ROTHAMSTED RESEARCH

Report for 1977 - Part 1

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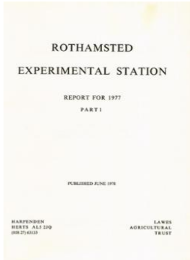

Physics Department

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Introduction

1977 was a year of change for both the fabric and the programme of the Physics Department. On 1 October, E. G. Youngs, A. Poulovassilis and G. D. Towner transferred to the department, on the disbandment of the ARC Unit of Soil Physics at Cambridge, where their work on soil water physics and its application to agricultural practice, especially land drainage, had earned an international respect and reputation. (The Unit's recent research has been surveyed by Youngs, *Memoirs of the University of Cambridge Department of Applied Biology* (1977), **49,** 4–10.) Their move has involved major reorganisations and structural alterations in the Department's section of the Bawden Building, changes that have affected most members of the Department through much of the year and that are still in progress at the time of writing. A high-ceiling laboratory has been created so that long, vertical soil columns can be accommodated, and two new workshops have been constructed, one housed within the Department and the other sited close to our field experiments.

Changes of emphasis in the Department's research programme have allowed more effort to be devoted to work related to the causes of yield variations in cereals. On the Little Knott mobile shelter site, a tillage experiment was conducted to determine whether tillage treatment, and the soil water content at the time of tillage, caused or promoted measurable changes in the physical properties of the soil, and whether those changes could, in turn, be related to barley growth and yield. Preliminary results suggest that the treatments had very significant effects on plant emergence, but no significant effect on final grain yield. Work on the aerobiology of the dispersal of cereal disease spores is being considerably expanded, and a fuller analysis has been made of the spore dispersal experiments and calculations that were mentioned in *Rothamsted Report for 1974*, Part 1, 207. The strengthening of the tillage and aerobiology programmes has been made possible by the transfer of resources from other projects. No experimentation was undertaken in 1977 either for the Great Field micrometeorological programme or for the large-plot studies of crop response to irrigation, but considerable effort was devoted to the analysis of large backlogs of data.

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The major conclusions of the Physics Department's contributions to the Rothamsted Soil Structure Working Group are summarised in the first section of this report, which also makes reference to a newly-commenced study of the effects of polysaccharides on the aggregation of clays. There has been an intensive analysis of the data collected during the 1976 drought experiment: reference will be made to an analysis of the variance of yield components resulting from that experiment, and to some theoretical and experimental studies of the rewetting after harvest of the dry soil profiles.

Several techniques and methods of measurement have been developed and improved during 1977. The porometer that was used in the 1976 drought experiment (*Rothamsted Report for 1976*, Part 1, 238) has been improved substantially; an important technical innovation has permitted, for the first time, a direct comparison of laboratory calibrations of continuous flow and diffusion porometers. A leaf chamber of new design has been constructed and tested: it gives more accurate measures of photosynthesis than its predecessor, can simultaneously provide estimates for transpiration, and is suitable for field use. Such field measurements of photosynthesis with the new chamber, or with any other continuous flow photosynthesis chamber, will be greatly assisted by a portable gas supply system of novel design that has been developed to provide air mixtures containing various specified concentrations of carbon dioxide. Such supplies have previously been manageable only in the laboratory. The new system will allow the determination of the photosynthetic response of field-growing plants to various concentrations of carbon dioxide.

The analyses of the plant physiological and plant nutritional aspects of the 1976 drought experiment have been pursued in partnership with members of the Botany Department and the Soils and Plant Nutrition Department; we have also cooperated with the latter Department in the use of the tank respirometers. Collaboration on irrigation experiments has continued with the Field Experiments Section and the Nematology Department, and we have worked closely with the Plant Pathology Department to commission and equip the new wind tunnel and to plan future aerobiological research.

Soil physics

Soil structure

Collaboration. The contributions of the Department to the multi-disciplinary working group on soil structure were described in last year's report (*Rothamsted Report for 1976*, Part 1, 243). The findings of the first phase of this collaboration, which were presented at a seminar at Rothamsted in June, have subsequently been prepared for publication in the scientific literature, and are summarised in the following sections of this report.

Crumb diffusion. Most soils exhibit structure. When soils become anaerobic, they are more likely to do so at the centres of the structural units, at all depths in the profile, rather than in the whole soil below some particular depth. Anaerobic conditions will not occur if there is an adequate diffusion of gases into and out of the units; and such diffusion will depend on the pore structure within the units. For that type of unit that we identify as the soil crumb, the coefficient, D_c, for diffusion of gases within the crumb may be measured by the method that was described in last year's report. For 26 samples of crumbs prepared from various horizons of soils from the Hanslope, Ragdale, Evesham, Denchworth, Flint and Salop series, D_c values were measured and expressed as the ratios D_c/D_o, where D_o is the diffusion coefficient when no impeding solids are present. For the first four of these series, similar diffusion properties were found: whereas the crumb porosity, ϵ_c, increased steadily with depth, the ratio D_c/D_o was lower in the B and equivalent horizons than in the horizons above and below.

