ROTHAMSTED RESEARCH

Report for 1969 - Part 1

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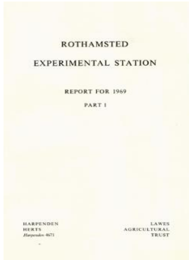
ROTHAMSTED

EXPERIMENTAL STATION

REPORT FOR 1969

PART 1

Physics Department

H. L. Penman

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PHYSICS DEPARTMENT

H. L. PENMAN

Plants grow by fixing solar radiation, at a rate depending partly on the income and partly on the environment in which it is received. There are many other sinks for the energy (evaporation accounts for about 40%) so that only about 1% of it is fixed in the very best of agriculture, and much less by commercially satisfactory farming. An energy balance for the crop is almost indispensable for interpretation of growth rates, and, gradually, as understanding deepens, it is being used to predict yields, necessarily with recourse to fitted empirical constants. Some of these constants are properties of the plant, arising on all scales of action from cell behaviour, single leaf behaviour, whole plant behaviour, to whole crop behaviour. The resultant growth represents a disturbed mass 'balance', in which only about one part per thousand of the water uptake is retained in plant structure, and a very uncertain fraction of the total carbon dioxide uptake is retained as the difference between assimilation and respiration. All of the processes involve movement, in transfers and exchanges, of which some are limited by energy supply (e.g. transpiration), and others by the physical environment in manifold ways: as examples, soil wetness may determine the ability of roots to penetrate the soil; temperature may control the rate of a bio-chemical reaction. The task in physics is to put numbers into these transport and transfer processes, to measure qualities and quantities, often for use in a general relation that may appear as flux $= K \times$ potential difference, or as flux $=$ potential difference $\div R$, where K is a transport constant for the system and R is the resistance with which the system impedes the transport. Custom, or convenience, determines whether K or R is used, and convenience may change custom. Early work on water employed K theory, treating the crop as a surface ('a sheet of wet green blotting paper') and was successful both in scientific return (crop weather relations) and in economic return (irrigation control), but now the crop is treated as a canopy in layers, and it is often more convenient to work in terms of resistances. As examples, in preview, an atmospheric resistance is used to estimate transport rates to or from the crop as a whole (for water, heat, carbon dioxide, and momentum) and, though this resistance mainly depends on weather, it is modified to an important degree by the nature of the crop surface (roughness). Next, important in assimilation and transpiration, there is a surface resistance arising from stomatal resistance, the integrated effect depending on leaf area index. Then, important in assimilation but not in transpiration, there is a mesophyll resistance that governs carbon dioxide movement within the leaf. It is very desirable to know more about these plant resistances, in the expectation that knowledge will lead to control of economic value. In one such attempt, briefly mentioned a year ago, leaves were sprayed with a silicone in the expectation—fully realised—that the stomatal resistance would be increased, with a consequent decrease in transpiration rate. Unfortunately, the relative increase in resistance to carbon dioxide

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transfer was six times as great as for water vapour, and though this could be acceptable, and even welcome in some plant or crop management as a hobby, it is not much use for agriculture (1.7). What is wanted is a cheap, persistent coating that will impose at most no more resistance to carbon dioxide than it does to water vapour, and preferably less. An industrial firm is considering whether any of its products would serve. (Parkinson)

At all levels within the crop there are transfers of heat, water vapour, and carbon dioxide: for these, at present, it is convenient to use *K* theory, and though from other measurements values of *K* can be inferred, the other measurements become much more valuable when an independent measure of *K* is obtained. To give scale from previous work, on a calm night in a very close canopy of short grass, it may approach the molecular value, near 2×10^{-1} cm^2 sec^{-1}; by day, in farm crops, it may increase from *c*. 10 to 10^3 cm^2 sec^{-1} between the soil and the top of the canopy, and have a value near 3×10^3 cm^2 sec^{-1} about 1 metre above the crop. With *K* known it will be possible to calculate rates of net assimilation throughout the canopy and relate them to radiation intensities and leaf characters.

