ROTHAMSTED RESEARCH

Report for 1957

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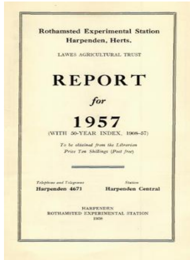
Rothamsted Experimental Station
Harpenden, Herts.
REPORT
for
1957

Physics Department

H. L. Penman

H. L. Penman (1958) *Physics Department ;* Report For 1957, pp 37 - 44 **- DOI: https://doi.org/10.23637/ERADOC-1-90**

PHYSICS DEPARTMENT

H. L. PENMAN

There have been changes in the established staff. W. W. Emerson left in May to join the Soils Division of the Commonwealth Scientific and Industrial Research Organization of Australia, and D. A. Pearce left in August. Dr. J. A. Currie joined the department in April, and Pearce was replaced by G. Szeicz in November.

Of the temporary workers, Dr. R. L. Davidson returned to South Africa in August, and Mr. H. D. Orchiston arrived from New Zealand in August. Among short-period workers, come and gone, we were happy to welcome Professor F. E. Kolyasev, of the Agro-physical Institute of Leningrad, who spent a month with us. In addition, Mr. G. Prillevitz of Wageningen used the department as a base for studies of irrigation activity in England.

G. H. Cashen took part in a two-day discussion meeting in Louvain, Belgium; P. F. Noble visited research laboratories in Holland and Germany; and, on an exchange basis, J. L. Monteith spent a month in laboratories in Leningrad and Moscow. H. L. Penman attended the Pacific Science Congress in Thailand.

During the year the degree of M.Sc. (London) was awarded to I. R. Cowan (former temporary worker) and Miss Margaret Dettmann.

SOIL PHYSICS

Soil cultivation

Two sets of experiments were started by E. W. Russell (now Director, East African Agriculture and Forestry Research Organization). The first of these, of simple design, compared deep and shallow ploughing, with and without subsoiling, mainly for potatoes on a number of commercial farms. Dr. Russell has now published an account of these experiments, and an abstract of his paper is on p. 262. As a supplement to this abstract, the paper contains the following: ". . . on the average, deep ploughing by itself, compared with shallow ploughing, puts up the yield of potatoes by about half a ton on the clays and loams, but puts down the yield on the organic soils, whilst subsoiling the shallow ploughed plots puts up the yield on the clays and perhaps on the sands, and subsoiling the deep ploughed plots appears to reduce the yield on the loams but to increase it on the light loams."

The second experiment, on our own farm, was more complex, involving six crops, and cultivation/fertilizer interactions. This has now completed its second rotation and come to an end. A statistical summary of the results has been prepared, and it is hoped that an interpretive analysis of the data will not be too long delayed.

Electrical charges on clay (G. H. Cashen)

The work on the electrical charges on kaolin has been continued using the technique in which the fall in pH of kaolin suspensions is measured as increasing amounts of cetyl trimethyl ammonium bromide (CTAB) are added. Previous results had shown that there was a lower limit to the net negative charge, and that with a deflocculant such as oxalate present a higher negative charge was measured, independent of pH, indicating that the planar charges had been isolated. If the difference between these two charges is taken as a measure of the maximum positive edge charge, the problem is to account for the presence and the amount of hydrogen ion on the planar faces necessary to develop the edge charge and give the marked fall in pH as the CTAB is added. The kaolin had been purified by washing with *N*-KCl, 10^{-3} *N*-HCl solution to remove any exchangeable aluminium or free aluminium compounds, and the planar charge should be almost completely satisfied by potassium ions prior to removal of excess electrolyte and washing of the kaolin with distilled water to get it chloride free. At this stage there should be little exchange acidity. This suggests that the kaolin crystals become unstable on washing because of the positive edge charges: equivalent amounts of the counter ions—chloride and potassium—must be washed away, and their removal will leave the crystal in a state of electrical stress. It is well known that clays which have been washed with acid are transformed to mixed hydrogen/aluminium clays on ageing, and the decomposition of the lattice to give aluminium in the exchange complex would be more easily explained if the positive charges on the edges were originally due to a loss of hydroxyl by the crystal edge, rather than to proton transfer. If it were proton transfer, then the stress could be relieved by a migration of protons within the crystal: if it is a loss of hydroxyl the stress could be relieved—in theory—either by ionization of water with hydroxyl groups discharging the edges and hydrogen ions occupying the sites of the lost cations; or by a decomposition of the crystal equivalent to stripping off the charged edge and giving hydrogen ions or complex aluminium ions in the exchange complex. If this concept is correct it may help to explain the deflocculation of kaolin by neutralization or destruction of the positive edge charge, as addition of alkali, for example, could be regarded as a neutralization of acidity, which might otherwise have given rise to positive edge charges by exchange.

