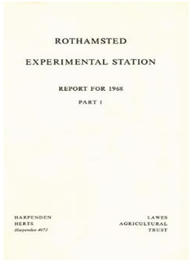
Report for 1968 - Part 1


ROTHAMSTED
EXPERIMENTAL STATION
REPORT FOR 1968
PART 1
HARPENDEN
HERTS
LAWES
AGRICULTURAL
TRUST

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Physics Department

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PHYSICS DEPARTMENT

H. L. PENMAN

Introduction

As new techniques come into farming old problems are revived. Several decades ago our field experiments showed that the main benefit in conventional cultivation operations was to suppress weeds. Now, experts in chemical control foresee complete success, so that cultivation as a cleaning operation could, in time, cease to be significant in agriculture, and already there have been large-scale attempts to minimise its use in seed-bed preparation. But even at the minimum, tractors and implements must move on the ground several times a year, and there will always be a need to loosen the soil to undo the compacting effect of this traffic. Hence some of our soil physics is returning to study of the effects of cultivation, or non-cultivation, on the seed and root environment of annual crops. The agricultural meteorology continues as before, partly as a problem in solar energy fixation (1.6, 1.7) and partly as an attempt to measure the whole environment of the growing plant, and thereafter to interpret plant response through the measurements. After the departure of Dr. J. L. Monteith in autumn 1967 the field work was curtailed: the macro-plots were not used, but were left clear for intensive farm operations to eliminate the weeds that had marred the experiment in preceding summers.

Agricultural meteorology

Micro-climate. The observations on kale, started as the summer experiment of 1967, were maintained until mid-January 1968 and gave first experience of new aspects of crop environment—a complete snow cover, and severe frost. There were periods when the plants were frozen stiff, offering a comparison of the air flow over and through a rigid crop with that for the normal state when the leaves can move. For the latter, B. Legg successfully used the Orion computer to calculate the mathematical shape of the wind velocity profiles over the crop, with uncertainties in the fitting smaller than expected.

With no following crop, the summer period was spent on a complete overhaul of all the field equipment, and the development of new sensors and recording systems that can be exploited when the sensing becomes automatic. The main effort went into anemometers for use inside a crop canopy. Small, three-cup, units for horizontal flow have an outside turning diameter of 105 mm, a starting speed of 4 cm sec^{-1} and a simple optical system of recording that can be monitored in several ways. Vane type units, for vertical flow, use the same recording system in two parts that give the upward and downward airflow separately. The object of these developments is measurement of the air movement and turbulence that affect assimilation and evaporation within the crop canopy. (Long)

Work on this problem is being intensified, and apart from outlining one

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pilot attempt, it is sufficient here to acknowledge, very gratefully, helpful discussions with Professor P. A. Sheppard, F.R.S., Imperial College, London, and Mr. A. C. Chamberlain, Atomic Energy Research Establishment, Harwell, on the theoretical problem and possible field techniques for tackling it. The key requirements are that some detectable material should be released at an adequate constant known rate from or at the soil surface, and that the material should play no part in either the chemistry or physics of the plant. Radon, a decay product of radium, satisfies the 'detectable' requirement; measurement, by Dr. J. A. B. Gibson of Atomic Energy Research Establishment, Harwell, on two samples of Rothamsted soil gave Ra^{226} activities of 1·41 and 1·32 pCi g^{-1}, which is entirely 'adequate'; but from elsewhere there was evidence (the first) that significantly large amounts of radon are carried in the water transpired by plants. This, together with foreseeable technical difficulties in getting adequate resolving power, all at great expense, provoked fresh thinking and an alternative plan. Nitrous oxide will be tried, supplied from cylinders, and in the course of calibrating infra-red gas analysers (1.4) it was found that concentrations can be measured to within 5×10^{-7}. After laboratory and field trials an array of point sources was designed, expected to give surface uniformity to better than 5%. (Legg)

