Report for 1982 - Part 1

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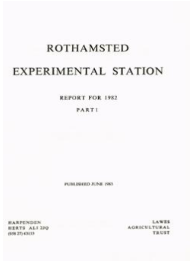
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PART 1

Physics Department

T. Woodhead

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Introduction

This 1982 report is the last report from a Physics Department that since 1913 has been the flag-bearer of agricultural physics research in Britain. In future years, research conducted by the Station's physicists will be described in the *Rothamsted Reports* of the Physiology and Environmental Physics Section and of the Soils and Plant Nutrition Department.

In 1982, work undertaken in Australia in collaboration with CSIRO investigated the effects of wind turbulence on the dispersal of heat above simulated rough ground cover and within a model crop canopy; the same dispersal process affects the movements of disease spores, pollen grains, and gases. Experiments using linear and planar heat sources showed that above rough surfaces turbulent dispersion can be modelled by diffusion theory; within canopies, diffusion theory is not applicable, and two alternative theories using Markov chain trajectory simulation and second order closure of the heat and momentum conservation equations, are showing promise of useful applicability. In crop physics, a rain-sheltered experiment at Rothamsted studied the effects of the timing and duration of drought on the growth and yield of winter wheat. Early drought depressed straw yield and increased harvest index, and late drought reduced mean grain mass; but neither of these effects was large, and the grain yield of fully irrigated plants, 7·6 t ha^{-1}, was only 0·5 t ha^{-1} higher than for unirrigated plants. In the modelling of crop response to drought, useful relationships have been derived, for spring barley, between the maximum lamina length of leaves and the proportion of plant extractable water remaining in the root zone. Excess, rather than shortage, of soil water is an important factor in the leaching from soil of fertilizer and other salts, and new theoretical work has exposed the limitations of models currently used to describe such leaching. Drainage of excess water has featured prominently in other components of the Department's soil-water

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research. The drainage equations currently available to the drainage designer have been reviewed and compared in a numerical analysis, and the most accurate of these equations have been cast in a convenient graphical form. In the field hydraulic conductivity of saturated soil below the water table may be measured using piezometers; in an analogue simulation, shape factors have been derived for piezometers that can be installed horizontally (from access pits) rather than vertically—an installation procedure that avoids disturbance of the soil above. In studies of soil structure, new results suggest that in swelling soils the diffusion of gases may be considered as a three-stage function of water content—as compared to a two-stage function in non-swelling soils; and effects of tillage on soil temperature have been demonstrated to be of a magnitude that may affect plant growth.

As an adjunct to the studies of gas diffusion, a computer simulation study has shown that an assumption that the diffusing gases are well mixed leads to inaccuracies of measurement of order 2–3%; patterns of change (relative values) can be assessed with higher precision. For the diffusion of soil water, the use of dimensionless (scaled) versions of space and time variables can be useful (*Rothamsted Report for 1979*, Part 1, 156) in situations where there is a known flux of water at some boundary. Such a technique is useful, for example, in deriving theories for water flow to roots or for groundwater recharge. Scaled variables have in the past been used mainly for conditions of constant boundary flux, but new methods have been developed in which it is possible to accommodate a time-varying boundary flux. In another development of technique, a design for a null-point tensiometer has been prepared, and production of a working system is proceeding, as is a theoretical consideration of the effects of any entrapped air bubbles on the performance of such a tensiometer.

In 1982, as in previous years, the Departments of Botany and of Soils and Plant Nutrition collaborated in the drought studies, and the Soil Survey in an investigation of the effects of tillage on the size distribution of soil pores. Work on the dispersal of fungal pathogens continued in association with the Plant Pathology Department and with CSIRO, Australia, and help was given to the programme of potato research undertaken at Woburn by the Departments of Entomology and of Plant Pathology. The investigation of shape factors for piezometers was carried out in conjunction with the Letcombe Laboratory.

Agricultural meteorology

The process of dispersal of atmospheric entities, such as disease spores, pollen grains, heat, and gases, has this year been studied by members of the Department both in field experiments at Rothamsted and in wind tunnel experiments in Australia. The latter experiments, performed under strictly controlled conditions, aimed to extend our understanding of the fundamentals of those aspects of wind turbulence that have a particular bearing on dispersal within crop canopies.

Measurement and deposition of particles.

