsin, A. W. Taylor was transferred to the Chemistry Department, so leaving another gap in the establishment strength of the Physics Department. Mr. P. B. Flegg and Miss I. Warman left in April. Mr. M. A. E. G. Frère, from Louvain, spent two months with us before taking up micro-meteorological research in the Belgian Congo. Professor J. A. Toogood, from the University of Alberta, came in September on sabbatic leave. Miss Margaret Dettman, from the University of Melbourne, has joined the department for a period of a year or two to assist W. W. Emerson in his soil structure studies. Mr. A. J. Wehrli, of the Technical High School, Zürich, spent two months working on soil structure. W. C. Game was given a suitably inscribed barometer by the Meteorological Office in appreciation of his services as Observer since 1911. J. S. G. McCulloch and J. L. Monteith received the Ph.D. degree of London University.

R. K. Schofield, J. L. Monteith and H. L. Penman attended the seven-day conference of agricultural physicists in Wageningen. At the invitation of the Volta River Project Preparatory Commission, H. L. Penman spent two weeks in the Gold Coast collecting local data as a basis for advice on evaporation problems that will arise if the new Lake Volta is created. During this period visits were paid to the Gold Coast University Department of Agriculture and its experimental farm, to a pilot irrigation scheme and to the Cocoa Research Institute at Tafo.

Soil Physics

There is a wide range of problems in the study of soil structure. First, and most difficult because of the heterogeneity of the material, there is the problem of the surface physics of the clay minerals; then there is the problem of the forces and compounds that can act as binding agents in aggregate formation, and the mechanisms of binding; there is the problem of testing in a reproducible way that will give a quantitative measure of "structure"; and beyond all is the problem of deciding whether there is any agricultural benefit from improved soil structure.

Electrical charges on clay (G. H. Cashen)

The intensive work on kaolin described in *Rep. Rothamst. exp. Sta. for 1953, 1954* has been continued to obtain further evidence of buffer action by the edge faces of kaolin crystals, i.e., to demonstrate the existence of positively and negatively charged edges in acid and alkaline conditions respectively. It is established that there are changes with pH of the charge carried by kaolin, but in spite of every care in the pre-treatment to " clean " the kaolin, it has not hitherto been possible to state definitely that the changes are due solely to buffer action by the edges. A method has now been

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found for measuring the charge on the cleavage faces by observing the electro-osmotic movement of water in samples of kaolin treated with increasing amounts of cetyl trimethyl ammonium bromide. The cleavage faces can be made positive, which shows that this organic cation does not move when the direct-current voltage is applied: consequently the ion must be held on the surface by specific forces—hydrogen bonds—in addition to the purely electrostatic force. Measurement of the amount of CTAB necessary to reduce the charge on the cleavage faces to zero over a range of pH thus gives a new type of titration curve. Ideally the test condition should be with the cleavage faces oriented parallel to the electric field if the side edges are not to contribute to the endosmotic movement of the water: to a very good first approximation the ideal is realized, because of the intense drying which takes place as the water moves to the electrodes.

Results have been very encouraging. For a pre-treated kaolin (washed with normal KCl at pH 3, followed by normal KCl and distilled water) the charge measured with the CTAB is constant to $\pm 0{\cdot}1$ m.e. in the pH range 4·5–10. This charge must be the negative isomorphous replacement charge. For such pre-treated samples the buffering observed in earlier experiments can be more confidently attributed to the edge faces of the kaolin crystals. In contrast, for an untreated Merck kaolin the amount of CTAB required to make the kaolin positive does change with pH, an effect most probably due to the presence of some "impurity" as yet unidentified.

Soil structure (W. W. Emerson)

Synthetic soil conditioners

Sodium-saturated clay flakes have been prepared from three pure clays (a montmorillonite, an illite and a kaolinite) and a range of polymers. The swelling pattern of the flakes has been studied in dilute salt solutions, and G. C. Dibley and R. Greene-Kelly of the Pedology Department have kindly taken X-ray photographs of some of the montmorillonite complexes.

