ROTHAMSTED RESEARCH

Report for 1980 - Part 1

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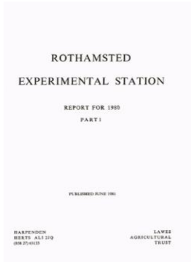
ROTHAMSTED
EXPERIMENTAL STATION
REPORT FOR 1980
PART 1

Physics Department

T. Woodhead

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Introduction

For the Physics Department, 1980 was a year that saw much effort devoted to the development and exploitation of new instruments and measuring methods. In soil physics, measurements of gaseous diffusion within *wetted* soil crumbs have been made for the first time; coefficients for the diffusion, determined at a range of water contents, were shown to correlate strongly with the within-crumb air-filled porosity. Water movement through unsaturated clay soils, and hydrodynamic dispersion of solutes, can now be studied more effectively as a result of improvements made respectively to the hydraulic conductivity cell and the dispersion apparatus that were each described in *Rothamsted Report for 1978*, Part 1, 200. The cell has now been equipped with an improved facility for imposing the required high pressures, and the solute dispersion can be quantified more precisely using a new opto-electrical colour matching system. For plant physics studies, the problem of monitoring plant water potentials is being tackled through parallel developments of a transducer technique to monitor stem diameter (with which the potential correlates) and of a method to simulate potentials corresponding to periods immediately pre-dawn, when plant turgor is maximal. At the larger scale, Rothamsted's research into plant: weather interactions will be helped by the availability, from autumn 1980, of measurements of solar radiation at Woburn. Other agricultural meteorological studies—those of the dispersal of disease spores and pesticide spray drops—will benefit from new equipment for simulating in the field a line source of drops and for generating in the wind tunnel turbulent eddies as large as those found within cereal crops. Into several of our purpose-built field instruments we shall, in the near future, incorporate dedicated microprocessors. To this end we have built up a hardware-and-software system that enables us to develop the required circuits and programs, and that has allowed us to offer advice on microprocessors to other Rothamsted departments.

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Collection of field data in far greater quantity than can be achieved by the microprocessor systems is being successfully undertaken with two Hewlett-Packard computer-controlled data acquisition systems that respectively support our tillage and drought experiments and our aerobiology research. The first of these systems was used to good effect in 1980 in a study of the effects of tillage on soil physical properties—particularly the coefficients for the transport of heat and water. The experiment exploited a new irrigation facility that allowed rapid wetting of the soil without damage to soil structure, and made full use of the scanning and measuring system for tensiometers and the thermal conductivity probes that were described in *Rothamsted Report for 1979*, Part 1, 154 and 157. Preliminary results suggest that, at a given water content, tillage lowered *thermal* conductivity, and, at water contents close to saturation, raised *hydraulic* conductivity. The data system that measures meteorological variables in our aerobiology experiments was also successfully commissioned and used in the summer of 1980 to investigate the effects of wind gusts on the lift-off from crop leaves of fungal spores. The mathematical modelling of the influence of electric charge on the trajectories and deposition of mildew spores, described in *Rothamsted Report for 1979*, Part 1, 161, has been applied, with appropriate modification, to studies of the trajectories of electrically charged water drops—such as are delivered by electrostatic crop sprayers. The calculations give a theoretical explanation for the experimental finding that electrical charging of the spray drops can give significant and worthwhile increases in spray deposition.

Mathematical models have helped advance also our research into plant: weather interactions and into soil-water physics. The plant: weather study sought to adapt, for Rothamsted conditions and for spring barley, a model of crop growth that was developed for winter wheat in the USA. Preliminary results show fair agreement between observation and predicition for variables such as grain dry matter and number of ears per unit ground area; moreover the model has substantial scope for refinement. The soil-water modelling was concerned with those empirical layered models of water movement that are frequently and effectively used in agronomic and hydrologic studies of soil wetting and drying. For some situations the wetting or drying can be described both by the layered models and by rigorous physical theory; for a few such situations, water profiles determined by the two methods were analysed to establish calculational procedures that can ensure that the layered models do produce solutions that are physically valid.