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For each horizon, the measurements of ϵ_c and of D_c/D_o may be combined to yield a parameter

$$k_c = \frac{\epsilon_c}{1-\epsilon_c} \cdot \frac{1-D_c/D_o}{D_c/D_o}$$

that is by definition a shape factor for the particles that constitute the crumb, and that increases from 1·5 for spherical particles to infinity for flat plates. In soil crumbs there is some orientation and cementation of particles, and the concept of particle shape has little meaning: k_c may be more appropriately interpreted as a complexity factor for the pores within the crumb, with higher values of k_c corresponding to lower diffusions at a given crumb porosity. For the four soils exhibiting similar diffusion properties, complexities were least in the Ap horizons, greatest within the B horizons, and less in the C or equivalent horizons. The greatest complexities were found for the Ragdale and Denchworth B horizons, both soils being classified as 'commonly problematic in management'. The following reasoning is suggested as an explanation for these findings. In comparison with sand grains, clay particles are plate-shaped, and as might be expected, measured values of k_c do correlate positively with clay content and negatively with sand content, in each case with 99% significance. For multiple regressions of k_c on sand, clay, and organic matter, the regression coefficient for clay is significant for all those equations in which it occurs, that for sand is significant either alone or with clay excluded, and that for organic matter significant, and negative, either alone or with clay, but not with sand alone. The complexities of the Ragdale and Denchworth B horizons are significantly greater than would be predicted by these regression equations.

It is suggested that the lower complexity of the Ap horizons results from the constant disturbance of soil in the plough layer. Under arable management, the soil particles in the Ap horizon are subjected to a variety of influences, imposed by cultivations and weather, that tend to move them apart, and once separated, organic matter may penetrate and maintain their separation. The low complexity is thus explained in terms of loose packing, a lack of strong orientation, and little inter-particle cementing. In contrast, the B horizons are not subjected to these disruptive influences; they do, however, experience frequent wetting and drying cycles, leading to swelling and shrinking, and are also subjected to vertical pressures from above. These processes produce a kneading of the B horizon soil that results in greater particle orientation and structural complexity. Wetting and drying cycles are less frequent in the BC and C horizons, the kneading will be less severe, and because also the soil will generally be wetter at this depth, a less complex crumb structure will develop.

The Flint and Salop soils contain more sand than do the soils of the other four series, and their complexities are correspondingly lower. For both Flint and Salop profiles, both ϵ_c and D_c/D_o decrease progressively with increasing depth, and complexity increases only slightly with depth.

For all series and horizons, the measurements of complexity were performed on dry crumbs. In the next phase of this research, complexity will be measured over the whole range of crumb wetness: from complete dryness to total saturation.

From the measurements of ϵ_c and D_c/D_o that were made for the several horizons of the six soil series it is possible to calculate corresponding values for $D_c/D_o\epsilon_c$. These values may be compared with that of Penman (*Journal of Agricultural Science, Cambridge* (1940), **30**, 437–462 and 570–581) to which many workers make frequent recourse when seeking a value for a diffusion coefficient, D, given only a porosity ϵ. Penman summarised many measurements of diffusion of gases through unconsolidated packings of porous materials (that included soils) in the form $D/D_o = \alpha\epsilon$, with α equal to 0·66 for the range of porosities found in agricultural soils. The values for $D_c/D_o\epsilon_c$ that derive

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from this present work and that relate to the fabric of the soil crumb, essentially a consolidated material, ranged from 0·06 in the Denchworth Bgl horizon to 0·29 in the sandy Salop topsoil, that is from 0·1 to 0·5 of Penman's value. (Currie and Scott)

Dispersion stability. The measurement by ultrasonic dispersion of the stabilities of the various horizons of these same six soils was described in *Rothamsted Report for 1976*, Part 1, 244. The relation of the measured stabilities to various soil parameters was also described; the form of this relation has been confirmed by the 1977 programme of measurements. However, little success was gained in relating the ultrasound measurements of soil stability to soil management experience, either for surface or subsoil horizons. In most cases the stability of the 'commonly problematic' soil was equal to or greater than that of its 'rarely problematic' partner. It is likely, therefore, that ultrasound measures of stability will not help in identifying soil management potential, but they will contribute to studies of the mechanisms of aggregate formation and breakdown. (North and Geraghty)

Aggregation of clays. Long chain molecules of polysaccharides of high molecular weight are able to effect aggregation of clay particles. The measurements here reported sought to determine the influence of polysaccharide molecular weight and charge on the amount of aggregation and on the shape of the resulting aggregates. Two molecular weight fractions of a neutral polysaccharide, dextran, were used, together with a positively charged derivative, DEAE dextran; the clay was a sodium montmorillonite, fractionated to give particles of 0·3–0·5 μm equivalent spherical diameter. For the dextran solutions and the clay and clay-dextran suspensions, average particle size and radius of gyration were determined through an analysis of the respective light scattering properties. Dextran concentration in the different clay-dextran complexes was determined from measurements of adsorption isotherms.

