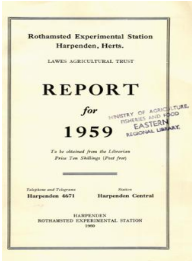
ROTHAMSTED RESEARCH

Report for 1959

Full Table of Content


Rothamsted Experimental Station
Harpenden, Herts.

REPORT
for
1959

Physics Department

H. L. Penman

H. L. Penman (1960) *Physics Department ;* Report For 1959, pp 31 - 37 **- DOI: https://doi.org/10.23637/ERADOC-1-92**

PHYSICS DEPARTMENT

H. L. Penman

Professor F. A. Brooks, from the University of California, spent six months with us as holder of a Guggenheim Fellowship. In September Mr. D. Rijks, newly appointed by the Empire Cotton Growing Corporation, started a six-month training in techniques for micro-meteorology before joining the research team in Namulonge, Uganda. Among many other visitors, Dr. J. F. Bierhuizen of Wageningen spent a period here for an exchange of ideas and experience on the physical aspects of transpiration and assimilation. J. L. Monteith was in Israel for three months, to advise the Government on research on crop evaporation. His mission was arranged and financed by the United Nations Bureau of Technical Assistance Operations, in co-operation with the World Meteorological Organisation. In January H. L. Penman attended a meeting of a European working party on irrigation, held in Wageningen by the Food and Agriculture Organisation.

Soil Physics

Electrical charges on clays

The delayed delivery of a new and more accurate conductivity bridge, and technical trouble in getting it working at its best, restricted work. Now, however, the new technique for estimating the nature of the electrical charge is doing all that was hoped for. Observations on illite were made, and others on montmorillonite are being organised, but the kaolins, about which so much information has been gathered in the past few years, were mainly studied. Past techniques were somewhat subjective in measuring changes in pH and observing electro-osmotic behaviour, as the clay was treated with successively increasing amounts of cetyl trimethyl ammonium bromide (CTAB). After the standard pre-treatment, the electrical state of the kaolin is that the planar charge is partly balanced by potassium ions, and partly by complex aluminium ions, the latter being relatively immobile. These cations are replaced by CTA^+ in two phases, during which the electrical conductivity changes in characteristic ways, the more mobile K^+ ions being replaced first. The new equipment gives more detail in these conductivity curves, some of which arises from the properties of the clay and some from the properties of the CTAB. Though the latter are important—the curves may help to show how other organic molecules are attached to clay—the main interest is in the behaviour of the clay. There is not always a sharp division between the phases (as suggested by the cruder results a year ago), but there is an overlap, at present interpreted by assuming that some of the K^+ ions are trapped in the aggregates, and are released only after the Al^{3+} ions start to be replaced. If there is no aggregation the phases *are* distinct. Whether this is relevant to the release of potassium and aluminium in field soil aggregates is not known. (Cashen.)

Soil structure

There was no test cropping on the field plots this year, but laboratory measurements (pore-space, permeability, gaseous diffusion) were made on soil crumbs from plots sampled to 6 inches. Some plots are on the site of the structure experiment, where, after 50 years of arable cultivation, they have been under fallow, ryegrass or cocksfoot for 4 years. The others are on Barnfield (continuously arable for over 80 years) and Highfield (permanent pasture). The grass seems to build up a more open (and more desirable) structure fairly rapidly, but stability in the structure increases more slowly. (Currie.)

Soil aeration

Accounts of the first stages in the basic work are ready for publication (see below 1.1, 1.2, p. 240). Part I, summarised last year, describes the technique and the check on its precision that leads to a new value of the coefficient of diffusion (D_0) of hydrogen in free air. Part II is based on a very detailed laboratory study of diffusion through dry, porous solids of varied particle shape. In the range of pore-space $0 < \varepsilon < 0{\cdot}8$ the general results satisfy $D = 0{\cdot}6\varepsilon D_0$, where D is the apparent coefficient of diffusion through the porous system, but this simple equation conceals interesting and important detail. For any material there is a small range of possible packing density, and within this range an equation of the form $D/D_0 = \gamma\varepsilon^{\mu}$ can be fitted, where γ lies between 0·8 and 1·0, and μ approaches the value of the index given by Bruggemann for the analogous electrical properties of two-phase media. Bruggemann's index is a shape factor for the *particle*; though what we need is a shape factor for the *pore*, two attempts were made to measure particle-shape factors. Measurements of surface area, and of settling velocity in a liquid, show only the expected general relationship with the values of μ, too imprecise to be of any quantitative use. Specification of a pore shape may prove easier for wetted materials. In the meantime a helpful generalisation is possible, for, using a simple model, it can be shown that for any porous system $D/D_0 = (l/l_e)^2 . f . \varepsilon$, where l_e/l is the tortuosity of the diffusion path, and f is a factor expressing the non-uniformity of cross-section of the path. This equation will probably be used for interpreting results being obtained from soils and other wetted materials. (Currie.)