Deposition of drops generated by a point source. In studies of cereal disease epidemiology it is important to know where spores, after they are liberated at some point, are subsequently deposited, and how the pattern of deposition is affected by wind conditions. Such information will help in the exploitation of disease control methods based on growing mixtures of cultivars of differing disease susceptibilities. Experiments were therefore conducted—using a spinning disc generator as an effective point source of spherical drops of 20 μm diameter—to measure the rates of deposition of drops as a function of lateral distance from the source and of height above ground, for conditions progressing from bare soil to full cover by a mature barley crop, and for the source fixed

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at mid-crop height. Along the direction of the mean wind and for a particular mean wind speed, decrease of deposition with distance from the source was affected rather little by foliage density once the canopy had closed. The cross-wind spread of deposition, as would be expected, showed influences of fluctuations of wind direction, and showed also modifications caused by changes in crop foliage density. (McCartney and Quayle, with Bainbridge and Creighton, Plant Pathology Department)

Dispersal of drops generated by a line source. To provide data against which to test models for spore dispersal within a barley crop, measurements were made on six occasions during July and August—when crop structure changed rather little—of the profiles of drop concentration and of rates of deposition to horizontal and vertical surfaces. The drops, 40 μm in diameter, were generated as a line source within the barley crop, and the concentrations and depositions were determined using the technique of chemical labelling that was described in *Rothamsted Report for 1979*, Part 1, 161. The horizontal and vertical surfaces on to which rates of deposition were monitored respectively comprised rectangular plastic strips, $1{\cdot}0 \times 4{\cdot}0$ cm, and glass rods of 4·0 mm diameter. Measurements of the drops were complemented by meteorological measurements: of profiles of temperature, water vapour pressure, wind speed and net radiation, and of soil heat flux at 3 cm depth, and of wind direction fluctuations above the crop. On each measurement occasion a determination was made of the profiles of the crop's leaf and stem area. Chemical analysis of the deposition rates and preliminary analysis of the meteorological data have been completed, and the fitting of these data to various dispersal models is now in progress. (McCartney and Quayle, with Bainbridge, Plant Pathology Department)

Applicability of turbulent dispersion theory. One approach to the modelling of the turbulent dispersal of small particles within a crop canopy is to consider the process to be analogous to molecular diffusion, but with a diffusion coefficient that is much larger and that varies with height. This approach is hereafter referred to as diffusion theory. The collaborative work pursued with CSIRO, Australia, has sought to determine the limits of applicability of diffusion theory, and to test the alternative theories of second order closure of the momentum and heat conservation equations, and of Markov chain simulation of fluid particle trajectories.

The experiments were conducted using neither solid nor liquid particles, but small quantities of heat that can be considered to constitute passive additives that do not affect the air flow. The turbulence characteristics of the air flows were studied for two simulated conditions of ground cover: a rough surface comprised of gravel particles $\sim$9 mm diameter—representing rough fallow ground, and an array of aluminium strips, 60 mm tall, serving as a small-scale model crop. Three different arrangements of heat source were used, all composed of electrically heated wires: (i) an elevated horizontal line source, transverse to the wind tunnel air flow, used with each of the simulated ground covers, (ii) a $1{\cdot}6 \times 2{\cdot}9$ m horizontal plane source, laid on the gravel surface and used only with that particular ground cover, and (iii) a $1{\cdot}6 \times 2{\cdot}1$ m horizontal plane source positioned at a height of 47 mm amongst the elements of the model crop, and used only with that model. For each of these source arrangements, measurements were made, at a sampling rate of 2000 data points per second throughout a 20 second period, of values of air temperature (θ) and streamwise (u) and vertical (w) wind speed at twenty heights at each of six downstream positions. Analysis of the data best proceeds in terms of θ', u' and w'—the fluctuations from their respective means $\bar{\theta}$, $\bar{u}$, $\bar{w}$ of the three measured variables—and of the mean values of the several double and triple products, such as $\overline{u'\ \theta'}$, $\overline{w'\ w'\ \theta'}$. Budgets for $\bar{\theta}$ and for the double product (second order) covariances were calculated, and

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from them were inferred the relative importance of advection, dissipation, turbulent production and transport, and a term that incorporates the pressure fluctuations. The measured data allowed also a test of the applicability of the three dispersion theories here investigated.

