Report for 1979 - Part 1

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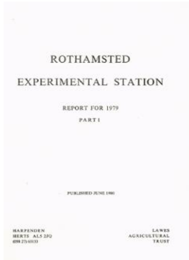
ROTHAMSTED
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REPORT FOR 1979
PART 1

Physics Department

T. Woodhead

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Introduction

1979 saw a gathering of momentum for several of the researches recently initiated in the Physics Department. Work relating to the movement of spray drops, cereal disease spores and pheromone vapours has progressed to the extent that preliminary experiments have been completed both in the wind tunnel and in Great Field. The new facilities for soil water physics have been used to good effect in studies of water flow through media composed of particles of dissimilar shape; and there have been useful advances in the understanding of the hydraulic effects of filter surrounds to drain pipes. There has been progress, too, in the applications of theory to the measurement of soil hydraulic conductivity and soil water pressure—for the latter, it is now possible to determine how best to select a tensiometer appropriate to a particular soil and its water content.

In the longer-established programmes, a drought experiment, similar to an earlier one in 1976, was successfully undertaken. The weathers of 1976 and 1979 contrasted greatly, and from a preliminary analysis of the two years' results it is already apparent that some of the plant responses to drought show an interaction with weather variables other than rainfall—and with temperature in particular. Temperature is an important variable, too, in our continuing studies of soil respiration; and refinement of an analysis of data gathered with sealed respirometers has shown how the temperature-dependence of the respiration can be combined, in one equation, with variables that allow for the continuing depletion of the substrate as respiration proceeds.

During the year there have been many useful developments of equipment and technique. The auxanometers that were described in *Rothamsted Report for 1977*, Part 1, 201, were operated successfully throughout the duration of the drought experiment; and the triaxial test rig and the hydraulic conductivity cell that were reviewed in *Rothamsted Report for*

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1978, Part 1, 200, have each undergone long-term leakage tests, and the triaxial rig is now being used in studies of swelling soils. In preparation for a 1980 tillage experiment an improved design of tensiometer and an associated scanning and measuring system have undergone successful field trials, and it will be possible in 1980 to deploy and monitor 84 such tensiometers. The tillage work will also be helped by a new design of thermal conductivity probe that currently is undergoing laboratory tests; for studies of soil aeration, work is well advanced in the development of a field apparatus for measuring *in situ* the coefficient of gaseous diffusion in soil. In plant physics, future measurements of the transpiration and photosynthesis of individual leaves will be more accurate as the result of the development of a new technique for calibrating humidity sensors—a technique based on the properties of crystals of ferrous sulphate heptahydrate. These individual leaf measurements, and our interpretations of them, will benefit also from the microprocessor units that will soon be incorporated into our porometers and leaf chambers. On a larger scale, data processing capability will be strengthened immensely by the new Hewlett–Packard data acquisition system that is being commissioned in readiness for the 1980 tillage experiment.

In 1979, as in previous years, the Departments of Botany and Soils and Plant Nutrition collaborated in the drought studies, and the aerobiology researches were undertaken in partnership with the Departments of Entomology, Plant Pathology, and Statistics, and with the Chemical Liaison Unit and the Chemical Defence Establishment. Our soils work involved useful cooperations with Soil Microbiology Department, Broom's Barn Experimental Station, the Letcombe Laboratory, the Ministry's Field Drainage Experimental Unit and the National College of Agricultural Engineering.

Soil physics

Soil water

Land drainage. In drained land, the water table height that results from a given rainfall rate depends on the effective radius of the drain pipe. This effective radius depends, in turn, on the geometry of the openings through which the draining water enters the pipe, and on the shape and thickness of any filter that surrounds the pipe. A theoretical study of the hydraulic effect of such filters, for various geometries of drain openings, has shown that the effective radius is more sensitive to changes of filter hydraulic conductivity than to changes of filter thickness. Furthermore, a filter surround much more permeable than the soil, even if it be thin, can ensure that the water table height for a given rainfall rate can be lowered to a level approaching that which would be achieved by theoretically optimum drain pipes installed at the same drain spacings. (Youngs)