It has been deduced that the polymers can stabilize clays in two ways. First there are inter-lamellar complexes in which the polymer links the basal surfaces of the clay crystals; this can be achieved by non-ionic polymers such as poly-vinyl alcohol, or by polymers containing both anionic and cationic groups, such as gelatin. Second, there are peripheral complexes, the polymer linking the edges of the clay crystals; up to the present only cationic polymers such as carboxymethyl cellulose, alginic acid and polyacrylic acid have shown this behaviour, and the interpretation of the mechanism depends on the existence of edge charges of the kind being studied by G. H. Cashen.

The two types of complex differ in their responses to leaching with a strong solution of neutral pyro-phosphate. The wet strength of inter-lamellar complexes is unaffected, but that of the peripheral complexes is reduced to that of the clay without polymer. Dilute alkali will disperse the ionic interlamellar complexes after prolonged soaking, but polyvinyl alcohol complexes are unaffected by concentrations up to $4N$–NaOH.

Similar experiments on the wet strength of crumbs from Rothamsted grassland showed no change on leaching with $M/10$-pyrophosphate but a very great reduction after leaching for one week with alkali. It is inferred that the grassland soil crumbs are stabilized by the formation of interlamellar complexes and that the active agents are polymers containing positively charged groups, probably amino groups.

Sodium saturation test

This technique for determining the wet strength of soil crumbs (*Rep. Rothamst. exp. Sta for 1953*) is not yet suitable for all routine measurements. It has been found that crumbs of near minimum strength are partly dispersed in 20 mN–NaCl, leading to blocking of pores in the sintered glass supporting the crumb bed. The permeability measurements have thus been made non-reproducible, and a modification of technique is being sought to avoid the difficulty.

Soil structure field experiment

A second set of four-year-old grass and lucerne plots was ploughed up in autumn 1954 : these and two fallow plots were later sown with spring beans. After soil analysis, appropriate nitrogen and potash fertilizer treatments were applied to plots, or part plots, to permit some discrimination between the effects of nutrients and the effects of soil structure. Unfortunately the crop was not sprayed, and grain yields were low. The appearance of the crop suggested that suspicions about last year's result were well founded : the 1953/54 differences were primarily reactions to fertilizer differences. The 1954/55 mean yield on the former fallow plots was 12·7 cwt./acre, with no response to additional N or K : the mean yield on the former ley plots was 14·7 cwt./acre. The increase of 2 cwt./acre is attributed to improved soil structure.

The first set of plots (beans in 1954) had winter wheat as a second crop, and was given a heavy dressing of a complete fertilizer to minimize differences in nutrient status. Former grass and fallow plots gave almost the same mean yield of 38 cwt. grain/acre : the former lucerne plots gave an extra yield of 5 cwt./acre.

Agricultural Meteorology

Micro-meteorology

(a) *Continuous recording* (I. F. Long)

The apparatus for continuous recording of temperature, humidity and wind-speed profiles in a potato crop has been used throughout the summer. The second set of equipment, originally intended for use on the irrigation experiment at Woburn, has been used instead on a wheat crop alongside the potatoes. Analysis of the great bulk of data now accumulated has started, and a useful preliminary operation has been the drawing up of a special set of tables and nomographs for rapid conversion of chart readings into relevant physical parameters.

New measuring equipment has been designed, made and used. An instrument for continuous recording of dew-point gradients employs nickel resistance thermometers of small dimensions. The

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design exploits the approximate relationship: dew-point temperature $\simeq 2 \times$ wet-bulb temperature $-$ dry-bulb temperature, known to be correct within $\pm 2{\cdot}5$ per cent in the temperature and humidity ranges in which it is used in night-time studies of dew formation on potatoes. The records show with acceptable accuracy the times of start and finish of dew formation, and can be used to estimate an order of magnitude of rate of condensation. This is the kind of information needed in the study of potato blight. Similar, but much smaller, nickel thermometers (1 mm. diameter and 5 mm. long) have been constructed to record leaf temperatures at two levels in a potato crop; and also for measurement of soil surface temperatures. First results indicate that in the sun leaves may be 10° C. warmer than the air round them, and on clear nights may be 2° C. colder in calm air. Leaf temperatures can change rapidly, and several times a rise and fall of 5° C. or more has occurred in 10 minutes.