For the line source disposed above the rough gravel, the budget in $\bar{\theta}$ was characterized by a balance between streamwise advection of heat and a vertical flux divergence—the streamwise flux divergence was in comparison small. The importance of streamwise advection, especially near to the source, was manifest also in the budgets of the covariance terms. Data for the vertical flux density $\overline{w' \theta'}$ showed that simple diffusion theory gave predictions that accorded well with observation except near the source where the theory is known to be inapplicable. Diffusion theory was reasonably successful also in predicting values for the streamwise flux density $\overline{u' \theta'}$ provided that the full tensor form of the diffusion coefficient was used. In the closure models, approximations for triple product covariances are sought in terms of the double product terms, so that the equations for $\bar{\theta}$ and for the double product terms can be 'closed' and hence solved. For the line source above the gravel, results showed that reliable approximations could be obtained for some, but not all, of the triple products. For the plane source on the gravel surface, budgets were simpler than for the line source because the streamwise derivative terms were very small. For diffusion theory, the ratio of the coefficient for vertical diffusion of heat to that of momentum was found to be 1·0 above 50 mm height, but increased below 50 mm to a value of about 2·0 just above the gravel. The latter result, though unexpected in this wind tunnel experiment, is consistent with recent field observations made above forest canopies; our measurements are unfortunately not able to indicate what mechanism causes this ratio to be 2·0 rather than 1·0. For the experiments with the model crop, the applicability of diffusion theory and of the second order closure models is still being investigated.

As a third approach to the modelling of turbulent dispersion, a Markov chain model was developed to simulate the trajectories of fluid particles. The model, which allows for streamwise and vertical fluctuations of the variables, and for skewed distributions of u' and w', was tested against data collected for the elevated line source deployed above the rough gravel. Results showed that simulated profiles of $\bar{\theta}$ were close to observed values for all distances downwind of the source—including small distances where diffusion theory was inadequate. Profiles of $\overline{u' \theta'}$ were also well simulated close to the source, but less well at larger distances. The success in predicting $\overline{u' \theta'}$ is encouraging, since $\overline{u' \theta'}$ is analogous to the correlation between instantaneous wind speed and spore concentration that is thought to be important for the field dispersal of fungal pathogens. For application within crop canopies, the Markov model must be refined—essentially to allow for the presence of a vertical pressure gradient force that results from the gradient of vertical velocity variance. A Markov model that accommodates this force has therefore been developed and shown to give predictions that agree, for large downwind distances, with those derivable from diffusion theory. Analysis is now proceeding to determine whether the predictions of this refined Markov model are in accord with measurements made for the aluminium model crop using the line source and the elevated plane source. (Legg, with Drs M. R. Raupach and P. A. Coppin, CSIRO Division of Environmental Mechanics, Canberra, Australia)

Plant physics

Response of cereals to water stress

Water use and growth and yield: winter wheat. Measurements and analyses of the effects of the timing and duration of drought on the growth and yield of field-grown spring

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barley were described in *Rothamsted Report for 1981*, Part 1, 180 and in several earlier *Reports*. In 1981/82 a similar study was conducted with winter wheat, using mobile shelters to keep rain off all the experimental plots, and applying or withholding irrigation in various regimes to give droughts of different durations at different stages of crop growth. The experiment sought to determine the limiting soil moisture deficit for winter wheat on Rothamsted soil, to identify the drought-sensitive processes and their influences on crop yield, and to provide data sets and physiological information in support of ARC's four-institute winter wheat modelling exercise. It also sought to match, during the first six months of growth, the cultivations, management practices and crop development that were experienced by winter wheat plants on a multifactorial large-plot experiment on a neighbouring field (p. 19).

Seed, of variety Avalon, was sown, with a basal fertilizer (N-P-K 0-14-28), on 23 September 1981; plants emerged about 3 October. To maintain similarity with the neighbouring multifactorial experiment, the plants were not sheltered from rain or other weather elements over the winter, and they experienced snow and very low air temperatures during December and January. Nitrogen fertilizer, 40 and 140 kg N ha^{-1}, was applied on 11 February and 16 March 1982 respectively; between 17 and 21 March some 15 mm rain helped incorporate the later nitrogen into the soil water solution, and the experimental plots were sheltered, during rain periods only, from 23 March. The first irrigations were made (or withheld from the plots that were scheduled for early or continuous drought) on 7 April—the date defining the commencement of treatment differences and comparisons. Subsequently, irrigation was applied each week in quantities equal to the preceding week's transpiration—as determined by Penman's method and by soil-water monitoring by neutron scattering—except that to avoid over-watering and through-drainage, the moisture deficits were not reduced below 25 mm. Any plot re-watered after a drought treatment received water applications equal to the preceding week's transpiration—plus an additional 10 mm weekly until the deficit was reduced to 25 mm.