Mole drains are used extensively in arable lands in southern England, and experiments recently started at the National College of Agricultural Engineering seek to determine the hydraulic role of the cracks that are produced around (mainly above) a mole channel by the mole-plough blade. So that the effects of the cracks can be isolated and measured, mole drains have been formed in two ways: (i) by a conventional blade-mounted mole bullet and expander, (ii) by jacking a bullet and expander horizontally through the soil between access ditches. Tensiometers have been installed to monitor soil water pressures in the two treatments, and data are being collected. (Towner and Youngs, providing supporting theory to Dr G. Spoor, National College of Agricultural Engineering)

Tensiometers: theory of time response. In laboratory and field experiments changes of soil water pressure can and do take place over periods of an hour or less. If such changes are to be reliably measured, as by a tensiometer, then there must be good understanding of the time response characteristics of the particular tensiometer/soil combination. In the

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measuring process, water is actually exchanged between the tensiometer and the soil, and hence the dynamics of the soil water must be included in any analysis of tensiometer response. The objective of such an analysis might be to ascertain how, for any particular soil and its water content, appropriate specification can be made for parameters of tensiometer performance. Appropriate in that the chosen values would ensure that the time dependence of the measuring process would be determined by the known properties of the tensiometer rather than by the probably unknown properties of the soil water. Towards this objective a theoretical analysis has been completed for tensiometers that have hemispherical cups as their soil water contacting elements. (It is possible that analyses could be successfully undertaken for other geometries also.) Under conditions appropriate to a 'tensiometer-determined' response, it is plausible that the soil's hydraulic conductivity and soil water diffusivity may each be considered constant. With these constancies, and with the initial and boundary conditions appropriate to the soil/tensiometer system, the differential equation that describes the system may be solved, with the help of Laplace transforms, to yield an analytic expression for the time dependence of the water pressure inside the tensiometer cup. The expression includes, as coefficients, combinations of values of physical parameters of the soil and of the tensiometer. By examination of these coefficients, it is possible to fulfil the objective of specifying, for any soil/tensiometer situation, choices of tensiometer parameters that will indeed ensure that the time response is determined by the tensiometer, independent of the soil properties. And for realistic situations the chosen parameters are readily achievable with available components. Furthermore, the analysis shows that under these tensiometer-determined conditions the expression for the time dependence of the tensiometer response has a simple exponential form. There is thus the possibility, for field or laboratory experiments, to transform mathematically a time series of *measurements* of soil water pressure into a series for the *actual* variations in pressure—a series not confounded by the effects of instrument lag. (Towner)

Hydraulic conductivity measurements. The flow of groundwater is of concern in both civil engineering and land drainage engineering. The consequent need to measure the hydraulic conductivity of saturated soils has exercised practitioners in each of these disciplines; and similar measuring methods have been developed, for example by Hvorslev, who measured the rates of intake of water to well points in confined aquifers, and by Kirkham who measured the rate of inflow to a piezometer in a soil with a water table. In each of these methods, the patterns of the flow lines must be allowed for, through shape factors, if the measured flow rates are to yield true values for conductivities. Hvorslev obtained approximate factors by analytic methods, but for Kirkham's method accurate values are available from electric analogue studies (Youngs, *Soil Science* (1968), **106**, 235–237). Comparison of the two methods reveals that they have the same shape factors if the water intake rates are measured at points deep below the respective upper water boundaries. Thus the accurate factors used with Kirkham's method may often be applied with Hvorslev's technique. To this end, a table has been prepared of accurate shape factors that have been determined through electric analogue measurements.

The hydraulic conductivity that is most pertinent to the water relations of arable lands is that which obtains when the soil is only partially filled with water. In such unsaturated states, achieved by draining off water from the macropores, laboratory measurements have been made of the hydraulic conductivities of three assemblages of soil aggregates—aggregates that were of a single graded size range within, but that differed in size range between, assemblages. Results show that at any particular water content in the unsaturated range, values of hydraulic conductivity were the same for all three sets. Furthermore, these values were approximately equal to the hydraulic conductivity at that particular

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water content of the material forming the aggregates multiplied by the fractional volume occupied by those aggregates. (Youngs)

