ROTHAMSTED RESEARCH

Report for 1973 - Part1

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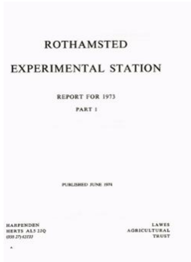
ROTHAMSTED

EXPERIMENTAL STATION

REPORT FOR 1973

PART 1

Physics Department

H. L. Penman

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PHYSICS DEPARTMENT

H. L. PENMAN

Introduction

The preceding 18 annual reports have all had a broad division into soil physics and agricultural meteorology, supplemented in recent years by sections on plant physics because the behaviour of the plant (other than crop yield) is now an important part of both the laboratory research and the field experiments. The topics interlock, so that some projects could be classified in two ways, but the coarse separation is useful in that somewhat different definitions of 'progress' are needed for each. In the soil physics it is probably fair to state that the past 20 years or so have produced very little that is new *as physics*: the gains have been in improved methods of measurement in laboratory and field—the neutron moisture meter is an outstanding field example—and with the increased precision and accuracy these have brought it has been possible to try out more complex theoretical ideas for interpretation, and, where successful, to increase confidence in extrapolation of conclusions to other sets of boundary conditions. The primary challenge, almost invariably, is in the change from laboratory to field. This is not always possible, and often the field material has to be brought to the laboratory for examination and experiment. The handicap imposed by this need varies with the three categories of physical problem. Where the problem is one of particles, it rarely matters, and particle physics is probably better done in the laboratory anyway. For the problems of pore-space physics we need interlocking field and laboratory experience, and for water studies we have it, but not for aeration problems. The respirometer experiment (see later, p. 41) covers one field aspect very effectively, but there are other *in situ* aspects of gas and vapour movements in the soil that we should like to measure, but, as yet, cannot. The third category of problem is essentially a field problem of structure, where the soil is behaving as a quasi-homogeneous solid, and to disturb it involves the risk of destroying the important properties of interest, properties that are dependent on the spatial distribution—and the changes with time—of the solid, liquid and air content of the system. To varying degrees, many of the practical problems of agriculture fall into this category (e.g. the effect of cultivation; see later, p. 41), but in the end understanding of what has been measured will come back to particle physics, or to pore-space physics, or to the combination of the two that we call 'soil structure'.

World progress on this topic is very slow. As an indirect indication of this, some of the ADAS units are today using Emerson's method to assess structural differences in soils from the field: Dr. Emerson left us in 1957, and on our resumption of work on the physics of structure about two years ago, the ideas he produced before 1957, and soon after, were the most valuable starting point we had for fresh thinking.

In agricultural meteorology things are—or were—otherwise. Crop–weather relationships as a statistical study are as old a topic as agricultural statistics itself, but as a physical study the main history of the subject is in the last 30 years: those of us fortunate enough to be in at the beginning got the easy bits done first. In this, as physicists, we could treat the crop cover as a sheet of wet green blotting paper, work out, and measure, short-term energy and water balances in which the growth of the crop was unimportant and could be safely neglected. But the crop could not be left out for ever and a mass balance had to be added to the energy and water balances, with a two-fold complication. First, the crop morphology and physiology brought new problems of measurement

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(what, and how), and second, the time scale of measurements had to be lengthened to include at least a whole phase in crop development. For many years now the physical measurements, in the soil, and in the air within and above the crop, have been made very intensively (many at 6-minute intervals) throughout the growing season. Since a change-over in 1970, output from sensors has been logged on paper tape: with the valuable help of a temporary appointee as programmer all the measurements for 1971 to 1973 are now in ordered form on single magnetic tapes. Physical measurements on the plants are not so intensive and, for the present, do not need to be, but they include measurements of various kinds on the crop in the field, and on plants (from the field) in the laboratory. Intermittently at chosen intervals, measurements and samplings are made for 'growth analysis', exploiting the ideas of Dr. D. J. Watson, former head of the Botany Department.

Gradually we are moving to a state in which a running estimate of 'potential' growth rate can be made, to be set alongside the potential transpiration rate we have had for 25 years, with ability to compare it with actual growth rate. Then will come the exercise of tracking down causes of discrepancy, with our job primarily, but not exclusively, to identify those that arise from the physical environment. Presuming success, the task will then be to see if these sources of limitation of crop yields can be affected by changes in soil management or in crop husbandry.