On the treatment irrigated each week from 7 April the total water use by harvest on 6 August comprised 305 mm of irrigation water plus 41 mm of extracted soil water. On the plots that received no water after 21 March, water use was equal to that on the fully irrigated plots until 20 May, when some 140 mm of stored soil water had been extracted from these unirrigated plots. After 20 May, the unirrigated plants used much less water than the irrigated, and by 20 July water use on these plots was 238 mm: some 108 mm less than on the fully watered plots. The unirrigated plants extracted water from as deep as 2·0 m—the lowest depth of sampling—but only 3 mm of the 238 mm total came from below 1·9 m, and only 25 mm from below 1·6 m. As would be expected, water was extracted first from near the soil surface: by 20 April the upper 0·2 m of soil had been depleted by one half of the water eventually extracted, by 4 May when water stress first affected leaf growth the corresponding depth was 0·7 m, and by 20 May when transpiration was affected the depth was 1·1 m. Measurements of leaf area and growth showed that leaf area index (LAI) for all plots was 1·2 on 23 March and 1·9 on 7 April, and by 4 May had increased to 5·4 on irrigated plots, but to only 4·3 on unirrigated ones. On the irrigated plots LAI was maintained at its maximum ($\sim$5·5) until early June, but on unirrigated plots had declined by then to 3·9. Through most of June and July, LAI was twice as large on fully irrigated as on unirrigated plots, and on all plots fell to zero by late July. Only leaves 11, 12 and 13 appeared after the commencement of the different watering treatments, and only they therefore could be expected to show differences in date of appearance or in rate or duration of extension or of maximum length as a result of those treatments. In fact, watering treatment had no effect on date of leaf appearance or on duration of extension, and leaf length was affected significantly only for leaves 12 and 13

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where maximum lamina lengths on fully irrigated and unirrigated plots respectively were 273 ± 7 and 238 ± 6 mm for leaf 12 and 233 ± 12 and 194 ± 6 mm for leaf 13.

Weighings of plant material were made on eight sampling occasions and at final harvest. Fully irrigated plants were slightly heavier in early July than unirrigated, but at final harvest differences in total dry matter (straw plus grain) were barely significant: 20·6 t ha^{-1} was accumulated by fully irrigated plants and also by plants irrigated until the second node stage, and 19·0 t ha^{-1} by unirrigated plants: on other treatments totals of dry matter were intermediate between these values. Differences in harvest yield of grain were correspondingly small: largest yield, of 7·8 t ha^{-1}, was achieved not by the fully irrigated plants but by those irrigated only until second node stage: lowest yield, of 7·1 t ha^{-1}, was however recorded for the unirrigated plants. The components of grain yield showed little effect of treatment, though irrigation before anthesis did reduce mean grain mass, and grain development on the unirrigated plants was some four days earlier than on the fully irrigated—probably a reflection of the generally earlier senescence of the unirrigated crop. Yield of straw was highest, 13·1 t ha^{-1}, and harvest index lowest, 0·37, for the fully watered plants; yield of straw was lowest, 11.7 t ha^{-1}, and harvest index highest, 0·40, for plants not irrigated until one week after anthesis. Thus, notwithstanding a maximum soil moisture deficit of 240 mm on the unirrigated plots, and a difference of some 40% in total water use as between the extreme treatments, grain yield, on this Rothamsted site, of the winter wheat variety Avalon was little affected by drought in 1981/82, and no reliable estimate can be given for the limiting soil moisture deficit, but measurements did show that straw yield was depressed, and hence harvest index increased, by early drought, and that late drought tended to reduce mean grain mass.

Physiological and environmental observations, of net photosynthesis, dark respiration, rooting patterns, amino acid and sugar contents, stomatal conductance and plant water potentials, and of irradiance and soil and air temperature, are currently being analysed, fitted to crop growth models, and compared with findings of the multifactorial large-plot wheat experiment. Preliminary results show that for leaves 12 and 13 stomatal conductance was some 20% higher on fully irrigated than on unirrigated plants; there was no effect on earlier leaves. Leaf water potential was unaffected by treatment until 20 April; thereafter the midday value for the unirrigated plants fell from −0·95 MPa (−9·5 bar) to −1·95 MPa by 9 July: during the same period the value for the fully irrigated plants was roughly constant at −0·90 MPa. Measured rates of net photosynthesis of leaves were fitted by the four-parameter model that was described in *Rothamsted Report for 1981*, Part 1, 180; initial findings demonstrate that the light efficiency is not so temperature-sensitive in winter wheat as it was in spring barley, that photorespiration and dark respiration increase with temperature, and that mesophyll conductance decreases with leaf age. (Parkinson, Leach, Scammell, Brown, Croft, Cuminetti, Day, French, Harrison, Shah, Tuck and Woodhead, with Lawlor, Botany Department, and Johnston and Weir, Soils and Plant Nutrition Department)

