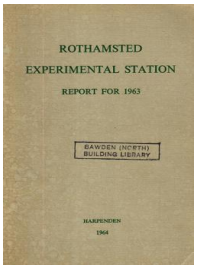
This work is licensed under a Creative Commons Attribution 4.0 International License.

Thank you for using eradoc, a platform to publish electronic copies of the Rothamsted Documents. Your requested document has been scanned from original documents. If you find this document is not readible, or you suspect there are some problems, please let us know and we will correct that.

Rothamsted Report for 1963

Full Table of Content



Physics Department

H. L. Penman

H. L. Penman (1964) *Physics Department ;* Rothamsted Report For 1963, pp 30 - 37 **- DOI: https://doi.org/10.23637/ERADOC-1-56**

This work is licensed under a Creative Commons Attribution 4.0 International License.

PHYSICS DEPARTMENT

H. L. PENMAN

After a year of part-time work W. C. Game retired fully. Recently, there have been several happy occasions when gratitude for his outstanding and long service has been expressed—in 1955 the Director-General, Meteorological Office, presented him with a barometer; in 1961 he received the B.E.M., and past and present members of the Station said "Thank you" at a jubilee ceremony. The place won't be the same without our Weather Man.

J. A. Currie returned in March after six months at Cornell University and visits to fifteen other American universities and research centres during the tenure of his Kellogg Fellowship. H. L. Penman attended the International Union of Geodesy and Geophysics Congress in California, with visits to several research centres before and after.

Dr. J. M. dos Santos completed his period as British Council Scholar, and Mr. E. F. Biddiscombe (Division of Plant Industry, Commonwealth Scientific and Industrial Research Organisation, Australia) and Dr. P. E. Waggoner (Department of Soils and Climatology, Connecticut State Experiment Station, U.S.A.) each spent six months in the Department. For one month Dr. F. H. Vanstone worked on micro-meteorological problems before joining the Staff of the Welsh Plant Breeding Station.

Agricultural Meteorology

Agricultural meteorology is a branch of physics in which conservation principles for mass and energy are applied to plants and animals. The energy income of a crop is dissipated in reflection, in re-radiation, in warming the environment, in evaporating water and in photosynthesis. Because the latent heat of evaporation is one of the largest terms in the energy balance of a crop, the transpiration rate may dominate the structure of the whole heat budget. In contrast the storage of energy in photosynthesis is relatively unimportant in the budget, seldom exceeding 2% of solar radiation, and to a good first approximation the only weather factor governing photosynthesis is the intensity of visible light. During photosynthesis the crop is a sink for carbon dioxide from the air or from the soil, the strength of the sink depending on light intensity. Hence much of agricultural meteorology is a study of the exchanges of heat, water and carbon dioxide between the crop and its environment, in daylight and in darkness.

Solar radiation. Recording began in 1926. In 1955 the original Callendar recorder was replaced by a Kipp solarimeter, and this is the standard for calibration of all radiometers we construct. On rare cloudless days the midsummer noon value reaches 1·3 cal cm^{-2} min^{-1}, and the daily total 700 cal cm^{-2}, which is about twice the long-period average for midsummer months. From detailed analysis of five years' records general relations

https://doi.org/10.23637/ERADOC-1-56

This work is licensed under a Creative Commons Attribution 4.0 International License.

were worked out to permit insolation to be estimated from cloudiness records, estimates that are fundamental to any study of potential evaporation or potential photosynthesis.

For field experiments several types of solarimeter were built to measure radiation in and above crops. Paired units, 4 cm diameter, with one sensor facing up and the other facing down, measure the reflected component of sunshine, which is usually near 25% for a complete green crop canopy. The active range for photosynthesis is between wavelengths 0·4 and 0·7 μ, and it is generally assumed that this contains about 45% of the total solar radiation reaching a crop. As a check, redesigned units were used in pairs during the summer of 1963, one unit having a plain glass filter (measuring "total") and the other having an RG8 filter which transmits only those wavelengths greater than 0·7 μ. The visible component will be obtained by difference.

Within a crop the horizontal distribution of radiation is very irregular, and to avoid the tedious task of taking many spot readings a tube solarimeter was designed to get a line average (1.12). The sensor is a thermopile in a glass tube three feet long, and one inch in diameter, and this, too, can be fitted with a filter. The only suitable filter is the Wratten 88A in a gelatine film, and this transmits the infra-red beyond 0·75 μ. During 1963 vertical arrays of these units, with and without filter, were installed on barley and kale plots, and the plants allowed to grow up around them undisturbed. Measured from the top of the crop, the decrease in transmission per unit increase in leaf area index is about the same for both crops.