There was some unavoidable curtailment of the work during 1973. The very welcome move into a new building produced some dislocation, and for two members a rather severe interruption of work. J. V. Lake's transfer to ARC headquarters effectively brought his Rothamsted work to a full stop, and the move to Canada by G. Szeicz in August had a similar effect on some of our work on radiation and agricultural hydrology.

Agricultural meteorology

General. Part 2 of this Report (p. 172), contains a survey of our weather as it is or has been, based on a mixture of extracts from the routine records and of examples from research projects, sometimes as averages, sometimes as typical results and, occasionally, as atypical results to display more clearly a meteorological point of principle. (Penman; 1.3)

Equipment and processing. The macroplots, under potatoes, were fully instrumented and for those sensors recording on paper tape the results are now on magnetic tape (as noted above). Broadly, the sources of nearly all erratic readings have now been identified and the troubles cured: as the components age, however, replacement, re-building or even redesign are needed to maintain the continuity of reliable output. (Long and French)

With the results for 1971–73 now in simple format a start was made in preparing programs to calculate evaporation rates, carbon dioxide fluxes, and crop surface parameters: continuation may be easier using Genstat. (Toyer)

Water use. Partly as a guide to possible quality control on the magnetic tapes, partly in the hope of clarifying the questions to be asked of the computer, partly to test a new idea for a very necessary correction (for atmospheric stability) in the transport equations, and partly to test the performance of the neutron moisture meter, an intensive desk exercise was undertaken, making some use of a print-out from the tape for 1971, when kale was the crop on the field site.

In the survey of water use by farm crops (*Rothamsted Report for 1972*, Part 2, 5–85) the estimate of water use by the kale (neutron meter) was about 1·3 times the potential evaporation: a ratio greater than unity was expected, but not by so much, and the

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suspicion is that the meter over-estimated whole-plot water use because it was used in plant rows, and probably too close to active roots. The aerodynamic method of estimating evaporation rate offered the possibility of a check on the meter estimates.

For a 44-day period, June to August 1971, the method was applied to records from the north plot, using averages of wind, temperature and humidity for 4-hour periods and a standard correction for stability. For 16 days within the 44, the new stability correction was applied to the records for both plots (the S plot had been irrigated and a clear difference in crop height established). The 44-day exercise showed that the aerodynamic estimate was almost the same as the potential value, and the ratio of 1·3 must be too big—a conclusion supported by the energy balances (for both plots) in the 16-day period. The calculated evaporation rate was greater from the irrigated plot, as expected and in conformity with the relative neutron meter readings. Over a period of a few consecutive fine days giving a smooth diurnal cycle the average distribution showed little or no evaporation during darkness, a very small evaporation rate in the first 4 hours after dawn, and more than 90% of the day's total occurred in the 12 hours from 8.00 in the morning to 8.00 in the evening.

The new stability correction looks promising and worth extended trial. (Long and Penman)

Micrometeorology. The carbon dioxide and water vapour infra-red gas analysers were used over the macroplots (potatoes) from mid-May to mid-August. Leaf water potential and the stomatal resistance of the top leaves were measured daily, and occasionally, hourly, but except for a few days in June, and again in August, there were no differences between irrigated and unirrigated plants. Although on clear days a large stress was measured in early afternoon, it was relieved a few hours after sunset and at sunrise it was always small. (Legg, Collins and Whitehead)

Irrigation and crop growth: Rothamsted. Of the three blocks used in most years, the southern block of the westerly pair was fallowed for weed control, and the northern block carried potatoes (King Edward) with, as experimental variables, normal and late planting, normal and wide spacing, two rates of nitrogen dressing, superimposed on irrigation *v.* none. Within the possible combinations there was selective sampling for growth analysis, supplemented by a photographic technique to estimate fractional ground cover: it seems to have worked well. Heavy rain at the end of June and beginning of July swamped the beneficial effects of early irrigation, and final (normal) yields showed a decrease on irrigated plots (average: 46–41 t ha^{-1}). Average fractional responses to other treatments were: nitrogen, +6%; late planting, −22%; wide spacing, −50%.

In reaching these harvest values it was again found from the sampling that the dry matter gain divided by the potential evaporation was linearly related to the fractional ground cover, with the normal and wide spacing results in fair agreement. At the maximum cover (95%) the value was 0·8 t ha^{-1} cm^{-1}—as it was for potatoes in 1971.