Soil physics

Tillage problems. Direct drilling of winter cereals often fails on clay soils, possibly because the coulters can produce an unfavourable environment for germination and root penetration when they move through wet soil. Sorting out causes and effects has short- and long-term aspects. Some simple laboratory experiments in controlled and constant conditions gave a valuable double answer, first in suggesting a very probable cause of failure in direct seeding of wheat and, second, as a guide to design and interpretation of the long-term experiments now started. Wheat seeds were germinated at the interface between sand and clay in a range of conditions, none of which had any harmful effect on germination. Each seed produced four or five roots, and, at a suitable stage, the number of roots that had penetrated the clay was counted. The degree of compaction of the clay is unimportant but the overburden provided by the sand is important (without it the roots push the seed away from the soil); penetration is more effective the wetter the clay, smearing of the clay very greatly decreases penetration, a sloping surface is much more easily penetrated than a horizontal surface, but in a combination of smear and slope the smearing effect exceeds the slope effect. The provisional practical inferences are that, if a wheat seed reaches the bottom of the coulter slit, and if this horizontal surface is smeared, then an overburden of soil is needed for roots to penetrate: even with the necessary load on the seed, failure to penetrate might occur at a degree of soil dryness around the seed that could be produced by a few working roots of unkilled plants in the stubble of the preceding crop. (Prebble, 1.13)

The long-term tillage problem has two phases. First, do different techniques of cultivation produce detectable differences in the physical environment of seed-beds and root-beds? Second, if so, do plants respond to the differences? Previous work on soil structure, done within a conventional

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tillage system, showed that it needed absurd mis-management to produce a harmful effect on crop growth: after minimum or zero tillage contrasts may be easier to detect. A field experiment will start in 1970, after management operations in 1969 to remove any existing compaction effects on the chosen site. Many sensors will be installed to measure attributes of the four factors that may be important: water, air, temperature, and mechanical strength of the soil. Where possible, attempts will be made to measure *intensity* (e.g. for water, this will be 'potential'), *quantity* (for water, volume per unit volume of soil), and *rate* (for water, soil permeability). During 1969 many instruments were constructed and calibrated: some are good and reliable, others are not as direct or as accurate as desired, and some have yet to be invented. (Brown)

Aeration and respiration. The work done at Wrest Park, Silsoe, in 1966, 1967, and 1968 was so valuable that it was decided to transfer the experiment to Rothamsted using an improved design of respirometer (1.4). Industrial accidents greatly delayed delivery of the eight fibre-glass tanks (each approximately 1 metre cube) and there was a lot of work to be done on them when they arrived. So, instead of 1 April—and the expectation of a good summer's use—it was mid-July before the tanks were in place, and most of the later work was a proving trial of the tanks and auxiliary equipment.

The tanks are in the meteorological enclosure, their tops are at ground level, and the monitoring apparatus is in a hut below ground level: there is no shading of the site. Soil from the exacavation was replaced in the tanks as far as possible in its natural order, omitting the top soil until measurements could be made on the seemingly inert subsoil. This, before excavation, had a good natural structure: it was replaced (through a shredder) as clods about 2 cm diameter. The subsoil was not inert. Carbon dioxide output was near 90 kg ha^{-1} day^{-1} in July when the mean soil surface temperature was 25°C, and decreased to 25 kg ha^{-1} day^{-1} at the end of September (12·5°C). These rates are about one-fifth of those measured at Silsoe for uncropped top soil. In mid-September some of the tanks were watered (0–20 mm). Where this was added to the surface carbon dioxide output increased by up to 25%: added at the bottom, there was no change, suggesting a possible interaction between watering and diurnal range of temperature.

Daily output of carbon dioxide correlated well with temperature, and seldom changed more than two-fold from day to day, but the oxygen demand could change ten-fold. Within a day there are important phase differences between the occurrences of maximum or minimum values of carbon dioxide and oxygen concentrations measured in the space between the lid of the tank and the surface of the soil: in effect, it seems that most of the carbon dioxide output from the sub-soil will arrive at the surface too late in the day to be much use for photosynthesis. (Currie)

In the tanks the soil surface is protected from atmospheric turbulence. More laboratory experiments, in simulated field conditions, confirmed that rates of gas transfer across the soil surface can be increased when the pressure fluctuates rapidly (see *Rothamsted Report for 1966*, 31). An

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attempt at field observations broke down because the turbulence meter did not match its laboratory behaviour when used outside. (Prebble and Currie)

Plant/water relations

Movement in the intact plant. A modification of the automatic potometer allowed aeration of the nutrient solution, and plants were kept healthy in experiments lasting up to one week. In a steady environment two simultaneous sets of measurements were made on field bean plants: (i) the rate of uptake of water by the roots (potometer); (ii) the change in total weight of the plant (a sensitive transpiration balance). Cyclic variations in transpiration rate, water uptake rate, and plant weight were measured, sometimes arising spontaneously, but always inducible by a 20-minute dark period, though these forced oscillations were frequently damped, and lasted for only a few cycles. The period is about 35 minutes, and water uptake lags behind transpiration by 6–10 minutes; the amplitude was such that the maximum was sometimes 6 times the minimum rate, and in many plants the amplitude of uptake was almost as great as that of transpiration. Measurements of leaf temperature showed that all leaves of a plant oscillated in phase.

