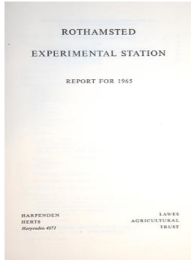
Rothamsted Experimental Station Report for 1965

Full Table of Content


ROTHAMSTED

EXPERIMENTAL STATION

REPORT FOR 1965

Physics

H. L. Penman

H. L. Penman (1966) *Physics ;* Rothamsted Experimental Station Report For 1965, pp 29 - 38 **- DOI: https://doi.org/10.23637/ERADOC-1-60**

PHYSICS DEPARTMENT

H. L. PENMAN

K. J. Parkinson joined the department in June, to work on the more biological aspects of the physics of plant growth. J. L. Monteith took part in the UNESCO symposium, in Copenhagen, on plant ecology; in December he delivered the Middleton Memorial Lecture to the Agricultural Education Association. F. J. Wangati attended a hydrological symposium in Budapest. H. L. Penman, as a guest of the American National Science Foundation, presented a paper at an International Symposium on Forest Hydrology, at State College, Pennsylvania. He also attended the meeting, in Paris, of the Co-ordinating Council for the International Hydrological Decade, as British delegate. Mr. W. Stiles (Grassland Research Institute) came to spend a year working on micro-meteorological problems, and Dr. T. Woodhead (East African Agricultural and Forestry Research Organisation) spent a few weeks in the department.

The National Institute of Agricultural Engineering kindly offered us the use of some field respirometers, out of service for several years, on condition that we take responsibility for scientific planning and experiment while they provide the necessary engineering maintenance. We accepted gratefully, and hope to have the equipment in working order for aeration experiments in 1966.

Stomatal Resistance

Much of the work of the Department is easily recognised as an attempt to identify factors in the soil, in the plant or in the atmosphere that might affect crop growth. After identification comes measurement, partly to test the significance of the diagnosis and partly to guide ideas on the possibilities of control and modification. In our narrow-minded thinking we see the plant as a channel between the soil and the atmosphere, taking part in energy and mass transfers, and growing because it takes in more than it transmits. The uptake is at both ends: from soil to roots, and from atmosphere to leaves, and it is here that the role of stomata is important. All agricultural scientists agree that when the stomata are open they are paths for escape of water vapour and for intake of carbon dioxide: many reserve judgement on whether they are the only paths that ever have to be considered. Fourteen years ago H. L. Penman and the late Dr. R. K. Schofield re-examined some of the pioneer work of Brown and Escombe, analysing the "resistance" encountered by diffusing molecules in moving from one side of the leaf epidermis to the other. It seemed then—and still does—that there might be an important difference between the two chief mass transfers. Both encounter a resistance in the atmosphere (r_a); both encounter a resistance in moving through the stomata (r_s); but only the carbon dioxide meets any further important resistance (r_m) as it moves in the plant tissue to the chloroplasts. In the earlier work r_a and r_s were expressed as equivalent

https://doi.org/10.23637/ERADOC-1-60

lengths of a still air column, but current expression sacrifices this simplicity for good physical reasons, set out below. The important inference is, however, independent of the unit used for r: the total resistance is made up of two (three) terms: $R = r_a + r_s + (r_m)$, and will have a minimum value, R_m, when r_s is a minimum, i.e., when the stomata are fully open (maximum transpiration and assimilation rates). If stomata provide the only control, then the relative transpiration and assimilation rates, as the stomata close, are R_m/R, both becoming zero when $r_s = \infty$ (stomata closed), but not reaching the limit by the same route. Hence, if stomatal opening can be controlled the escape of water might be restricted more than the uptake of carbon dioxide, i.e., at the expense of slower growth, to achieve a relatively much greater saving in the water used during the growth. Short-period experiments (*Rothamsted Report* for 1963) showed that chemical sprays did cause stomata to close, and retarded transpiration, but the effect on growth was not measured.

Current work has several aspects, but before outlining them the concept of resistance needs explanation. In a diffusive process the transfer rate per unit area is equal to the product of a diffusion coefficient and a partial pressure gradient, and when expressed in terms of a finite partial pressure drop across the system it becomes $VP = D\Delta p/\Delta l$ or $\Delta p/r$, with $r = \Delta l/D$, where V, the volume flow per unit area per unit time, is measured at pressure P. The alternative form is analogous to the flow of electric current—hence the concept, the name and the symbol. The first form is still useful, but in the atmosphere the diffusion coefficient increases very rapidly with height above the crop, and it is very much easier to analyse field observations in terms of an atmospheric resistance r_a rather than an equivalent length Δl_a. Convenience then dictates that the stomatal resistance should be similarly treated, and this becomes almost imperative in a theoretical study of gas flow through stomata.