The decrease in cation exchange capacity on heating kaolin to 300° C. (R. Greene-Kelly (1955), *J. phys. Chem.* **59**, **1151**) has been confirmed, but apparently kaolin differs from montmorillonite in that the decrease is limited to an amount approximately equal to the positive edge charge, whereas for lithium montmorillonite the cation exchange capacity may be almost wholly eliminated. Another feature for kaolin is that a similar decrease is obtained for the sodium kaolin, and as Na^+ is too large to fit into the octahedral spaces it seems that the effect is independent of the size of the exchangeable cation. If the reduction in base exchange capacity is caused by entry of a cation into the lattice, then these phenomena would be explained if the penetrating ions were protons, equivalent in amount to the positive edge charge.

Soil structure

Organic matter in soil (W. W. Emerson)

With Dr. Emerson gone (and not yet replaced), and Miss Dettmann's departure imminent, there may be a check to the impetus of this work. Emerson had already given a broad survey of his work (*Rep. Rothamst. exp. Sta. for* **1956**), and since then has published a preliminary note on the stereo-chemistry of organo-clay complexes in which organic compounds are taken up between the basal surfaces of montmorillonite and halloysite to form interlamellar complexes. Considering simple alcohols, he suggests that the orientation of the carbon chain is perpendicular to the 001 plane—and not parallel to it as originally assumed. By invoking a hydrogen bond between an oxygen atom of the alcohol and an oxygen atom of the clay surface, and putting in the best available estimates of bond lengths and directions, he has obtained good agreement between calculated spacing and that measured by X-ray analysis. Emerson's work goes on, and it is hoped that Commonwealth Scientific and Industrial Research Organization reports from the Soils Division, Adelaide, South Australia, will take over as these Rothamsted reports come to an end.

Sodium saturation technique (W. W. Emerson and M. Dettmann)

The modified technique (*Rep. Rothamst. exp. Sta. for* **1956**), though simplified, remains very tedious in application. It has been applied to soils from Rothamsted, Jealott's Hill and Bayfordbury for testing purposes, and to a Woburn experiment operationally. In the first group the interpretation of the results is largely a reflexion of field experience and intuition, but it is satisfying to find that the technique does put soils in an expected order of stability, i.e., the soil from old grassland is more stable than the same soil after arable cropping. The test on the ley–arable experiment at Woburn showed that stability was greater on the ley plots than on the arable plots, and both were better than the uncropped and frequently cultivated headlands.

Cross comparisons between soils of different texture cannot yet be made, and our own use of the technique is limited to estimating the effects of management on the structural stability of a given soil. Even here some control of acidity may be necessary, but experiments on buffering near pH 7 are not yet conclusive. The work done so far reveals that acid soil crumbs have a greater cohesion than similar calcareous crumbs, for two reasons. (i) In acid crumbs there is an additional attractive force between the positively charged edges and negatively charged faces of the clay crystals, revealed by a reduction in cohesion when the soil is brought to pH 7. (ii) Exchangeable trivalent ions increase the attractive force between clay crystals, for Fe^{+++} and Al^{+++} have been extracted from such soils, with a reduction in cohesion; and on adding these ions to a sodium clay the treated material remains stable in distilled water, whereas the untreated clay disperses in $0{\cdot}02N$-NaCl.