As in previous years, several of our projects involved inter-departmental collaboration and research. Soil and plant water relations were studied as one component in a multi-disciplinary investigation of barley's response to deep cultivation and fertilisation (p. 24), and several physics topics featured in multidepartmental displays in Rothamsted's 1980 Subject Day: 'Soil: Basic Research and its Applications'. In tillage and soil structure research we have enjoyed active collaboration with the Department of Soils and Plant Nutrition and the Soil Survey of England and Wales; analysis of drought experiments has been undertaken with the Departments of Botany and Soils and Plant Nutrition, and aerobiology studies have been pursued jointly with the Departments of Plant Pathology and Insecticides and Fungicides and with the Chemical Liaison Unit. Topics in soil-water physics have been researched collaboratively with the Letcombe Laboratory, the National College of Agricultural Engineering, and the MAFF Field Drainage Experimental Unit.

Plant physics

Response to water stress: spring barley

A model for growth and yield. Experiments in 1976 and 1979 that investigated the effects on spring barley crops of droughts of various intensities at different growth stages were described in Parts 1 of the *Rothamsted Reports for 1976*, 236, and *for 1979*,

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159. For these crops, which experienced very different weathers in 1976 and 1979, growth and yield have been analysed in relation to an unpublished mathematical model of the effects on crop growth of environmental variables—notably water supply and temperature—that was developed for winter wheat by Dr J. T. Ritchie and colleagues (United States Department of Agriculture, Temple, Texas). The model comprises a set of empirical functions that describe the important physiological processes and the inter-relationships and responses to the environment of these processes. In applying the model to spring barley, many of the functions could be adopted unchanged, but parameters that related to properties such as leaf area, and depth of soil water abstraction, were chosen to match the values measured for these properties on the *extreme* treatments in the 1976 and 1979 experiments. The model was then used to predict, for the other (non-extreme) treatments, values for particular variables (e.g. grain dry matter) for which measured data were also available. Results were encouraging. Root-mean-square differences between predictions and observations ranged from 9%, for ears m^{-2}, to 18% for grain dry matter. However, the systematic component of these differences, which is appreciable, can be lessened through refinement and further adaptation of the model. For example, the model consistently gives overestimates for evaporation from a wet soil surface beneath a standing crop, and hence for the water use from those of our treatments irrigated late in the season. Similarly, further work will be required, in studying relationships between light interception and total dry matter production, to determine whether dry matter, consistently over-estimated in 1976 but under-estimated in 1979, can be predicted more accurately through a modified model. (W. Day, with Gallagher, Botany Department, and Parry, Rayner and Weir, Soils and Plant Nutrition Department)

Dry matter production and water use. These same 1976 and 1979 data provided, for each treatment, totals of dry matter production and of water used during the growing season. Analysis has shown that in 1976 the treatments that used more water produced more matter—and the correlation was clearly linear. For 1979, the data were more scattered and had a less significant linear correlation, and, of more import, the 1979 correlation had a gradient significantly larger than that for 1976. The difference can be explained in terms of the different air humidities of the two years: changes in air humidity have a direct effect on evaporation, but not on photosynthesis, and the ratio of evaporation to assimilation is, for many field data, proportional to the mean saturation water vapour pressure deficit (Bierhuizen & Slatyer, *Agricultural Meteorology* (1965), **2,** 259–270); calculations confirm that our spring barley data accord with this thesis. (W. Day)

Leaf growth. In the 1979 experiment, measurements of leaf growth featured prominently (*Rothamsted Report for 1979*, Part 1, 159). The three leaves that appeared last on each main stem showed differences in *area* that resulted from the imposed drought treatments. However, it is not yet known whether it was the *rate* or the *duration* of growth that mediated this response. Measurements of leaf *length*, by auxanometer, showed that rates of leaf extension responded more to temperature than to any other environmental variable—in a response that was almost linear, but with a base temperature that increased from about 3°C, when leaf 7 appeared, to 5°C or more when ears were appearing. (W. Day and Leach, with Lawlor, Botany Department)

Effects of deep cultivation. Measurements of stomatal resistance and of leaf and soil water potentials were made, for a 1980 spring barley crop, as part of a multidisciplinary study of the effects of subsoiling and deep incorporation of P and K fertilisers. The measurements, of which a full report appears on p. 25, showed no significant treatment