Soil water

The rate of water used by growing plants can be estimated reasonably when soil water supply is not limiting, but it is not easy to specify what soil factors determine when water supply becomes " limiting ". A new study of water movement in unsaturated soils began, to try to distinguish between transfer as liquid and transfer as vapour, and though the latter is expected to be more important when there is a temperature gradient, the first work was done at constant temperature. As a further technical simplification, not affecting the basic physics of the processes, the first working materials are consolidated, being small blocks of building stone. Much is already known about the pore-size distributions in these blocks because they were used here in other suction studies. A technique was devised, tested and is apparently working well. A sealed diffusion cell contains the sample held between two saturated pads (" source " and " sink "), from which it is separated by fixed air gaps. The suction gradient imposed is regulated by saturating the pads with sodium chloride solutions at concentrations chosen to match the suction in the sample, in such a way that equal fluxes of water vapour distil from the source to the upper surface of the sample, and from the lower surface of the sample to the sink, i.e., transmission through the sample takes place at constant moisture content. As a check on performance, experiments without a sample gave a value of the coefficient of diffusion of water vapour in air as $D_0 = 0{\cdot}263$ cm.^{2} sec.$^{-1}$ at 25° C. Standard values range from 0·256 to 0·275 cm.^{2} sec.$^{-1}$, corrected to 25° C.

First results with two materials having very different pore-size distributions indicate that the liquid and vapour transfer interact, so that the total conductivity falls rather slowly from its value at complete saturation until the water content of the sample is so small that liquid continuity (it is presumed) no longer exists. Then the conductivity decreases very rapidly with decreasing water content, tending to a limiting value (D) for pure vapour diffusion, for which D/D_0 agrees with the value expected from the work of Currie. (Rose.)

The neutron-scattering technique for estimating water content in the field was tested thoroughly during the dry summer, with very disappointing results. Though much of the failure to achieve any close correlation between meter reading and measured soil-water content probably came from unavoidable variation in soil sampling, there are other causes attributable to the meter itself. It is hoped to eliminate these by converting the instrument from a rate meter to a scaling meter. (Long.)

Agricultural Meteorology

Because 1959 will long be remembered as a drought year it may be useful to give a summary table (Table 1) of the weather in which

TABLE 1

Weather Summary—Rothamsted 1959

Month	Mean Air Temp. (° F.)	Dew-point Temp. (° F.)	Soil Temp. at 1 foot (° F.) *	Wind Speed (m.p.h.) †	Rain (inches) ‡	Evaporation (inches) §	Sunshine (hours)	Solar radiation cal. cm.$^{-2}$ day^{-1}
Jan. ...	34 (37)	30	36	4·6	3·3 (2·5)	0·1	79 (52)	60 (54)
Feb. ...	38 (38)	35	37	3·6	0·1 (1·9)	0·2	62 (69)	82 (98)
Mar. ...	44 (41)	41	43	4·9	2·6 (1·9)	1·1	89 (118)	158 (202)
Apr. ...	49 (46)	43	48	5·1	2·5 (1·9)	2·0	135 (157)	279 (261)
May ...	54 (52)	46	54	4·9	1·3 (2·2)	3·7	219 (196)	403 (353)
June ...	59 (57)	50	59	4·1	1·2 (2·2)	4·0	233 (202)	445 (405)
July ...	63 (61)	55	64	4·1	4·5 ‖ (2·5)	4·6	277 (194)	455 (361)
Aug. ...	63 (60)	56	64	3·5	1·6 (2·6)	4·0	229 (183)	366 (306)
Sept. ...	59 (56)	52	60	3·5	0·2 (2·4)	3·0	208 (145)	282 (228)
Oct. ...	54 (49)	48	54	4·2	2·4 (3·0)	1·9	150 (104)	158 (129)
Nov. ...	43 (42)	41	45	3·4	2·4 (2·8)	0·4	65 (62)	68 (64)
Dec. ...	41 (39)	39	42	6·2	4·7 (2·6)	0·2	31 (45)	29 (40)
Total or mean	50·0 (48·2)	44·7	50·5	4·3	26·7 (28·5)	25·2	1,777 (1,525)	232 (208)

* Under grass.
† At 2 metres.
‡ $\frac{1}{1000}$-acre gauge.
§ Open water: M.O. 6-foot × 6-foot tank.
‖ 2·3 inches on 10 July.