From this and other evidence it appears that liming an acid soil *decreases* the cohesion of the aggregates, and it may be that the known beneficial effect of liming lies in promotion of micro-bio-

https://doi.org/10.23637/ERADOC-1-90

logical activity, and in the maintenance of a sufficiently high concentration of Ca^{++} in the soil water to ensure re-flocculation of dispersed clay, so keeping drainage waters clear.

Water uptake by clays and clay soil (M. Dettmann)

Detailed time-and-motion studies on the wetting of clays suggest that if (depending on the clay mineral) the crystal lattice is allowed to take up one or two monolayers of water slowly, then subsequent flooding does not produce the shattering effect (slaking) that it has on a dry clay. The explosive effect of entrapped air seems to be very slight, and in our experiments has only been diagnosed in field crumbs of very low stability. The time needed to form the monolayer(s) appears to be of the order of about 10 minutes in a saturated atmosphere, and it may be that the slaking action of rain on dry field soil is limited to the surface, because water vapour can diffuse downward ahead of the liquid wetting front, so permitting an orderly controlled swelling of the clay, without disruption.

Measurements of such controlled swelling on pure sodium clays have shown that in N-NaCl (equivalent to 97 per cent relative humidity) montmorillonite expands to twice its original thickness, an increase which is consistent with the acquisition of three monolayers of water between each pair of unit crystal sheets, an effective area of 800 $m.^2 g.^{-1}$, and available X-ray evidence on lattice spacing in this state. For an illite (usually considered as having a non-expanding lattice) the swelling is 33 per cent.

Optical study of thin sections of field soils in polarized light has shown small patches of oriented clay around sand grains, and others randomly distributed in the general matrix. Rapid wetting could lead to rapid swelling along preferred lines, so causing breakdown. Slow wetting could leave time for local relative motion of particles to take up the strains, so preventing disruption at the expense of some dislocation.

Soil structure field experiment (W. W. Emerson and J. A. Currie)

The first block, ploughed up in 1953–54, had carried three test crops of spring beans, wheat and barley, and a new cycle was started in spring 1957 with a simplified arrangement in which the effect of ryegrass and lucerne will be compared with the effect of fallow. Both crops were cut for hay, and, in effect, provided fourth test cropping. The lucerne on the plots which were formerly cut for hay (1949–53) showed considerable differences in growth, that on the former lucerne plot being very good, that on the former ryegrass plot being markedly inferior. In contrast, the growth was much more uniform on plots on which grazing had been simulated.

On the second block, carrying barley as its third test crop, plants on the former fallow plots were less vigorous than those on former grass plots, being shorter, thinner stemmed and paler green in the early stages of growth. Though the differences became less noticeable as the season progressed, they persisted to harvest and in yield corresponded to about 5 cwt./acre.

The third block, ploughed up in 1955, carried its second test crop, the first, in 1956, being half beetroot and half carrots. Red beet and carrots were again grown on half plots where carrots and beet had been the year before. A month after germination, the former grass plots were markedly better in appearance than the former fallow plots, with larger though slightly fewer plants, but the differences in appearance became less apparent during the summer, and at harvest the mean weight per carrot was about the same, so that the former fallow plots gave a slightly greater total yield. For the beet, the main difference in response was the production of an extra 2 tons/acre on the former "grazed" plots as compared with the former hay plots.

From the present evidence it seems that such structural changes as we are able to produce are important at the time of germination and during the early stages of growth, and this aspect of the problem is to be examined a little more closely.

Soil aeration (J. A. Currie)

Experiments have started on a field method for measuring gaseous diffusion into and within a soil. Progress in the preliminary laboratory work has been encouraging.

Agricultural Meteorology

Micro-meteorology (I. F. Long)

All the available micro-meteorological equipment was concentrated in a single crop of spring wheat to permit a better study of the fine detail, and it is hoped that current analysis will answer a few of the questions posed by the 1955 and 1956 results. As before, the temperature and humidity gradients were measured at six levels and the wind at four levels in and above the crop, the telescopic mast again being used to allow constant observation heights above the growing crop. In addition to the anemometers, the "slow-response hot-bulb anemometer", constructed during 1956, was installed in the crop to give an idea of crop ventilation, and has functioned satisfactorily throughout the growing season. The "dew-point-gradient recorder" was also installed to give the general picture of water-vapour movement, and measurements of soil temperature at surface and 10-cm. depths, along with leaf temperatures at two levels, were continuously recorded.