This study, pursued somewhat desultorily in the past few years, has been intensified under the stimulus of having some excellent laboratory measurements on wheat leaves from Prof. F. L. Milthorpe. These include measurements of leaf resistance, r_V, to viscous flow of air as it is pushed through a leaf; the differential diffusive flow of air and hydrogen ($V_H - V_A$) when these gases are supplied to opposite sides of the leaf; and the main component in the hydrogen transfer ($V_H{}^1$) by itself. Calculations, based on stomatal shape, size and population, lead to theoretical relations between r_V and $V_H - V_A$ and $V_H{}^1$, and between $V_H - V_A$ and $V_H{}^1$. A test, so far limited in detail to only one leaf, shows extremely good agreement with observations. Transforming the same ideas to estimate what would happen to water-vapour transfer gives a resistance, at maximum opening, near 3 sec cm^{-1} for the lower side of the leaf. The upper surface has about $\frac{4}{3}$ times the population of the lower, so for the leaf as a whole, the resistance is near $\frac{3}{7} \times 3$, i.e., about 1·3 sec cm^{-1}. (Penman)

Our field experience on a similar crop (barley) suggests that until the Leaf Area Index reaches about six, the leaves behave almost independently, but thereafter there is little change, i.e., during the period of "full" leaf cover, the resistance of the crop as a whole could be as small as 0·2 sec cm^{-1}. This is so, as shown in a survey (*Rothamsted Report* for 1964)

https://doi.org/10.23637/ERADOC-1-60

of world results on cereals and other crops. Continuous records of transpiration rate (to give V), and of temperature and humidity in and above the crop (to give Δp), lead to values of $r_a + r_s$. From the profiles of wind velocity above the crop a value of r_a is readily obtained, and hence r_s is determinable, so that its daily cycle, and day-to-day and seasonal changes, can be studied. These will be linked with contemporary measurements of carbon dioxide movement and radiation exchanges in an ultimate attempt to set down the environmental factors affecting crop growth rate and final yield. (Monteith and Szeicz)

The importance of stomatal resistance to diffusion is two-fold. As indicated in the preceding paragraph, it is important in the physics of the transport processes: it is also a valuable quantity of physiological significance as an indicator of the adequacy of the plant's water supply. Nearly all previous attempts to estimate it made a measurement of a resistance to viscous flow (symbolised r_V, earlier). Now, copying Dr. C. H. M. van Bavel of Arizona, a diffusion resistance can be measured directly. Our porometer follows his general design, but by using a sulphonated polystyrene humidity sensor in the form of a flat narrow strip it can be adapted to use on very narrow leaves (cereals and grasses). Most of the snags seem to have been overcome (adsorption of water on the cup; leaks; stability and sensitivity of the associated electronic circuit). The final assembly is small and easily portable, and is a very welcome addition to the equipment used in our field experiments. (Stiles)

Evaporation and Related Studies

Early in the year the two field transpiration balances were transferred to the large plots (100 × 100 m) to be used for our main micro-meteorological work. New fibre-glass tanks (92 cm deep, 142 × 142 cm surface) were fitted, filled with local soil at the beginning of April and sown with barley when the surrounding field was drilled on 26 April. At the beginning and end of the season water evaporated at almost the same rate from both balances, but during July the rate was about 25% less from the north balance (not irrigated) than from the south balance, given 2·5 cm irrigation on 1 July. This is not a direct effect produced by withholding water: the plants on the balance were not even representative of the poor crop on the non-irrigated area round them, but were shorter, and their smaller leaves permitted much more sunshine to reach the soil beneath them, the difference being almost enough to account for the difference in transpiration rates. Here is a warning that evaporation measurements with a field balance may be misleading unless the plants on it are similar morphologically and physiologically to those growing around them. The source of the trouble may be that our clay soil needs more than a month or two to settle and repack after excavation and refilling.

Analysis of the 1963 measurements on barley shows the diurnal and seasonal changes in stomatal resistance, r_s (1.11). There is a good correlation with the resistance to viscous flow (r_V) measured with an Alvim porometer, both parameters decreasing in the same way as light intensity increases, both being independent of wind speed and both increasing when

https://doi.org/10.23637/ERADOC-1-60

the crop is sprayed with a chemical that partly closed the stomata (r_s from 0·4 to 0·7 sec cm^{-1}; r_V from 1·2 to 1·7 sec cm^{-1}). The seasonal change in r_s was correlated with the area of leaves and their age.