Development of soil water profiles. *Rothamsted Report for 1978* (Part 1, 200) described studies of the development of water profiles in columns filled in two layers by two materials with pores of different size but similar shape. Reference was also made to the scaling according to similarity principles of the layer depths and the flow durations. Attempts have now been made to apply the same scaling analyses to the flows of water through assemblages of variously sized and shaped particles, but with the particles in any particular assemblage having only one shape and size (so far as grading allowed). Analyses were undertaken for various grades of sands and of glass beads, and for two fine silty loam soils. In each analysis, three estimates each for the appropriate scaling factors were derived from measurements of the soil water pressures, the hydraulic conductivities, and the integrals with respect to pressure of the hydraulic conductivities. For the various assemblages, measurements were made of vertical infiltration, horizontal infiltration, and capillary uptake of water; between assemblages, the measurements differed over several decades of magnitude, but were rendered comparable by one or other of the scaling procedures. Specifically, scaling factors derived from the hydraulic conductivities were the most successful in making comparable the vertical infiltration results, and those from the integrated conductivity and from the soil water pressures respectively best fitted the horizontal infiltration and the capillary uptake data. The scaling techniques have also been employed with some success in studies of hysteretic systems, and they seem to hold much promise. (Youngs and Price)

Other work on the hysteretic development of soil water profiles in unsaturated layered soils has import for the water relations in rooting zones in arable lands. If a soil with a water table at depth is saturated near its surface, as by rainfall, then the resulting soil water profile is much influenced by the hysteresis of the water movement. With a permeable layer at the top of the soil profile, as results from ploughing, the soil water desaturates initially near the soil surface, with the soil at lower depths remaining saturated. Without an upper permeable layer, as in direct drilled lands, the whole profile desaturates uniformly. (Youngs)

Soil structure

Tillage. In a 1977 tillage experiment (*Rothamsted Report for 1977*, Part 1, 196) soil temperatures were measured at 3 cm depth at 6 min intervals throughout the growing season on groups of fallow plots that had previously been subjected either to consolidation by a Cambridge roller, to no disturbance, or to a tine cultivation to 30 cm depth. At the time of tillage the plots differed also in their water contents; but, through subsequent waterings, the volumetric water content of the 0–5 cm surface layer of each fallow plot came to the same value, $0{\cdot}11 \pm 0{\cdot}01$, by late May. Thereafter, until a later irrigation, temperatures at 3 cm depth showed differences, generally significant, as between cultivated and undisturbed plots and as between undisturbed and rolled plots that were typically and respectively 1·5 and 1·0 K in maximum temperatures of about 30°C, 1·0 and 0·3 K in daily average temperatures of about 20°C, and 0·6 and 0·4 K in temperature-wave amplitudes of about 10 K. Differences so small as these are likely to have had little effect on the germination of the barley in the adjacent cropped plots, but in a frosty spring, when soil temperature might be close to the germination threshold, such differences could be important.

In the same 1977 experiment, values were determined for the thermal conductivity profiles for the 0–30 cm layers of soil in one cultivated and one undisturbed plot, both

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fallow (*Rothamsted Report for 1978*, Part 1, 199). These values, relating to a period in early July 1977, showed little effect of tillage treatment, but it was argued that treatment effects should be more pronounced nearer to the time of cultivation. However, subsequent analysis of May and June data has shown that when water content profiles were similar on the two plots, so, within experimental uncertainty, were their thermal conductivity profiles.

However, later in the season the cultivated and undisturbed plots did differ in soil thermal conductivity, but this difference arose indirectly: the cultivation produced a difference in pore size distribution, and hence in the movement of water following irrigation. Thus the cultivated plot drained more rapidly than the undisturbed, and had, in consequence of the high thermal capacity of water, a lower thermal conductivity—lower by some 10%. (Brown, North, Dawes and Wilson)

Thermal conductivity probe. Despite the negative evidence from May and June 1977, different tillage treatments are nonetheless expected to produce real differences in thermal conductivity, at the same water content, and such differences would be indicative of differences in soil structure that could be agriculturally important. In order that these thermal differences may be revealed, a greater precision of measurement of soil thermal conductivity is needed, and an improved sensor is therefore being developed. It comprises a 20 cm long, narrow bore (0·7 mm) stainless steel tube probe inside which a fine wire set in epoxy resin electrically generates a constant supply of heat. The resulting change with time of the temperature of the probe, monitored by resistance thermometry, can be directly related to the thermal conductivity of the material into which the probe is inserted. (North and Kellaway)