Leaf growth and crop development: spring barley. An analysis summarized in *Rothamsted Report for 1981*, Part 1, 180 showed that in spring barley the maximum lamina length of leaves 5–9 was significantly reduced by drought, and that this reduction was caused by differences in rates rather than durations of extension. These effects on lamina length have now been linearly correlated with a soil-water variable, viz. the proportion of plant extractable water remaining in the root zone during the growth phase of the particular leaf. For each leaf, four different values for the soil-water variable were set by the four imposed drought treatments: drought from emergence to harvest, drought from emergence to one week after anthesis, drought from six weeks after emergence to harvest, and no drought. For leaves 6, 7 and 8, the measured values for maximum lamina length

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were related to the soil-water variable through one single straight line equation; a linear dependence was found for leaf 9 also, but of a lesser slope, indicating a smaller response to drought. The duration of the phase of maximum lamina length also correlated with the soil-water variable, but the rate of senescence did not.

The adaptation for spring barley of Dr J. T. Ritchie's mathematical model for the growth and yield of winter wheat was described in *Rothamsted Report for 1980*, Part 1, 166. A required component of that adaptation is a submodel to describe the rate of progression through successive growth stages; such a submodel has now been developed. It relates the duration of growth stages to the time integral of temperature (the 'degree day' value), and allows for effects of daylength during primordia initiation and for effects of water stress as mediated through increased leaf temperature and through effects on leaf length and area that are expressed in terms of the plant extractable water remaining in the root zone. Parameters for this phenology submodel have been determined from rain-sheltered experiments conducted in 1976 and 1979, and the submodel has been incorporated into the computer program formulation of the full crop-growth model. That full model is now being used to simulate growth and yield of spring barley at Rothamsted for each of the 20 years 1962–81, and the simulated yields will be compared with the yields actually recorded; if the simulations are successful, they will permit an estimation of the loss of barley yield that can be ascribed to water stress. (Scammell, Leach and Woodhead, with Dr W. Day, Long Ashton Research Station)

Soil Physics

Soil Water

Leaching of soluble salts: a physical model. In some currently used (field capacity) models for the redistribution down a soil profile of soluble salts applied to the soil's surface, the assumption is made that the amount of water transferred into a soil layer from the layer immediately above is equal to the excess over field capacity of the water content of that higher layer. There is a further assumption that the additonal water that carries the salts into the soil—whether it be irrigation water or rainfall—moves from layer to layer as one parcel. These assumptions have been examined through a theoretical treatment of the leaching process using a simplified version of the dispersion equation in which the diffusive term is omitted—thus yielding the convection equation. This convection equation can be solved analytically, and it can also be approximated by a finite difference representation that can be shown to be the same as that which results from an algebraic formulation of the field capacity models. Both analytical and numerical solutions therefore were derived for the case of surface-applied salts being redistributed by surface-applied water draining to field capacity. Results showed that the assumptions of the field capacity models are invalid—in particular, the amount of transferred water cannot be equated, nor even approximated, to the excess over field capacity of a layer's water content. (Towner)

Land drainage. For the design of land drainage installations, drainage engineers have recourse to various equations that relate water-table height, drain spacing, depth of impermeable barrier, the nature of the drain channel, the drain discharge, and the hydraulic conductivity of the saturated soil. These equations each involve their own specific physical assumptions and mathematical approximations, and it is not clear how accurate each is. For the case of cylindrical ideal drains in a soil above an impermeable barrier, eleven drainage equations have been examined, both as regards their assumptions and approximations and also as regards their accuracy as assessed by comparing their predictions with measured data and with accurate theoretical predictions derived for the

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cases of infinite soil depth and of the drain laid on the impermeable barrier. Most of the equations were inaccurate, but those formulated by Hooghoudt and by Childs gave acceptable results, and they have been put into a graphical form convenient for the land-drainage designer. (Youngs and Lovell)

In a drainage experiment conducted by the Letcombe Laboratory and the MAFF Field Drainage Experimental Unit, measurements are being made *in situ* of the hydraulic conductivity of the site's clay soil. The conductivities are measured with the piezometers that are used also to monitor soil-water pressures on the site and that are installed horizontally from access pits rather than vertically from the soil surface so as to avoid soil disturbance in a vertical plane. The rate of water flow into a piezometer depends on the piezometer's geometry and orientation, and conductivities can be derived from piezometer measurements only if shape factors are known for the particular tips forming the piezometer cavities. Using an electric analogue method, shape factors have been determined therefore for horizontal piezometers with perforated cylindrical cavities—as used in the drainage experiment—and also for horizontal piezometers with open cylindrical cavities. Results showed that for the piezometers with perforated tips the shape factors were approximately half those for an open cavity. In field use, the perforated tip piezometers yielded values for hydraulic conductivity that were similar to those determined from laboratory measurements on undisturbed soil cores. (Youngs and Dailey, with Dr M. J. Goss, Letcombe Laboratory)