For the neutral dextrans, adsorption on the clay was greater for the variety D 2000 of mol. wt. about 2×10^6, than for variety D 500, of mol. wt. about 5×10^5. Light scattering showed that, with D500, average clay particle size did not increase during adsorption, suggesting that adsorption was predominantly on individual clay particles. With D 2000, average radius of gyration doubled during adsorption, indicating a bridging between clay particles by the polymer; it is likely that clay dimers were produced, and that end-to-end association of clay particles had occurred.

The charged dextran, DEAE, which had the same molecular weight as D 500, was adsorbed in greater quantities than were the neutral varieties; analysis of the light scattering properties indicated that trimer aggregates of clay had been formed, but the geometry of their aggregation has not yet been determined.

It is probable that the charged dextran adsorbs on the clay by cation exchange. Thus DEAE, by providing strong anchor points for the inter-clay polymer bridges, would promote stronger bonding, and hence more aggregation, than would its neutral counterpart, D 500. For the neutral dextrans, D 2000 has longer molecules, and hence more sites for Van der Waals bonds, than does D 500; it is thus the more effective in bonding to the clay particles and in bridging between them. (North and Green)

Tillage. A preliminary experiment on tillage using the Little Knott mobile shelter site was conducted in 1975 and described in the *Rothamsted Report for 1975*, Part 1, 230. A similar, but larger, experiment in 1977 sought to determine whether tillage treatments and the soil water content in the 0–30 cm layer at the time of tillage, caused or promoted measurable changes in the physical properties of the soil and whether these changes could, in turn, be related to crop growth and yield. The tillage treatments, which followed

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a preliminary tine cultivation to 40 cm depth in March 1977 to ensure site uniformity, were effected in April 1977 and were identical to those of 1975, and comprised consolidation by a Cambridge roller after seeding (T_1), no further cultivation (T_2), and an additional tine cultivation to 30 cm depth (T_3). Because the soil water content at the time of tillage is likely to influence the soil particle mechanics, each tillage treatment was combined factorially with three volumetric water contents at tillage of 0·15, 0·22, and 0·31, respectively selected to achieve Proctor test bulk densities of 1·66, 1·75, and 1·58 t m^{-3}, values that, in turn, are representative of soils that in practice would be considered about right, too compact, and too loose, for seedbed preparation. The technique for achieving these required water contents was more effective than that used in 1975, but there were still some problems with ponding. The experiment plots, 3·0 m × 2·3 m, were shorter than in 1975: by this shortening of plots, and also of plot-dividing discards, it was possible to achieve a 36-plot randomised block design that permitted four replicates, two cropped with spring barley and two fallow, of each tillage: watering combination. Chemical analyses prior to cultivation showed all 36 plots to be effectively identical in nutrient status. After cultivation, half the plots were drilled with spring barley, and then all plots were watered to achieve field capacity. The water requirements of the cropped plots were supplied throughout the growing season by trickle irrigation, rainfall being excluded by the mobile shelter.

Instruments, replicated wherever possible, were installed on some or all plots to measure solar radiation and soil heat flux and the vertical profiles within the soil of temperature, bulk density, water content and pressure, and carbon dioxide concentration. From these and supporting laboratory measurements, analysis is proceeding to determine values, for selected fallow plots, of thermal and hydraulic conductivities and of carbon dioxide fluxes.

For the cropped plots, plant emergence was measured by counting the numbers of plants along 18 1·0 m lengths of row on each plot, and leaf area index was assessed from visual observations. Grain and straw yields were determined at harvest, and six of the 18 plots were harvested row-by-row to evaluate plot uniformity and edge effects. Table 1 shows, for both replicates of each treatment:watering combination, the final numbers of emergent plants per m row: the effects of treatment and watering and of their interactions are all 99·9% significant.

TABLE 1

Plant emergence. Final numbers of emerged spring barley plants per metre row, on small plots at Little Knott, 1977

(Measurements are presented for both replicates of each treatment:watering combination)

Volumetric water content in the 0–30 cm layer at cultivation	Cultivation: Rolled, but not cultivated	Not cultivated	Tine cultivated to 30 cm
0·15	54·2	58·2	55·8
	53·2	51·4	61·2
0·22	26·2	48·4	63·2
	26·6	46·8	55·0
0·31	19·2	46·0	49·8
	23·6	45·2	46·6

The effects of cultivation, water content, and their interactions are all significant at the 99·9% level

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These effects were not paralleled by any significant differences in grain yield: as Table 2 shows, compensatory growth resulted in the plot yields being more nearly equal, and, indeed, the plot having the second highest number of emergent plants gave the lowest yield. Some current opinion holds that cultivation might be regarded as an insurance