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effects. (W. Day, French and Leach, with McEwen, Field Experiments Section, and others)

Use of microprocessors. The need to incorporate microprocessors into our porometers and leaf chambers was explained in *Rothamsted Report for 1979*, Part 1, 160. A microprocessor development system has now been constructed that allows programming, in assembler languages, of RCA, Synertek/MOS Technology, Intel and Zilog microprocessors, and that includes an EPROM programmer and eraser. In preparation for incorporation into a porometer, a microcomputer has been built and tested. It uses an RCA 1802 microprocessor and a 2k EPROM and RAM, can take inputs either from BCD switches or from analogue signals via an analogue/digital converter, and can give output either on a light-emitting diode display or on a liquid crystal display. (Parkinson)

Agricultural meteorology

Movement and deposition of particles

Wind gusts and the lift-off from leaves of fungal spores. In studies of the dispersal of fungal spores it is often assumed that mean wind speed can be used to represent spore velocity—and hence to calculate deposition rates. This assumption is probably valid for spores that are ejected by their fungus and can thus enter the airstream regardless of its wind speed. However, other spores are released only when acted on by an external force, that usually is generated by a wind gust. These latter spores, therefore, will become airborne more readily at high wind speeds than at low, and will, near to their sources, correspondingly have atmospheric concentrations that will be larger at higher wind speeds. In comparison, the ejected spores will have near-source concentrations that are much less dependent on wind speed. As an experimental test of this hypothesis, two sources of spores of *Lycopodium* (club moss) were separately exposed to natural wind conditions. From one source spores were caused, by a gentle artificial airstream, to emanate continuously regardless of the natural wind speed; from the other, which comprised a dusting of spores either on a flat aluminium plate or on immature barley plants, spores became airborne only when caused to do so by the wind. Measurements were made, over six periods of ~ 1 h, of the spores' rates of impaction to sticky cylinders, of various diameters, exposed at distances from the sources of ~ 1 m. The frequency distributions within the ~ 1 h periods of the instantaneous wind speed were derived from continuous measurements by hot wire anemometers. Analysis of the spore catches and wind speeds showed that the observed rates of impaction of those spores blown from the plate or the barley could be satisfactorily explained only if it was assumed that there was indeed a threshold wind speed below which the spores did not become airborne. Furthermore, preliminary results from a later experiment using natural spores of barley mildew (*Erysiphe graminis*), which are released passively (as opposed to ejected) by the fungus, tend to confirm this conclusion. Models and analysis of spore dispersal must therefore be adapted to take account of this finding. (McCartney and Quayle, with Bainbridge, Plant Pathology Department, and Dr D. E. Aylor, Connecticut Agricultural Experimental Station)

Electric charge and the deposition of pesticide spray drops. In *Rothamsted Report for 1979*, Part 1, 161 a description was given of experiments and mathematical analyses that sought to determine whether spores of barley mildew might carry electric charge, and what influence such charge might have on the movement and deposition of the spores. Similar analyses have now been applied to the case of pesticide drops sprayed at ultra-low rates (with drop diameters 10–100 μm) to calculate what magnitude of electric

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charge needs to reside on such drops to give rise to the increased rates of drop deposition to crop foliage that have been observed in Rothamsted field experiments (p. 130). We conclude that for 100-μm water drops a several-fold increase in deposition, due in part to enhanced impaction to the undersides of leaves, will result if sufficient charge can be imparted to a drop to give a charge per unit mass of $1{\cdot}4 \times 10^{-3}$ C kg^{-1}. For the electrostatic spray system developed in the Insecticides and Fungicides Department (p 129). Arnold and Pye report laboratory determinations of charge : mass ratio that varied between 0·5 and $2{\cdot}0 \times 10^{-3}$ C kg^{-1} for a drop size distribution extending from 50 to 150 μm. For a 100 μm drop, $1{\cdot}4 \times 10^{-3}$ C kg^{-1} corresponds to a charge equal to about one-tenth of the maximum charge that the drop can retain against the disruptive force of its own electric field intensity. There is thus sound reason that designs for electrostatic spray systems have aimed to achieve the largest possible charge per drop. (McCartney)