Flow in heterogeneous media. Although classical soil-water theory treats the soil as a continuum, the soil-water system of interconnected pores between solid particles is inherently heterogeneous. The validity of continuum theory depends on there being a representative elementary volume of soil that can be considered to be repeated throughout the soil volume under study. Heterogeneities at a scale larger than this elementary volume cause difficulties in the development and use of predictive theories of soil-water behaviour. For additive properties, such as soil-water content, the value for an extensive heterogeneous volume can be shown to be equal to the weighted mean of the values for the constituent elemental volumes. With transport properties, such as hydraulic conductivity, matters are more complicated. For example: for flow between parallel planes, macroscale hydraulic conductivity of one class of porous body is given by $\sqrt[3]{(K_a^2 K_h)}$, where K_a and K_h are respectively the arithmetic and harmonic means of hydraulic conductivities of the constituent elements. However, the measurement of soil-water properties at a point is difficult, and for many purposes it is easier and more appropriate to measure directly the bulk properties of the extensive system. (Youngs)

Soil Structure

Tillage. Reference was made in *Rothamsted Report for 1980*, Part 1, 169 to measurements by moisture characteristic (suction curve) analysis (MCA) and by image-analysing computer (thin section analysis, TSA) of the pore size frequency distributions at various depths in undisturbed and tilled plots of a 1980 tillage experiment. Distributions determined by MCA relate to three-dimensional properties of the soil, such as concern the statics and dynamics of soil water, but the relation depends on the particular function that is chosen to express the correspondence between pore size and soil-water suction. Conversely, TSA gives a direct measure of pore size—but in two dimensions only. Results from the 1980 experiment showed qualitative agreement between the determinations of tillage-induced changes in pore size distribution that were respectively made by TSA and by MCA of both laboratory and field data; however, the changes were determined as more significant by MCA. Moreover, TSA did not reveal the progressive loss of pore space with increase of depth to 30 cm (the depth of cultivation) that was found

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by both laboratory and field MCA for both tilled and undisturbed plots, and that was confirmed by bulk density measurements. The lower limit of pore resolution by TSA was about 90 μm diameter: below this diameter, porosity was determined as zero for all depths and both treatments. In contrast, MCA, both in laboratory and *in situ*, showed large effects of both depth and treatment on the porosity ascribable to pores of <90 μm equivalent diameter.

Although the laboratory and *in situ* MCA determinations of pore size frequency distributions were in qualitative agreement, they differed quantitatively. The laboratory measurements showed less pore space at a given pore size (or suction) than did the *in situ* measurements, so that laboratory estimates for the total volume of transmission pores (<50 μm equivalent cylindrical diameter) were less than the field estimates; correspondingly, the slopes of the moisture characteristic curves were markedly different, particularly for pores less than $\sim 0{\cdot}3$ mm equivalent diameter. Results may be biased, therefore, if moisture characteristics determined in the laboratory are used to estimate field water contents from field measures of moisture suction—as is frequently done. (Brown, North, Cuminetti, Shah and Tuck, with Bullock and Murphy, Soil Survey)

On both the tilled and undisturbed plots, measurements of soil temperature at several depths to 95 cm were made every 10 min throughout July and August 1980. Daily minimum temperatures did not differ between treatments for any depth of measurement. But daily maximum temperatures were, at all depths, higher on tilled than on undisturbed plots, though the difference was statistically significant ($>0{\cdot}5$ K) only for depths <20 cm; at 5 cm, differences of ~ 2 K were observed on cloudless days. Correspondingly, on tilled plots the amplitude of the diurnal temperature wave was higher, by as much as 20%, for depths <20 cm, and daily mean temperature higher by 0·5 K or more for depths <15 cm. In the 0–30 cm layer, temperature gradients were at all depths larger on the tilled plots: on the assumption that heat flux density at a particular depth was the same on both treatments, this finding would imply that thermal conductivities were lower on tilled than on undisturbed plots—as the measurements summarized in *Rothamsted Report for 1981*, Part 1, 179 confirmed.