Data acquisition. In preparation for a 1980 tillage experiment, and for tillage and drought experiments in subsequent years, a Hewlett–Packard computer-controlled data acquisition system was purchased early in the year, and is now being commissioned prior to its installation at Little Knott. Computer programs are being written to help file, retrieve and process the field data, to guard against data loss in the event of mains power failure, and to permit direct on-line input of data from Little Knott to the Station's ICL–470 computer. (North and Cuminetti)

Gaseous diffusion in natural and remoulded crumbs. Measurements of gaseous diffusion coefficient, and of porosity, for natural and remoulded crumbs of Parklands soil—a highly stable grassland soil—were described in *Rothamsted Report for 1978*, Part 1, 198. Similar measurements have this year been made on soil from the unmanured plot on Barnfield—a soil with poor structure and poor stability of structure. In a factorial combination of treatments, the crumbs were moistened either with water or with a water/glucose solution, and were incubated for 1 week either aerobically or anaerobically; all samples were then subjected for three weeks to cycles of wetting and drying. Diffusion and porosity measurements were made before the first and after the fifth cycle of wetting. Predictably, crumb porosity, ϵ_c, initially 0·238, was increased by remoulding; the size of the increase, 0·020, was 99·9% significant, but was smaller than the 0·059 determined for the Parklands soil. The effects of both glucose and of five cycles of wetting were each to decrease porosity by 0·005—trivial, but 95% significant. Diffusion coefficients, expressed as the ratio D_c/D_o of the coefficient within the crumb to that when no impeding solids are present, were increased by remoulding (from 0·039 to 0·048, 99% significant) and were decreased by aerobic incubation (from 0·047 to 0·040, 99% significant). The effectiveness for diffusion of unit pore volume, described by the variable $D_c/D_o\epsilon_c$, was increased by remoulding—from 0·164 to 0·185 (95% significant), demonstrating that the increase in

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D_c/D_o was not merely a reflection of the increase in porosity but indicated also a less complex pore structure within the remoulded crumb. Aerobic incubation also decreased $D_c/D_o\epsilon_c$: from 0·188 to 0·160, 99% significant. (Currie, with Skinner, Soil Microbiology Department)

Gaseous diffusion in field soils. Although coefficients for gaseous diffusion can be reliably measured for soils in the laboratory, there are difficulties of measurement for soils in the field: difficulties that derive in part from the mass flow of gas that results from gradients of total gas pressure. A field method of measurement has now been developed in which corrections for the pressure gradients can be calculated—and have in some situations been shown to be negligible. A hollow metal cylinder, 6·0 cm diameter, 60 cm long and open at both ends, is pushed vertically into the soil. Through a port, midway along the tube, nitrous oxide is injected at a measured rate into the enclosed soil; and through other ports, spaced at 2·5 cm intervals for 10 cm above and 10 cm below the injection port, samples of soil gas may be withdrawn for measurement of their nitrous oxide concentrations. When steady state conditions are established, the measured concentrations, and the known injection rate, allow calculation of the upward and downward nitrous oxide fluxes, and hence of the corresponding diffusion coefficients and of their corrections for gas pressure gradients. Laboratory tests on dry samples, of varying porosities, of sands and soils showed the method to give values for diffusion coefficients that were in excellent agreement with values determined on the same samples by established laboratory methods. (Pritchard and Currie)

Soil respiration. For measurements on a continuously fallowed soil, an initial analysis had shown that within any individual year the relation

$$R_T = R_o \cdot Q^{(T-T_o)/10} \tag{1}$$

would successfully describe the rate of respiration R_T, over a period in which soil temperature was T°C, in terms of the rate R_o at some reference temperature T_o. For weekly values of R_T, values of Q ranged between 2·34 and 2·58, and in any one year the relation accounted for between 0·96 and 0·98 of the variance. However, the analysis suggested also that the substrate for respiration decayed with time, with a half-life of about three years, and a temperature–respiration relationship has therefore been derived that incorporates this decay of the substrate. Respiration, q_n, expressed as carbon dioxide evolution per unit ground area in the nth time period, of length Δt and with temperature T_n, may be expressed