The third set of equipment was used for short-period experiments, which were as follows: (*a*) Measurements at constant level on a line north–south across the experimental plot, at intervals of 7 m. Air flow was measured at crop height, or at 1 m. above ground; temperature and humidity were measured at crop height, or at 35 cm., or at 10 cm. above ground. (*b*) Vertical profiles in fine detail in and above the crop.

Good progress is being made with the analysis of the records, and some interesting results are emerging. For example, it seems clear that dew formation frequently occurs, but it does not always persist until 9 hours G.M.T., when the routine weather observations are taken. As many dew nights may be missed as are recognized. An *ad hoc* experiment to influence condensation (and evaporation) by electrostatic charge was tried, using metal plates at 300 volts above and below earth potential. The experiment was unsuccessful.

Comparison of leaf temperatures shows that the smaller narrower leaves of wheat do not heat up so much as potato leaves during the day, and the night cooling, though of the same order, is slightly less.

Heat and water balance (J. L. Monteith)

From April–August 1957 a continuous record was obtained of the evaporation from a crop of spring wheat using a large recording balance. Designed by Mr. L. G. Morris, the machine was built under his direction at the National Institute of Agricultural Engineering and has been installed in Great Field II, near the meteorological enclosure. Beneath the pan of soil in which the crop is grown and which has an area of 56 × 56 inches and a depth of 25 inches, crossed strips of beryllium–copper provide a robust suspension free from hysteresis and deformation. The "balanced" position is obtained by altering a fixed load at the end of a counterweight arm, and when evaporation, or rainfall, or condensation causes a change in soil-pan weight an electric motor moves a riding weight until equilibrium is restored. A pen attached to the rider records its position on a clock drum, so producing a graph of weight against time on which 1 cm. represents an evaporation of 0·3 mm. water. For dew studies, the rider weight can be decreased to give a sensitivity of 0·04 mm. condensation per cm. scale.

From the time of sowing at the end of March until harvesting in mid-August, evaporation was about 29 cm. and rainfall 17 cm., the hot dry weather of early summer being responsible for an unusually high soil-moisture deficit. Preliminary analysis of the records suggests that at times the recorded evaporation rate may have been higher than that in the surrounding crop because of the inadequacy of guard plants round the perimeter of the balance. After allowing for this effect, it appears that transpiration, and evaporation from the standard open water tank, were of the same order during active growth with a maximum rate of about 5 mm./day in early June. Transpiration was so closely controlled by available radiant energy that sunny and cloudy periods during a day could easily be picked out from inspection of the weight record. Hour-by-hour measurements of evaporation are being correlated with net radiation measured with a ventilated Gier and Dunkle radiometer and with the temperature and humidity profiles obtained by Long.

Condensation on mustard grown after harvesting the wheat reached 0·2–0·3 mm. on several nights in late September and in October. These amounts are greater than those previously observed with very short grass (maximum 0·13 mm. per night), but are still insignificant compared with evaporation over periods of two or three days.

Radiometry (J. L. Monteith)

Commercial instruments for measuring solar radiation are too big and too heavy for work inside crops, so a small, simple and inexpensive thermopile solarimeter has been designed and built. It has a linear response, and sufficient output to operate a portable galvanometer, but the design must be improved to eliminate an unacceptable dependence on solar azimuth.

https://doi.org/10.23637/ERADOC-1-90

On a cloudy day (when azimuth error was negligible) little variation was found between the reflexion coefficients of different green crops: sugar beet 26 per cent; kale 27 per cent; potatoes 27 per cent; lush grass 5–10 cm. high 27 per cent; cut grass in meteorological enclosure 30 per cent; dry bare soil 19 per cent. Short-wave radiation intensity in a mature stand of wheat was found to decrease exponentially below the top of the crop. With some knowledge of the transmission factor of the leaves, this attenuation might be used to give values of Leaf Area Index without destructive sampling of the crop.