Soil physics

Soil structure

Tillage. Results for a 1977 tillage experiment (*Rothamsted Reports for 1978*, Part 1, 199, and *for 1979*, Part 1, 156) showed that soil heterogeneity can mask the real effects that tillage has on soil physical properties such as hydraulic conductivity K and thermal conductivity λ. A 1980 experiment therefore has sought again for such effects, employing greater sensitivity and replication of measurement than was possible in 1977, but using the same site. There were two treatments: the first comprised a soil left fallow and undisturbed for 2 years, the second involved tine cultivations to 30 cm depth followed by a deep harrowing. Each treatment was replicated three times; the six plots, each $2{\cdot}3 \times 9{\cdot}2$ m, were maintained fallow throughout the experiment. Watering of the plots was achieved with the aid of a mist irrigation facility—developed specifically for this experiment—that can apply water continuously at a rate of 25 mm h^{-1} without causing premature ponding or damage to the delicate soil structure created by the cultivations. The need for such a facility arose because measurements of K were to be made through a method that requires that the soil can initially be saturated.

On each plot, hourly measurements were made, during periods ranging from 3 weeks to 4 months, of profiles of soil-water pressure and of soil temperature and thermal conductivity, using equipment whose development was described in *Rothamsted Report for 1979*, Part 1, 154 and 157. Control and recording of these measurements were undertaken by a computer-based Hewlett-Packard data acquisition system that also allowed on-line processing and examination of the observed data and their derived parameters. Profiles of soil-water content θ were measured at frequent intervals by the neutron moderation method, and undisturbed cores of soil were extracted for laboratory determinations, by suction curve analysis and by image-analysing computer (Bullock, Soil Survey), of their pore size distributions. Measurements of K, by the instantaneous profile method (*Rothamsted Report for 1978*, Part 1, 201), were made, on parts of the plots, on two occasions. Preliminary results indicate that, at values of θ close to saturation, K may be increased by tillage, in keeping with the expectation that cultivation should create additional coarse pores, but have little effect on fine ones. And for λ, the measurements suggest that on both tilled and untilled plots λ (at a given θ) may increase with depth, and that it may be lower in tilled than in untilled soil. (Brown, North, Croft, Cuminetti, Dawes, A. T. Day, Kellaway and Wilson)

Gaseous diffusion in dry and in wetted crumbs. Studies of the diffusion of gases within the air-filled pores of dry soil crumbs have been described in previous *Reports* (e.g. *Rothamsted Report for 1976*, Part 1, 243). The coefficient for this diffusion, D_c, has

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hitherto been measured only for completely dry crumbs: results for wet crumbs have been too prone to measurement uncertainties. Values of D_c for dry crumbs have been useful in giving measures of intra-crumb structure, but they have been of less value in predicting movements of gases within soil crumbs in the field. In 1980, measurements of intra-crumb diffusion were made for the first time on wetted crumbs. The crumbs were derived from Highfield permanent pasture, and diffusion was measured over a range of water contents. The observed dependence of D_c on ϵ_c, the *air-filled* pore space expressed as a fraction of the crumb volume, can be well described by the equation

$$D_c/D_0 = 0{\cdot}267\ \epsilon_c \qquad (1)$$

with $r^2 = 0{\cdot}95$, 15 degrees of freedom, for $0{\cdot}074 \leqslant \epsilon_c \leqslant 0{\cdot}348$, and where D_0 is the diffusion coefficient with no impeding solids. This equation can be compared with that of Penman (*Journal of Agricultural Science, Cambridge* (1940), **30**, 437–462 and 570–581) for loosely packed materials: $D/D_c = 0{\cdot}66\ \epsilon$. A fit better than equation (1) is represented by the quadratic expression

$$D_c/D_0 = 0{\cdot}368\ \epsilon_c^2 + 0{\cdot}153\ \epsilon_c + 0{\cdot}00374, \qquad (2)$$

for which $r^2 = 0{\cdot}9986$, with 13 degrees of freedom. Notwithstanding the high correlation associated with equation (2), the measured values of D_c are still insufficiently precise to allow deductions as to whether, for example, diffusion is affected by there being pores of multimodal size distribution. Furthermore, these measurements require extreme care and very long equilibration times. An alternative method, that will give precise results quickly, must therefore be developed. (Currie and Pritchard)

