Report for 1970 - Part1

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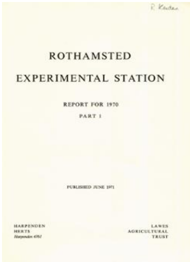
ROTHAMSTED
EXPERIMENTAL STATION
REPORT FOR 1970
PART 1

Physics Department

H. L. Penman

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PHYSICS DEPARTMENT

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Soil physics

Tillage. The broad pattern of land use in Britain is determined by the British climate—arable in the south-east where irrigation need is likely in more than five years in ten, grassland in the north-west where the frequency is less than five years in ten (see map, p. 149 in Part 2)—and the success of British farming was achieved because farmers came to terms with the climate. Some have broken the agreement, exploiting their newly-found ability to cultivate or work on fields in conditions that were impossible a century ago. 'Should they?' provokes 'Why not?', to which there is no complete answer. Further, even when the soil is firm enough to carry working implements, passage of modern heavy tractive equipment may compact the soil. Accepting that this is undesirable, some later cultivation is needed to undo the damage. Here one form of the problem question emerges, relevant to both the 'wet' and 'dry' traffic: What, after weed control, does cultivation do to the soil that matters to the plant? (1.6). It can be posed in other ways, and several Agricultural Research Council units have started tillage experiments to deal with their own variant of it: discussions have shown that some co-ordination is possible, in ways that will enhance the value of all of the experiments. Ours (*Rothamsted Report for 1969*, Part 1, 32) is based on cross-comparisons of cultivation *v* no cultivation, and of barley *v* fallow. Instruments to monitor temperature, aeration, water and soil impedance will take several years to instal, and the timing of the financial year usually wastes a season. A few items of equipment ordered in April arrived quickly, but most did not come till the end of August, too late for anything more than proving trials. Some differences in the soils' physical properties were measured in the contrast of cultivation *v* no cultivation, but they were all as expected: the surprises may come later. (Brown)

Aeration and respiration. In the first full season's use of the new respirometers (in the meteorological enclosure), accurate daily measurements were obtained of carbon dioxide output and of oxygen intake by soil organisms (no crop) and by these and plant roots (dwarf beans—chosen for their stem geometry). At the beginning of 1970, the eight tanks were watered to help the sub-soil to settle, and, by accident (fully exploited later), one got too much and another too little. During the three-month settling period the average daily rates of emission of carbon dioxide were: 0·14 g m^{-2} (very wet); 0·7 g m^{-2} (very dry); 0·56 g m^{-2} (remainder). After drainage, in April, only the first changed detectably, to a rate near 1 g m^{-2} day^{-1}. Addition of top-soil trebled the respiration rate. Bean seeds were planted, 4 $\times$ 4 per tank, on six of the eight tanks, and soil respiration was measured throughout the growing season. Three intensities of growth and respiration were observed. The best was the 'wet' tank with a complete crop cover (respiration rate was twice that of uncropped tanks); four, including the 'dry' tank, were intermediate (factor, 1·6 to 1·7); and the worst, with very poor cover, had a factor of 1·3. This one had a peculiar packing history and its behaviour offers valuable guidance on future experiments relevant to 'tillage' problems.

Seasonal respiration closely followed soil temperature, with peak rates, cropped and uncropped, at the beginning of August. Average maxima for the four intermediate tanks were 4·5 g CO_2 m^{-2} day^{-1} (about 31 kg ha^{-1} day^{-1} as carbohydrate equivalent) while the uncropped tanks were producing 2·8 g m^{-2} day^{-1}. Daily cycles of respiration rate depend much more on maximum temperature than on minimum, partly because warmth

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increases both the microbial population and its vigour, whereas cooling has no immediate effect on numbers but causes loss of appetite. But some skewness is expected even for a constant population. There is evidence that soil organisms conform to the respiration ratio $R_1/R_2 = Q^{(T_1-T_2)/10}$ with $Q \simeq 3$ and T in °C. For a daily range of 10°C (realistic near the soil surface) the ratio of maximum to minimum rates will be 3. Deeper in the profile the ratio will be smaller. The measurements show that on hot days in July and August the maximum rate of uptake of oxygen by day was more than twice the minimum rate at night.