Net radiation. The net radiation income of a surface is the amount left after deducting the losses by reflection and by long-wave exchange between the surface and the sky. There are few more important parameters in agricultural meteorology. For direct measurements three ventilated radiometers (Gier and Dunkle type) were built some years ago and used at a fixed height above a crop, and several polythene-shielded radiometers (Funk type) were more recently made for use within the crop. Analysis of records from the freely exposed units during some hundreds of cloudless hours during the past seven years shows that net radiation is a linear function of solar radiation. Exploiting this relationship, net radiation can be calculated from measured solar radiation when the reflection coefficient, and a "heating coefficient" of the surface are known. Neither of these coefficients varies significantly with crop type while there is a complete crop cover and adequate water for transpiration. (Monteith, Szeicz and dos Santos)

Evaporation and heat balance. To measure evaporation from an undisturbed sample of crop a weighing machine was installed in Great Field II in 1957. The surface area is 56 × 56 in., the soil depth is 24 in. and the mass of soil is about 2 tons. A second gauge was installed in 1961. Since 1957 the cropping on the field (and on the first gauge) has included three years of ley (Timothy and Meadow fescue cut for hay), wheat (twice), sugar beet, beans and barley. Near the balances are the radiometers, and I. F. Long's equipment for measuring profiles of temperature, humidity

https://doi.org/10.23637/ERADOC-1-56

This work is licensed under a Creative Commons Attribution 4.0 International License.

and ventilation, with heat flux plates and thermometers buried in the soil, all continuously recorded.

The formidable analysis of the records progresses slowly, but much of interest has already emerged. Over periods of several months the ratio of energy used in evaporation to net radiation is close to unity, but over periods of a week the ratio varies widely, depending upon soil water content and weather. At one extreme, the evaporation from the barley crop on 10 June 1963 was 6·6 mm, an exceptionally large value more characteristic of Israel than of England. The heat equivalent was 384 cal cm^{-2}, and the net radiation was 354 cal cm^{-2}, giving a ratio of 1·2. At the other extreme, the ratio was 0·2 for grass during dry weather in May 1960.

A recent refinement of the expression used to calculate potential transpiration rate from weather data introduces two parameters that depend upon the surface from which the evaporation takes place. One is the aerodynamic "roughness" of the surface; the other is the resistance of the stomata to gaseous diffusion through them. Some of the wind velocity records suggest that grass, sugar beet and beans become smoother as wind speed increases, probably because individual leaves are flexible enough to streamline themselves without the plant moving much as a whole. In contrast, wheat becomes rougher as wind speed increases, probably because the stems are so flexible that the whole surface of the crop is distorted—a source of visual pleasure in watching eddies sweeping across a cornfield.

The determination of the effective stomatal resistance of a crop needs profiles of temperature, humidity and wind speed, and preferably a direct measurement of evaporation. Without explaining the origin of the most convenient unit for mathematical analysis, the daylight range is about 0·4–0·9 sec cm^{-1} for grass, Rothamsted results, in May 1961, agreeing with those at Davis, California, in 1962, where the summer evaporation rate (measured on a gauge of 20 ft diameter) was twice that at Rothamsted (1.7). These meteorological estimates need confirmation. One possible way is from measurements of stomatal populations and sizes: this is difficult, but not impossible, and may be more helpful in interpreting results obtained in the second possible way, tried with some success during the summer. Dr. P. E. Waggoner used a portable leaf-porometer to measure the rate at which air could be forced through a leaf, effectively measuring the total viscous resistance of two sets of stomata and the intervening mesophyll tissue. Plastic replicas of the epidermis were taken and examined under a microscope to determine stomatal shapes and sizes. Good progress was made in the attempt to convert a resistance to viscous flow into a resistance to diffusive flow.