Soil water

Development of soil water profiles. Agronomic models of crop growth and yield, and hydrologic models of catchment behaviour, often include empirical submodels that describe the movement of water into and out of hypothetical soil layers. The submodels usually involve an application to the successive layers of an approximate formulation of Darcy's Law, and, having regard for the constraints of soil-water continuity and conservation, proceed by calculating for a sequence of equally-spaced times the water contents θ of the various layers. The layer thickness Δz and the time increment of calculation Δt are chosen arbitrarily; however, unsuitable choices can lead to wrong values of θ, to wasteful use of computing time, or both. Fortunately, for certain soil-water situations it is possible to derive profiles for θ both through the layered models and also through application of rigorous soil-physics theory, and to thereby establish criteria for Δz and Δt that *will* allow calculation of valid estimates of θ. Two particular cases have been studied: each has application in situations both of soil wetting and of soil drying. The cases respectively relate to conditions at the soil surface either of a fixed water *flux* (as in the first stage of evaporative drying or as occurs during irrigation at a constant rate) or of a fixed water *content* (as in the second stage of drying or when irrigation is so applied as to keep the surface just ponded). For both cases, and for wetting or drying, the criterion for ensuring that valid solutions may be obtained is:

$$D\ \Delta t \leqslant 0{\cdot}50\ \Delta z^2 \qquad (3)$$

where D is the soil-water diffusivity. A choice for Δz is usually dictated by the availability of measured data, or by the particular objective of the calculation, and equation (3) thus becomes a criterion for determining Δt. In some applications D may be ascribed a constant value, for all layers; alternatively, if it is desired that D should vary, with θ and by layer, then Δt may still be calculated through equation (3) provided that D be there represented by its largest value likely to occur in the profile. We now surmise, from these

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and other calculations, that equation (3) may *generally* be adopted as a criterion that will enable valid profiles of θ to be determined through layered-model simulations—and this regardless of whether a corresponding rigorous solution can be derived. (Towner)

Infiltration and run-off. The use of scaling techniques based on similar media theory in describing water flow through unsaturated porous materials was reported in *Rothamsted Report for 1979*, Part 1, 156. In particular, descriptions were given of procedures through which microscopic characteristic lengths could be defined and measured, and of the use of such lengths in comparing the infiltration of water into unsaturated assemblages of variously sized and shaped particles (and hence voids), but with the particles in any specific assemblage having only one shape and size. The adopted scaling procedures were eminently successful in helping represent by one single equation the time course of infiltration, from a ponded surface, into each of the assemblages—which comprised materials as different as glass beads and silty loam soil. Extension of the analysis has now led to the derivation of a new equation:

$$i=\alpha\, K_0^{1/4}\, t^{1/2}+K_0 t, \tag{4}$$

where i is the cumulative infiltration into a soil of semi-infinite depth, and t is the elapsed time. Equation (4) involves only one soil parameter, the saturated hydraulic conductivity K_0, and one arbitrary constant α that for all the materials investigated took the value 4·1 mm$^{3/4}$ s$^{-1/4}$ when i was measured in mm, t in s and K_0 in mm s^{-1}.

When precipitation, commencing at time $t=0$, falls on to an unsaturated soil of semi-infinite depth at a steady rate F_0 that is insufficient to pond the soil surface initially, all the precipitation will infiltrate the soil. Later, if F_0 is large enough, the soil will at some time t_p become unable to transmit all of the precipitated water, and ponding and run-off occur for times greater than t_p—the ponding time. For situations where F_0 exceeds K_0, the preceding similar media analysis of infiltration has been developed to give an expression for an appropriately scaled and dimensionless form of t_p:

$$t_p=\beta/[G(G-1)], \tag{5}$$

where $G=F_0/K_0$ is the relative precipitation rate, and β is a constant that depends on the particular method of defining the microscopic characteristic length. Additionally, the cumulated total of run-off, when appropriately scaled, has been shown to relate to the scaled elapsed time t^* by a curve that, for various dissimilar materials, depends only on G. A family of such curves has been published, together with a curve for one *single* relationship that, at the expense of a little more algebra and scaling, allows curves for all values of G to be coalesced. (Youngs and Dailey)