Given the value of r_s for a crop, our standard formula for potential transpiration is easily converted to an expression for actual transpiration, and a simple method of estimating r_s from weather measurements is being sought. There is promise of success, in that r_s seems to be closely correlated with the ratio of saturation deficit to net radiation. (Monteith and Szeicz)

Alongside and in the balances there were routine measurements of soil water content by the neutron-scattering technique. The summer was characterised by somewhat more rain than average, in frequent small amounts, and very much less sunshine and lower air temperatures, so that evaporation was much less than average and no great soil moisture deficit was reached at any time. For all of the summer, up to the end of September, the neutron meter showed a persistent deficit below 70 cm, established during 1964 and not neutralised by the winter rain 1964–65: the amount was near 15 mm in rainfall equivalent. In the top 70 cm, with measured and calculated values agreeing acceptably well on the irrigated barley, the deficit increased from zero to about 40 mm during May, changed little until the last week of June and then increased to its summer maximum near 70 mm on the non-irrigated crop by the end of the first week of July. Measurements in the gauges and in the field early in October, when profiles were assumed to be at field capacity, show some conflicts, not all resolved yet, but suggesting that the soil in the balance was drier than in the field at the end of June by the equivalent of 30 or 35 mm of water, perhaps lost during storage and during refilling. (Long and French)

Ultimate detailed discussion of this work must include consideration of the accuracy of the neutron meter. It is customary to assume that a single reading in water will give 100% volume/volume, and that at intermediate water contents readings are simply proportional to this. Although there is no need to question the assumption, it seemed worth testing, and as part of another laboratory experiment a check is being made. A box of just over 1 m cube is filled with a uniform stone-free loam and is supported on metal water-filled cushions connected to an external pressure gauge: the gauge reading is a measure of the weight of the box, soil and water, easily calibrated. Neutron probe measurements showed that estimated changes in water content agreed very well with quantities added to or taken from the soil, and the absolute total agreed very well with the absolute total estimated by soil sampling, or by calculations based on the known volume of soil and its bulk density. So far, so good, but the neutron meter underestimates water content near the surface, although it measures changes in water content with adequate accuracy. "Near the surface" means within 15 cm in water, 20 cm in soil at 30% water content and possibly more in drier soil. (Wangati)

Part of this experiment is intended to explore the nature and speed of the redistribution of water when an equilibrium profile is disturbed either by adding water at the surface or by its rapid removal from the main root zone of transpiring plants. Here, too, the flux equation involves the product

https://doi.org/10.23637/ERADOC-1-60

of a transport coefficient and a potential gradient: both change very rapidly from field capacity towards air dryness.

Experiments were done on columns of soil long enough to be "semi-infinite" in a formal mathematical analysis. All started at uniform water content, achieved by careful initial wetting and draining after careful packing: a variation of less than 1% of the mean was obtained in 1-cm segments of a 30-cm column. When the open end of a column, initially at field capacity, was exposed to constant drying conditions the evaporation rate decreased linearly with the square root of the time, producing a gradually changing profile of water content in the column, approaching air-dryness at the surface. Synthesis of all the profiles for a given material shows that the moisture content at any level, z, after time, t, is invariant with z^2/t, which has the dimensions of a diffusion constant (usually as cm^2/sec), confirming, probably explicitly for the first time, that water movement even in drier soils can be described by the diffusion equation. Replicates agreed well, with more scatter for a Woburn topsoil than for a Rothamsted subsoil. These two demonstrate a difference arising from soil texture. Most of the first evaporated water comes from a shallow layer near the surface, producing a clear "drying front" that slowly moves deeper into the soil. This is very pronounced in the Woburn and similar soils, less so in the heavier soils. From the profiles and their changes with time, diffusivities were calculated. At field capacity they are near 10^{-3}–10^{-4} cm^2 sec^{-1}, reach a minimum near 10^{-6} cm^2 sec^{-1} before the soil reaches air dryness, and then increase to near 10^{-5} cm^2 sec^{-1} at air dryness. There is less variation in the heavier soils. Corresponding pF curves for the soils are not yet complete, but from those obtained conductivity was estimated: there is a steady fall from about 10^{-7} cm sec^{-1} at field capacity to about 10^{-11} or 10^{-12} cm sec^{-1} at air dryness.

