ROTHAMSTED RESEARCH

Report for 1958

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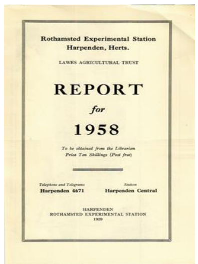
Rothamsted Experimental Station
Harpenden, Herts.
LAWES AGRICULTURAL TRUST
REPORT
for
1958

Physics Department

H. L. Penman

H. L. Penman (1959) *Physics Department* ; Report For 1958, pp 33 - 40 **- DOI: https://doi.org/10.23637/ERADOC-1-91**

PHYSICS DEPARTMENT

H. L. Penman

Before taking up an appointment with a soil mechanics unit of the Commonwealth Scientific and Industrial Research Organization of Australia, Margaret Dettmann left the department in June to work for a few months at the Institut für Bodenbearbeitung in Brunswick, Germany. Mr. H. D. Orchiston and Mr. P. F. Noble returned to New Zealand early in the year. Dr. M. S. Ahmad, of the Geophysical Institute, Quetta, West Pakistan, was with us for two months. Mr. D. A. Rose came in October as an Agricultural Research Council scholar for a period of two years.

Margaret Dettmann and J. A. Currie took part in a discussion on Soil Structure in Ghent, Belgium; I. F. Long paid a four-day visit to the laboratory of Dr. R. Geiger in Munich, Germany, during which he gave a lecture on our work; H. L. Penman, at the invitation of the East Africa High Commission and the Empire Cotton Growing Corporation, spent a month in East Africa studying water problems in Kenya and Uganda.

A Darton Prize of the Royal Meteorological Society was awarded to I. F. Long for his paper on micro-meteorological instruments.

Soil Physics

Electrical charges on clay

Previous work showed that kaolin possesses a permanent negative charge; this can be measured by changes in pH and electro-osmotic behaviour as the negative charge is progressively reduced by adding cetyl trimethyl ammonium bromide (CTAB), but only when deflocculants are present. A lower value of the effective charge is obtained in the absence of deflocculants. It has now been found that both the lower charge and permanent negative charge can be obtained from a single experiment, without adding deflocculants, by measuring the change in electrical conductivity of a kaolin suspension as increasing amounts of CTAB are added to it. When the change in conductivity per unit increment of CTAB is plotted against the total amount of CTAB added, the points lie on smooth curves, almost linear, with distinct changes in slope at characteristic values of added CTAB, values that are reproducible and are regarded as indirect measurements of the lower and upper limits of the charge mentioned above.

The probable explanation depends on the ideas put forward a year ago, in which it was suggested that the standard pre-treatment with an acid KCl solution, followed by washing with distilled water, leaves the crystals under a very great electrical stress: some decomposition of the crystals takes place and complex ions containing aluminium are released from the lattice. These ions can, of course, take part in the electrical balance of the clay system, but do not dissociate from the clay surfaces (so forming a Stern layer) as do

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the more mobile K ions. Consequently the permanent charge is balanced by two classes of ions, mobile and non-mobile. The direct measurement of the charge in the electro-osmotic test is a measure of the mobile ions, i.e. the lower limit of the charge, and it is only when the complex ions are made mobile by the addition of deflocculants that the full negative planar charge can be measured.

In phase I of the conductivity measurements the K^+ ions are replaced by CTA^+ and the effective planar charge is reduced to zero. In phase II the complex ions are replaced by CTA^+, but as they move slower than K^+ in an electrical field the transition between phase I and phase II is detected. In phase III (all K^+ and all complex ions having been replaced by CTA^+) the change in electrical conductivity records the addition of CTAB without exchange, though part may be adsorbed by the kaolin. The advantage of the conductivity experiment is that it shows that the complex ions are replaced by CTAB in phase II.

As has been mentioned, once the mobile K ions have been replaced the effective charge is zero. If, in phase II, the complex ions were completely exchanged by CTA^+, then the planar charge would remain zero until the start of phase III. In the direct measurement of the charge by the electro-osmotic test, the transition between I and II is measured as the lower limit of the charge; this means that some CTAB is adsorbed without exchange, which may be an effect of mutual attraction between the long hydrocarbon chains, or of a direct adsorption by the kaolin.

The conductivity tests also throw some light on the effect of heating kaolins to 300° C.: the same three phases are obtained as for the acid-treated kaolins. Consequently the effect of heating is again a decomposition of the crystals; and an apparent reduction in cation exchange capacity at pH 7, as determined by the use of N ammonium acetate, is attributed to the difficulty of replacing the complex ions by NH_4^+. The conditions for replacement are more favourable in a conductivity experiment, since distilled water should give the greatest possible expansion of double layers, and CTA^+ has a greater replacing power than NH_4^+. (Cashen.)