Land drainage. In soils and aquifers water flow can have both horizontal and vertical components. Moreover, in a heterogeneous medium, the hydraulic conductivity K will vary from place to place, horizontally and vertically, and mathematical descriptions of the three-dimensional water flow and potentials are obtainable only for certain restricted situations where particular pieces of mathematics can be brought to bear. Analyses by the method of seepage analysis can be undertaken where three-dimensional distributions of potential can be recast in two dimensions: the required mathematics can then be somewhat simpler, and solutions can be obtained. The method requires that the three spatial coordinates x, y, z shall have influences on K that are algebraically separable. Thus, for the particular case where $K=\kappa c^{(Ax+By+z)}$ with κ, c, A and B constants, K varies only in a direction normal to the inclined plane $Ax+By+z=0$, and this restriction of variation is being exploited in studies of seepage of water through aquifers formed by inclined strata. (Youngs)

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Hydraulic conductivity measurements. The spatial variability of hydraulic conductivity causes difficulties generally in the application to land drainage of existing theories of groundwater movement. Although theories have been developed that allow for a dependence of hydraulic conductivity on depth, they have been little used, because the problems of field measurement of such a dependence are considerable. The field measurements are best carried out on prototype drainage installations on the particular site (Youngs, *Agricultural Water Management* (1976), **1**, 57–66), but they can also be made using an undisturbed soil monolith in a lysimeter. The latter method depends on the theorem of mean potential (Youngs, *Water Resources Research* (1970), **6**, 1792) and requires measurement of the difference in hydraulic head between the ponded surface and the base of the lysimeter and of the rates of discharge from drainage ports in the lysimeter side. Laboratory tests of the method are showing promise. (Youngs and Dailey)

Tensiometers: theory of time response. In *Rothamsted Report for 1979*, Part 1, 155, it was suggested that existing theory might be developed so that, given an appropriate tensiometer/soil combination, a time series of *measurements* of soil-water pressure could be transformed mathematically into a series of *actual* variations in pressure—a series not confounded by the effects of instrument lag. Algebraically, the true soil-water pressure ψ_s relates to the observed tensiometer pressure ψ_T as:

$$\psi_s = \psi_T + \tau \frac{\mathrm{d}\psi_T}{\mathrm{d}t}$$

where τ is the time constant of the tensiometer in pure water. Application of this expression to a time series of values for ψ_T requires the establishment of suitable manipulative procedures, and work is in progress, in laboratory experiments and numerical and theoretical analyses, to determine the best sampling strategies appropriate to values of τ for tensiometers currently in use.

Time response has also been studied for tensiometer sensors installed within clay peds that were subjected to external wetting and drying. Existing soil-water theory indicates that if a clay, saturated and prevented from swelling, is exposed to water at some non-zero pressure, then the clay-water pressure should come to equilibrium at the imposed pressure effectively instantaneously. Recently reported measurements have contradicted this prediction, in that in confined clay samples the water pressure, as registered by a tensiometer, required 30 days to come to equilibrium following the application of a suction to the base of the sample. Laboratory experiments have therefore been conducted to investigate this apparent contradiction. A clay paste, confined within a test cell and enclosing a tensiometer sensor, was subjected at the cell base to a range of step changes of soil-water pressure. Analysis of the time course of the consequent tensiometer responses confirmed the theoretical prediction that the change of *pressure* in the clay water is communicated immediately, but because a finite *volume* of water must be actually exchanged between clay and tensiometer before the latter can register the pressure change, and because the duration of this exchange is long in consequence of the clay's low hydraulic conductivity, so the response in tensiometer output can give the misleading impression that equilibration of clay-water pressure can be a slow process. Furthermore, we surmise that these laboratory findings will apply also for clay peds in field soils, and that tensiometer measurements of changes of soil-water pressure in clay peds *in situ* may not truly represent such changes unless the measurements be corrected for the effects of instrument lag. (Towner and Dailey)

Tensiometers: considerations of overburden pressure. Within a body of soil, the total soil-water potential ϕ at any point includes a component that derives from the weight