Within the season there were short-period shading experiments, attempting some control of rate of photosynthesis: there was a decrease in soil respiration rate attributable to the shading of the plants, but the important implication needs more evidence. (Currie)

Soil stability. Ten years ago part of Highfield, previously permanent grass, was ploughed, and since then has been kept fallow by intermittent rotary cultivation. There has been a measureable decrease in soil stability. It is still good enough to stand up to gentle rain, but there is some slaking under heavy rain or the equivalent of the watering rate used on the irrigation experiments. (Currie)

Agricultural meteorology

Automatic recording of micro-meteorological elements. The equipment referred to a year ago (p. 40) arrived in batches. Though commercially produced, it is by no means standard, and each of the nine units has to be set up and trimmed individually. The job should be complete in time for 1971 field work, but it took up so much time that no sensing equipment was set out on the macro-plots this year. (Long)

Water use. Although there were no surface instruments out on the macro-plots, there were 16 access tubes in the plots for soil moisture measurements to 150 cm under irrigated and non-irrigated crops (4 and 4 for sugar beet, 2 and 2 for both barley and beans). Assuming all the metered water reached the plot, and that the soil round an access tube got an average amount, the estimates of water use over the main period of active growth were:

Sugar beet	17 June–22 September	O, 25·2;	I, 27·2 cm
Beans	6 May–20 July	O, 16·8;	I, 23·5 cm
Barley	4 May–20 July	O, 23·6;	I, 28·0 cm

The estimates of potential evaporation for the stated periods were, in order, 22·5, 21·6 and 22·1 cm. As in previous years there is the expected difference between the estimated actual water use by tall rough crops and the potential water use by a short grass surface. (French)

Subject to possible but unlikely changes that may come from a thorough review of all the evidence it seems clear that the real deficits under farm crops exceed those calculated from estimates of potential evaporation. This in no way invalidates the application of the concept of limiting deficits (Part 2, p. 150) provided that the timing of an irrigation operation is based on the calculated deficit and on the limiting deficit inferred from the same kind of calculation.

Irrigation. There is a general review of 19 years' work at Woburn in Part 2 of this report, p. 147 (1.5).

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Woburn 1970. The department continues to supply watering instructions for the management experiments that include irrigation as a variable. Regrettably, the first instructions were very late and there is little doubt that responses were smaller than they might have been. In the complex *potato* experiment, at the extremes of quality of environment and tolerance of it, the responses to 10 cm of irrigation were:

Best	Maris Piper	$Y_0 = 33$	$Y_I = 43$ t ha^{-1}
Worst	Pentland Dell	$Y_0 = 3$	$Y_I = 5{\cdot}5$ t ha^{-1}

For *barley*, given 7·6 cm before 17 June there was a response from 2·1 to 3·3 t ha^{-1} for grain. (Legg and Penman)

Rothamsted. There was sugar beet on the macro-plots (only one irrigation treatment) and beans and barley on the other sites (early, late, early and late watering). The system was in use almost every week from the end of May to the beginning of August: the most watered plots got: Sugar beet, 12·1 cm; beans, 16·0 cm; barley, 13·4 cm.

The *sugar beet* top growth soon showed a response to watering but the harvested roots did not—the response was negative. As there was also the expected decrease in sugar content, the sugar yield was decreased even more than the root yield. Values were: $Y_0 = 9{\cdot}3$, $Y_I = 8{\cdot}4$ t ha^{-1}.

The *bean* crop was poor, like all other bean crops on the farm. There was a response to early watering ($Y_0 = 1{\cdot}25$, $Y_I = 2{\cdot}21$ t ha^{-1} for 6·4 cm irrigation before mid June), but the best given here is still a small yield.