TABLE 2

Grain yields, t ha^{-1} of spring barley at 85% dry matter, on small plots at Little Knott, 1977

(Measurements are presented for both replicates of each treatment: watering combination)

Volumetric water content in the 0–30 cm layer at cultivation	Cultivation		
	Rolled, but not cultivated	Not cultivated	Tine cultivated to 30 cm
0·15	4·91	5·38	6·44
	6·70	4·89	3·94
0·22	5·41	4·90	5·47
	4·35	5·55	5·01
0·31	4·79	4·13	4·24
	4·99	4·59	5·10

No significant effects of cultivation, water contents, or their interactions

against soil structure deterioration during a year of adverse weather; it might also be considered a method of ensuring germination of a superfluity of plants as an insurance against some plant loss during the growing season. However, the data of Table 2 do display a large residual variance that cannot be explained by the treatments and their interactions. In the extreme case, for two replicates of the same carefully managed treatment, the grain yields were in the ratio 1·63:1. Some of this variance may remain ascribable to soil physical conditions. (Brown, North, Woodhead, A. T. Day, Pritchard, Zemroch, Connell, Croft, Dawes, Geraghty, Gordon, Scott, and I. Stead)

Soil respiration

Tank respirometers. Continuous measurements by the tank respirometers of field soil respiration were discontinued during 1977. During September, two tanks were used in a short experiment designed to evaluate a new method for measuring surface fluxes of soil carbon dioxide that has been developed in the Soils and Plant Nutrition Department and described more fully on p. 284. In a separate experiment, the ratio of the respiration rates in two other tanks was established through a 10-day series of measurements. The soil in one tank was then lightly forked over: respiration in the disturbed soil showed an initial increase of 60% and was still enhanced by 10% 6 weeks after forking. (Currie, with Powlson, Soils and Plant Nutrition Department)

Profiles of carbon dioxide concentration. The collection and analysis for carbon dioxide concentration of samples of soil air were described in *Rothamsted Report for 1975*, Part 1, 231. The technique was improved in 1977 by the adoption for the sampling probes of capillary tubing of 0·9 mm wall thickness—thicker and stronger than had been used previously. The measured concentration profiles may be used, in conjunction with estimates for the gaseous diffusion coefficient in the appropriate soil layers, to calculate values for the fluxes of carbon dioxide at various depths. Concentrations of carbon

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dioxide were measured for samples withdrawn daily from four depths under the fallow plots that comprised part of the Little Knott tillage experiment; independent measures of the surface fluxes of carbon dioxide were obtained from a field respirometer deployed on these same plots at intervals of a few weeks.

A preliminary examination of the data suggests that during the early part of the season, when no water was added to the fallow plots, carbon dioxide concentrations were similar for all tillage: watering treatment combinations, and differences subsequently arose only as a result of irrigation. In a similar experiment in 1975, carbon dioxide concentrations in fallow plots were unaffected by irrigation. But in 1977, concentrations in the wettest rolled plots increased greatly, in the uncultivated plots moderately, and in the cultivated plots only slightly, after irrigation, which was applied less frequently, but in larger applications, than in 1975. For the wettest rolled plots, the fractional change in respiration was comparable to that of the cropped plots in 1975; however, absolute concentrations on the 1975 cropped plots were twice those of the 1977 wettest, rolled plots.

Surface fluxes of carbon dioxide, as calculated from the concentration profiles and as measured by the respirometer, increased in response to irrigation. These increases cannot be ascribed to the loss of air-filled pore space that results from the entry of irrigation water; and it is suggested that on fallow plots, after water has been withheld for a long period, irrigation can stimulate soil respiration. (Pritchard and Scott)

Soil water

Rewetting of dry soil profiles. In the weekly routine of the 1976 drought experiment at Little Knott (*Rothamsted Report for 1976*, Part 1, 236) soil water profiles were measured 5 days after irrigation applications. Some of the applied water would therefore have transpired or evaporated before the profile was measured, and the moisture profile that initially resulted from the irrigation was not determined. Knowledge of these initial profiles is required in estimating evaporation from the soil surface, in modelling plant water uptake, and in calculating from soil porosity values corresponding estimates for gaseous diffusion coefficients. However, measurements of soil moisture profiles that are made immediately after irrigation may be invalid because 2 or 3 days are required for the soil moisture to equilibrate horizontally, and the small volume of soil monitored by the neutron probe could have an unrepresentative moisture content.

To further the development of a physical model that would describe the initial rewetting process, the four Little Knott plots that were driest after harvest in 1976 were rewetted in September and October 1976 by applications of 25 or 50 mm of water at approximately weekly intervals; the plots were covered between irrigations to prevent evaporation. The resulting moisture profiles were measured, by the neutron scattering method, 3 days and 7 days after irrigation. The profiles measured at 3 and 7 days were, in fact, essentially identical, so that water movement to depth was quite rapid, except when water was added to a soil already at field capacity, when a perched water table was observed to persist for several days. The measurements also showed that the water content at field capacity of the top 1·5 m of soil was the same, to within 18 mm in 550 mm, before and after the exceptional summer of 1976, confirming the validity of the field capacity concept for this soil. Furthermore, it was observed that during this rewetting exercise there was virtually no drainage of irrigation water from the top 1·5 m until field capacity was achieved. As a result of each irrigation, including the first, all depths received some water, although initially the upper levels rewetted more than the lower ones. One plot differed from the other three, in that its 0·5—1·1 m zone rewetted before the upper 0·5 m.

