Report for 1956

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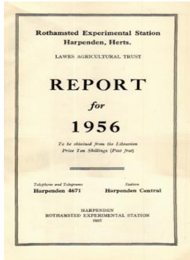
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Physics Department

H. L. Penman

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PHYSICS DEPARTMENT

H. L. PENMAN

Professor Toogood returned to the University of Alberta in September; Dr. M. Dagg spent four months, based on the department, before going to the East African Agriculture and Forestry Research Organization; Mr. P. F. Noble, of the New Zealand Department of Agriculture, came in March to spend two years with us, and Dr. R. L. Davidson, of the University of Johannesburg, came in September for six months with a Nuffield Fellowship. D. A. Pearce returned from National Service and resumed duties in January.

G. H. Cashen, W. W. Emerson, Margaret Dettmann and H. L. Penman, with Professor Toogood and Mr. Noble, attended the Soils Congress in Paris. J. L. Monteith was the British delegate to a UNESCO meeting in Australia surveying problems in arid zone micrometeorology, and spent a few days before the meeting at the Soils Division of the Commonwealth Scientific and Industrial Research Organization, Adelaide, and a few days after the meeting at the Meteorological Physics Division, C.S.I.R.O., Melbourne.

H. L. Penman is being asked by the Food and Agriculture Organization to act as co-ordinator of a project for co-operative research in irrigation in western Europe.

Soil Physics

Electrical charges on clay (G. H. Cashen)

Further work on the electrical charges carried by kaolin has shown that a suggestion made in the 1955 report should be modified. In treating kaolin with cetyl trimethyl ammonium bromide (CTAB) two sets of data are obtained: a CTAB/pH titration curve of the suspension which normally shows two straight sections meeting in a bend; and a direction of endosmotic flow of electrolyte in a paste when a d.c. voltage is applied. It had been found that the amount of CTAB necessary to cause reversal of the endosmotic flow was independent of the initial pH of the kaolin suspension, and equal to the critical amount required at pH 4 to neutralize the planar charge, as judged from the position of the bend in the titration curve. It is now known that, because of edge-to-face flocculation (of which we have an electron micrograph for kaolinite), the planar faces cannot always be completely accessible to the CTAB: only if the positive edge charges are neutralized by sufficient pyrophosphate or oxalate can the full planar charge be measured by the two standard techniques. When this edge neutralization is achieved the value of the planar charge so measured is constant in the range pH 3–7, and thus represents the permanent isomorphous replacement charge. It has the same value as the cation-exchange capacity measured by the method using neutral ammonium acetate.

In the absence of dispersing agents the charge measured by the

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titration near pH 4, and by the endosmotic technique, is more closely associated with the minimum possible net negative charge, i.e., with an upper limiting value of the positive charge on the edges. The latter can be produced in the endosmotic test because the paste round the anode becomes acid in the process of electrolysis. This suggestion of a maximum possible edge charge is in agreement with the results of H. R. Samson (*Rep. Rothamst. exp. Sta. for* **1952**) on the buffer capacity of kaolins, which showed that the net negative charge on the clay reached a limiting value at low pH.

There is thus a difference between the critical amounts of CTAB taken up by the planar faces in the absence and presence of a dispersing agent. If it is assumed that this difference is a measure of the maximum positive edge charge it becomes possible to estimate the area of the edges, because theoretical value of the maximum charge density, based on crystal structure, has been given by R. K. Schofield and H. R. Samson. Calculated values for Merck and Peerless kaolins give the edge areas as 12 and 19 per cent, respectively, of the total areas; these are of an acceptable order of magnitude and permit a more accurate calculation of the planar charge densities.

The decrease in cation-exchange capacity that occurs when kaolins are heated to various temperatures is being investigated by means of the CTAB techniques.

A full account of this work is almost ready for publication.

Soil structure (W. W. Emerson and M. Dettmann)

Synthetic soil conditioners

It has been shown that the concentration of carboxylated polymer needed to stabilize Na–montmorillonite gels in water is extremely small, too small for X-ray examination to reveal conclusively that the polymer is not linked to the basal silicate sheet. An optical technique is helping to resolve this difficulty. If thin sections of oriented flakes of Na–montmorillonite are immersed in dilute salt solutions they swell laterally and vertically. When viewed on the stage of a polarizing microscope, bands are observed near extinction, and if the small amount of polymer added to the clay does form an inter-lamellar complex, then the stabilized crystals will be visible perpendicular to the bands. Measurements of the dimensions of swollen flakes of Na–montmorillonite, with and without carboxylated polymer, have been made at various values of pH over a range of decreasing salt concentrations. The relation between lateral and vertical swelling as sodium-ion and hydrogen-ion concentrations are changed shows some signs of order, unexpected and perhaps fortuitous, but indicates that the process of deflocculation that occurs as the salt concentration is reduced might be caused by breakdown of linkages at the edges of the crystals. This is in conformity with other evidence that the carboxylated polymers form peripheral complexes with the Na–clay.

