ROTHAMSTED RESEARCH

Report for 1950

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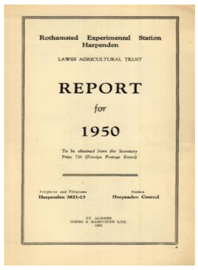
Rothamsted Experimental Station
Harpenden

LAWES AGRICULTURAL TRUST

REPORT
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Physics Department

R. K. Schofield

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DEPARTMENT OF PHYSICS

By R. K. Schofield

No change has occurred in the permanent staff during the year. Mr. I. F. Long was awarded a National Certificate in Applied Physics by the Institute of Physics. Dr. H. C. Aslyng was granted an extension of his scholarship by the British Council and was subsequently appointed Reader in Soil Science at the Royal Veterinary and Agricultural College at Copenhagen. He obtained the Ph.D. degree of London University.

In October Mr. J. P. Quirk, of the Soils Division of the Australian Commonwealth Scientific and Industrial Reaserach Organization, joined the depratment for a two-year period, and Mr. E. M. Clegg started a year of training for the Colonial Agricultural Research. Dr. L. Cavazza, of the University of Bari, Italy, spent two months of his summer vacation working in the department.

Dr. Schofield has continued to serve on the Joint Committee on Soils appointed jointly by the Department of Scientific and Industrial Research and the Ministry of Supply. The Technical Panel of the Land Drainage Legislation Sub-Committee of the Ministry of Agriculture's Central Advisory Water Committee, on which both Dr. Schofield and Dr. Penman served, presented its report in October.

Three members of the department attended the Fourth International Congress of Soil Science at Amsterdam, Dr. Schofield giving the special discourse to the section of Soil Physics. Useful contacts were made, and valuable personal reactions obtained to previous work of the department on soil moisture equilibria, evaporation studies and gaseous diffusion in soils. The department also supplied an exhibit as part of the section " Meteorology and Agriculture " of a Science Museum special exhibition to celebrate the centenary of the Royal Meteorological Society. Mr. W. W. Emerson was seconded for three months to the University of Madrid to assist in the preparation of the English translation of Professor Kubiena's new book on the Systematics of European Soils and to study his micro-pedological technique.

Soil Cultivation

Deep ploughing

The six-course deep cultivation experiment has now run seven years. Each of the six blocks of the experiment has carried a rotation of potatoes, spring oats, sugar beet, barley, ley and wheat, a different crop starting the rotation in each case. Half of the plots on each block have been deep-ploughed (12 in.–14 in.) for potatoes, sugar beet and wheat. At these times the remaining plots were shallow-ploughed (6 in.–8 in.), otherwise all plots in the same block have received the same cultivation treatments.

Depth of ploughing has had no consistent effect on the yields of potatoes grown without potash or with 1 cwt. K_2O per acre ploughed in ; but on all seven occasions (i.e. on every block in turn and on one block twice) the deep-ploughed plots which received this amount of potash applied in the bouts yielded more than the corresponding shallow-ploughed plots. The difference was 3 tons per acre in 1948 and 1·8 tons per acre in 1945, but was less than 1 ton per acre in the other five years. Although a statistically significant benefit from deep ploughing under these conditions cannot yet be claimed, it is possible that it may emerge before the experiment is finished.

In 1947 the sugar beet crop yielded 47 cwt. of sugar per acre on the deep-ploughed plots and only 35 cwt. on the shallow-ploughed. In 1948 and 1950 the yields of sugar were some 5 cwt. lower on the deep-ploughed than on the shallow-ploughed plots, although the tops were slightly larger. In the remaining years the deep-ploughed plots into which 0·6 cwt. P_2O_5 per acre as superphosphate was incorporated by ploughing yielded consistently four to five cwt. more sugar per acre than the corresponding shallow-ploughed plots. Where superphosphate was applied in the seedbed it gave no consistent increase in yield, and there was no consistent difference between deep and shallow ploughing. It has nearly always proved more advantageous to plough-in superphosphate for sugar beet than to harrow the same amount into the seedbed.

There is, as yet, no sign that deep ploughing—which has now been carried out four times on some plots and three times on others—is producing any cumulative benefit. Interpretation of the data is complicated by seasonal effects. Thus in 1950 45·3 cwt. of hay was obtained from the ley plots deep-ploughed in 1948 for sugar beet, whereas 54·5 cwt. were obtained from the corresponding shallow-ploughed plots; but in other years the differences have not been significant. In the dry summer of 1947 the barley on the deep-ploughed plots yielded 32·4 cwt. per acre compared with 30.0 for the shallow-ploughed plots, whereas in other years the difference has been less than 1 cwt. per acre and insignificant. The yield of wheat was depressed 2·8 cwt. per acre in 1947 and 3·5 cwt. per acre in 1948 by deep ploughing, but in other years the effects have been smaller and insignifcant. No significant effects are to be seen in the yields of spring oats.