A simple physical model successfully described the fractional rewetting of the three plots that behaved similarly: for an existing deficit $D(z)$, the fractional rewetting at depth

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z may be represented by $D(z) . exp\ (-az)$, where a is a constant. In addition, rewetting at all depths is constrained by the requirement that the total increase in water content over the whole profile must equal the total of irrigation applied. Although this model gives a satisfactory mathematical description, it is physically unreal in that wetting of the surface layer is made to depend on the deficit existing at 1·5 m. An alternative model, that is more realistic, considers the soil profile as a sequence of layers, and allows rewetting of the layer at depth z to proceed at a rate that is a function of $D(z)$. If water be applied to the top of any layer at a rate greater than the layer can accept, then the excess penetrates to the next lower layer. This model gave an adequate description of the three similarly-behaved plots, but more measurements are necessary, at different irrigation rates, to further test the model's validity. (W. Day, French, Legg and Zemroch)

Water content and water potential relationships. In the 1976 drought experiment at Little Knott, five plots were extensively instrumented (*Rothamsted Report for 1976*, Part 1, 238). For depths of 15, 30 and 60 cm on these plots, relationships have been derived between field measurements of soil water content, as determined through neutron scattering, and of field values of soil water potential, as measured by psychrometers and tensiometers. For those occasions when the soil was drying and there was no complication by hysteresis, these relationships will be used to estimate soil water potential from values of soil water content for those plots on which the latter, but not the former, was measured. (W. Day)

Plant physics

Plant response to water stress

Yield response and nutrient uptake. Grain yields for the 1976 experiment that investigated the effects on barley yield of droughts of various intensities at different growth stages were presented in the *Rothamsted Report for 1976*, Part 1, 236. Further analysis has sought to determine the effect on the components of grain yield of the mean soil moisture deficit that persisted through each of three growth periods: (1) 27 April to 1 June, which included tiller production and spikelet initiation, (2) 2 June to 22 June, which included tiller and spikelet death and anthesis, (3) 23 June to 13 July, the grain filling period. The three components of yield were ears per unit ground area, grains per ear, and mean grain mass, and their variations could largely be accounted for by the moisture deficits that respectively occurred in periods (2), (1) and (3). Total grain yield was significantly affected by drought in all periods. (W. Day, Legg and Zemroch)

For the same experiment, the uptakes of N, P, K, Ca, Mg and Na were determined by chemical analyses of the grain and straw that resulted from the various watering treatments. Nitrogen uptake ranged from 90 kg ha^{-1} for the driest treatment to 180 kg ha^{-1} for four of the wettest ones. However, the total of nitrogen applied as fertiliser and as a constituent of the irrigation water did not exceed 96 kg ha^{-1}. The extra nitrogen taken up is thought to have originated by mineralisation of organic nitrogen in 1975 when the site was fallowed; little of this mineralised nitrogen was leached during the dry 1975/76 winter, and there was thus nitrogen available in 1976 and its uptake was facilitated by the irrigations. Phosphorus uptake for the wettest treatments was 28·5 kg ha^{-1}; for the driest treatment it was only 7·2 kg ha^{-1}, corresponding to a phosphorus concentration in the grain of $(0{\cdot}23 \pm 0{\cdot}01)\%$, a value as low as that found in barley grown in phosphorus-deficient soil. It is possible, therefore, that prolonged water stress affects plant growth by reducing the uptake of phosphorus, hence reducing the plant's store of adenosine diphosphate and adenosine triphosphate, leading in turn to a slowing of many biochemical processes in the plant. (W. Day, with Johnston, Soils and Plant Nutrition Department and Lawlor, Botany Department)

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Porometer development. A new porometer has been designed, constructed and successfully tested. The chamber is made of stainless steel, which should promote more rapid temperature equilibration than did the polypropylene previously used; temperature and humidity signals, in digital form, are derived from a Lee-Dickens 'humigun' that incorporates a Vaisala sensor.