Tillage-induced soil temperature differences of ~ 2 K may be sufficient to affect plant growth and perhaps crop yield, particularly were they to persist through a whole growing season. One physiologically useful measure of a changed thermal regime is the time integral of temperature that was discussed in a preceding section of this *Report* in connection with leaf growth and development. Integrals have been calculated for these July and August soil temperatures, for each depth of measurement, using each day's 144 data points, and taking as a threshold (base) temperature the 10°C adopted in the ARC's four-institute wheat model exercise. For July, time integrals thus determined were, for 5 cm depth, as much as 10% higher in tilled than in undisturbed soil, and for 95 cm, some 2–3% higher; effects were smaller for August, but may have been larger earlier in the season. In the ARC wheat model, temperature input comprises only two values per day—the daily maximum and minimum air temperatures—and from them a daily temperature sine wave is simulated. A similar procedure could be adopted for the simulation of a soil temperature wave: comparison with the 144-point measured data set showed that such a procedure yields temperature integrals that overestimate true values by as much as 10% on some days but by no more than 6% over a month. (North, Brown and Cuminetti)

Gaseous diffusion in swelling soils. In laboratory experiments on aeration and diffusion of gases in soils, a structured soil can be approximated by a bed of soil crumbs. Earlier work using such beds suggested that in tilled or structured soils the diffusion of gases could be considered as a two-stage function of water content. Thus, in soils at or drier than field capacity, diffusion would change little with water content and would be

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unlikely to limit aeration of the bulk soil, but increases in water content beyond field capacity would cause a large decrease in diffusion and hence lead to inadequate aeration. These earlier measurements were made either on natural crumbs wetted with paraffin, or on ignited crumbs wetted with water: both procedures adopted to eliminate effects of swelling or slaking. In new work, effects of swelling and slaking have been explicitly studied using beds of 1–2 mm crumbs taken from 0–15 cm depth on each of three contrasting soils. Results showed that, in these packings of crumbs of swelling soils, diffusion changed with water content in three stages compared with two for the corresponding non-swelling soils. In the first stage, swelling is accommodated within the crumbs and there is a small decrease in diffusion coefficient that results from both reorganization and loss of intra-crumb pore space. For the second (extra) stage, the crumbs swell into the inter-crumb pore space and there is a further loss of intra-crumb pore space: the decrease in diffusion coefficient is relatively greater because of an increasing loss of the more important inter-crumb space. The third stage, as for the non-swelling soil, corresponds to a loss of the remaining (inter-crumb) air-filled pores. Effects of pore size and shape may contribute to the decrease in diffusion with wetting, but are not thought to cause the two-stage pattern within the crumb. There is some evidence that in the crumbs from a grassland soil the decrease in diffusion may be influenced by an intra-crumb 'ped' structure with associated structural swelling. There seems to be no hysteresis in diffusion with water content on wetting or drying, and only a small decrease due to slaking in the crumbs from an arable clay loam. (Currie)

Gaseous diffusion in dry and in wetted crumbs. The need for a method for measuring quickly and accurately the effective coefficient for the diffusion of gas within soil crumbs was expressed in *Rothamsted Report for 1980*, Part 1, 169. Progress towards meeting this need has been made through an exploitation of the phenomenon of hydrodynamic dispersion (miscible displacement): if the species of gas flowing into one end of a column of soil crumbs is changed abruptly, then the effluent concentration of the second gas increases with time, after a short time interval, in a sigmoid manner: the second gas emerges earlier, and the first gas for longer, than would be expected were the gases each to diffuse as one 'parcel'. The shape of the curve of effluent concentration *versus* time (the breakthrough curve) is determined by flow rate, tube length, diffusion coefficient, and the amount and nature of the inter-crumb pore space. It is also influenced by the rate at which the second gas can interchange with the (first) gas that initially fills the intra-crumb pores: this interchange depends on the effective diffusion of the two gases within the crumb—the property of interest—and on the amount of intra-crumb pore space. Breakthrough curves have been measured for columns of soil crumbs of contrasting internal diffusivity; results so far suggest that the effects of intra-crumb diffusion are partly masked by those of inter-crumb dispersion, and interpretations are difficult because, for gases, transfers by convection and by diffusion are of comparable magnitude. (Currie and Ferguson)

Staff and visiting workers

T. Woodhead resigned at the end of December to become leader of the new Physics Programme at the International Rice Research Institute, Los Baños, Philippines. From that same date, members of the Physics Department joined either the Physiology and Environmental Physics Section or the Department of Soils and Plant Nutrition.