An attempt has been made to establish correction factors for the Rothamsted radiation records obtained with a Callendar receiver and recorder between 1923 and 1954, this being one of the longest available British records. Penman's broad survey of the correlation between radiation and duration of sunshine has been extended to find correlations for each month of the year. Analysis is still in progress, but it appears that for some months the best empirical estimate of solar radiation is the long-term average for the month.

Heat flow in soil (P. F. Noble)

Continuous records of temperature variations down to a depth of 40 cm. in heavy clay soil have been obtained for several periods when the diurnal variation in amplitude of the surface temperature closely resembled a sine wave. Most of these records have been obtained under conditions of artificial heating, but some very satisfactory data have been obtained under natural heating in the early summer. Preliminary analysis of these records has been made, and in spite of considerable variations in moisture content, particularly in the surface layers, the same general pattern of thermal constants exhibiting marked discontinuities between 15–20 cm. has been shown in nearly all data analysed.

Unfortunately the flux plates which were placed in the soil at the same depths as the thermometers broke down, due to moisture absorption, and no records are available for the periods in which temperature records were satisfactory for analysis.

Soil water (I. F. Long and P. F. Noble)

A neutron ratemeter monitor has been built, based on the Harwell monitor type 1262 C but with some modifications in the power supply and ratemeter circuits. For electrical calibration and checking, auxiliary electronic equipment has been built, including a pulse generator.

A polonium–beryllium source is used, and laboratory calibrations of the system as a moisture meter indicate that it may be possible to use the equipment with source and detector lying on the soil surface, at least on the irrigation experiment. Field checks will be made in the coming year.

Irrigation at Woburn (H. L. Penman, T. W. Barnes and P. F. Noble)

There has been a change in cropping with the start of a new rotation. Beans replaced the potatoes (forbidden because of eelworm infestation), and spring wheat replaced the barley. Sugar beet—in the rotation—and grass remain as before. The bean experiment

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was made a simple 2×2 treatment with irrigation and spraying against black fly as variables, half plots being dunged. On the grass, nitrogen dressings were doubled so that the new lower dressing is the same as the old upper dressing, and on some of the plots an attempt has been made to do a nitrogen balance based on soil and plant analyses.

The weather of 1957 was much the same as that of 1956, a dry spring and early summer leading into a wetter period so that the irrigation season was effectively ended by mid-July. The grass and beans responded very markedly to the early watering, and the differences in the final yields are a reflexion of this better early growth. Early growth of the wheat was similarly affected, but the difference in appearance became less marked as the crop aged, and the final difference in yield is only partly a direct effect of irrigation, for some of the control plots, one severely and two mildly, were attacked by fungus. The table gives responses to full irrigation designed to keep the plots near field capacity (C plots) at two levels of nitrogen dressing (N1 and N2) for three of the crops. For the beans neither spraying nor dunging had any measurable effect, and only the general means are given.

Woburn Irrigation, 1957

Crop	Period	Rain, inches	Irrigation, inches	Plot	Yield, cwt./acre	
Grass	1 Apr.–27 Sept.	12·6	—	ON_2	63	Dry matter 8 cuts
				ON_4	85	
		12·6	5·4	CN_2	82	
				CN_4	102	
Sugar beet	1 May–27 Sept.	12·4	—	ON_1	59·9	Sugar
				ON_2	63·6	
		12·4	3·6	CN_1	59·3	
				CN_2	60·1	
Spring wheat	1 Apr.–5 Aug.	6·4	—	ON_1	25·4	Grain
				ON_2	25·8	
		6·4	3·2	CN_1	28·0	
				CN_2	33·0	
Beans	1 Apr.–19 Aug.	9·1	—	O	15	Grain
		9·1	4·0	C	30	

During the irrigation season changes in soil moisture were determined by regular sampling on O and C plots of the grass. In addition, gypsum blocks and porous-pot tensiometers were used, and while the latter behaved fairly well, the gypsum blocks changed their calibration after being some months in the soil.

Miscellany

I. F. Long has designed and built metering equipment for assessing the humidity and temperature of the forced-air draught of the farm grain dryer.

H. L. Penman has about half-finished writing a survey of the role of vegetation in hydrology, and nearly finished a revision of the evaporation map of the British Isles.

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