Soil structure field experiment

Two blocks are in the third phase of a sequence: 4 years' ley or fallow: 3 years' test cropping: return to ley or fallow. No visible differences were observed this year in the growth of the crops.

The third block carried its third set of test crops since it was ploughed out from grasses in 1955. In 1956, cropped with beetroot and carrots, and again in 1957, cropped with carrots and beetroot (plots interchanged), the indications were that any structural differences resulting from previous cropping were having their effect during germination and for a short period after emergence. The 1958 test was, therefore, made a germination test. Barley, sugar beet and kale were sown successively at the ends of March, April and May, each crop being allowed to germinate and develop for a short period before being extirpated with the minimum of soil disturbance to make room for the next. All plots received a basic dressing of fertilizer (10 : 10 : 18) at 10 cwt./acre.

Low soil temperatures in April delayed emergence of the barley,

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but all plots were equally affected. Counts of coleoptiles per unit row length a month after sowing showed significantly higher numbers on those plots that had carried ryegrass and timothy (with simulated grazing) in the years 1951–55, non-significantly higher numbers on those plots that had carried ryegrass, timothy and cocksfoot cut for hay during the same period. Previous test cropping showed a small effect. Where the order was ley, carrots, beetroot, barley, the counts were higher than for ley, beetroot, carrots, barley, especially where the ley had been grazed. The carrot/beetroot order had no effect on former fallow plots, and in general the barley emergence on these plots was as good as on the best of the former grass plots.

Short heavy showers in a mainly dry period after sowing the sugar beet caused dispersion of the surface soil, which then dried to produce a thick crust on all plots. Germination counts three weeks after sowing showed no differences between plots.

The kale germinated in a wet period during which the surface soil was frequently puddled. As for the barley, the sequence ley, carrots, beetroot, kale gave a better emergence on the former grass plots than the sequence ley, beetroot, carrots, kale.

Measurements of soil stability, soil water and soil temperature showed no differences corresponding to observed differences in emergence counts. (Currie.)

Soil aeration

The gaseous exchange between the soil and the atmosphere is mainly a diffusion process in which the gas molecules concerned (O_2 and CO_2) have to find their way through a system of tortuous channels of irregular and varying cross-section. It is easy to predict that the interchange rate will increase as the air-filled pore-space of the system is increased, and a laboratory study (H. L. Penman (1940), *J. agric. Sci.*, **30**, 437–462) showed that for dry granular solids the relation $D = \frac{2}{3}SD_0$ held in the range of pore-space $0 < S < 0{\cdot}6$, where D_0 is the coefficient of diffusion in free air. Subsequent work elsewhere has sometimes confirmed this relation: and as frequently contradicted it, particularly when the material was not dry. A thorough study of the effect of water in sealing off parts of the pore-space, in increasing tortuosity and in reducing cross-sectional area available for diffusion seems worth while; but it must be thorough, for there are already too many first approximations available. Progress so far has been satisfactory. Hydrogen is being used as the test gas, partly because it is not a normal component of soil air or atmospheric air. A simple technique, based on thermal conductivity, has been devised to measure the concentration of hydrogen in a small volume, and this is accurate and reproducible over the whole range 0–100 per cent. Laboratory measurements of diffusion in dry porous media have produced results in general agreement with the equation given above, and an estimate of the value of D_0 for hydrogen into air agrees very well with one of the standard values of this " constant ". With this reassurance that the technique is adequate, measurements are now being made on wet materials.

In parallel with the experimental work, considerable thought is

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being given to the theoretical aspects of the problem. Until we know why diffusion rates are affected by soil geometry and water content it will be difficult to suggest how soil management might be modified to produce a desired condition. (Currie.)

" Docking disorder "

Physical measurements have been made on soils from good and bad sites where " Docking (or Docking-type) disorder " is found. (See below, p. 195.) (Currie.)

Soil water

Field checks of the neutron-rate meter monitor have not been discouraging. From early June the soil was never far from field capacity, and all the observations were at the top end of the range. By the end of the summer the source had decayed so much in power that the rate-meter circuit was inadequate, and a counter unit is being added to the monitor so that both instantaneous rates and total counts per standard time can be determined. (Long.)