In any porometer that depends on the measurement of relative humidity, uncertainties of measurement arise because of the finite differences between leaf and sensor temperatures. However, calculations show that if the stomatal resistance measurement, r_s, be made when the difference between leaf and chamber temperatures has settled to a steady value, then a true value for r_s may be obtained by subtracting from the measured value a temperature-dependent correction that has been derived from laboratory determinations of the transfer of heat between leaf and chamber structure. The correction is small, typically 0·1—0·2 s cm^{-1}, but its derivation and tabulation have allowed the determination of true values of r_s without need of measurement of leaf temperature. With the new porometer, the necessary steady conditions are achieved within half a minute. (Parkinson and W. Day)

Two types of porometer are in general use: the continuous flow type and the diffusion type. The former is calibrated through an absolute calibration of the humidity sensor, the latter through measurements using drilled plates of known resistance. The plates cannot be used in continuous flow porometers, because of the rapid air movement within the porometer chambers. When comparisons of the two types have previously been made, on growing leaves, the continuous flow porometers give resistance values generally lower than those from diffusion porometers. Laboratory comparison of the two types of porometer became possible when a porous polypropylene film, 'Celgard', became available. Small pieces of this film, when placed above a piece of wet filter paper, constitute artificial leaves of known resistance that can be placed in either type of porometer. The film is supplied in large sheets, and typically 1·0 cm^2 area of film has a resistance of 0·7 s cm^{-1}, although there is a variation over one sheet, and different samples purchased over the last 2 years have had unit area resistances that ranged from 0·6 to 1·3 s cm^{-1}. To achieve a range of higher resistances for calibration purposes, pieces of film may be stacked as a multi-layer. A 'Celgard' calibration of a continuous flow porometer agreed with that derived through calibration of the humidity sensor. In measurements on a series of 'Celgard' multilayers, a diffusion porometer that had been calibrated by a drilled plate gave resistances that, over the resistance range 1–12 s cm^{-1}, were about 2 s cm^{-1} higher than those calculated. (W. Day, Parkinson, Scott and I. Stead)

Auxanometer development. Our various studies of cereal growth, including our investigation of cereal response to water stress, would benefit from the availability of a proven technique for measuring leaf extension over periods of an hour or so. An acceptable technique requires a sensitivity that would ensure a workable signal-to-noise ratio, would impose minimal tension on the measured leaf, and would generate a signal amenable to electronic data collection. Possible extension sensors, or auxanometers, that have been investigated include direct mechanical units, rotary potentiometers, and linear voltage differential transducers (LVDTs); of these only the LVDT satisfies all three conditions, and a series of LVDT auxanometers is being developed for deployment in the proposed 1978 drought experiment. (W. Day and Scott)

Photosynthesis

Photosynthesis: field studies. The analysis in terms of Monteith's model of photosynthesis (Monteith, *Annals of Botany* (1965), **29,** 17–37) of a 1974 series of field canopy

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enclosure measurements on potatoes was reported in *Rothamsted Report for 1976*, Part 1, 240. That analysis has been extended to simulate the growth of the potato crop over an 80-day period in 1974. A simplified version of Monteith's model relates photosynthesis, P, to incident light intensity, I, through the equation

$$P = 1/(a+b/I)$$

where a and b are constant parameters that, for this analysis, were derived from laboratory measurements. After modelling the actual crop growth, opportunity was taken to examine the sensitivity of the model to changes in the chosen values of a and b: changes in a of $\pm 20\%$ would change the predicted final yield of potatoes by $\pm 10\%$, and changes in b of $\pm 20\%$ would alter yield by $\mp 12\%$. A fuller version of Monteith's model includes a parameter s that represents the fraction of incident light that passes through unit leaf area without being intercepted. In modelling the 1974 potato crop, s was taken to be 0·6, a value derived from measurements of leaf distributions for various potato crops. In a sensitivity analysis, assumed s-values of 0·4 and 0·8 predicted yield reductions of 0·2 and 20%, respectively. It may be, therefore, that for the leaf area and radiation of 1974, the chosen s-value of 0·6 was close to that which would result in maximum yield. (Parkinson)

A portable leaf chamber to measure photosynthesis in field plants was described in *Rothamsted Report for 1976*, Part 1, 239. Subsequent tests have shown that, although the chamber fan does generate rapid movement of the enclosed air, the movement is helical, rather than end-to-end, and gives rise to unacceptable gradients in carbon dioxide concentration. An improved instrument has been designed and successfully tested. It consists of two parallel cylindrical chambers—one for the leaf and one for a humidity sensor that permits concurrent measurement of transpiration. A fan circulates air through the leaf chamber and on through the humidity chamber; the resulting airflow promotes a mixing of the chamber air that ensures acceptably low gradients of carbon dioxide concentration. The two chambers are constructed of a plastic, polymethylpentene, that absorbs very little water vapour and thus causes little distortion of the transpiration measurement. (Parkinson, Sillar and W. Day)