These estimates of diffusion constants in the soil can be turned into a parameter to express the water-supplying ability of the soil quantitatively. For a non-soil material, sepiolite, it is 0·6 cm^2 day^{-1}; for one of our most difficult soils (Barnfield) it is 0·15 cm^2 day^{-1}; between, other soils come in an order well in accord with other known structural parameters.

The formation of an upper dry layer has, of course, been recognised before, and this "self-mulching" action can be even more effective when strong sunshine heats the surface. Then, as known from the Rothamsted drain-gauge records, the total evaporation from bare soil increases as the cube-root of the time, i.e., in the field evaporation is checked more than in these laboratory experiments. The water movement in this dry layer may be important, and measurements were made on samples of eight soils, all drier than pF 4·5 (i.e., beyond the wilting point for plants), wetting and drying semi-infinite columns by sorption and desorption, so giving both a "drying" diffusivity and a "wetting" diffusivity. The former agreed well with those from the main experiment at the overlap, but showed an ill-defined maximum in very dry soil. The "wetting" diffusivity had a sharp maximum, but not at the same water content. (Rose)

Application of previous work continues. Theoretical estimates were made of evaporation from trees, and compared with measurements of the annual water balance for the sites. Two were well-separated mountain forest catchments in East Africa, which, by coincidence, have almost the same average annual total of net radiation. The prediction was that the annual evaporation should be near 1,380 and 1,290 mm: the actual values are 1,550 and 1,140 mm respectively. The other comparisons were for the Netherlands (Castricum), where very complete measurements are made on contiguous areas under conifers, deciduous trees and mixed dune vegetation (partly evergreen, partly deciduous). Here the estimated annual evaporation for an evergreen tree cover was 580 mm, and for a short evergreen cover, 500 mm. The observed values are: conifers 655 mm; deciduous 500 mm; mixed 460 mm. (1.12). (Penman)

Since 1955 H. L. Penman has served on a Committee supervising measurements of evaporation from the open water of a reservoir near Kew Observatory, with the kind co-operation of the Metropolitan Water Board. The Committee's report (C. F. Lapworth, *J. Instn Wat. Engrs* (1965), **19**, 163–181) includes monthly values of observed evaporation, and that calculated from the Kew weather records and measured water temperature. The mean annual totals agree extremely well (660 *v*. 665 mm), the individual annual totals rarely differ by more than 5% and the annual cycle shows a tendency for the meteorological estimate to be a little too small in winter and a little too great in summer.

Other Agricultural Meteorology

Photosynthesis and carbon dioxide. Uptake of carbon dioxide from the atmosphere can be calculated from measurements of concentration above the canopy (1.1), and these were made throughout the summer. It is much more difficult to estimate uptake within the canopy (1.7), but a few trials were made to explore possible techniques.

The rate of photosynthesis must depend on the distribution of radiation throughout the depth of the crop, and the theoretical model (*Rothamsted Report* for 1964) was used to analyse the production of dry matter by sugar beet in 1958, and barley in 1963. Because the leaves of sugar beet expanded slowly, they failed to intercept one-third of the radiation received during the growing season: another third was ineffective because the efficiency of photosynthesis decreased in bright light (1.10). It seems that this effect of light-saturation occurred because there was not enough carbon dioxide near the leaves to keep sites of assimilation supplied fast enough (1.10). In the barley the loss by light saturation was smaller, because the leaf orientation is more favourable. After ear emergence in July the leaf area decreased, but gross uptake of carbon dioxide continued to increase because of efficient photosynthesis by ears and awns. At the same time, however, respiration by ears and stems increased, so, on balance, dry matter was produced more slowly. Towards the end of July 1965 the area of barley ears and awns was equivalent to a leaf-area index between 2 and 3. This helps to explain why they were able to make a significant contribution to photosynthesis, and perhaps simultaneously to slow transpiration. (Monteith)

The controlled environment apparatus built by Dr. P. Gaastra (*Rothamsted Report* for 1961) was reassembled to an improved design. (Parkinson)

https://doi.org/10.23637/ERADOC-1-60

Radiation. Accurate measurement of solar radiation is the foundation of much of our work on agricultural meteorology (1.3), and our interest extends to seasonal changes over the whole of Britain. We have queried the reliability of records from Aberporth (1.9) on the west coast of Wales, where the mean intensity per hour of sunshine is almost 20% more than at Rothamsted. We now accept that the Aberporth records are not significantly in error, and there seems to be a narrow coastal strip where the air transmits more radiation because it is relatively free from soil particles, spores and other pollution of terrestrial origin. This strip is very narrow, for an integrating solarimeter was set up at the Welsh Plant Breeding Station in 1964, only 3 miles from the coast, and the records, kindly supplied by Dr. H. Vanstone, show that the relation between radiation and sunshine is almost the same as at Rothamsted. Those artists who claim a special quality in the light of the Cornish and Welsh coasts may be correct.