The structure of the expression for potential transpiration is such that there is a critical value of net radiation at which transpiration is independent of wind speed and surface roughness (1.7). During summer in Britain, and during early spring in sunnier climates, the critical value is often reached, and then transpiration from well-watered crops with fully open stomata will be almost independent of crop type and of wind speed; but then transpiration will be most sensitive to stomatal closure. A few field tests were successful (1.13). The barley on and near one of the transpira-

https://doi.org/10.23637/ERADOC-1-56

This work is licensed under a Creative Commons Attribution 4.0 International License.

tion gauges was sprayed with a chemical compound that makes stomata close (half methyl ester of non-enyl succinic acid (NSA)); the other balance was unsprayed. On the day after spraying the transpiration from the sprayed gauge was about 20% smaller than from the control, and stayed below for 3 or 4 days. Closure of the stomata after spraying and subsequent re-opening were measured with the porometer. (Monteith, Szeicz and Waggoner)

Photosynthesis and carbon dioxide flux. Measurement of carbon dioxide concentrations above a growing crop were started in 1958 (two levels). Calculated values of flux to a sugar-beet crop were consistent with estimates of net assimilation rate found by sampling. More detailed profiles (six levels) in and above the crop were measured from 1960, and a third analyser, acquired in 1963, now monitors the absolute concentration of carbon dioxide at a height of 2 metres.

Early analysis from the two-point records suggested that the downward flux of carbon dioxide increased with increasing radiation intensity up to about 0·5 cal cm^{-2} min^{-1} (before 0800 h, and after 1600 h on a sunny summer day) and then remained constant at greater intensities. Current analyses, now possible with greater accuracy because of more detail in the profiles, may produce a revision of this statement. The total uptake is found by adding the upward flux from the soil to the downward flux from the atmosphere. New measurements of this soil flux give values of 6–8 g m^{-2} day^{-1} in summer, irrespective of kind of surface cover. As the gross uptake by a vigorously growing crop may be 40 to 50 g m^{-2} during daylight, the soil's contribution is not as great as we previously thought.

To assist the interpretation of field measurements, field-grown plants were brought into the laboratory to study carbon dioxide exchange in controlled conditions, using the equipment built under the guidance of Dr. P. Gaastra in 1961. Barley plants were studied in June and July, kale plants in August and September. In strong light (near full sunlight) the maximum gross photosynthesis of barley reached nearly 3 g m^{-2} hr^{-1} when the leaves were young, decreasing by about 20% per week as the leaves aged. After ear emergence at the beginning of July many of the leaves succumbed to a fungus infection: by the end of the month the measured photosynthesis per ear was about two-thirds of the amount estimated per plant. For kale, the maximum gross rate was about 2 g m^{-2} hr^{-1} and varied erratically with age. For both barley and kale the estimated daily ratio of respiration/gross photosynthesis increased with age, reaching 35–40% at the time of maximum leaf area.

Mr. E. F. Biddiscombe sampled the barley crop every week during June and July. Dry weight increments agreed well with estimates from the laboratory measurements, and a similar comparison with atmospheric CO_2 fluxes is now in progress. The maximum leaf area index, at the beginning of July, was 5·1 and the dry matter content of the crop was then 43 cwt/acre (540 g m^{-2}). The leaf area index decreased to 1·0 by the beginning of August, but the dry matter increased to 76 cwt/acre, including an ear weight of 28 cwt/acre. Leaves were removed in layers 10 cm thick and areas calculated from linear dimensions. The distribution in barley was

https://doi.org/10.23637/ERADOC-1-56

This work is licensed under a Creative Commons Attribution 4.0 International License.

nearly uniform, the densest 10 cm layer having a leaf area index of 1·5. The canopy of kale is much more concentrated: at the middle of September about half of the total leaf area (index = 6) was in the top 10 cm. (Armstrong, Biddiscombe, Monteith and Szeicz)

Micro-meteorology. The field crop was barley, after winter wheat 1961–62, and the routine recording was much the same for the two crops. Because of the experiments on transpiration control by spraying, reviewed above, some of the measurements were duplicated on the remote (west) side of Great Field. No significant difference in either vapour pressure or temperature profiles was detected between the two halves of the field, either before the chemical treatments or during the periods in which they were known to be successful. Occasional differences in wind profile depended on wind direction, but were never great enough to cause concern about Great Field as the site of the future irrigation experiment. (Long)

Agricultural meteorology (general). The technique for relating growth to weather through an adjusted value of potential transpiration rate, developed during the analysis of the Woburn irrigation experiment, was applied with an acceptable degree of success to the results of the potato course in the Rothamsted six-course rotation experiment, 1930–60 (1.8). Another paper on the micro-climatology of the crop (1.6) was based on the records obtained in 1955: both were presented at a conference on "The Growth of the Potato" at Sutton Bonington (Penman and Long). A start was made on a similar analysis of the growth/weather relationships for the wheat in the same six-course experiment. Very little is expected, but it will be significantly different from zero. (Penman)