Explanation is very difficult in terms of facts, but the phenomenon is a fact, and somewhere in the plant there must be a place where there is hysteresis between water content and water potential (it occurs in soil) and a first suggestion is that it lies between the guard cells and the main body of the leaf. Ascribing some reasonable numbers, and correct values of external environmental quantities then the oscillations can be reproduced in period, amplitude and phase. Use of the computer helped greatly in showing the effects of changed assumptions, and varied boundary conditions. (Rowse)

Irrigation: Woburn 1960–69. The Physics Department's experiment ended, after 19 years on the site. A detailed account of the first nine years results was published in three papers in 1962 (*Rothamsted Report for 1960*, 33–38) and three new ones cover the period 1960–69 (1.9; 10; 11). The summaries are full, and only general comment is needed here. The experiment has been very valuable in three ways. First, it provides the main British evidence for the value of supplementary irrigation as a farming technique, and a demonstration that times and amounts of irrigation can be decided on the basis of suitable weather records. Second, in spite of the few and simple weather records taken on the site, it has given material for study of crop-weather relations from which potential transpiration has emerged as a very good growth index when water is non-limiting, and permitted quantitative estimates of likely losses in yield when water supply is inadequate. Less important, but a valuable third return, the results have been much used in lectures and symposia. (1.12)

For the site, the expected frequency of irrigation need was 6 or 7 years in 10, based on a climatological estimate of the final out-of-balance of rain and potential evaporation at the end of September. In the first nine

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years the specification was satisfied five times: in the second ten it was again satisfied five times. Both figures come within the expected spread of a climatic 'average', and in any event the frequency of benefit is much more important, and this usually depends on what happens in May and June, rather than later. Until 1966 there was regular rotational cropping on three series, and a ley of some sort on the fourth. From 1951 to 1965 there were 60 sets of crop yields of which 38 showed good or very good responses to irrigation, almost every year by leys and potatoes, rarely by sugar beet, and intermediately by spring cereals and beans.

The theoretical studies in crop meteorology interpret the responses in an unfamiliar way—as the decrease in yield caused by not having water there when it is needed. 'When it is needed' is specified through a limiting soil moisture deficit that imposes no check to growth; estimates of this quantity (see summaries) differ from crop to crop, with variety (evidence mainly from elsewhere), and possibly with soil type (evidence accumulating from the Rothamsted Irrigation Experiment.) The synthesis of ideas produced a prediction formula for the maximum possible response to irrigation (see 1.9 and 1.12), which, when tried on the field results worked well enough for most crops in most years, but with a few outstanding exceptions: sometimes the response exceeded the prediction by more than acceptable uncertainty. The reason is clear, and shows a second benefit of irrigation. During a 'dry' period the unirrigated crop may reach such a state of senescence that it cannot fully exploit such rain as does fall, and the response of the irrigated crop is not only to the applied irrigation but also to all of the rain in the 'dry' period: between 22 June and 29 September 1964 a clover crop responded to 8·9 cm of irrigation as though it had used 4·6 cm of rain (in a total of 7·3 cm) more than the unirrigated crop.

From 1966 onward the site was used for management experiments, the chief being one in nematology, comparing growth of potato varieties resistant and susceptible to cyst eelworm, grown in continuous and alternating cropping. Irrigation is little more than a minor variable. This experiment will continue, but irrigation research will be at Rothamsted only, accumulating experience on a different soil, and with the hope of better interpretation because of the accuracy and frequency with which soil, plant and weather parameters are measured in and about the growing crop.