It has frequently been observed that fewer weeds germinate in the seedbeds on the deep-ploughed than on the shallow-ploughed plots. The contrast was particularly marked on the sugar beet plots of 1947, and severe weed competition before hoeing could be carried out may have been the main cause of the striking difference in yield already referred to. It is to be expected that this contrast will disappear in time, and in fact it was not observed in 1950.

Agricultural Meteorology

Irrigation

Two centres were used in 1950, one for sugar beet, the other a forest nursery. At Kesgrave, Ipswich, the sugar beet experiment followed the pattern described in previous reports, Dr. Penman, assisted by Mr. Long, being responsible for installation of meteorological equipment on the site and interpretation of the weekly records received. Although the summer was wetter than that of 1949 there was a positive gain from irrigation :

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Yield of sugar (cwt.)

					Rain (from 1st May)
Total irrigation up to 1st July	0	2	1½	2	2·8
Total irrigation up to 1st Sept.	0	2	2	3	7·5
Total irrigation up to 25th Sept.	0	2	2	4	10·7
"Nitrochalk" (cwt./acre)					
0	52·4	63·9	58·8	60·9	
2½	51·9	67·2	59·9	65·9	
5	54·8	63·9	58·8	64·0	
7½	52·1	62·7	58·9	63·4	

The insensitivity of yield to nitrogen dressings was as in former years, but a new feature of the results was a significant difference in yield for two irrigation treatments giving the same total water. Future experiments at Woburn (see below) will be designed to check the implications of this result.

At Kennington Nursery, Oxford, the Research Branch of the Forestry Commission has started an experiment on controlled watering as a variable in seedbed experiments, and here, too, weekly weather records from the site have been the basis of controlled irrigation. Because of the shallow root layer of the seedlings, necessitating frequent small waterings, control from a distance has been difficult and the most that can be said of the experiment is that in spite of the wet summer, the watered beds have been better than those left to natural rain.

Drain gauges

The attempted repair of the 40-inch gauge appears to have been unsuccessful. Drainage totals for the year are: 20, 14·81 in; 40, 15·29 in.; 60, 14·32 in. Rainfall: 32·13 in.

Evaporation and transpiration

The agricultural application of the work is primarily in irrigation (as at Kesgrave). During the year the Ministry has made a grant for installation of equipment at Woburn, and from 1951 onwards this will be the main centre for field experiments on a variety of farm crops, and the experimental plots will provide useful opportunities for the study of physical and biological effects of irrigation. As forecast in the 1949 report, the Agricultural Meteorology branch of the Meteorological Office is now issuing fortnightly estimates (about one week in arrears) of potential transpiration for one or two places in each of the provinces of the National Agricultural Advisory Service, so that farmers—if they wish—can eliminate much of the guesswork from irrigation operations. Interest in this physical study of evaporation has been shown at many places abroad, to the great encouragement of the department; within one week there were requests for advice from the equator and from within the Arctic circle!

The work has been extended backward and forward. With Dr. Schofield, Dr. Penman has shown that an empirical factor connecting evaporation from vegetation with that from open water can be deduced theoretically from considerations of stomatal geometry and length of daylight, and extension of the ideas has shown that a theoretical ratio of transpiration to assimilation can only be brought into line with observed values if concentration of carbon dioxide in the air cavities of leaves is always very close to the atmospheric value. This is a conclusion of some botanical significance and needs further testing.

In the first of two forward extensions, Dr. Penman has published an account of the water balance of the Stour catchment area showing that some of our water supply problems are amenable to a physical treatment that is more precise both in detail and in long-term behaviour than prevailing statistical correlations. An evaporation map of the British Isles has also been published, showing the estimated mean annual evaporation at a hundred places and checked very satisfactorily by figures of rainfall *minus* run-off for forty catchment areas. The evaporation ranges from 14 inches per annum in north Scotland to 21 inches per annum in south England, and it is clear from the known seasonal distribution that in most years much of England south-east of the line Severn-Humber has not sufficient summer rain to produce maximum crop yields.

Two general reviews of this work have appeared in 1950. The first is a survey of the physical aspects up to but not including the evaporation map, by Dr. Penman; the second is a survey of the biological and agronomic aspects by Dr. Schofield, being an account of the special discourse he was invited to give at the International Soil Congress in Amsterdam.