Measurements of solar radiation and its infra-red component, to give the visible component by difference, continued (1.13), with some valuable co-operation from Mr. M. J. Blackwell of the Meteorological Office, Cambridge. Our eye inspection of records suggested that the ratio of visible/total radiation was usually between 0·40 and 0·45: running the apparatus at Cambridge to produce records on punched tape, backed by computer processing, indicates that during the summer the ratio has a mean value of 0·45 under clear skies, and increases to 0·47 under overcast skies. (Monteith and Szeicz)

General micro-climatology. A new experiment, to last a few years, was started. The main deviation from all other Rothamsted field experiments is that the plots are large (*c.* 100 × 100 m) and there are only two, one of which will be irrigated and the other not. The size is barely sufficient to satisfy the requirement of adequate fetch, essential for both aerodynamic and radiation balance reasons. To extract the maximum amount of information from these "macro-plots", every available piece of equipment was set up on them, including the transpiration balances, as already noted. For interest: the measurements on one of them (there are minor differences) include: temperature and humidity at five levels above the crop; wind speed at six levels above and four within the crop; leaf temperature at four levels; soil temperature at eight levels; wind and temperature measurements at two other sites to check horizontal uniformity; a temperature/humidity system to estimate dew formation; a Hirst dew balance; a wind direction recorder above the crop; four sampling tubes for the neutron moisture meter, with a fifth in the transpiration balance. All, except the last, provide continuous records, and much thought is being given to automatic recording in a form, or forms, suitable for computer processing. (Long and French)

In addition, there are radiation recorders (total, net, reflected, infra-red) in and above the crop; intakes for sampling carbon dioxide concentration in and above the crop, six levels in all. (Szeicz)

The crop was barley, and in the early weeks of growth was much poorer on the north plot (unirrigated) than on the other. There was only one brief period of inadequate rainfall, and as the irrigation given then was

https://doi.org/10.23637/ERADOC-1-60

soon rendered superfluous, the net result of the summer's work was some useful experience, but no significant scientific progress. The experience includes: the south plot is more sheltered from south and south-easterly winds—wind speed at 2 m above the crop is smaller in this quadrant. Other differences between the plots can be accounted for by the known difference in plant cover.

A new field laboratory and equipment store should be ready for use early in 1966. It replaces three overcrowded huts for housing recorders, and will eliminate the present need to haul equipment back to the laboratory for winter storage and servicing. (Long)

Irrigation

At both Rothamsted and Woburn there was no long period of need, and there was abundant rain in the weeks that followed irrigation. The general result is easily predictable: no major response anywhere.

Rothamsted. Leaks in the underground pipeline dictated a complete overhaul. This the contractors did, and some 80% of the line was replaced in January. There was no further trouble.

Test crops were:

Potatoes. Two varieties had several forms of management imposed. One inch of irrigation was applied early in July. The response, on average, was negative, at 1·0 tons/acre below the control (16·6 tons/acre).

Beans. Here, too, there were several management variants. Half an inch of irrigation early in June had a similar depressing effect (1·1 cwt/acre) on a mean yield of 24 cwt/acre.

Barley. The early obvious difference of plant stand on the two macroplots probably had more influence on final yield than the inch of irrigation given to the better stand at the beginning of July. The grain yields were: 35 cwt per acre, irrigated: 27 cwt per acre, unirrigated. (Penman and French)

Woburn. The prescribed three-course rotation was disturbed, spring wheat replacing spring barley in the hope that "scorch" symptoms might appear and perhaps confirm a suspicion that "scorch" is attributable to water shortage. In the event, the wheat grew magnificently on all plots, and when scorch did appear, it was the irrigated plots that suffered most. Yields were 38 cwt grain/acre with 1·5 in. of irrigation, 36 cwt without irrigation.

There was no response to 1·5 in. of irrigation of clover, cut three times (yield, 68 cwt dry matter/acre), or on ryegrass, cut five times (yield, 83 cwt dry matter/acre). The same amount of water decreased the yield of sugar (65–59 cwt sugar/acre).