Sodium saturation test

The difficulty referred to in last year's report has been overcome and the test itself simplified. While the clay was supported by

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sintered glass there was trouble if the clay dispersed and blocked the pores of the sintered glass. Now a layer of glass beads (½–1 mm. diameter) is used to support the crumbs, and only one concentration of NaCl is used, sufficiently high to prevent deflocculation of all unstable clays. The crumbs are now wetted under suction with 50 mN. NaCl solution, and the permeability measured using the same solution, which is then allowed to percolate for 24 hours before the permeability of the crumb bed is measured again. The decrease in permeability is a measure of crumb instability; tests on soil from the 80 plot of Barnfield (calcareous, unmanured and continuously arable) show a drop to very near zero permeability, whereas crumbs from an adjoining area of permanent grass have shown no change in permeability.

Soil structure field experiment

The last set of four-year-old grass and lucerne plots was ploughed up in the autumn of 1955; these and two control strips which had been fallow for the four years were sown in the spring with beetroot and carrots. The fallow strips were split for 3 levels of K and 2 levels of N; the higher level of N and an intermediate level of K being applied to the ley plots. After sowing there was a prolonged dry spell. The beetroot germinated very much better on the fallow plots and on the lucerne plots than on the grass plots, resulting in a 20 per cent increase in stand after singling. This is ascribed to the more rapid drying out of the surface soil on the grass plots, as the cultivations necessary to produce an adequate tilth on the fallow strips had left a very "fluffy" tilth on the ploughed-up grass. The carrots germinated more quickly than beetroot, and uniformly over the whole area. There was, however, a spectacular increase in the rate of growth of the carrots after the grass compared with the fallow and lucerne plots. This could be due to easier penetration of the tap roots into the grass plots. By the end of the summer, although differences were still visible, the total mean yield of roots from the grass plots—28 tons/acre—was only 4 tons/acre greater than from the fallow. The difference in saleable roots was even less marked, because of the much greater number of fanged roots after grass; which, it is suggested, is due to microbiological attack of the growing tip. There was no response to N on the fallow, and only a slight response to K, as judged by root yield. For beetroot the additional N on the fallow increased the yield from 5·8 to 7·8 tons/acre; but there was no response to K. There was a parallel increase in yield from 5·6 to 8·3 tons/acre between the hayed plots and the repeatedly cut plots (to simulate grazing), which may also be an N effect. The weight per root was higher after the grass.

The yields of the second test crop on the second block (autumn wheat after spring beans) were the same from the former fallow and grass plots, but the lucerne plots yielded an extra 5 cwt./acre grain. These results are in accord with the previous year's results on the first block. This block had spring barley as the third test crop. The barley on the old grass plots was more severely attacked by wireworm than that on the old fallow plots, but recovered sufficiently to give a slightly higher yield.

Agricultural Meteorology

Micro-meteorology

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

Temperature, humidity and wind measurements have been made among and above potatoes and wheat throughout the summer. We now have five years' data for potatoes, and these should be sufficient to answer questions about the environment of the growing plant. The instrument for recording dew-point temperature gradients has been made more precise, and we now accept its indications with considerable confidence. During its use in the potato crop it has registered periods of dew formation of short duration, and also occasions of very slight dew formation not detectable by other instruments. It has also shown that on some occasions the routine meteorological report of "observed dew" has in fact been reporting guttation, dew formation being impossible during the night before. Leaf temperatures at two levels, and soil temperatures at two depths have been continuously recorded and shown the same general behaviour as in 1955. Out of these observations, and those on wheat, we are gradually building up a coherent picture of the physics of the heat and vapour exchanges between soil and plant environment and free atmosphere.

A full account of the instruments has been written and submitted for publication.

Similar equipment has been used in spring wheat without introducing the variable of plant density. A telescopic support was used so that all observations above the crop were taken at fixed height intervals above the top of the crop. Detailed analysis of the two years' records is well advanced, and, among other information, has indicated that during part of the day the dominant controller of evaporation rate may be turbulence, and at others it may be radiation. For a short period soil temperature was recorded under the wheat at eleven depths 0–10 cm., and the temperature profiles show a very nearly constant temperature gradient (i.e., constant heat flux) at the surface throughout the night.

New equipment built, tested and ready for use, includes a slowly acting anemometer for long-period continuous recording of the low wind speeds characteristic of night conditions in the field. It is a "hot-wire" instrument using a helix of heated wire co-axial with, but not touching, a small cylindrical nickel thermometer. Its working range is 5–70 cm./sec.

(b) *Heat and water balance* (J. L. Monteith)

The main experiment planned for summer 1956 was not started because the special weighbridge was not ready in time. Considerable progress has been made in building auxiliary equipment, and in analysis of existing records.