$$q_n = M_o[1-\exp\{(-R_o\Delta t/M_o)Q^{(T_n-T_o)/10}\}][\exp\{(-R_o\Delta t/M_o)\sum_{i=1}^{n-1} Q^{(T_i-T_o)/10}\}]$$

where M_o is the amount of substrate, expressed as CO_2, in unit area of soil at $t = 0$; the temperatures in the preceding periods $i=1, \ldots n-1$ are respectively $T_1 \ldots T_{n-1}$, and R_o/M_o, equal to R_i/M_i, is the rate of CO_2 evolution at $T_o = 0$°C. For weekly averages of q_n and T_i, the equation accounted for 0·98 of the variance for 242 consecutive weeks between May 1970 and December 1974. There was also a suggestion of a phase difference in the annual cycles of q_n and T_n, with respiration lagging behind temperature.

In cropped soils, because there are unknown inputs of CO_2 from the growing roots and their associated residues, it is not possible to establish a temperature–respiration relation that is continuous over the whole growing season. However, cropped soil respiration can be described by equation (1) during each of two periods—the first being before and just after seeding, when respiration is effectively from soil only, and the second occurring later, for about 8 weeks, when the plants are mature and their input of CO_2 to the soil

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is nearly constant. During the latter period, deviations of R_T-values from those predicted by equation (1) were found to correlate strongly with solar irradiance: suggesting a direct influence on root respiration of the photo-assimilation in the leaves. (Currie)

Plant physics

Plant response to water stress

Yield response and nutrient uptake: spring barley. The findings of a 1976 experiment that investigated the effects on barley growth and yield of droughts of various intensities at different growth stages were presented in Parts 1 of the *Rothamsted Reports for 1976*, p. 236, *for 1977*, p. 200, and *for 1978*, p. 195. An experiment in 1979, using the same Little Knott site and mobile rain shelters as in 1976, sought to build upon and extend those findings and to investigate, in particular, the role of specific physiological processes in the barley's response to drought. The processes of leaf growth and senescence, and of the photosynthesis and respiration of single leaves, leaf sheaths and ears, were studied in detail, as was the effect of drought on the uptake of nitrogen and other nutrients. Data of very high quality were gathered throughout the whole growing season: leaf extension was monitored by the auxanometers that were previewed in *Rothamsted Report for 1977*, Part 1, 201, and measurements of the dependence of photosynthesis on light intensity and on carbon dioxide concentration were carried out for some 400 single leaves and heads using the technique that was described in *Rothamsted Report for 1978*, Part 1, 197. Throughout the season there were supporting measurements of the physical environment, both above and below ground, and analysis and modelling of the various plant–environment relationships is under way.

Four drought treatments were applied—full, early, late and no drought. The early and late droughts were imposed during time periods that were determined by the crop phenology so that comparison could be made with corresponding treatments in the 1976 experiment. The full and no drought treatments were additionally, in 1979, combined factorially with a full nitrogen: no nitrogen comparison. The weather in 1979 contrasted markedly with that of the exceptional 1976: temperatures and sunshine durations were much lower. Nonetheless, grain plus straw dry matter yields in 1979, listed in Table 1, were comparable to those of 1976, and grain yields were generally higher. The fully droughted barley, growing on stored soil water only, produced 1·4 t ha^{-1} more of grain plus straw dry matter than did the corresponding treatment in 1976: the increase is ascribable, in part, to a greater exploitation of the soil by deeper root growth. The fully watered (no drought) treatment produced 0·8 t ha^{-1} less of grain plus straw dry matter than in 1976—the measured uptake of nitrogen was also less than in 1976. The 1979 treatments to determine nitrogen: drought interactions (Table 1) showed that under drought conditions nitrogen (applied to the seedbed) depressed yield, particularly of grain, and that with no drought added nitrogen increased yield.

TABLE 1

Dry matter yields at harvest for spring barley on small plots at Little Knott, 1979

	Nitrogen applied at 75 kg ha^{-1}				No nitrogen applied	
	Full drought	Early drought	Late drought	No drought	Full drought	No drought
Grain yield (t ha^{-1})	3·7	4·6	5·1	6·1	4·4	5·3
Straw yield (t ha^{-1})	3·5	4·5	5·6	6·2	3·9	4·8
Grain plus straw (t ha^{-1})	7·2	9·1	10·7	12·3	8·3	10·1
Mean single grain mass (mg)	42	41	45	43	44	43

The standard errors on these preliminary data are typically ±5%.