Barley reacted as expected. It responded a little to irrigation before mid-June ($Y_0 = 4{\cdot}3$, $Y_I = 4{\cdot}7$ t ha^{-1} of grain, for 7·6 cm irrigation) with slightly negative responses to later watering. (French, Legg and Penman)

Radiation. Several years' field and desk work on the fate of solar radiation were brought together within a frame-work somewhat wider than that of Rothamsted interests (1.1). Of the total solar spectrum, only part is photosynthetically active. The total is made up of direct and diffuse components, and each of these is affected by cloudiness, aerosols and water vapour in the atmosphere, and these factors vary with site, time of day and season. A thorough theoretical study was tested against our measurements and others from Sutton Bonington, Cambridge and Locarno. The reassuring conclusion—with only minor reservations for special cases—is that the ratio of active radiation to total income is very nearly constant at 0·48, and that climatological measurements of total solar radiation, now much more easily obtained than they were ten years ago, can safely be used to estimate the total amount of energy available for photosynthesis by crops.

In the course of experiments, measurements were made of the penetration of total solar, photosynthetically active and near infra-red radiation into crops of barley, sugar beet, beans, kale and spring wheat, with measurements of leaf transmission factors for some. The transmission through a crop as a whole can be expressed in several ways: one is by use of Monteith's sunfleck parameter, which is a measure of the fractional clear space in unit leaf layer. Once full crop cover is established this changes very little for a given crop. Extreme values were: kale, 0·42 to 0·48; beans, 0·64 to 0·68. The other three crops gave intermediate results. Within all crops the ratio of active/total radiation changed with depth in the canopy: compared with its value just above the crop (*c.* 0·48) it reached a value near 0·24 at depths where the total leaf area index above the sampling level was 3·5 for kale, 4 for wheat and 5 for beans.

From these estimates of light distribution between top and bottom of a crop canopy,

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plus knowledge of light response curves obtained by colleagues in the laboratory, it is possible to estimate a potential rate of crop growth (Monteith model). Comparisons with measurements of dry matter on the plots showed encouraging agreement with both weekly changes and final yields: the discrepancies suggest that respiration losses are very important. (Szeicz)

Transport constant. Analysis of the 1969 results on the use of nitrous oxide (*Rothamsted Report for 1969*, Part I, p. 38) continued, but is not yet complete. Aspects to be commented on here are chosen for their relevance to problems that will—or may—arise in computer programming of the micro-meteorological recording.

(i) To calculate the transport constant above the crop it is necessary to know how wind speed increases with height above some effective zero plane in the crop, at a level that has to be deduced from the measurements (symbol, d). Similarly, the processing has to extract a measure of crop roughness (z_0). The formal expression for the transport constant assumes that d and z_0 are constant, independent of wind speed, but all our experience on farm crops shows this is untrue. To date, we have found it expedient to fix d and allow z_0 to vary during the day (for justifiable physical reasons): detailed analysis of 50 hourly profiles over wheat, 125 cm high, shows that about the same degree of coherence can be achieved by fixing z_0 and allowing d to vary during the day—without convincing reasons. (Legg and Long)

(ii) The wind profile controls the distribution with height of other transported materials, such as the nitrous oxide used in the experiments. An attempt to work from a gas profile to a wind profile was not very successful: it needs a degree of precision in the value of d not yet attainable.

(iii) This causes no concern, but some other experimental results do. Nitrous oxide (day and night) and carbon dioxide (night only) were sampled for an hour at a time at constant height (70 cm: crop height 125 cm) at horizontal intervals of 250 cm, expecting that the nitrous oxide concentrations would show a steady increase with distance downwind. They did not. There was a systematic variation, reproduced in the carbon dioxide measurements, indicating that there are significant horizontal fluxes of the gases at this level inside the crop that can be 5–10% of the vertical flux, for a 10 cm layer. The phenomenon needs examination at other levels, but it looks as though a simple one-dimensional layer by layer analysis of transport will be impossible for periods as short as one hour.