The portable photosynthesis chamber would be immensely more useful in field studies if it could be provided with air of various carbon dioxide concentrations that were known and controlled. From measurements at different concentrations, plant resistances to carbon dioxide transfer can be calculated. Because of the bulkiness of gas cylinders and gas mixing equipment, such measurements have previously been undertaken only in the laboratory. A new method has been devised and successfully tested that allows the desired concentrations to be achieved, in the field, and that requires one cylinder only, and that portable, containing air of known carbon dioxide concentration. The key component in the new system is an orifice plate, for which a watch pivot jewel is used. Provided that the gas pressure upstream of the plate exceeds a critical value, which for this system is about 1·0 bar above atmospheric pressure, then the plate generates a gas flow rate that is independent of downstream pressure. Gas leaving the plate is fed to a two-way valve that allows the gas to pass to the leaf chamber either directly or through a carbon dioxide absorber. Several plate: valve units are connected in parallel with each other and in series with the air supply cylinder, and their direct and carbon dioxide-free outflows are combined and routed to the photosynthesis chamber. Thus, by appropriate setting of the various valves, it is possible to pass to the photosynthesis chamber an airstream of different, but known, carbon dioxide concentrations up to a maximum equal to the concentration in the supply cylinder. (Parkinson and Joyce)

Photosynthesis: laboratory studies. Measurement, using a field canopy enclosure, of the effects of temperature, at constant relative humidity, on the photosynthetic rates of

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field-growing wheat, barley and potato plants was reported in *Rothamsted Report for 1976*, Part 1, 240. In continuation of that study, the effects of both temperature and vapour pressure deficit on the photosynthetic rates of pot-grown plants of wheat and field beans have been measured in controlled environment chambers. Air temperature was varied between 15 and 30 °C, and vapour pressure deficit from 5 to 15 mbar. Carbon dioxide uptake, mesophyll resistance, and carbon dioxide evolution during photorespiration and during dark respiration were all determined by gas exchange techniques. Stomatal resistance and leaf water potential were respectively measured by continuous flow porometer and pressure bomb.

As was found for field-growing plants, photosynthesis under constant humidity conditions was maximal at 25°C, and declined by 20% at 30°C. For the field-grown plants, the decline was associated with an increase in both stomatal and mesophyll resistances; for the pot-grown plants, mesophyll resistance, increasing by 3·0 s cm^{-1}, changed much more than did stomatal resistance. At a constant temperature of 25°C, photosynthetic rates were identical at vapour pressure deficits of 5 and 10 mbar. At 15 mbar, photosynthesis declined by 15%: again, mesophyll resistance increased more than did stomatal resistance, and there was in addition a decrease in leaf water potential that was indicative of plant water stress. Under conditions of high irradiance in the field, plants are exposed to both high temperatures and large vapour pressure deficits. These conditions were to come extent simulated in the cabinet when a temperature of 30°C was combined with a vapour pressure deficit of 15 mbar. The resulting photosynthetic rate was less than had been measured at 30°C and 10 mbar, and the decline was associated with increases of 3·0 and 2·5 s cm^{-1} in the mesophyll and stomatal resistances, respectively. Stomatal resistance had also been found to increase for field-growing plants that experienced a similar temperature and humidity regime in the field enclosure.

Dark respiration and carbon dioxide compensation point were both observed to increase with temperature; unexpectedly, the ratio of photorespiration to net photosynthesis showed no dependence on temperature. For each of these findings, the range of observation was from 15 to 30°C. (Leach)

Agricultural meteorology

Analysis of micrometeorological records. Good progress has been made in the analysis of the micrometeorological records that were gathered between 1971 and 1976 on the macro-plots at Great Field I. Effort has been concentrated on the data collected for beans, in 1972, and for potatoes, in 1973. The computer programs for quality control and for wind profile examination have been progressively improved as the analyses have proceeded. The wind profiles measured under conditions of neutral stability have been fitted to the Monin-Obukhov equation (see Legg and Long, *Quarterly Journal of the Royal Meteorological Society*, (1975), **101**, 611–628); from such fitting, values can be determined for three parameters: the friction velocity, the roughness length and the zero plane displacement. These values, and those for the drag coefficients that are also estimated, permit a quantitative description of the differences between the aerodynamic properties of different crops at different growth stages. Analysis of the wind profiles in conjunction with the measured profiles of temperature and humidity has allowed the calculation of estimates for the sensible and evaporative heat fluxes: these are compared with the corresponding estimates derived from the supporting energy balance measurements. (Zemroch, Legg, Long and Gordon)

Irrigation, crop growth and water use

Water use: spring barley. For irrigated spring barley that was grown on Great Field I

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in 1976, the actual evaporation between 1 April, the date of emergence, and 15 July, the date of ripening, was determined by neutron scattering to be (328±8) mm. The corresponding potential evaporation for short grass, E_T, was 338 mm, as calculated by Penman's method. However, the mean evaporation rate was only 0·77 E_T in April and May, when much of the evaporation was from the soil surface, and was 1·24 E_T in June and early July. The evaporation rate exceeded E_T in June and July because barley is taller, and therefore aerodynamically rougher, than short grass. For the same April–July period, evaporation from non-irrigated barley was (244±7) mm, comprising 77 mm of rain that fell after 1 April and 167 mm abstracted from the store of soil water that existed on 1 April.