As this is the end of the Woburn experiment in these reports, I record my great gratitude to the late Dr H. H. Mann, C. A. Thorold, and T. W. Barnes, colleague of both, for the supervision and work they put into the experiment; also to J. R. Moffatt, A. Neill and the farm staff. (Penman)

Irrigation 1969. The summer of 1969 was characterised by a late dry period, from the end of August, but in the main growing season most weeks had enough rain to meet transpiration needs. In total, from May to August, summer sunshine was again less than the long-term average, but it is characteristic of English weather that within this period there was a record-breaking week in June that supplied more than 100 hours sunshine, and towards the end of the month the soil moisture deficit moved to

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more than 4 cm. From previous Woburn experience (1.11) now applied to the Rothamsted experiment, it was expected that subsequent irrigation would have no effect on spring barley yields, and only a very small effect on spring wheat yields—less than the expected standard error in the measurement. Both expectations were realised: the barley yields were poor and the wheat yields good. The potatoes at Rothamsted were expected to respond, and they did, but by only about half of the expected amount. (Variety effect? Soil type effect?)

At Woburn the continuous cropping continued in the nematology experiment. By now (the fourth year) differences in yield, according to treatment, are enormous: extremes are given in the summary that follows.

Rothamsted

Potatoes. The control yield was 39·5 tonnes ha^{-1}. Irrigation in mid-June (2·5 cm) increased this by 2·1 t ha^{-1}; irrigation, July to mid-August (10·2 cm) increased yield by 5·7 t ha^{-1}, and a combination (12·7 cm) increased yield by 7·3 t ha^{-1}. It is possible that the second treatment was a little too much: it is probable that the combined application produced some leaching.

Barley. Treatments were: early (2·5 cm), late (4·5 cm), early and late (7·0 cm). None had any effect on an average grain yield of 2·2 t ha^{-1}.

Wheat. The treatment was: 10.2 cm from mid-June to late July. There was no response (non-significantly negative) with an average yield of 5·1 t ha^{-1} of grain.

Woburn

Potatoes. The best yields were on fumigated plots of Maris Piper on the series that started with few potato cyst-nematodes present. On these the response to 6·5 cm irrigation was from 42 to 50 t ha^{-1}. The worst, averaged over the same treatments, were on the non-fumigated plots of Pentland Dell on the series that started with many cyst-nematodes present. The response was from 6 to 9 t ha^{-1}, with the same irrigation.

Agricultural meteorology

Micro-climate. Both of the macro-plots, under spring wheat, were fully instrumented to measure temperature, humidity, ventilation, and radiation, including eight sites at which soil water profiles were measured by the neutron meter, almost every week, to 150 cm. In addition, on the irrigated plot, several other sets of observations were made, including tests of horizontal uniformity at constant height, and of vertical and horizontal air movement within the crop canopy. There was no irrigation need before mid-June when the crop was well established; thereafter four equal applications totalled 11 cm. With no response in growth it is a fair presumption that water use by the two crops was not significantly different, although that for the irrigated crop was expected to be detectably greater because of the extra opportunity for more rapid evaporation of intercepted water.

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The neutron-meter records suggest the opposite—the non-irrigated crop used somewhat more water than the irrigated, but the discrepancy occurs in stages, always at the times of irrigation and not in between. Possible causes—there are several—are being examined, and although interpretation of the season's results will depend on the diagnosis, it is already clear that the rate of water use of the green crop is some 20% greater than the calculated potential transpiration rate. This repeats previous experience with other tall crops, e.g. beans (1966) and kale (1967), and conforms with prediction of the behaviour of what are aerodynamically much 'rougher' crops than the short grass to which the concept of potential transpiration applies.

As an example of detail, the ventilation records are of great ecological interest. Miniature anemometers (*Rothamsted Report for 1968*, Part 1, 31) showed that the vertical component of airflow inside the crop was usually about 70% of the horizontal speed, but sometimes exceeded it by 30% for a period of a few hours. Occasionally the ratio of upward to downward component reached 10 : 1, or 1 : 10, for several hours by day or by night, possibly because of slowly moving convective cells (hot or cold spots) as detected in the 1956 wheat crop. (Penman & Long, *Q. Jl R. met. Soc.* (1960), **86**). Gusts penetrate the gaps between the plant rows more easily than the rows, and on balance this may preferentially increase the rate of upward water vapour transport.