The thermocouple method of measuring relative humidity in the range 95–100 per cent (last referred to in *Rep. Rothamst. exp. Sta. for 1956*) has now become a routine laboratory method, and has been used by other members of the station to determine soil moisture tension (pF), and the osmotic potential of solutions. A full description has been published (1.4, p. 236 below). It takes several days for very wet soils to come to equilibrium with the air in the small test chamber, and as during this time hourly temperature changes must be maintained within $\pm 0{\cdot}001^\circ$ C., the useful upper limit of the equipment is 99·98 per cent relative humidity, corresponding to a tension of 3 metres of water, or pF = 2·5. As a dozen soil samples, all at different water contents if desired, can be handled simultaneously, the moisture characteristic curve of a soil in the range pF 2·5–4·8 can be obtained more quickly than by the standard techniques currently available. The curve for Great Field soil, determined in the new way, agrees well with the curve for soil from a nearby site previously obtained by centrifuge and freezing-point techniques. (Monteith and Szeicz.)

Agricultural Meteorology

Micro-meteorology

Considerable progress has been made with the analysis of the temperature, humidity and ventilation data collected in spring wheat during three summers 1955–57. A detailed survey will be given in a later report when digestion is more complete, but the type of information that is emerging includes: the persistence of high humidity inside the crop; the conditions that lead to active condensation on the crop, and the sources of this dew; the relation between air movement inside the crop and that over the crop; heat transport from the crop, upward and downward, water vapour transport from the crop; and, perhaps of most general importance in trying to specify a " crop climate ", the existence of detectable differences, persisting for hours at a time, in the temperature and humidity at the same level above ground at sites only a few feet apart horizontally.

The field work in 1958 has been on sugar beet, and the disposal of the equipment much the same as for the wheat. Vertical profiles of temperature, vapour pressure and air-flow have been recorded continuously for a period of six months in the middle of the experimental area, and also at the south-west and north-east corners to get a picture of horizontal variations. Soil temperatures have been recorded from 0 and 24 cm. depth, in the rows and between the rows, and leaf temperatures, too, have been measured. Cursory examination of the records shows that they carry plenty of interest. As examples: (i) there have been many day-time periods in which the humidity under the crop has remained close to saturation (not surprising in the summer of 1958), and the vapour-pressure gradients have indicated a downward movement of some of the transpired vapour to the soil surface. (ii) The broad-leaved crop has shown much greater night cooling on clear nights than we ever observed in wheat, but daytime leaf temperatures have not shown any correspondingly greater day maxima. (iii) As recording was maintained until early December, some frost periods were included. Leaf temperature can go down to $-2{\cdot}5^\circ$ C. before freezing occurs, when it rises instantaneously to 0° C., and thereafter progressively falls.

The general observations on the frequency of occurrence of dew (summarized in publication 1.2 of the 1957 report) have been maintained. It is estimated that dew occurred on 78 nights from July to October inclusive, but only on 30 did it persist until 0900 G.M.T., the time of official observation and recording. (Long.)

Heat and water balance

Sugar beet was grown on the field balance described in the 1957 report, in the middle of the area over which Long's observations are made. Evaporation, net radiation exchange and heat flow in the soil were recorded continuously throughout the growing season, characterized by wet surface soil except in the early stages of the crop. During seedling stage the rate of evaporation—mainly from the soil—was about half of that from the 6-foot-square open water tank nearby, but for the period July–October, when the leaves completely shaded the ground, crop transpiration exceeded tank evaporation by 6 per cent. At no time did the soil-moisture deficit exceed 4 cm., whereas under wheat in 1957 it reached 11 cm. In comparing the two seasons there is thus a contrast in crop and a contrast in weather.

As part of the study of crop contrasts measurements have been made, for different crops, of the reflexion of short-wave radiation using radiometers constructed at Rothamsted, and of the emission of long-wave radiation using a Linke–Feussner radiometer kindly lent to us by Professor P. A. Sheppard of Imperial College, London. Seasonal variations in the short-wave reflexion coefficient of sugar beet, wheat and potatoes have been related to leaf area, and it has been found that when leaves completely shade the ground the coefficient is 0·26, independent of crop type or visible colour. A lower value for spring wheat (0·21) is attributed to incomplete cover, and a value of 0·27 for winter wheat (in May) suggests that this crop had

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by then produced more leaf than the spring-sown crop ever attained. Measurements of reflexion coefficient may give useful estimates of leaf growth without laborious sampling.

The long-wave radiation measurements lead to a radiative leaf temperature, accurate to about $\pm 1°$ C., and it is doubtful, at least in full sunlight, whether direct measurement can achieve anything much better. In such bright sunshine the order of increasing surface temperature was open water, grass, sugar beet, ripe wheat, with a range of 7° C., equivalent to about 10 per cent range in net radiative loss. For the green crops, actively transpiring, the range is smaller, and with their short-wave reflexion coefficients equal, it seems unlikely that there are any significant differences between the values of net radiation received by such crops. The sharing of this energy among transpiration, heating of the air and heating of the ground is being studied as the wheat (1957) and the sugar beet (1958) data are being analysed. (Monteith and Szeicz.)