Observations of lodging in the barley, using the Hirst plant balance, show that it is the weight of water retained on the head of the plant that causes the bowing, and wind speed is not always a major factor. Indeed, at one extreme a strong wind may shake off water during heavy rain, so preventing lodging, as noted on several occasions of such storms in 1963. At the other extreme the main lodging of the crop occurred (shortly before harvest) during a calm night when the heads collected a heavy precipitate of mist droplets. The lodging starts when the water load exceeds about 1·5 g, the plants bending over in the downwind direction. They recover, almost completely, if the water is shaken off. (Long)

It is hoped that by early summer 1964 there will be an irrigation system on the Rothamsted farm, designed to perform three functions. First, in Great Field there will be an experiment similar to that at Woburn, with opportunities to exploit all the meteorological equipment in and alongside Great Field. Second, other departments will be able to include water supply as a variable in their experiments. Third, it will be possible to irrigate commercial crops. (Penman and French)

Woburn irrigation experiment 1963. The fifth three-year rotation started. (There is a brief summary of the first four in 1.9.) In the fourth there was a sequence: early potatoes, trefoil or fallow, barley, so the 1963 barley crop belongs in part to the previous cycle. The effects of the trefoil are

https://doi.org/10.23637/ERADOC-1-56

This work is licensed under a Creative Commons Attribution 4.0 International License.

discussed under "Woburn Experimental Station", p. 202. In the fifth there is a sequence: barley with undersown clover, clover, sugar beet, and in this, the first year, a pure clover stand (Variety: Crimson) was sown with the expectation that only one cut would be achieved. In the event, two cuts were taken from the unirrigated plots, but only one worthwhile cut was taken from the irrigated plots: the aftermath was very poor and patchy, and was not improved by irrigation. (Penman and Barnes)

TABLE 1

Woburn Irrigation, 1963

Crop	Period	Rain (in.)	Irrigation (in.)	Plot	Yield (cwt/acre)	
Lucerne	30 April–23 Sept.	8·9	0·0	O	64	Dry matter, 3 cuts
		8·9	3·2	C	59	
Clover	30 April–8 July	3·6	0·0	O	16	Dry matter
		3·6	2·7	C	25	
	8 July–19 Aug.	2·5	0·0	O	23	
		2·5	0·5	C	?	
Barley	30 April–9 Sept.	8·7	0·0	O	24	Grain
		8·7	2·7	C	28	
Sugar Beet	30 April–30 Sept.	9·5	0·0	O	63	Sugar
		9·5	3·2	C	67	

Soil Physics

Electrical charges on clays. As an aluminium clay is neutralised by alkali, complex aluminium ions are presumably formed on the surfaces of the clay particles. If so, then some mechanical properties of partly neutralised aluminium clays should have maxima or minima at 83% neutralisation, i.e., when five-sixths of the charge is balanced by alkali cations. The reasoning, summarised in our Report for 1962, was successfully tested by some simple viscosity tests on gels: both kaolin and montmorillonite exhibited maximum rigidity when the neutralisation was close to 83%. This indicates that the bonds between the particles are provided by the complex ions that balance the remaining one-sixth of the charge.

A gel in this state of maximum rigidity is very suitable material for studying the effects of changes in particle arrangement. When subject to shearing stress the gel becomes more fluid, and there is a decrease in the suction registered on a manometer, i.e., the free energy of the water is increased. When the shear is removed the rigidity returns, and the suction increases, and both rates of return to the initial state are much more rapid than other people have found for homo-ionic or natural clays. The preferred explanation is that the shear breaks the bonds linking the particles and so decreases rigidity; and it also produces a closer packing of the particles. Accepting this assertion as reasonable, standard diffuse layer theory predicts that there will be an increase in hydrostatic pressure between the particles, i.e., a decrease in suction—as observed. On removing the shear the compressive component is withdrawn, there is a return to more open packing (increasing suction) and re-formation of the bonds restores the rigidity. (Cashen)

https://doi.org/10.23637/ERADOC-1-56

This work is licensed under a Creative Commons Attribution 4.0 International License.

Soil water movement. In discussing the movement of water in soils (1.10, 1.11) it is convenient to recognise six kinds of flow between complete dryness and complete wetness. 1. *Adsorption* occurs from complete dryness up to a relative humidity near 0·60 (pF 5·85). Conductivity has no meaning in this phase. 2. *Vapour flow* takes place through a continuous air space, diffusing as any other gas would. 3. When water content is great enough to produce a discontinuous liquid phase in the air continuum *Distillation* occurs, the liquid phase acting as a short-circuit in a process of liquid-assisted vapour flow. 4. When both liquid and air phases are continuous *Surface creep* takes place in thin films on pore-walls, the conductivity increasing as the third power of the water content over this range, and the process is vapour-assisted liquid flow. Stages 1 to 4 are covered by an increase in water content from zero to 8–16% of full pore-space, or down to pF 4·4–4·0 in suction, depending on material. 5. *Unsaturated liquid flow*, already occurring in 4, is now characterised by a discontinuous air phase acting as an obstacle to liquid flow. 6. When the air is all displaced *Saturated liquid flow* occurs.