(iv) With the wind profile analysis of (i) there are values of the transport constant, K, calculated from the nitrous oxide profiles at 40, 60, 80 and 100 cm height. A multiple regression of K on wind speed, leaf area index, temperature gradient and wind direction shows that the last is, in general, the most significant variable, probably because of crop heterogeneity round the sampling mast, of which the phenomenon in (iii) may be another facet. The remaining variables come in order of importance: temperature gradient, leaf area index, and finally wind speed. This is a reversal of the order usually applied in models of crop canopies, but it may be because the canopy was very dense (leaf area index near 7), and most crop canopies are more open than this. (Legg)

Plant physiology

The sources of some of the limitations on crop yields may lie in the soil, or in the weather, but even for healthy plants there may be biochemical or physical factors amenable to some sort of control or modification when they have been identified and understood. A physical attack, based on botanical expertise, needs detailed measurement of plant

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environment in the field (now part of departmental routine—except in 1970!), can benefit from possible modification of it (one of the objectives of the leaf canopy enclosure—see 'Equipment', later) and can reveal much by laboratory experiments that grow out of field experience, in which a desired environment is imposed. Interpretative ideas are needed too, and previous reports put much emphasis on fluxes, transport constants and resistances, among which stomatal resistance plays so important a part that it was worth while spending time on trying to find a way to measure it directly. Accounts of design (1.12) and performance (1.10) of an instrument are now in print.

The external and measurable manifestations of growth are in transpiration (1.8), assimilation and respiration (1.9). Current and past field measurements (see 'Aeration' and 'Radiation', above) agree with the results of laboratory experiments in showing that respiration rates are on the same scale as those of net assimilation, and the dominant topic in 1970 was the search for the sources and causes of respiration, in the hope of finding out if any is truly 'loss' and possibly avoidable.

Controlled environment. Some tropical crops (maize, sugar cane) have a maximum rate of photosynthesis greater than that of temperate crops, and they have a carbon dioxide compensation concentration (usually symbolised by Γ) very close to zero. Both of these attributes are thought to stem from interactions of respiration processes with light and oxygen concentration. Experiments were done in new controlled environment equipment completed during the year. (Parkinson and Owen)

In the first of these, bean plants were grown in water culture, aerated at 21% oxygen, under atmospheres controlled at 5 or 21% oxygen, and with carbon dioxide controlled at $300 \pm 10 \times 10^{-6}$. Control was good and after 14 days the estimated net carbon dioxide uptake, as carbohydrate equivalent, was 38 g (15 plants) for both treatments: the measured dry weight gains were 30 (5% O_2) and 33 (21% O_2) g. This degree of agreement is regarded as satisfactory. (Parkinson)

On *cotton* leaves, carbon dioxide and light response curves were obtained in oxygen, air and nitrogen. At 25°C, and light intensity 140 W m^{-2}, the respective values of Γ were 170, 50, and 0×10^{-6}: below the first two compensation points the response curves were non-linear, for which there is no immediately obvious explanation. (Parkinson and Lake: results reported at Dublin meeting of Society of Experimental Biology, July 1970)

The main continuing work on cotton (1.9) was measurement of the effects of oxygen concentration and of temperature on the carbon dioxide exchange of cotton leaves. The rate was linearly related to the inter-cellular concentration of carbon dioxide when this was great enough to ensure a positive rate of uptake, and while illumination was bright enough to be non-limiting. Backward extrapolation of the lines produced a common point of intersection—varying with temperature—at a value thought to represent the rate of carbon dioxide production by a respiratory process independent of oxygen concentration. As already noted, at more than the compensation concentration, the net rate of carbon dioxide uptake is depressed by oxygen. Hypotheses are in conflict: it seems that there are two respiratory processes that occur during photosynthesis, one dependent on temperature and independent of oxygen concentration, and the other with exactly the contrary attributes. (Lake)