The neutron-meter records show clearly where the plant roots are getting their water from. Since 1964 evidence has been obtained for grass, barley, beans, kale, and spring wheat. There are differences between crops and between varieties: in 1969, for spring wheat (variety: Kolibri), there were barely detectable changes in soil water content at 150 cm, and it seems that this variety, on this soil, can build up a deficit of about 20 cm without any check to transpiration, and takes about 90% of this water from the top 110 cm of the soil profile. (Long and French)

Growth analysis. In the hope of understanding how much the different parts of a plant contribute to total water use, total crop photosynthesis, and in the end, to economic yield, it is necessary to measure foliage distribution with height and its seasonal change, to measure the penetration of radiation (total, visible, and net), and to know how the turbulent exchange coefficient (K) varies. The radiation recording is part of routine and, alongside the temperature, humidity and ventilation records, the information remains on file, temporarily: when a trace reader arrives rapid conversion to computer-compatible tapes is expected. For 1969, at present only the weekly foliage measurements have meaning. As the leaf area index of the spring wheat increased to about 2, the transpiration rate increased to about the potential value, and continued to increase to perhaps 20% more before stabilising at this excess while the leaf area index changed from 3 to 5 (including ears). The average growth rate of total dry matter was near 21 g m^{-2} day $^{-1}$ during June and July, and, with some fluctuations, was not greatly different later. The important later history was that maximum standing dry matter was reached in mid-August, at 17 tonnes ha^{-1}, corresponding to an efficiency of conversion of total

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solar radiation, May to August, of 1·3%: during June and July, the average efficiency was 1·9%, and during a 10-day period in July, the average was 2·5%. (The final harvest yields were: grain 5·1 t ha^{-1}; straw 5·5 t ha^{-1}). (Szeicz and Legg)

Transport constant. During the summer, measurements were made to compare three methods of estimating *K* in the wheat crop. They are: energy balance (Szeicz); momentum balance (Long); and a new method, using nitrous oxide gas, in which a uniform distribution of gas is liberated at ground level over a large area of the field.

The distribution was achieved by laying out a network of 5 km of 6 mm nylon tubing over an area 80 m diameter, with holes at 25 cm intervals near the centre, increasing to 200 cm at the edges. Each of the 4500 holes had a 20 cm length of nylon capillary tubing glued into it and was then covered by a protective metal cap. Gas was supplied at a known rate, and its concentration measured at twelve heights at the centre of the area by drawing samples through an infra-red gas analyser, sensitive to 10^{-7} parts nitrous oxide. Measurements of variation in the horizontal were made to permit corrections for limited fetch, and a computer program prepared to handle the information obtained.

During the summer there were experimental runs (lasting several days) at various stages in the development of the crop, and in a range of weather situations. The few sets of gas profiles and wind profiles so far analysed are enough to indicate trends. During daytime the shape of the nitrous oxide profile is as expected, but the *K* value at the top of the crop is often larger than the aerodynamic estimate, perhaps because of limited fetch, for which a correction can be made. On clear calm nights there were some unexpected results. Above the crop *K* is small (< 10 cm^2 sec^{-1}) corresponding to very stable air flow, but inside the crop it is large (100 cm^2 sec^{-1}) probably because of large temperature gradients. (Legg)

Plant physiology

During experiments to measure rates of diffusion of water vapour and carbon dioxide through leaves sprayed with silicone, a possible source of error in the theory was exposed and put right (1.8). The equipment for measuring response curves was used a lot for its primary purpose and also to help others in various ways, e.g. to measure the stomatal and mesophyll resistances of the wheat on Great Field, and of cotton leaves (Lake); for calibration of carbon dioxide/air mixtures for workers at Rothamsted (Botany Department), Sutton Bonington, and Reading.

Analysis of results for 1967, with kale, goes on apace. Carbon dioxide and light response curves for 38 leaves from various heights in the crop during one week in August and another week in October were determined. Using Monteith's crop transmission factor (from the radiation profiles measured by Szeicz) it is possible to calculate the fraction of leaf area that is directly illuminated and the intensity on the shaded fraction. Combining this information with the response curves measured in the laboratory, rates of photosynthesis or respiration can be estimated at

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various levels in the field crop, integrated over the whole profile, and the result compared with field measurements. First comparisons, generally encouraging, reveal a discrepancy that Legg's measurements may resolve. From field profiles of carbon dioxide it seems that stalks and older leaves have negligible rates of respiration: from laboratory measurements there are similar rates of respiration per unit dry weight for stalks, petioles and older leaves, at a rate about one-third that of the youngest leaves.