Radiometry

The Kipp solarimeter on the laboratory roof now feeds into a potentiometer-type recorder, which provides simultaneously a continuous pen record of intensity and an integrated total in calories/sq. cm.

With this as standard, other methods of integration of solar radiation are being compared, using instruments kindly loaned to us by their manufacturers. These include a photo-cell unit, working into an electrolytic meter (developed at the National Institute of Agricultural Engineering and now made by Megatron Ltd.), and the Gunn–Bellani distillation-type gauge (made by Baird & Tatlock (London) Ltd.). Over periods of several weeks there is a good linear relation between daily radiation totals (Kipp) and the illumination as measured by the photo-cell, but the response of the Gunn–Bellani gauge is non-linear. Experience in East Africa shows that a linear regression to convert distillation readings to radiation can be used with confidence: our greater range of radiation intensities, and larger day-to-day variations in totals are apparently taking the instrument outside its best working range.

For field use, the development of small sensitive radiometers continues. The latest has a circular sensing unit about 2 cm. diameter, consisting of 32 copper—constantan junctions that give an output of 15 mV for 1 calorie/sq. cm./minute (midday, midsummer value for a fine day). Performance is good, apart from a suspected dependence of sensitivity on cloud amount. (Monteith and Szeicz.)

Measurement of carbon dioxide flux

A very generous grant from the Rockefeller Research Foundation, followed by rapid development work by the manufacturers, produced for us within a few months an infra-red gas analyser with a nominal range (on high sensitivity) of -5 to $+5$ parts/million CO_2 about an (arbitrary) zero near 300 p.p.m. This was in use from August to October over the sugar beet, and has given records of the diurnal changes in CO_2 concentration differences over a height interval of 25 cm. (10 and 35 cm. above the crop). In August and

September the daytime gradient of concentration was downward (CO_2 moving from air to crop) as the crop assimilated: by night it was reversed as CO_2 was released to the atmosphere by respiration. In October, however, the flux of CO_2 from air to crop was detectable only in bright sunshine, and there is some evidence that in other daytime periods the CO_2 requirements of the crop were obtained from the soil.

Quantitative estimates of flux are being calculated from the measured gradient and an estimated transport constant derived from weather measurements on the same site, and these estimates of "growth rate" will be linked with other meteorological elements (radiation, temperature, to name two). Over longer periods there will be comparison with the dry-matter increments obtained from direct sampling by the Botany Department (see p. 80), and from such a comparison it may be possible to estimate CO_2 production by soil micro-organisms. (Monteith and Szeicz.)

Irrigation at Woburn

Once again the summer weather pattern has been unkind, with a dry, rather cold spring and a wet summer starting in mid-May and persisting throughout growing and harvest periods except for a fortnight in mid-July. The result was that plots irrigated before the beginning of June were then brought to field capacity, and it is estimated that during June and July the rainfall equivalent of 4 inches of water passed down through the profile of the irrigated grass plots, presumably removing nitrogen in the process. Details

Woburn Irrigation, 1958

Crop	Period	Rain, inches	Irrigation, inches	Plot	Yield, cwt./acre	
Grass	28 Apr.–29 Sept.	14·2	—	ON_2	74	Dry matter 8 cuts
				ON_4	88	
		14·2	3·8	CN_2	76	
				CN_4	88	
Sugar beet	28 Apr.–29 Sept.	14·2	—	ON_1	42	Sugar
				ON_2	50	
		14·2	1·7	CN_1	38	
				CN_2	54	
Spring wheat	28 Apr.–1 Sept.	11·9	—	ON_1	24	Grain
				ON_2	28	
		11·9	1·5	CN_1	23	
				CN_2	25	
Beans	28 Apr.–29 Sept.	14·2	—	OD_1	18	Grain
				OD_2	17	
		14·2	1·0	CD_1	19	
				CD_2	17	

(Penman and Barnes.)

of the individual cuts on the grass appear in the Woburn report (p. 188) and the results of the third cut (24 June) and the fourth (15 July) are of some interest. By 24 June the irrigated plots had about 1·25 inches of leaching, and the control plots none; the nitrogen response on the former was negligible, but was very good on the latter. By the time of the fourth cut, the irrigated plots had a further 1·75 inches of leaching, and the control plots 1 inch, and neither showed any response to nitrogen.

The table gives, as usual, a statement of responses to full irrigation designed to keep the plots near field capacity (C plots) at two levels of nitrogen (N_1 and N_2, or N_2 and N_4 for grass, dung for beans).