Equipment and techniques

Infra-red gas analysers. (IRGA). Measuring carbon dioxide concentrations in gas mixtures needs both accuracy and precision: sources of error must be identified and

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eliminated; calibration must be dependable. In nearly all experiments there are changes in the water vapour content of the gas being analysed, so changing the gas volume and with it the concentration of carbon dioxide. The effect can be important in some leaf-chamber and field experiments. The theory (1.11) is given for a range of possibilities. (Parkinson)

Reliable calibration has long been a problem. A new method, applicable to all infra-red gas analysers, uses only one standard gas. The analysis tube is made up of two cells in series, of lengths 0·9 and 0·1 of the length of the reference tube. Experiments show that when a gas mixture is passed through both cells the calibration is linear up to within 100×10^{-6} difference in concentration between analysis and reference tubes, and when passed through the short cell only is linear up to 1000×10^{-6} difference. Hence only one calibration point should be needed for the whole range: experiments show that this is so for both carbon dioxide and water vapour analysers, at least over the range of field concentrations. (Parkinson and Legg—who gratefully acknowledge interest and help from the manufacturers, The Analytical Development Co. Ltd., in supplying specially made tubes for the experiments)

Field leaf canopy enclosure. A canopy is now ready for use. Gas inputs can be controlled, and both input and exhaust monitored. It will provide some control of the natural environment of crops in the field in several desirable ways. (Lake and Tregunna)

Conductimetric carbon dioxide analyser. The IRGA is expensive. A very much cheaper solution of the problem, devised some years ago (Begg, J. E. & Lake, *Agric. Meteorol.* (1968), **5**, 283) measures the electrical conductivity of de-ionised water over which the gas mixtures passes. A four-channel version was built for the laboratory plant enclosures (Lake, Parkinson and Owen): after discussions with a manufacturer a circuit for differential measurements can now be bought. One will be used with the leaf canopy enclosure.

Staff and visiting workers

Professor E. B. Tregunna (University of British Columbia) joined the department for a year, supported by the Underwood Fund of the Agricultural Research Council. His interests are in photo-respiration: he is hoping to work also on possible damage to plant leaves produced by excessive rates of transpiration, and on the more biological implications of the physical measurements we make on plant environments. R. D. Owen (Brunel University) spent six months as a sandwich course student; A. C. Arnold (Sheffield University) and G. Ludbrooke (formerly assistant to J. A. Currie, and now at Sheffield University) came for a few weeks each, as vacation workers.

G. Szeicz was seconded, for a year, to take up a post-doctoral fellowship at Texas A. and M. College, partly for research, partly for specialist teaching in micro-meteorology. D. A. Rose returned in December after three years in Australia, two as a Queen Elizabeth Fellow and the third on a grant from the Australian C.S.I.R.O. J. V. Lake spent two weeks in Israel as a consultant for the F.A.O. High Value Crops Project. He and K. J. Parkinson took part in the Dublin meeting of the Society of Experimental Biology and visited research laboratories of the Irish Agricultural Institute. Parkinson and B. J. Legg, with A.R.C. support, had a week of visits to laboratories in Versailles, Ghent and Wageningen. N. J. Brown convened and organised the 1970 Annual Conference of the Institution of Agricultural Engineers on 'Cultivations', and took a major part in arranging an international conference at Silsoe on 'Tillage Research Methods', attended by 50 delegates from 12 countries. H. L. Penman was one of two English members of a Working Group set up by the Irish Agricultural Institute to examine the

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present, and possible future, place of physics in the Institute's research programme. He also attended the Sixth meeting of the Co-ordinating Council of the International Hydrological Decade, in Geneva, as leader of the British delegation, and then, as one of the hosts, the I.H.D. symposium on 'World Water Balance', held in Reading with the support of H.M. Government. (1.3)

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