Field measurements on water content and water potential met the inevitable variability in field soils, the usual troubles with the flints in our soil, and a limited range of water content because the summer was wet. Using a wax-coating technique to estimate the porosity of unsaturated clods, direct comparisons of water content with those estimated by the neutron-scattering technique were made on a few occasions. The agreements were good. Similar measurements on samples taken at the end of July were made on the soil in the transpiration gauge, and on the surrounding soil: distribution of water with depth was not the same, presumably because the root range of the barley on the balance was restricted. (Rose)

Soil aeration. At saturation a layer of soil crumbs contains no air, and the total soil pore space is full of water. After free drainage air has replaced water in the inter-crumb pore space, but the crumb pore space remains full of water. This is the condition at field capacity. Oven-drying will remove all this water, to leave a mineral matrix with a complex internal geometry. Experiments on gas diffusion in such dry crumbs gave a measure of the complexity, and as an index to soil structure the complexity factor enabled a number to be associated with each of the field descriptions between very good and very bad. In the field, however, the limit of drying is attained when the soil water content reaches the so-called "wilting point", and the air content of the crumbs is then equal to the available water at field capacity. It is convenient to call this part of the pore space the *available air space*, to recognise it as the agronomically important part of the total crumb pore space and to associate with it another complexity factor which can be interpreted as an index of crumb aeration. Current experiments are showing the value of having two complexity factors for soil crumbs: the total crumb complexity, as the basic parameter for crumb structure, determines the possibilities for movement of ions, water and gases; the available air space complexity, as the basic parameter for crumb aeration, determines the actual diffusion of gases.

During the tenure of a Kellogg Foundation Fellowship at Cornell Uni-

https://doi.org/10.23637/ERADOC-1-56

This work is licensed under a Creative Commons Attribution 4.0 International License.

versity (winter 1962–63) there was a critical study of the efficiency of the platinum micro-electrode as a tool to measure oxygen movement in solution. The platinum wire is supposed to simulate a plant root, and reasonable expectation is that the oxygen flux should increase as the soil gets drier and the films get thinner. Some published results show that just the opposite occurs below a critical water content—the electrode response changes as though the flux was decreasing. The results of the experiments suggested that, in dry soil, the electrical resistance of the soil rather than the flux of oxygen determined the response of the electrode (measured as a current), and there must be considerable doubt about the validity of some of the results and conclusions already published.

One of the technical problems in aeration (and soil water) studies is to measure the volume of a crumb and the volume of the solid in it. An inexpensive apparatus was built to measure the volumes of granular materials (*c.* 2-g samples) to 0·01 cm^3, and the main cause of uncertainty is in specifying what is the surface that defines the outside boundary of a crumb. Tests on a lot of soils show that the fractional pore space in crumbs varies from about 0·2 in arable soils devoid of organic matter to 0·4 in horticultural soils taken from permanent pasture.

The soil structure experiments were concluded. In these, good and bad cultivation treatments were applied to plots with previous periods under grass or kept fallow. The shortest summary is that all results are in accord with the tenets of good husbandry; that measured differences in total porosity, crumb porosity and water content were non-significant; but inspection of the root systems of the test crop (beans) suggests that the different treatments produced differences in mechanical impedance to root growth. (Currie)

Soil water. A minor circuit modification improved the resolving power of the neutron moisture meter. Regular readings were taken throughout the growing period under a crop of barley, and in bare soil near by, and, as noted, several absolute checks during the summer agreed well with direct measurement by D. A. Rose. The most encouraging benefit is in ability to measure short-period changes in water content. For example, on one sunny day, with the barley in full growth, readings taken at depth intervals to 90 cm, at 0900, 1300 and 1700 h, clearly showed the midday uptake of water in the main root zone of the crop, and subsequent upward movement from below to replace the transpired water. Over periods of days the changes in water content agree well with values from the continuously weighed transpiration gauge, with a slight excess readily accounted for by the limited depth of soil in the gauge. (Long and French)

https://doi.org/10.23637/ERADOC-1-56