On the macroplots, also with King Edward potatoes, the only contrast was in irrigation. Two applications (25 mm in June, 25 mm in July) gave 4% increase at an average yield of 47 t ha^{-1}. (French, Croft, Anita Jellings and Legg)

Irrigation and crop growth: Woburn. Again our role was in advising the Nematology Department when to irrigate in the eelworm experiment. Because of the now widespread nematode infection all yields were small: the best were for Maris Piper (partly resistant) treated with a nematicide, and a 10% increase in yield from 62 mm of irrigation in June and late July was not statistically significant. The mean for this variety was 21 t ha^{-1}. (Legg, as adviser)

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Plant physics

Canopy enclosure. There were improvements in the field structure and in the associated measuring equipment. It was used over the macroplot potatoes on 24 days for periods ranging from $2\frac{1}{2}$ to 11 hours, and good records obtained for estimating short-period changes in transpiration and net assimilation rates (analysis in progress) and for surface resistance. This varied, within cloudless days, from 0·4 to 0·9 s cm^{-1}, but on dull cloudy days reached 3·6 s cm^{-1}, implying some leaf response to low light intensity. (Leach)

Other measurements. Leaves of potato plants from the site were subject to laboratory measurements of light and carbon dioxide response curves (80 sets), and the two groups of information will be sorted out together. (Parkinson)

Field measurements on the Woburn potatoes (Nematology experiment, above) first showed a close relation between stomatal resistance and leaf water potential, until in a period of June drought the unirrigated plants adapted by a decrease in leaf water potential (from −4 to −8·5 bar, 4–18 June) with stomatal resistance at about 1 s cm^{-1}. The water potentials of severely infected plants were always more negative than those of lightly infected plants, and the stomatal resistances were greater too. (Parkinson, and members of Nematology Department)

Stomatal resistance. From experiments on sorghum in a very different climate (Texas, USA) there are strong correlations among stomatal resistance, leaf water potential and solar radiation, and the relationships seem to be applicable to other plants. Given measures of stomatal resistance of individual leaves and of the leaf area index of the crop, then canopy resistance per unit ground area can be calculated and used to produce estimates of rates of evaporation and photosynthesis. (Szeicz, and Texas colleagues)

Solar radiation. Summarising many years of Rothamsted measurements and the experience of others, the spectral composition of incoming solar radiation is constant over a wide range of weather: radiation values obtained in routine climatological measurements can be used with confidence to estimate the energy supply for photosynthesis and crop growth. Within the crop, the rate of attenuation with depth varies with leaf arrangement, and for the five crops studied there is rapid extinction of the photosynthetically active part of the radiation. (Szeicz)

Soil physics

Water and solutes. Salts move through soil in two ways, by diffusion in the absence of water movement, and by hydrodynamic dispersion in a moving stream of water. Hydrodynamic dispersion is a complex process (1.5) and the mathematics is difficult. The computer was used to get numerical solutions of equations relevant to at least two important problems: the movement of solute from a band of fertiliser, or from a plug of pesticide. On the whole, the solutions agree well with previous experience. (Rose and Toyer)

A band of fertiliser greatly modifies its immediate environment (1.6). The experiments were done in Canberra. In soil at field capacity, with water at rest, fertiliser moves by diffusion and the rate of dissolution depends on the solubility, the soil water content, and a diffusion coefficient. While the band remains, water moves *to* the band as vapour, causing a small but significant drying of the soil nearby (as predicted some years ago). In very dry soils dissolution of fertiliser cannot start until enough water has been brought in by vapour flow to wet the soil adjacent to the band. This is physics, but there is also an analogous chemical problem for banded (nitrogen) fertiliser. Study of the trans-

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formations of urea and ammonium sulphate showed that suitable conditions for nitrification rarely occurred near a fertiliser band and, even when they did, they lasted such a short time that there was only a small conversion of applied fertiliser to useful nitrate. (Rose, with Australian colleagues)

Techniques, both in experiment and in interpretation, are important. Saturated salt solutions exert a constant vapour pressure and so are invaluable in attempts to impose or maintain a fixed water potential, but for the range important in soils there is a dearth of suitable salts (they seem to be either poisonous or unstable) and there is inadequate information about the temperature variation of their vapour pressures. The search continues. In analysis, an earlier theory of gravity segregation has been improved—relevant to what happens when saline water encroaches on fresh water. (Rose)