In July, B. J. Legg completed his 2-year study period at the CSIRO Division of Environmental Mechanics, Canberra, Australia, and G. E. Harrison has given assistance since June to the Department's contributions to multidisciplinary studies. Dr A. J. Peck,

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CSIRO Division of Groundwater Research, spent 3 weeks in the Department working on soil-water physics topics, and Dr J. T. Ritchie, United States Department of Agriculture, Temple, Texas, spent one week in a collaborative workshop on crop growth models. C. J. Lovell (who was awarded the degree of M.Sc. from Cranfield Institute of Technology) and C. J. P. Shipway undertook postgraduate research in the Soil-Water Physics Group, and K. Brunson, B. Ferguson and Eileen Mills were sandwich students.

P. F. North gave a paper at the Ninth Conference of the International Soil Tillage Research Organization, held in Osijek, Yugoslavia, H. A. McCartney a paper at a Conference of the European Plant Protection Organization in Geneva, Switzerland, E. G. Youngs gave an invited paper and chaired a session at the Ninth Annual Meeting of the European Geophysical Society, in Leeds, and T. Woodhead gave a paper and chaired a session at an International Conference on Organic Matter and Rice at the International Rice Research Institute, Los Baños, Philippines. Within Britain, several members of the Department presented papers, seminars and invited lectures at various colleges, universities, conferences and workshops.

Publications

Thesis

1 Lovell, C. J. (1982) *A critical examination of steady state land drainage equations.* M.Sc. Thesis, Cranfield Institute of Technology.

General Papers

2 (Aylor, D. E.), Bainbridge, A. & McCartney, H. A. (1981) Aerial transport of particles blown from the surface by wind. *Proceedings of 15th Conference on Agriculture and Forest Meteorology*, Anaheim, April 1981. American Meteorological Society, Boston, Mass. 16–17.

3 Youngs, E. G. (1983) The contribution of physics to land drainage. *Journal of Soil Science* **34,** 1–21.

Research Papers

4 Leach, J. E., Parkinson, K. J. & Woodhead, T. (1982) Photosynthesis, respiration and evaporation of a field-grown potato crop. *Annals of Applied Biology* **101,** 377–390.

5 Leach, J. E., Woodhead, T. & Day, W. (1982) Bias in pressure chamber measurements of leaf water potential. *Agricultural Meteorology* **27,** 257–263.

6 Legg, B. J. (& Raupach, M. R.) (1982) Markov chain simulation of particle dispersion in inhomogeneous flows: the mean drift velocity induced by a gradient in Eulerian velocity variance. *Boundary Layer Meteorology* **24,** 3–13.

7 (Leuning, R.) & Legg, B. J. (1982) Comments on 'The influence of water vapour fluctuations on turbulent fluxes' by Brook. *Boundary Layer Meteorology* **23,** 255–258.

8 McCartney, H. A., Bainbridge, A. (& Aylor, D. E.) (1982) The importance of wind gusts in distributing fungal spores among crop foliage. *Bulletin of the European Plant Protection Organisation* **13,** 133–137.

9 McCartney, H. A. & Woodhead, T. (1983) Electric charge, image charge forces and deposition of pesticide drops. *Pesticide Science*, **14,** 49–56.

10 North, P. F. & Brown, N. J. (1982) The effect on some field-measured soil physical properties of restructuring a soil mechanically. *Proceedings of 9th International Conference of ISTRO*, Osijek, Yugoslavia, 505-510.

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11 (Raupach, M. R.) & Legg, B. J. (1982) The uses and limitations of flux-gradient relationships in micrometeorology. *Proceedings of the Workshop on Evapotranspiration, Bunbury, Western Australia.*

12 Towner, G. D. (1982) Analysing one-step outflow experiments to calculate soil-water diffusivities, using Gardner's equation. *Journal of Soil Science* **33**, 351–364.

13 Towner, G. D. (1982) A method for improving cheaply the time response of pressure transducer tensiometer systems. *Agricultural Water Management* **5**, 285–293.

14 Youngs, E. G. (1982) Use of similar media theory in infiltration and runoff relationships. In: *Modeling components of hydrological cycle. Proceedings of the International Symposium on Rainfall Runoff Modeling*, Mississippi State University, 149–162.

15 Youngs, E. G. (1982) Calculation of ponded water drainage for flow regions of various geometries to demonstrate effect of disturbed soil-zone shape on drain performance. *Journal of Agricultural Engineering Research* **27**, 441–454.

16 Youngs, E. G. (1983) Scaled space and time variables in soil-water and groundwater flux-boundary problems. *Journal of Hydrology* **60**, 303–309.

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