Surface properties of crops. Above the canopy much is known about the wind profile, how its shape depends on surface properties, and how this shape is related to evaporation and assimilation rates. An important factor in formal description is the 'roughness', often assumed to be a crop constant independent of wind speed. Collected records, extramural and our own, show that the roughness, as a length, is about one-tenth of the crop height in general (maize and sugar cane are exceptions), and increases significantly at wind speeds less than 2 m sec^{-1}. There was little information about trees until Dr. S. Tajchman of Munich published his Ph.D. thesis. From the thesis, and extra information kindly supplied by Dr. Tajchman, the generalisation applies to pine trees too, with the implication that, other things being equal, the transpiration rate of pine trees should very greatly exceed that of agricultural crops in the same weather. There *is* an estimated excess, probably real, but very obviously other things are not equal, and from Dr. Tajchman's measurements it seems that the surface resistance of the trees (a measure of stomatal control of transpiration) is always about three times as great as that for farm crops. (1.10)

Stomatal resistance is equally important in assimilation where, in addition, there is a further, usually very large, mesophyll resistance in the path of carbon dioxide moving to the chloroplasts. In the agricultural hydrology, recent Rothamsted experience was successfully extrapolated to embrace results from California (and from Munich, for other crops): in the growth problem a broad comparison of dry years and wet years in Denmark (ten, in total) showed that when water use decreased to about 65% of its maximum, the yield of hay, as dry matter, decreased to about 80% of its best. This differential transpiration and assimilation response to stomatal closure is easily accounted for quantitatively by putting in the 'correct' value of the mesophyll resistance: the value needed is the same as

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that previously calculated by J. L. Monteith to account for the growth of grass at Rothamsted in a much more intensive study over a short period. (1.11) (Szeicz and Mrs. G. Endrodi)

There are other reasons for seeking more knowledge of mesophyll resistance, and leaf chamber experiments were started to get it. Results are for the future, but the successful start was greatly helped by the generosity of Imperial Chemical Industries, who gave us some necessary plastic and allowed the use of their laboratory to make it up into the form required. (Lake)

Surface properties of leaves

(i) Technique. Infra-red gas analysers are used in the field and in the laboratory, chiefly for carbon dioxide. Great precision is needed and reliable calibration is essential. Direct calibration with so-called standard gas mixtures is unacceptably crude, and the preferred method of establishing the sensitivity of an analyser is to impose a series of total pressure changes on a known composition, taking the concentration as proportional to the pressure. Tests showed this to be in error by about 30%, and a reason was found in the known broadening of the absorption bands of carbon dioxide with increase of pressure. A theory of the effect predicted that over the range used in laboratory experiments a pressure calibration might be as much as 75% in error. The manufacturers (Hilger and Watts-I.R.D.) kindly supplied several detectors for trial. These revealed large differences in the corrections required, and since the account was published (1.4), two oversea workers have repeated our experiments and found errors of 20–50% in their pressure calibrations. A reliable alternative is very much needed, and some of the published values of carbon dioxide concentrations and derived values of assimilation are suspect. (Legg and Parkinson)

(ii) Experiments. The equipment for study of photosynthesis and transpiration of single leaves (1.5) was used to measure the effects of spraying with di-methyl silicones, at viscosities of 20, 1000 and 12500 centistokes. The first experiments on excised leaves showed that after either aerosol spraying or painting, the stomata were completely plugged: no movement of either carbon dioxide or water vapour could be detected. All other experiments started on intact sugar-beet plants, sprayed in the field, and leaves were detached at intervals for laboratory measurement of light and carbon dioxide response curves (*Rothamsted Report for 1967*, p. 32), and of transpiration. The least viscous compound had little effect: the other two greatly increased stomatal resistance to water vapour, by an order of magnitude in the first day or two, and the resistance was still about twice that of the controls 16 days after spraying. Relatively, the rate of photosynthesis was decreased more than the rate of transpiration—the opposite of what was hoped for—and though this may be because carbon dioxide diffuses through the silicone more slowly than water vapour, evidence from the response curves suggests that in addition the silicone may have affected the mesophyll tissue and increased its resistance. (Parkinson)

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Equipment and techniques—miscellaneous

(*i*) ***Field balances.*** After twelve years of mixed success in use, the balances on the macro-plots were taken out. They have had some rough service, including several complete floodings in winter, but the mechanisms are still in good working order. Excellent under a short grass crop, they are unsuitable for bigger plants such as kale, beans and others.