Field conditions of dry soil in late summer have provided a strong contrast with previous years. Such dew formation as there has been on potatoes has come from the air rather than the soil, and there are indications that some of the water on potato leaves after a " dew " night may have been exuded by the leaves themselves. The new field observations on wheat have given a comparison of a thick (normal) crop and a thin (hand-pulled to 25 per cent normal) crop. Marked differences in temperature and humidity gradients occur—as expected—on sunny days and clear nights.

(b) *Short-period experiments* (J. L. Monteith)

Work has been concentrated on instruments to measure the components in the energy balance sheet of a crop, particularly the net radiative flux and the storage of heat in the soil.

Radiation. The old Callendar receiver and recorder of solar radiation were replaced in May 1955 by a Kipp solarimeter linked with a recording potentiometer. A simple portable solarimeter is being built for field use among growing crops.

A Gier and Dunkle type radiometer has been built and used. When this is exposed above a crop its electrical output is proportional to the *net* radiation received by the crop and its underlying surface. So, by day, it gives a direct measure of energy available for evaporation and heating; and, by night, the amount derived from condensation and by cooling. Tests during cloudless days in August showed a good correlation between net income for a potato crop and total income on the Kipp instrument, the slope of the regression line indicating that the potato crop was reflecting 17 per cent of incoming solar radiation.

Heat flux in soil. Heat-flux plates have been made, calibrated and used in the field. The plate, of glass or paxolin, is thin and carries a thermo-couple array to measure the small temperature difference that may be set up between its two faces. Laboratory work has shown that plate response becomes less dependent on soil conductivity as the ratio of area to thickness is increased. For paxolin, 8 cm. square and 0·15 cm. thick, the sensitivity changes by only a few per cent for a six-fold change in soil conductivity. During the dry period from 18 August to 8 September plates in the potato crop showed that heat stored in the soil was often about one-tenth of

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the net radiation income in a day. Later rain cooled the top soil, and the subsoil then supplied 10–30 cal./cm.^{2}/day to the surface.

Other equipment. A large recording balance to hold ten normally spaced potato plants is being constructed for the department at the National Institute of Agricultural Engineering. This will provide a direct measure of evaporation and condensation per unit area of ground surface, and so will give a measure of the latent heat term in the energy balance.

Thermocouples have been made from copper–nickel tubes 0·5 mm. diameter, and used to measure leaf temperatures (see also (*a*) above). Inserted in the stems of arbitrarily chosen leaves, the leaf–air temperature differences has ranged from 7·3° C. (net radiation gain 0·68 cal./cm.^{2}/min.) in sunshine to —1·7° C. (net radiation loss 0·12 cal./cm.^{2}/min.) in darkness. There have been indications that as the net radiation income becomes small in late afternoon the leaf temperature may fall below air temperature because of cooling by maintained evaporation.

(c) *Miscellany* (J. L. Monteith, P. B. Flegg, I. Warman, M. Frère)

Short-period laboratory experiments have included: (i) Tests on titanium oxide elements for measurement of relative humidity, kindly given to us by British Scientific Instruments Research Association. (ii) An attempt to exploit an idea of Dr. D. C. Spanner (Imperial College, London) that the Peltier effect can be used to measure relative humidities close to 100 per cent. Encouraging progress has been made. (iii) Tests on varied designs of anti-radiation shields for thermocouples, and for small resistance thermometers. A reassuring result was that the device used in our field equipment is as satisfactory as much more elaborate shields.