New work on cotton (see later) produced response curves for carbon dioxide (light invariant) and for light (carbon dioxide invariant), and separately, these can be very closely described by equations with fitted constants. However, when the constants for one are used to predict the form of the other the result is wrong. The known cause is the assumption that the respiration rate measured in darkness is the same in light: assuming that the rate increases with light intensity in the form

$$R_I - R_0 = I/(a'I + b')$$

where R_I is the respiration rate at intensity I and a' and b' are constants, the equation will account for the results from cotton, and will qualitatively explain otherwise puzzling results by other workers. (Parkinson)

During photosynthesis, carbon dioxide passes from the inter-cellular spaces of a leaf to the chloroplasts, and estimation of the transport resistance in this pathway—the mesophyll resistance—depends on knowledge of the concentration at the two ends of the path, and of the photosynthetic and respiratory fluxes. Cotton plants were used (grown in the new controlled environment cabinets) partly because some of this work was first done on cotton, in Australia, and partly because there is a good understanding of the physiology of cotton; also its leaves are conveniently large, flat, and amphistomatous. Maize was used, too. Testing a hypothesis, part of which is implicit in the preceding equation, in bright light the rate of uptake of carbon dioxide (while it was positive) was linearly related to the intercellular concentration, controlled by a flushing technique, the slope depending on oxygen concentration. When the lines for 0 and 21% of oxygen are extrapolated, they intersect at a negative rate of carbon dioxide uptake, which is considered to be a rate of production by some respiratory process that is independent of oxygen concentration, and which exceeds the rate of dark respiration: Parkinson's measurements should show how it depends on light intensity. From other parts of the evidence comes an estimate of resistance to transport between the respiratory sites and the intercellular spaces. For cotton it was only slightly less than the total mesophyll resistance, near 3 sec cm^{-1}, suggesting that most of the carbon dioxide from this respiratory source is readily available for re-use at the chloroplasts.

Other experiments were started, on cotton and maize, to measure the effects of defoliation on the physical resistances to carbon dioxide transport, and on the rate of one of the respiratory processes. Leaf removal, by grazing, mowing, or disease, stimulates photosynthesis within a few days, perhaps because of an effect on the carboxylation process, but there are other plausible explanations, and some physical measurements should help to sort out the possibilities.

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Instruments and components for a leaf canopy enclosure were tested in the laboratory. The apparatus should be ready for field measurements on sugar beet in 1970 (1.5). (Lake)

Equipment and techniques—miscellaneous

(*i*) ***Peltier effect psychrometer.*** The use of short cooling times, which eliminates errors arising from the geometry of the test container, makes the instrument sensitive to contamination by minute amounts of salt. Frequent re-calibration is necessary, but the automatic equipment makes this easy. (Rowse)

(*ii*) ***Equipment for study of photosynthesis and transpiration of single leaves.*** Pure nitrogen and pure oxygen from cylinders can now be used instead of air. A dew-point hygrometer was incorporated, replacing the psychrometer, and behaved satisfactorily. (Parkinson)

(*iii*) ***Automatic recording of micro-meteorological elements.*** A logging system was evolved in consultation with manufacturers and the Computer Department. The nine units ordered will give 144 channels with chart records for on-site monitoring, and can be used with voltage, current, or resistance type sensors. The output is on standard 8-hole paper tape in ISO-7 code. (Long)

(*iv*) ***Radiometers.*** Two improved instruments—ventilated—were built, with outputs of 7 mV per cal cm^{-2} min^{-1}. They can be used for net radiation, for total radiation, or, with filters, for limited parts of the spectrum. (Long)

(*v*) ***Neutron moisture meter.*** The electrical circuit was improved and simplified. The 'dead' time of the scaler unit is now less than 10^{-5} sec and no correction for dead time is needed. (Long and French)

Staff and visiting workers

Mr R. E. Prebble returned to the Commonwealth Scientific & Industrial Research Organisation, Division of Soils, Brisbane. Dr T. J. Marshall (C.S.I.R.O., Adelaide) spent two months in the department, and Miss Ruth Parker (Nottingham University) helped in field and laboratory work during the summer.

H. Rowse at the end of his post-graduate course, was appointed to the staff of the National Vegetable Research Station at Wellesbourne. L. ter Veer was appointed to assist J. A. Currie.

J. V. Lake contributed to the International Biological Program technical meeting in Trebon, Czechoslovakia. In August, H. L. Penman gave a course of eight lectures at an international Summer School in Delft, on evaporation in hydrology and agriculture, and in December he led the British delegation at the inter-governmental mid-decade meeting, in Paris, to consider the past and future programme of the International Hydrological Decade.

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