(*ii*) ***Radiometry.*** Two radiometers were built for J. V. Lake, to estimate leaf surface temperature in his leaf chamber experiments.

From June onward there was continuous recording of solar radiation in five spectral bands. A few spot checks show a constant ratio of visible intensity/total intensity, between 0·45 and 0·48. (Szeicz)

(*iii*) ***Nuclear magnetic resonance.*** A new technique has been successfully used elsewhere as a quick non-destructive method of measuring the water content of many kinds of materials, and an instrument was hired and tried on five soils, a sand and vermiculite. As a routine method it is not suitable: each soil needs a separate calibration, and the calibration changes with the state of packing of the soil. For some special task it might serve, but a cheaper and equally efficient way can usually be found for this. (Prebble and Currie)

(*iv*) ***Neutron moisture meter.*** There were 12 sampling tubes on Great Field, 4 to each crop, with 2 each on irrigated and non-irrigated plots. The extra-ordinary use was to monitor changes in soil water content under kale, as part of an experiment in co-operation with the Radiobiological Research Laboratory, Wantage, on the uptake of labelled phosphate and calcium. Moisture profiles were measured to 150 cm depth on three dates. Differences were small in a wet summer, but the totals agreed extremely well with estimates made from the weather records. (French and Long)

(*v*) ***Kipp radiometer.*** The field instrument was struck by lightning, and the thermopile destroyed. A new thermopile was built, and it is better than the commercial unit it replaced. (Long)

(*vi*) ***Peltier effect psychrometer.*** Uncertainty in calibration was overcome. Previously, as others have found, the response depended on the geometry of the test chamber in which the calibration was done. It was expected that the geometry would have less effect the shorter the cooling time of the Peltier junction, and to shorten the time meant decreasing the mass to be cooled. Now a satisfactory method of butt welding wires 0·025 mm diameter gives junctions that need only 1/250 of the cooling charge that was used for the original units: 4 mA for 1 second give a calibration independent of chamber geometry (1.9). (Rowse)

Soil physics

Aeration and respiration. The results (up to November 1967) given last year need no amendment after completing the 1967 experiment and repeat-

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ing it—again on kale—in 1968. Interpretation is difficult. In 1967 there were 3 tanks under kale, and three without crop: soil respiration rates were in the ratio 5:2. In mid-January 1968, the plants in one tank were uprooted, in another they were sawn off at ground level and in the third they were left alone while further respiration measurements were made on all tanks. The three 'cropped' tanks continued to respire at the same rate irrespective of treatment, at about twice the rate for the uncropped soil. At no time during the winter did respiration cease, even under several inches of frozen soil, and for the first six weeks of the year the uncropped soil averaged about 1 g m^{-2} day^{-1} of carbon dioxide evolution, equivalent in total to the combustion of about 2 cwt $acre^{-1}$ of dry matter. Organic matter measured in the six tanks showed no significant difference between cropped and uncropped soils. The average fresh weight yield at harvest was equivalent to about 60 tonnes ha^{-1}.

These plants had grown well. Those in 1968 did not. After some mixing of the top soil, four of the tanks were cropped and, of the two uncropped, one had been cropped in 1967. In spite of the mixing, the once-cropped soil respired at one-and-a-half times the rate of the twice-uncropped, at first: the ratio decreased during the summer. Of the cropped tanks, those carrying their second crop respired more than those carrying their first, but the difference vanished 16 weeks after planting. It seems safe to conclude that respiration may be enhanced by the presence of an actively growing crop, and by residues from a previous crop, and the second effect is gradually swamped by the first: one year's fallow is not enough to annul the effect of old crop residues.