For the next few years the tidy pattern of experiments will be broken, to permit more *ad hoc* work. In 1966 the scorch search will be continued, and a potato experiment will occupy the rest of the area, exploiting a major

https://doi.org/10.23637/ERADOC-1-60

difference in degree of eelworm infestation, to explore the build-up of populations, and growth responses of the potatoes for resistant and non-resistant varieties, with and without irrigation. (Penman and Barnes)

Soil Physics

Aeration. The measurement of D/D_0, as an index of crumb structure relevant to gas exchange in the soil, continued. Here, D is the effective coefficient of diffusion of the test gas (hydrogen) in the crumb, and it depends partly on the pore-space (i.e., on the bulk density and on the water content) and partly on the way the particles are arranged (i.e., on the particle shapes and the tortuosity of the gaps between them) (1.6). A year ago results were reported for initially dry crumbs slowly wetted, up to a tension of 50 cm water. The same samples have now been dried over salt solutions, values of D/D_0 measured and the same path was retraced—no hysteresis, as predicted some years ago—down to dryness over phosphorus pentoxide, where the initial value of D/D_0 was reached with a minor deviation attributable to a slight loss in sample weight over the many months the experiment lasted. The experiment, in a very much quicker form, will be repeated on a range of soils at three water contents only: none, at plant wilting point, at field capacity.

Previously the plot of D/D_0 against air-filled pore-space showed only one major change of slope, at field capacity, where gas movement is restricted to the pore-space between the crumbs. The experiment above gave much more detail and evidence of a second change of slope for three soils (Highfield, Barnfield and an outside boulder clay subsoil) occurring at the wilting point for plants. This is unexpected: wilting is a facet of plant behaviour, and it may be simply coincidence that there is some abrupt change in soil properties at the same soil pF. At pF 4·2 the radius of pores being drained is 1,000 Å, and here the concepts already applied to diffusion through stomata should apply too: the diffusion constant of hydrogen in the air of such fine pores may be only one-half that in the larger pores between the crumbs because of the effect of collisions with the walls. Hence what has been called the pore "complexity" is greater in the drier soil, partly because the available paths are more complex and partly because movement in them is governed by a transport constant that depends on path cross-section. As another coincidence, the change of slope on the diffusion graphs occurs at the moisture content D. A. Rose identifies as the transition between surface creep and hydraulic flow of water under a suction gradient.

Measurements continued to determine the possible effect of atmospheric turbulence on gas transfer across the soil surface. The net transfer over even a short finite period must be zero, but it is evident that the composition of the air as it comes out of the soil can differ from what entered a second or less previously, and experiments—supported by analagous experience elsewhere on other fluids—show that the change in composition will be affected by the soil structure. For a shallow homogeneous soil there was no net increase in D/D_0 with pressure amplitudes below 2 mb and frequencies below 1 cycle per second, but for a soil with a surface crust—usually

https://doi.org/10.23637/ERADOC-1-60

stated to be a detrimental state for soil aeration—something did happen. Within the same range of experimental variables increases in D/D_0 of up to 25% were measured over the whole profile, and much more in the crust. Omitting the detailed reasoning needed to justify any inferences, the quick build-up of wind from calm over such a crusted soil might so accelerate carbon dioxide release from the soil that the equivalent of one day's steady-state transfer might come out within a few hours. Something of the kind has already been suspected in micro-meteorological experiments elsewhere, and further work with improved equipment should strengthen this link between soil physics and agricultural meteorology. (Currie)

Electrical charges on clays. New work on the flow properties of suspensions of montmorillonite and kaolin was mentioned last year (Cashen, *Rothamsted Report* for 1964) and some results are in press (1.5). The clays, suitably treated to carry both sodium and polyvalent cations, formed gels, which were subjected to alternating periods of shear and rest. On shearing, water is forced out of montmorillonite and drier kaolin pastes, an effect compatible with a loosening of structural bonds, and a compression of domains in the gel with an increase in the pore water surrounding the domains. At rest the domains swell again because of diffuse double-layer repulsion before the gel finally resets. In wetter kaolin pastes the behaviour is reversed: water is drawn into the gel on shearing, and is released again at rest. A possible explanation is that in the wetter paste the particles have more room to turn, and on shear they do so, and the water required for the extra pore-space is supplied by a withdrawal from the gel/air interface. (Cashen)

https://doi.org/10.23637/ERADOC-1-60