Fully irrigated barley was grown in 1976 both on the Great Field macro-plots and also on small plots at Little Knott (*Rothamsted Report for 1976*, Part 1, 236). For June and early July, when crops completely covered the ground on both sites, the water use of fully irrigated barley was found to be 13% higher on the small plots than on the macro-plots. The additional transpiration is thought to have been caused by advection of warm dry air from adjacent non-irrigated plots. (French and Legg)

In the 1977 tillage experiment, also on small plots, barley grain yields were found to correlate slightly, and positively, with a measure of plot exposure to advection from adjacent fallow plots: crop water use may demonstrate a corresponding correlation, and analysis of the pertinent data is in progress. (Brown, Woodhead and Dawes)

Spring beans. The commencement of a multi-disciplinary experiment to study causes of variations in yields of spring beans was reported in *Rothamsted Report for 1976*, Part 1, 242. In 1977, the second year of investigation, temperatures were lower than average in every month from April until August; there was an exceptionally dry spell between 26 June and 4 August, and the maximum potential soil water deficit was calculated to be 135 mm for unirrigated plots. Between 2 July and 30 July, irrigated plots received 120 mm of irrigation water: this caused severe lodging and a reduction in yield of 1·1 t ha^{-1}, mean yield being 4·6 t ha^{-1} at 85% dry matter. (Legg, with McEwen, Field Experiments Section, and others)

Grass and legumes. 1977 was an introductory year for the Rothamsted contribution to a multidisciplinary experiment, originating from the Grassland Research Institute, that seeks to study on different soils the causes of variation of grass and legume yields. Plots were laid down at Rothamsted and Woburn, and irrigations were applied to them to maintain potential soil moisture deficit below 25 mm on fully irrigated plots, and below 50 mm on plots that will be unirrigated in 1978 but required good grass establishment in 1977.

At Rothamsted, partial and full irrigation treatments, of 105 and 130 mm, respectively, were applied to plots of ryegrass, clover, lucerne, and grass-clover mixtures. The dry matter yields showed no detectable response to the difference in irrigation. At Woburn, where the partial and full irrigations were respectively 113 and 138 mm, the additional 25 mm irrigation resulted in an increase from 1·7 to 2·4 t ha^{-1} in ryegrass dry matter yield and in insignificant decreases in yields of clover, lucerne and grass-clover mixtures. (Legg, with McEwen, Field Experiments Section, and others)

Movement and deposition of disease spores. An increasing portion of our micrometeorological research is being directed to an investigation of the dispersal and deposition of pathogenic fungus spores. Our studies of these essentially physical processes are being pursued in collaboration with the Plant Pathology Department. A physical model for the dispersal and deposition of spores within a cereal crop has been developed. It aims to

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predict, for a given weather and crop architecture situation, the vertical profile of spore concentrations at any distance downwind of a known concentration profile. Experimental data have been collected against which the model's predictions can be tested. Sources of spores of *Lycopodium* (club moss), and in another experiment of *Erysiphe graminis* (barley mildew), were created within a field of growing barley, and concentrations of the liberated spores were measured at various heights at various distances downwind of the sources. *Lycopodium* was chosen because it afforded a simpler system for study than did the more realistic, but more complicated, *E. graminis*.

For *Lycopodium*, the predictions of the model were in good agreement with the measured values, provided it was assumed that impinging spores could not adhere to barley awns, an assumption that is supported by the findings of other workers. For *E. graminis*, the measured concentrations of spores decreased with downwind distance at a much faster rate than was predicted by the model. The reason for this discrepancy may be connected with the fact that spores of *E. graminis* are released, dispersed, and deposited as clumped, rather than as single, spores. The measured rapid decrease with downwind distance of *E. graminis* spore concentration was attributable mainly to sedimentation, and less to turbulent transport out of the crop.

Further studies of spore deposition, whether by sedimentation or by turbulent transport, and of within-crop spore diffusion, will be prominent in our developing programme of aerobiological research. A new wind tunnel is being constructed and instrumented to facilitate these researches, and the macro-plots of the Great Field site are being so managed as to ensure their future suitability for supporting field experiments. (Legg, with Bainbridge, Plant Pathology Department)

Staff and visiting workers

From October, A. Poulovassilis took up a 1-year appointment as Professor of Agricultural Hydraulics in the University of Athens; for the duration of Poulovassilis' absence, R. I. Price will be attached to the department and will pursue research in soil water physics.

J. E. Leach has been awarded the degree of Ph.D. at London University; Miss N. M. Mal-Allah, Institute of Agricultural Technology, Aski-Kelak, Iraq, has joined the department for a few months to further her studies. J. Connell, R. Green, J. Joyce and R. Sillar all spent several months in the department as sandwich course students, and P. Norman a few weeks as a vacation worker. M. Stead and S. Wilson have joined the department and will give assistance to our soil research, as for short periods did J. Geraghty, M. Harley, K. Heasman, I. Stead and R. Taylor.

Publications

Thesis

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