Evaporation

Application of the results of previous work continues. Consideration of the data from American experiments at Wagon Wheel Gap and at Coweeta has indicated that Coweeta conclusions about the hydrological consequences of forest clearance may need re-examination. In a different kind of hydrological problem, an attempt has been made to estimate the annual evaporation loss from the 2,000 square miles of the Lake Volta that will be created if the damming of the River Volta does take place as part of the Gold Coast scheme for generation of hydro-electric power. This was an interesting exercise, for meteorological stations in the area are few and their records of short duration.

For the introductory lecture at the Wageningen Conference on "Physics in Agriculture" the opportunity was taken to outline the physical principles, and some of the soil and biological aspects of water use by plants. From the extended discussion of the topic it became clear that while there is still much that the physicist can do by himself, most progress will be made by co-operative activity of physicist, biologist and pedologist. In his individual contribution to the symposium J. L. Monteith showed that the small night-time rates of evaporation from grassland were controlled by a transport constant not very much greater than the molecular coefficient of diffusion of water vapour in air.

Irrigation at Woburn

After 1954, the kind of year in which we expect—and get—nothing out of irrigation of any crop, 1955 has been a welcome change, particularly from the end of June onward. For the first time since the Woburn experiment started there has been dry weather in July and August, and we have been able to see the effect of late summer irrigation. Crops were as in 1954.

Grass. A good uniform stand of S 37 Cocksfoot was available. Colour change in low-water plots appeared about mid-July.

Sugar beet. A very uneven stand, gappy after singling. Treated for mangold fly. Plants never recovered from bad and irregular start.

Barley. A very even crop that made all its growth while natural rain was almost adequate. Some rust on all plots.

Potatoes. Main crop, which grew well under all treatments. Mid-July colour contrast was most striking, the watered plots being much lighter green, with flowering appreciably delayed.

Up to the end of June there was little need for irrigation: thence, to mid-September demand was continuous, and was so successfully met by T. W. Barnes that C plots of grass, sugar beet and potatoes were kept within 1 inch deficit below field capacity.

As usual, the table that follows ignores intermediate levels of watering, and merely reports extremes of no irrigation (O plots) and full irrigation (C plots) at two levels of nitrogen dressing (N_1 and N_2) imposed on a standard basal dressing of P and K appropriate to each particular crop. There was rain in excess in the five weeks 9 May–13 June (5·9 inches).

Woburn Irrigation 1955

Crop	Period	Rain, inches	Irrigation, inches	Plot		Yield
Grass	25 Apr.–26 Sept.	9·3	—	ON_1	37·2	Dry matter cwt./acre 7 cuts
				ON_2	54·5	
			7·7	CN_1	63·5	
				CN_2	81·9	
Sugar Beet	25 Apr.–26 Sept.	9·3	—	ON_1	32·8	Sugar, cwt./acre
				ON_2	35·6	
			6·4	CN_1	43·9	
				CN_2	51·6	
Barley	25 Apr.–1 Aug.	7·1	—	ON_1	31·6	Grain, cwt./acre
				ON_2	40·4	
			1·4	CN_1	32·4	
				CN_2	39·4	
Potatoes	25 Apr.–26 Sept.	9·3	—	ON_1	10·8	tons/acre
				ON_2	11·4	
			6·3	CN_1	19·0	
				CN_2	21·7	

As in most previous years, extra nitrogen is more important than extra water for barley. The grass responded to both, and it may be that an even bigger response to irrigation might be obtained by increasing the nitrogen dressing beyond the N_2 level. The sugar-beet response is disappointing when compared with what is known to have happened on irrigated commercial crops. Irrigated potato yields are the best ever obtained at Woburn: the non-irrigated yields are much in excess of any others at Woburn in 1955. One wonders why.

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Miscellany

A brief survey of the effect of the weather of 1954 on farming productivity indicated that yields of main crops were about average, and the chief effects of the poor summer were in the delays caused by bad weather, a higher incidence of disease, and poorer quality in crops harvested.

During the year the Institute of Physics has published a short monograph on *Humidity*, by H. L. Penman. This is intended for students in technical colleges, and though mainly standard material, it includes a little of our special Rothamsted experience in handling problems of soil and atmospheric humidity.

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