C

research and farming operations were done. (Some long-period averages are given in brackets.) The only two features to which special attention is directed are the high values of summer solar radiation (both in duration and intensity), and the high rainfall in July, which statistically brought us back to average for the first seven months of the year, and agriculturally saved many farm crops.

The micro-meteorological work in Great Field II was impaired in two ways. Half of the field was sown in May with a timothy/fescue mixture, but germination and growth were retarded during subsequent dry weather, and it was the beginning of August before a complete ground cover was established. Meantime the severe storm of 10 July flooded the field balance and lessened its efficiency.

On the other half of Great Field kale was grown, and simultaneous measurements were made over the kale and the grass.

Before outlining the 1959 work it is convenient to complete the history of earlier work.

Micro-meteorology

A long paper on the micro-meteorology of spring wheat is summarised below (1.8). A few general comments are made here, primarily to link this work with that of Monteith on radiation and on assimilation. The part of the survey dealing with transpiration shows how the flux of water vapour above the crop is built up within the crop. The flux of carbon dioxide for photosynthesis, physically similar but in the opposite direction, may be governed by a rather more complicated plant response to the intensity and distribution of light. All the green leaves of the wheat plant probably contribute equally to the transpiration stream: some day it may be possible to state how they contribute to assimilation and respiration.

The ventilation part of the survey reveals that air movement in the crop does not vary greatly with external wind speed, because the upper leaves bend over in stronger winds, tending to form a "self-seal" at the top of the crop; insects that prefer calm conditions for flight will usually find them inside a wheat crop. Conditions for dew formation were examined, and precise estimates can be given of when dew formed and how long it persisted. Though dew forms on wheat as drops, each covers perhaps 30 stomata and so is big enough to provide fungus spores with room enough to germinate and infect.

Professor Brooks studied some of the topics that were only briefly mentioned in the survey. E.g., an adventitious temperature ripple—of no British agricultural significance—has a parallel in Californian orchards at the time when the frost hazard is greatest. Professor Brooks left us with four possible explanations of the phenomenon, broadening our ideas in the process. (Penman and Long.)

So far there has been little opportunity to analyse the 1958 results with sugar beet, and none at all for the 1959 data for grass. Observations made in 1959 were similar to those in 1958, but a more sensitive system for measuring temperature differences was introduced. This will be fully exploited when aspiration of the wet- and dry-bulb thermometers is achieved, and it is hoped that in the summer of 1960 reliable wet-bulb depressions, correct to 0·02° C. or better, will be continuously recorded.

Recording in and over the test site began immediately after drilling of the grass seed and continued into mid-winter. Later in the season, detailed enough observations over kale were taken to compare estimated transpiration rates, for which the aerodynamic formula will be used. (Long.)

Heat and water balance

The grass cover on the field balance was not complete until August. Average transpiration during that month was 3·35 mm./day, a few per cent more than the evaporation from the nearby 6 feet square open water tank. In previous years transpiration from wheat and sugar beet never exceeded tank evaporation by more than 24 per cent over a month, so the balance records show that differences in the water consumption of crops having different heights and structures are small. The grass was cut at the end of August, and in September (nearly rainless) there was no obvious growth, and transpiration was only 32 per cent of tank evaporation.

During the growing season, net radiation was recorded over both grass and kale, and in these and other crops on the farm the profiles of short-wave radiation (solarimeter) and of visible light (photocell) were occasionally measured. There are important differences in the amount of light that gets through crop canopies. A mature stand of kale intercepted 99% of radiation incident at the top of the crop; a potato crop intercepted 95%; spring wheat, 100 cm. high in July, intercepted only 70%. This failure to absorb completely, a consequence of leaf arrangement, may be one factor that reduces the net assimilation rate of cereals below that of other crops.

Analysis of net radiation records for the past 3 years shows that the amount received by crops during daylight hours is a constant fraction of the incoming short-wave radiation throughout much of the growing season, the constant varying little with crop species. There is here the possibility of a useful short cut to estimating the net radiation term in the expression for potential transpiration, i.e., it may simplify our computations of irrigation need.