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As between 1976 and 1979, differences in responses to the drought treatments were apparent most in the grain sizes (Table 1). In 1976, mean grain mass ranged from 29 to 39 mg, and the small grains came from treatments under drought in the grain filling period. In 1979, grain mass ranged from 40 to 45 mg, and though differences in mass were barely significant, the lighter grains came from treatments droughted prior to anthesis. One may surmise from these two years' results that the effect of drought on grain filling is strongly influenced by temperature during the grain filling period. In 1976, duration of grain filling, shortened by the very high temperatures, was probably contracted further by drought, leading to the large treatment differences. In 1979, temperatures were lower, grain filling consequently persisted longer, and drought had little effect. (W. Day, Parkinson, Croft, A. T. Day, Evans, French, Graham, Leach, Legg, Long, Mitchell, Scott and Zemroch, with Lawlor, Dowson and Ridley, Botany Department, and Johnston and Hoare, Soils and Plant Nutrition Department)

Porometer and leaf chamber calibration. Reports of the development of a porometer and a leaf photosynthesis chamber, each operating on continuous flow principles, were respectively contained in Parts 1 of the *Rothamsted Reports for 1977*, p. 201 and *for 1978*, p. 197. Each of these instruments contains a humidity sensor that requires precise and accurate calibration: there thus arises a need to establish a range of constant and known humidities in a flowing air stream. Investigations have shown that if an air stream is passed through a column of crystals of ferrous sulphate heptahydrate, then the relative humidity of the emergent air stream is determined by the temperature of the crystals, provided that their quantity, as determined by the length and diameter of the column, is matched to the required air flow rate. A system has been developed, working at crystal temperatures in the range 10–40°C and at air flow rates up to 4 ml s^{-1}, that establishes the required humidities to a precision and accuracy, as measured by their dew point temperature, of $\pm 0{\cdot}2$ K. (Parkinson and W. Day)

Use of microprocessors. The porometer and leaf chamber do not directly give estimates for transpiration and photosynthesis, but rather give values for other variables from which the required data can be subsequently calculated—using the Station's ICL-470 computer. If these calculations could be completed immediately, in the field, then the measurement programme could be adapted to take account and advantage of the current findings. To this end, development work has started for a microprocessor system that can be incorporated into our field instruments. (Parkinson and Scott)

Agricultural meteorology

Research in agricultural meteorology has this year concentrated on the movement and deposition of aerosols and disease spores. Work in the wind tunnel has been directed to the production and detection of particles of uniform size, and preliminary experiments have been conducted on the Great Field site that has been reserved for this aerobiological programme. Analysis of the backlog of micrometeorological data has continued, and the findings from the first of the analyses—on beans and potatoes—have been submitted for publication.

Movement and deposition of particles

Deposition of aerosols to vegetation of large leaf area index. Aerosols of diameter 10–40 μm can be deposited to vegetation by sedimentation or impaction. The combined deposition, by the two processes, is often expressed in terms of a deposition velocity, which, for complete crop canopies, generally increases with wind speeds. Such increase

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has often been attributed to increased impaction at higher wind speed, but for vegetation with a large leaf area index there can also be a substantial increase with wind speed in the number of particles deposited to the lower leaves by sedimentation. This increase in sedimentation can be estimated if the vertical distribution of foliage and the variation with height of the turbulent diffusion coefficient, K, are known. The estimation requires the solution of a differential equation, and the equation has been solved for a uniform leaf distribution and with K, among the foliage, assumed to depend linearly or exponentially on height above ground level. For K-profiles having these dependencies, and chosen also to be compatible with realistic values for the friction velocity, u_*, sedimentation rates have been calculated for 30 μm particles depositing to two hypothetical crops, of horizontal foliage area densities 2·0 and 4·0, and each 1·0 m tall. For these two foliar indices, respectively, the deposition velocity due to sedimentation alone increased by factors of 2·2 and 3·4 as u_* increased from 0 to 0·7 m s^{-1}. These increases are comparable with those found by Chamberlain and Chadwick (*Annals of Applied Biology* (1972), **71**, 141–158) for *Lycopodium* (club moss) spores depositing to dry cereals and grass. (Legg and Price)