Soil respiration. At the end of four years of use the confounding of the effects of current treatment and of past history suggests that the maximum amount of information has now been obtained. The present range in water content is more than 2 : 1—depending on the sequence of cropping in the four years—and one aspect of this was the almost complete failure to get a crop (16 plants of dwarf beans per cropped tank) established even by resowing after an unhelpful period of very hot weather at the beginning of June after the first sowing. The fairest description is that one tank (6) had a crop, five had some plants, and two (4 and 8) were uncropped, as they have been for four years. Carbon dioxide output for the 42 weeks 1 January–21 October reflects in parts the vigour of the crop growth, the water content of the soil, and the residual organic matter from previous crops (unlikely to be detectable by conventional analysis against the total organic carbon in the soil). To give some idea of scale of contrast the entries in Table 1 are for three tanks at about the same water content. Roughly, 1 g per tank is about 10 kg ha^{-1}. (Currie and Pritchard)

TABLE 1

Carbon dioxide production, 1973 and 1972

Tank	Dry matter g/tank	CO_2 g/tank	
(a)	(a)	(a)	(b)
3 (p)	21	434	955 (c)
6 (c)	170	737	683 (u)
8 (u)	—	345	384 (u)

(a) 42 weeks 1973; (b) 52 weeks, 1972
(p) with plants; (c) cropped; (u) uncropped

Soil structure. Too much time has had to be spent on problems of instrumentation. Two instruments were bought in the expectation that they could be used immediately as research tools in the study of clay/polysaccharide interaction and of soil stability. On one some development work was needed first, and it is now in use, but not so the other. After two months of incorrect performance and attempts at servicing the manufacturers decided to replace it by a new instrument. (North)

Tillage: Woburn. In the final year of the experiment comparing cultivated *v.* uncultivated soil, and crop *v.* fallow it was possible, for the first time, to get some measurements of soil properties two weeks before the first treatment cultivation and seven weeks before drilling the crop. The soil water estimates (neutron meter) show greater scatter, but within groups there is sufficient coherence to discern trends with time. Analysis of the three years' results is in progress and may be complex, but the agronomic result is clear and simple. As in 1971 and 1972, whatever was done, or left undone, on the

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uncultivated plot depressed the yield, this year from 2·67 to 2·24 t ha^{-1} for grain, and from 1·66 to 1·52 t ha^{-1} for straw. A lot of work has been put into this small area in Road Piece, and Soil Survey has kindly agreed to provide a detailed soil description. (Brown)

Tillage: Rothamsted. Future experiments will be on Little Knott as part of a joint tillage/plant water use experiment designed to concentrate in alternate years on one or the other. For the tillage half of the site six 10 m long concrete tracks have been laid, at about 2·5 m spacing, and a tractor with wheel spacing suitably modified has been hired. The five strips of soil can thus be cultivated as desired without imposing unwanted tractor wheel compression. The facility of major importance in the other half of the joint exercise can, if desired, be exploited to provide control of the water content of the soil at the time of cultivation operations. Outside the concrete tracks, and for twice their length, are two parallel low walls carrying rails on which a mobile glasshouse can run. Assembly is not yet complete but when it is it will be possible to keep a chosen half of the site free from rain and to manage soil water content by controlled irrigation. (Brown and Legg)

Staff and visiting workers

Professor J. P. Quirk left in May. Dr. P. R. Maurya (India) came in October for 12 months: Dr. B. Spasojevic (Yugoslavia) and Mr. E. Taitt (West Indies) each spent a few weeks in the Department. Dr. P. J. M. Sale (Australia) arrived at the end of December for a stay of seven months.

J. V. Lake and G. Szeicz left.

J. Toyer spent nine months in a temporary post as computer programmer. There were three sandwich-course students (Anita Jellings, Bath University; D. Collins, Brunel University; and Caroline Philpot, Hatfield Polytechnic), and two student vacation workers (R. P. Norris, St. Catherine's, Cambridge; and W. M. Cunnington, Imperial College).

Two members attended overseas conferences. N. J. Brown was at the Sixth International Conference on Tillage, in Wageningen, and B. J. Legg was at the WMO Symposium on Agrometeorology of the Wheat Crop, in Braunschweig. D. A. Rose was elected a Fellow of the Institute of Physics.

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