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(overburden) of the soil and soil water that overlie the point. The effect of this overburden pressure on the readings of tensiometers is often misinterpreted, partly because of confusions in terminologies. A definitive analysis of the effect has therefore been undertaken, for both swelling and non-swelling soils. It is confirmed that for *all* soils the total potential is given by $\phi = u + h$, where u is the pressure registered by a tensiometer, and h is the vertical distance of the point above an arbitrary datum. A second finding relates to the possibility of using tensiometer measurements of water pressure u to give, via a water content/water pressure curve determined with no overburden, values for soil-water content θ. For *non-swelling* soils, such a θ/u correspondence can validly be made, but for *swelling* soils a value of u is not sufficient of itself to predict a value for θ: it is necessary to know also the overburden load. (Towner)

Staff and visiting workers

A. Poulovassilis left in January to take up the post of Professor of Agricultural Hydraulics in the University of Athens. P. J. Zemroch left in May to join Shell Research, S. A. Strange in March and P. Scott in May to work respectively with the British Standards Institution and the General Electric Company. Corinne J. Quayle joined the Department in September to give assistance in aerobiology research. Rachel A. Kellaway, A. Coffey and H. J. B. Orr each spent several months in the Department as sandwich course students. Gillian Dawes was awarded the degree of B.Sc. and a Polytechnic Prize, following studies at Hatfield Polytechnic.

B. J. Legg has spent the first 6 months of a 12-month sabbatical study period at the CSIRO Division of Environmental Mechanics, Canberra, Australia; during these same 6 months Dr D. E. Aylor, of the Connecticut Agricultural Experimental Station, has been a welcome visiting worker in our aerobiology group.

T. Woodhead attended the Seventh Annual Meeting of the European Geophysical Society, held in Budapest. Within Britain, several members of the Department presented papers and gave courses of lectures at various conferences, colleges and universities, and in September the Department was host to the first meeting of the British Soil-Water Physics Group.

Publications

Research Papers

1 (Callander, B. A.) & Woodhead, T. (1981) Canopy conductance of estate tea in Kenya. *Agricultural Meteorology* **23**, 151–167.

2 (Crowther, J. M., Dalrymple, J. F.), Woodhead, T., (Coackley, P. & Hamilton, I. M.) (1980) A correlation method for the estimation of retention times at full-scale sewage treatment plants. *Water Research* **14**, 567–574.

3 Cuminetti, R. & Rossmanith, G. (1980) Small amplitude non-linearities in the mechanical response of an asynchronous flight muscle. *Journal of Muscle Research and Cell Motility* **1**, 345–356.

4 Day, W., Lawlor, D. W. & Legg, B. J. (1981) The effect of drought on barley: soil and plant water relations. *Journal of Agricultural Science, Cambridge* **96**, 61–77.

5 (Harrison, R. M.) & McCartney, H. A. (1980) A comparison of the predictions of a simple Gaussian plume dispersion model with measurements of pollution concentration at ground level and aloft. *Atmospheric Environment* **14**, 589–596.

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6 (Harrison, R. M.) & McCartney, H. A. (1980) An automated mobile laboratory for continuous monitoring of atmospheric pollutants. *Proceedings of the Institution of Mechanical Engineers* **194**, 357–364.

7 Lawlor, D. W., Day, W., Johnston, A. E., Legg, B. J. & Parkinson, K. J. (1981) Growth of spring barley under drought: crop development, photosynthesis, dry matter accumulation and nutrient content. *Journal of Agricultural Science, Cambridge* **96,** 167–186.

8 Leach, J. E. (1980) Photosynthesis and growth of spring barley: some effects of drought. *Journal of Agricultural Science, Cambridge* **94,** 623–635.

9 Legg, B. J., Long, I. F. & Zemroch, P. J. (1981) Aerodynamic properties of field bean and potato crops. *Agricultural Meteorology* **23**, 21–43.

10 McEwen, J., Legg, B. J. *et al.* (1981) The effects of irrigation, nitrogen fertilizer and the control of pests and pathogens of spring-sown field beans (*Vicia faba* L.) and residual effects on two following winter wheat crops. *Journal of Agricultural Science, Cambridge* **96,** 129–150.

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