Electric charge and the deposition of barley mildew spores. If the spores of barley mildew (*Erysiphe graminis*) carry electric charge, then the theories that would describe their motion and deposition would necessarily be much more complex than the theory of aerosol deposition just described. To determine whether the spores do carry charge, comparative experiments on infected and uninfected barley plots have been carried out on the Great Field site. The experiments, benefiting from a collaboration with the Chemical Defence Establishment, sought charges through three different methods: (i) direct measurement by a sensitive electrometer of the charges carried by spores entering, during a 3 h period, spore traps deployed on the two plots, (ii) by measuring upwind and downwind of infected plots the electric field intensity in the air layer 0–5 cm above ground level, (iii) by comparison of the numbers of spores captured by positively, negatively, and neutrally charged cylinders of 5 mm diameter oriented vertically a few cm above an infected crop. Rigorous theoretical analyses of the sensitivities of the three methods, for charged particles of 20 μm diameter, have been carried through, and show method (iii) to be the most sensitive—capable of detecting a spore charge of 8×10^{-15} coulomb (the magnitude of 5×10^4 electron charges). The same analysis showed that charges less than 8×10^{-13} coulomb (5×10^6 electron charges) are not likely to affect either impaction or sedimentation of spores to a field-growing barley crop, and that methods (i) and (ii), as well as method (iii), had adequate sensitivity to detect charges of this magnitude. In the experiments, all three methods gave null results, and it is thus concluded that if naturally released barley mildew spores do carry electric charges, these are so small that they will not influence the spores' deposition. (McCartney, Legg and Strange, with Bainbridge, Plant Pathology Department, and Dr. C. D. Jones, Chemical Defence Establishment)

Chemical labelling of spray drops. Studies of the spread of mildew spores within a crop canopy would ideally require the release of known numbers of spores and the subsequent monitoring of their concentrations at various heights within the canopy. To simulate this unattainable ideal, one may use liquid drops of similar size to the spores; and by adding a fluorescent tracer to the liquid, the deposition patterns of the sprayed drops can be measured. Laboratory tests have shown that thiabendazol and fluorescein, in polyethylene glycol, can each be successfully sprayed and traced and that, furthermore, either chemical, if deposited on barley leaves, can be quantitatively and completely re-

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covered by washing with acid. (McCartney and Marsden, with Cayley, Chemical Liaison Unit)

Diffusion of gaseous plumes within crop canopies. For some insects of agricultural importance the female can attract a male by releasing a pheromone vapour. For pea moths there is evidence that males can be attracted, by a mechanism that is not fully understood, from as far as 100 m downwind. A possible mechanism could be provided by individual gusts of wind that persist in a constant direction for 100 m: a male could thus locate the female by flying upwind when pheromone concentration was maximal, and ignoring any change of wind direction that was accompanied by a decrease of concentration.

To seek evidence for this mechanism, a plume of nitrous oxide, released from a point source within a mature barley crop, was continuously monitored, for concentration, by a downwind sampler; wind direction, alongside the sampler, was also recorded continuously. The correlation between these concentration and wind direction data, and the dependence of the correlation on source-to-sampler distance, would provide such evidence, and they are currently being calculated. The concentration data have shown, already, that if the flow of nitrous oxide is stopped at the source, then at 10 m downwind, nitrous oxide will continue to be detected for about 1 min: a time much longer than would be required for a parcel of air to travel directly from source to sampler, even for a speed as low as $0{\cdot}5\ m\ s^{-1}$. We thus conclude that significant amounts of gas are delayed, possibly in slowly moving air pockets near the ground, or by absorption and subsequent release by soil or plants. The movement of pheromone vapours may be similarly complicated. (Legg and Strange, with Wall, Entomology Department and Perry, Statistics Department)

Staff and Visiting Workers

I. F. Long retired in March: apart from an interlude of war service he had worked continuously at Rothamsted since 1939. The quality of his instruments and measurements in micrometeorology was renowned in Britain and overseas, and his sets of field data, impressively complete, supported many important advances in agricultural meteorology.