Heat flux plates, to measure the rate of heat transfer in the soil, have been tested in a variety of granular materials of different thermal conductivity, both air-dry and saturated with water. Using plates $9 \times 2 \times 0{\cdot}16$ cm., the responses to a constant heat flux over a range of moisture contents have varied by ± 8 per cent in our

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Rothamsted clay, but only by ± 2 per cent in the Woburn sand. The cause of the variability is not known, but assuming that it may be a reflexion of particle size and the physical contact between soil and flux plate, a change in design is being considered.

In the field, the flux plates have been set under potatoes, wheat and grass, and the sensible heat flow and storage compared with the net radiation received, as measured by the radiometer described in last year's report. On calm nights, with the top-soil wet, the net radiation loss was almost completely accounted for by the sensible heat transfer through and from the soil, implying that dew formation, if any, should be attributed to vapour transfer from soil to leaf, rather than from air to leaf. (Some of Long's measurements of vapour-pressure profiles indicate the same bias, though not so markedly.) During one cloudless period of 24 hours at the end of July the net heat stored beneath all three crops was approximately 10 per cent of the net radiation received during the period; but in more normal cloudy weather, when soil temperatures showed little day-to-day variation, the net storage was only about 2 per cent of net radiation, or less. This heat-storage term is usually neglected in the estimation of evaporation rate from weather data, and it is clear that the neglect is justified in all but exceptional circumstances.

One of the factors in the energy balance out of doors, affecting evaporation estimates among other things, is the "albedo" or reflexion coefficient of the surface. Data on reflexion are very scarce, and it has been necessary to assume a value—round 20 per cent—much the same for all covers that look about the same colour. A small solarimeter incorporating a Hatfield heat-flux disc has been built and used to measure the reflexion coefficient of different crops. Tests over grass showed a nearly constant value of about 21 per cent throughout the day; but over a young crop of spring wheat the reflexion coefficient varied from 14 to 20 per cent with decreasing solar altitude. At the time, the soil was visible between the rows, and it appears that with a high sun more radiation was reflected from the soil (albedo about 13 per cent) than from the vegetation (albedo about 20 per cent). The usual method of measuring albedo by taking upward-facing and downward-facing readings on the same radiometer is inconvenient over tall crops, and is unreliable, anyway, if variable cloud causes radiation intensity to change rapidly. A simple double unit has been designed, and a first model built, of two arrays of thermocouple elements back to back, and with one looking at the sky and the other at the ground a potentiometer can give instantaneous measurements of albedo.

Measurement of high humidities. Under "*Miscellany*" in last year's Rothamsted Report reference was made to a method of measuring relative humidities close to 100 per cent. In collaboration with P. C. Owen (see Botany Department report) progress has been made. When current is passed through a bismuth–chromel junction (in the right direction) sufficient cooling can be produced at the junction to condense water from air at or above 98 per cent relative humidity, and the junction can then be used as the "wet-bulb" of a psychrometer. Used as such, the wet-bulb temperature is a linear function of the relative humidity between 98 and 100 per cent, and in this range the humidity can be estimated to better than 0·1 per cent. It appears to be a useful way of measuring high humidities, especially in small enclosed spaces and, as Owen reports, has made possible the measurement of equilibrium relative humidity of small soil samples. Temperature stability is absolutely essential, and there is little prospect of the method being much use in the field.

Soil water and soil temperature (P. F. Noble)

Some of the work of J. S. G. McCulloch (*Report Rothamst. exp. Sta. for* **1953**) was presented in a paper, read at the Paris Soils Congress, which discussed the theory of heat flow in a soil with marked heterogeneity. The available records were too coarse, and the number of sunny days too few, for the check of the theory to be completely satisfactory, and an artificial source of " sunny " days has been built. A patch of bare soil—close to McCulloch's working site—has been heated from above by a heating mat controlled by a cycling mechanism that gives a periodic change of energy input of adjustable amplitude. After initial difficulties it is now working. Miniature nickel resistance thermometers (given a trial run in Long's experiment) are buried at depths from the surface to 40 cm. below, and continuous records taken from them. Heat-flux plates have also been buried. First records are promising, and are now being analysed.

After a visit to the Atomic Energy Research Establishment, Harwell, components have been bought for the construction of equipment to measure the scattering of neutrons in soil. The extent of this scattering is uniquely dependent on the water content of the soil, and application of this technique of measuring soil-water content should help in several kinds of research and technical problems.

The first steps have been taken in the study of the movement of the transpiration stream through the plant. American experiments have shown promise, the technique being to introduce heat at one region of the stem, and measure the rise, and rate of rise, of temperature a short distance above.