Instruments were improved, and the unbroken records of carbon dioxide evolution obtained for most of the season revealed a correlation with seasonal temperature. Oxygen uptake was measured hourly, and the results are puzzling (with no hint of an instrumental defect to explain them). In brief: during a succession of fine days there is a peak in oxygen demand at about 1400 h, (when the average soil temperature is near its maximum—which may be relevant) and there is a minimum between 1700 and 1900 h, sometimes zero. For the next 17 or 18 hours the demand is more or less constant, at the average value for the day. On dull days, there is neither peak nor trough, and when a fine day follows a dull day, again there is neither peak nor trough: it needs at least two fine days to establish 'fine day' behaviour. The effects occur on both cropped and uncropped tanks—this is soil, not plant, behaviour. (Currie)

Tillage problems. A decade of British farming experience (summarised in 1.3) indicates that minimum tillage or direct drilling can be economically successful on the lighter soils, but where there is maximum demand there is minimum hope—on the heavier clay soils, where farmers would like to establish winter wheat without tillage. The core of the problem seems to be the possibly unfavourable environment for germination and root penetration left by a vertical cutting edge moving through wet soil, and experiments were started to measure the physical properties of the smeared surfaces produced by shearing forces of the kind met in direct drilling. (Brown)

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These shearing forces move soil relative to soil, and soil relative to water, and final configurations will depend, to some extent, on the interactions of the soil, as a particulate material with a surface electrical charge, and the water, as an electrolyte. In field soils the ratio of water to soil is too small for any rewarding study of the interactions, and progress in the physical chemistry is better served by using pastes. Experiments were done on clay pastes, and either sodium or hydrolysed aluminium ions as the exchangeable cations. At suitable concentrations some pastes exhibited a structure that was solid at rest and fluid when stirred (one possible source of the smearing?). At the concentrations used, the problem lies in the source of the rigidity at rest, and the experiments were designed to test one of the two possible explanations known (the second comes from Dr. P. F. Low of Purdue University, U.S.A.). In the event, the resolving power of the equipment was just not sharp enough for a clear decision: the trends were as expected but the errors were large. (Cashen)

Irrigation

Since 1951 the weekly Woburn requirement has been based on weather records collected on the site of the experiment. The records were as simple as possible. At Rothamsted, since 1963, similar weekly calculations of potential evaporation have used the records from better and more comprehensive instruments. In 1968 the Woburn records were collected as usual but were not processed until the end of the summer, and the Rothamsted estimates of evaporation (with Woburn rain) were used to control Woburn irrigation operations. Late comparisons show that no important error could have resulted: only in two weeks were the estimates very different, when Rothamsted had much more sunshine than Woburn (35 km away).

The summer was wet at both stations and there were only two or three periods in which an irrigation need started to build up. Satisfying the need invariably provoked a downpour, and the water was wasted. (This is an accepted occupational hazard, occasionally inevitable in attempting to work close to field capacity in experiments.)

Rothamsted

Beans. Both early and late watering decreased yield, but not significantly. The combination of early and late watering produced a significant decrease. Yields were small at a mean of 1940 kg ha^{-1} of dry matter.

Potatoes. On Majestic potatoes irrigation, early, late or both, had no effect on a mean yield of 32 tonnes ha^{-1} of tubers. On King Edward potatoes early watering had no effect, but late watering decreased the yield a little below the mean of 44 tonnes ha^{-1}.

Woburn

Beans. Watering (31 mm) increased yield, but not significantly. The mean yield was 3420 kg ha^{-1} of dry matter.

Potatoes. For Pentland Dell, 38 mm of water increased yield of tubers from 19 to 21 tonnes ha^{-1}, and for Maris Piper, from 38 to 38·5 tonnes ha^{-1}.

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Barley. Grain yield was slightly decreased by 31 mm of water (3200 to 3120 kg ha $^{-1}$). (French and Penman)

Staff and visiting workers

D. A. Rose continued his 2-year Fellowship in Australia, and, as an informal exchange, Mr. R. E. Prebble (C.S.I.R.O. Division of Soils, Brisbane) came to work for 15 months on problems of root environment. Dr. J. V. Lake (formerly at National Institute of Agricultural Engineering, Wrest Park, Silsoe) was appointed to work on the bio-physics of assimilation. Mrs. G. Endrodi (Hungarian Meteorological Service) used a W.M.O. Fellowship to study here, and for part of the time was with Professor J. L. Monteith at Sutton Bonington. Miss E. M. Haynes (Nottingham University) spent several weeks helping in field and laboratory.

H. L. Penman attended the International Soils Congress in Adelaide, the C.S.I.R.O./UNESCO Symposium on 'Land Evaluation' in Canberra, and visited many laboratories before, between and after these events.

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