A. Poulovassilis returned from his Athens secondment, and R. I. Price, attached to the Department during Poulovassilis' absence, left for Australia. R. Cuminetti joined the Department in June to give support to the tillage and drought studies. N. J. Fletcher left in September to resume full-time education, and A. G. Dailey has, from November, given assistance in soil water physics research. M. H. Evans, C. Gardiner, Rachel A. Kellaway and C. R. Mitchell all spent several months in the Department as sandwich course students, P. K. Marsden a few months as a temporary assistant, and R. Graham a few weeks as a vacation worker.

N. J. Brown, P. F. North and T. Woodhead attended the Eighth Conference of the International Soil Tillage Research Organisation, held in Stuttgart, and B. J. Legg spent a week in Wageningen, giving two lectures and discussing different proposed models for disease spore dispersal. Within Britain, several members of the Department presented papers and gave courses of lectures at various colleges, universities and conferences.

Publications

General Paper

1 WOODHEAD, T. (1979) Physical properties of the soil that may limit yield of cereals. *Proceedings of ADAS-ARC Symposium (Harrogate)*. In: *Maximising yields of crops.* London: HMSO, pp. 57–62.

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PHYSICS DEPARTMENT

Paper in Rothamsted Report, Part 2

2 Croft, J., Day, A. T. & Woodhead, T. (1980) Rothamsted and Woburn weather: 1970–79. *Rothamsted Experimental Station Report for 1979*, Part 2, 91–103.

Research Papers

3 Currie, J. A. (1979) Rothamsted studies of soil structure IV. Porosity, gas diffusion and pore complexity in dry soil crumbs. *Journal of Soil Science* **30,** 441–452.

4 Currie, J. A., Bullock, P. & Thomasson, A. J. (1979) Rothamsted studies of soil structure I. Purpose of the project, soils selected, and general conclusions. *Journal of Soil Science* **30,** 377–390.

5 Day, W. & Parkinson, K. J. (1979) Importance to gas exchange of mass flow of air through leaves. *Plant Physiology* **64,** 345–346.

6 (Harrison, R. M.) & McCartney, H. A. (1979) Some measurements of ambient air pollution arising from the manufacture of nitric acid and ammonium nitrate fertiliser. *Atmospheric Environment* **13,** 1105–1120.

7 (Harrison, R. M.) & McCartney, H. A. (1979) Ambient air quality at a coastal site in rural North West England. *Atmospheric Environment* **14,** 233–244.

8 (Johnson, P. A.) & Zemroch, P. J. (1980) Manurial experiments with spring barley on non-chalk soils. *Experimental Husbandry* **36,** 34–43.

9 Leach, J. E. (1979) A field enclosure apparatus for measuring crop photosynthesis. *Annals of Applied Biology* **92,** 125–132.

10 Leach, J. E. (1979) Some effects of air temperature and humidity on crop and leaf photosynthesis, transpiration and resistance to gas transfer. *Annals of Applied Biology* **92,** 287–297.

11 Legg, B. J., Day, W., Lawlor, D. W. & Parkinson, K. J. (1979) The effects of drought on barley growth: models and measurements showing the relative importance of leaf area and photosynthetic rate. *Journal of Agricultural Science* **92,** 703–716.

12 Legg, B. J. & Price, R. I. (1980) The contribution of sedimentation to aerosol deposition to vegetation with a large leaf area index. *Atmospheric Environment* **14,** 305–309.

13 North, P. F. (1979) Rothamsted studies of soil structure VI. Assessment of the ultrasonic method of determining soil structural stability in relation to soil management properties. *Journal of Soil Science* **30,** 463–472.

14 Parkinson, K. J. & Day, W. (1979) The use of orifices to control the flow rate of gases. *Journal of Applied Ecology* **16,** 623–632.

15 Pritchard, D. T. (1979) Carbon dioxide production in soils, under barley, subjected to a range of drought treatments. *Journal of the Science of Food and Agriculture* **30,** 547–557.

16 Youngs, E. G. (1980) The analysis of groundwater seepage in heterogeneous aquifers. *Hydrological Sciences Bulletin* **25,** 155–166.

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