Evaporation

Application of previous work has continued, by ourselves and by others at home and oversea. The only minor advance has arisen in a private communication to the Swiss Forestry Service commenting on the hydrology of the two catchments (Sperbelgraben and Rappengraben) that have been gauged for about fifty years. Both are very steep valleys, and it was necessary to calculate the effect of slope on evaporation. For these valleys, with a slope of about 23° and a south-westerly exposure the estimated increase is about 18 per cent in midsummer, 100 per cent in midwinter and 28 per cent over the year, as compared with a flat area.

Irrigation at Woburn

P. F. Noble has installed transpiration gauges in an irrigated and in a control plot on the grass area. There was too much summer rain for anything useful to emerge from the first season's work.

A start has been made on the analysis of the six years' data now

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available from Woburn. A close-to-linear relation has been found between the accumulated growth of grass expressed as dry matter, and the accumulated effective potential transpiration, the integrations extending through the winters as well as the main growing periods. It seems clear that, apart from increasing yield, one of the beneficial effects of nitrogen fertilizer is to increase the drought tolerance of the grass in the sense that plots with higher nitrogen dressings can build up a larger soil-moisture deficit without a check to growth than plots with less nitrogen. This work is essentially exploratory, but it is encouraging to find some sign of order in crop–weather relationships.

On the whole, the first six years of work at Woburn have been carried out in average to wetter-than-average summers. A summary table follows, showing the results of the maximum irrigation on each crop in each year, some of the maxima being greater than would be recommended for farming use: this is an experiment. The yields are means of two fertilizer treatments and are given in two columns: O, the control plot, not irrigated; C, the maximum irrigation plot. Under I is the amount of irrigation applied to the C plots. Under " Rain " is a coarse indication of the rainfall in each of the summer months April to September.

Irrigation Results at Woburn up to End of Second Three-course Rotation

Year	Rain	Barley Grain, cwt.		Barley I, in.	Grass Dry matter, cwt.		Grass In.	Sugar beet Sugar, cwt.		Sugar beet I, in.	Potatoes Tons		Potatoes I, in.
	A M J J A S	O	C		O	C		O	C		O	C	
1951	w A D D W W	26	31	3·2	43 *	53	3·6	50	54	3·4	4 †	8	2·2
1952	A A D D W W	22	25	2·9	55	86	5·1	51	59	5·6	6	10	2·7
1953	w A A W d A	27	26	0·8	89	100	5·6	84	82	3·6	11	13	2·0
1954	D A W W W A	34	35	1·8	33 *	30	2·9	45	45	1·2	16 †	15	2·2
1955	D W A D D d	36	36	1·4	46	73	7·7	34	48	6·4	11	20	6·3
1956	D D A W W A	29	32	2·6	68	85	3·9	64	60	1·4	15	15	0·5

A = average ± <0·5 in. $\genfrac{}{}{0pt}{}{w}{d}$ = average ± 0·5–1·0 in. $\genfrac{}{}{0pt}{}{W}{D}$ = average ± > 1·0 in.

* Newly sown—grass/clover 1951–53, S.37 cocksfoot 1954–56.
† Earlies 1951–53, Maincrop 1954–56.

Woburn irrigation 1956

After a dry spring, the summer was very wet, and except for one fortnight in June there was no need for irrigation after the end of May.

Grass. The first two cuts showed the effect of irrigation in May and account for the whole of the difference between O and C in the final totals.

Sugar beet. The stand was good, but as the main need for water came after the drought very little irrigation was called for.

Barley. The effect of spring watering was very marked in the early growth. From June to harvest the differences gradually disappeared.

Potatoes. Little need, and little response.

The table gives the responses to full irrigation (C plots) designed to keep the plots near field capacity throughout the summer, at two levels of nitrogen fertilizer dressing (N_1 and N_2) imposed on the standard P and K dressing appropriate to each particular crop.

Woburn Irrigation 1956

Crop	Period	Rain, inches	Irrigation, inches	Plot		Yield
Grass	30 Apr.–1 Oct.	13·2	—	ON_1	55·2	Dry matter, cwt./acre, 6 cuts
				ON_2	81·1	
			3·9	CN_1	71·9	
				CN_2	99·0	
Sugar beet	30 Apr.–1 Oct.	13·2	—	ON_1	60·3	Sugar, cwt./acre
				ON_2	67·4	
			1·4	CN_1	55·3	
				CN_2	65·2	
Barley	30 Apr.–30 July	6·9	—	ON_1	26·1	Grain, cwt./acre
				ON_2	31·2	
			2·6	CN_1	29·1	
				CN_2	34·7	
Potatoes	30 Apr.–1 Oct.	13·2	—	ON_1	14·2	tons/acre
				ON_2	15·7	
			0·5	CN_1	14·8	
				CN_2	16·0	

Because of eelworm infestation, potatoes will be excluded from the next rotation, to be replaced by beans. Spring wheat will probably replace the barley.

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