Radiometry

In its final form (1.4) the small portable solarimeter can be made quickly and cheaply; models worked without trouble at Rothamsted throughout the year, were used successfully in Israel and are being tried in East Africa. A combination of two units, with a suitable potentiometer circuit, accurately and rapidly estimates the reflexion coefficient of any surface over which it is exposed (1.5). (Monteith and Szeicz.)

Another instrument in the trial stage is a net radiometer not needing forced ventilation. Progress was good, and there is now a prospect of getting accurate weekly totals of both net radiation and short-wave radiation from equipment costing less than £40 altogether.

Study of the performance of the commercial Gunn–Bellani radiation integrator was completed (1.6). The existence of a temperature-dependent threshold of response probably results from incomplete evacuation of air during manufacture. (Monteith and Szeicz.)

Carbon dioxide flux

The meteorological aspects of the carbon dioxide flux over a crop of sugar beet were published (1.7). During August and September the calculated value of net assimilation was 3·8 mg. $cm.^{-2}$ day^{-1}, based on measured gradients, and other weather parameters: the " observed " value was 5·2 mg. $cm.^{-2}$ day^{-1}, based on plant sampling and estimation of dry matter increase by the Botany Department. During October and November, the atmosphere apparently ceased to be important as a source of carbon dioxide, large quantities then coming from the soil, much more than the crop could take up.

A correlation of calculated rate of photosynthesis and weather is being attempted. For short-wave radiation intensities below 0·4 cal. $cm.^{-2}$ $min.^{-1}$ the assimilation rate of sugar beet is proportional to light intensity: above, there is evidence of light saturation. Wind speed is important too, for assimilation rates decrease when atmospheric turbulence does not maintain the normal concentration of carbon dioxide above the crop: on one calm, sunny day it was decreased to 220 p.p.m. (normal $\simeq$ 300 p.p.m.).

Carbon dioxide gradients over the kale were measured, but no worthwhile records were obtained over the grass because of technical trouble with the gas analyser. Late in the season the carbon dioxide flux from the soil was measured to compare with the high values observed during the sugar-beet study in 1958. (Monteith and Szeicz.)

Irrigation at Woburn

Though the mid-July storm at Woburn was less severe than at Rothamsted, there was heavy rain then and early in August, so that Woburn had not quite the intensity of drought experienced elsewhere in the country. Nevertheless, it was the kind of summer in which benefit from irrigation was a foregone conclusion, and the crop responses ranged from 50 to 150 per cent increase with full irrigation (C treatment in Table 2). For the first time in 9 years irrigation continued into September. The table should be read with the following notes. *Grass:* After five years the quality of the stand in spring 1959 was rather poor, with much *Poa annua*. It was decided to leave it for one more season, and the plots were ploughed up in September 1959 after watering the non-irrigated plots to make ploughing possible. As a result of the poor initial stand, and the shorter season, the best yields are less than some previously obtained. *Sugar beet:* On occasions during hot, dry periods plants wilted on all plots, even while the top-soil of the irrigated plots was visibly wet. Presumably assimilation was checked in these periods. *Spring wheat:* There was a little disease on the crop, irregularly distributed without any clear association with either fertiliser or watering treatment. Yields are as dry matter, i.e., smaller than the conventional figures, which include some water. *Spring beans:* The response to water was fantastic, the irrigated plants growing to more than twice the height of the controls, so that they interfered with the spread of water, and the plants near the spray lines grew much taller than those more remote. Because of this variability the yields on the irrigated plots are not very precise. There was no

TABLE 2

Woburn Irrigation, 1959

Crop	Period	Rain (inches)	Irrigation (inches)	Plot	Yield (cwt./acre)	
Grass	27 Apr.–7 Sept.	5·5	—	ON_2	28	Dry matter 6 cuts
				ON_4	35	
		5·5	6·8	CN_2	57	
				CN_4	73	
Sugar beet	27 Apr.–28 Sept.	5·6	—	ON_1	62	Sugar
				ON_2	58	
		5·6	7·3	CN_1	88	
				CN_2	88	
Spring wheat	27 Apr.–20 July	3·3	—	ON_1	15	Grain
				ON_2	14	
		3·3	4·7	CN_1	24	
				CN_2	25	
Spring beans	27 Apr.–3 Aug.	4·7	—	O	9·4	Grain
				OS	7·7	
		4·7	4·5	C	21	
				CS	21	

response to dung, and the other variant (treatment S) in the table is a spray against black-fly: this seems to have depressed the yield on the unwatered plots. Again, yields are as dry matter. (Penman and Barnes.)