Micrometeorology

Dr. Broadbent (Plant Pathology) has now published an account of his physical measurements among potato crops, based essentially on the thermistor bridge made in the Physics Department. His observations, necessarily discontinuous, have given quantitative measures of diurnal changes in environment that were predictable qualitatively. To fill in some of the gaps in the records, Mr. Long has successfully adapted the thermistors to be used with a continuous recording galvanometer, and an extended trial over a period of three months among brassica plants has been successful. From a first analysis of records Mr. Long has found interesting inversions of the vapour pressure gradient during some nights, but as it rained either before or during these periods the direct (qualitative) check of dew formation was not possible.

Mr. Long's first model of the thermistor bridge has been redesigned and has been on loan to the Grassland Research Station, Drayton, where it has provided some interesting and useful data on the micrometeorology of varied kinds of herbage.

The dew problem, of minor interest in British agriculture—except during hay-making—is supposed to be of major importance elsewhere, and the physical process is important even here in fog problems. Mr. Long is, therefore, attempting to construct—from thermistors—a small wet and dry bulb thermometer system that can be fitted in a probe for use in confined spaces. If it works we hope to get some measures of vapour pressure gradients in the soil to see if there is any appreciable upward movement of water vapour in the soil during the night.

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Heat balance of the soil

Whatever the results of this experiment, the experience gained will be useful for a desirable extension of Dr. Hutchinson's work on heat flow in the soil. As noted in 1949, a set of thermometers has been installed down to 6 feet and connected to a 12-point recording galvanometer. Because the thermometers and recorder are necessarily some distance apart it is not possible to keep all the system at the same temperature, and to obtain reliable records it has been necessary to use good quality auxiliary components and to adjust them carefully. In spite of delayed delivery of components the job has been completed, and reliable records are now being obtained. In the meantime Dr. Hutchinson has worked out a neat method of analysis that will be of great value later. The next stage is to obtain corresponding records for heat flow in the air, for vapour transport in the air, and for radiant energy exchanges. For the first two the continuous recorder described above will be useful, and for the last, Dr. Hutchinson, assisted by Mr. Long, has started the construction of a portable radiation meter.

In all of this work close contact is being maintained with the radiation laboratory of the Meteorological Office at Kew Observatory.

LABORATORY WORK

Soil structure

The general problem of evaluating quantitatively the difference between soils with good and bad structure has been investigated by Mr. W. W. Emerson with particular reference to two clay soils from the Grassland Research Station at Drayton. These have approximately the same mechanical analysis, but one had been under arable cultivation for four years and had so bad a structure that it was considered necessary to put it down to ley, while the other had just been ploughed-out after four years in ley. These will be referred to as "arable" and "ley" soils.

There are two interpretations of bad structure, possibly inter-related. Firstly, a low water stability producing a break-down and silting-up of the soil when wet with consequent loss in aeration and permeability. Secondly, a comparatively low moisture range over which the soil can be worked, i.e. a rapid transition from the hard cloddy to the adhesive state.

For measuring water stability the normal Yoder method of wet sieving was considered inadequate, as it really only measures "slaking," i.e., the break-down of dry aggregates on immersion in water. To simulate field conditions more closely, a modification of the Vilensky-McCalla falling drop method was used. A given size of natural air-dried aggregate was placed on a variable width slit and the number of drops of water required to break it up to pass the slit was measured. The aggregate itself is not immersed in water but is merely exposed to the effect of the falling drops. Based on fifty aggregates, both soils have a high-water stability, but for aggregates of 4-5 mm. and 1-2 mm. the arable soil was slightly superior. The method is apparently very sensitive, as preliminary tests on Barnfield plots gave three-fold differences between 4A and 10 in the amount of water required. The only disadvantage is that it is very tedious.

As the above method did not yield any large difference between the two fields, the stability of 1-2 mm. natural aggregates to wetting and drying was measured by using Childs' method of determining the suction-water content relationship of the inter-aggregate spaces. The interpretation of the resultant graphs was improved by determining the slope of the curves at 16.8 cm. suction, corresponding to Haines' determination of the maximum entry value for pores, thus eliminating the effect of the actual arrangement of the aggregates in the Büchner. On this basis the ley was superior to the arable. At the same time, two other samples from the Drayton farm were compared: one from each half of a field which had been half in ley and half in arable for three years. These showed up approximately the same difference between ley and arable, although their stabilities were lower than the previous ones. The method is accurate and could be easily developed into a routine test.

Finally, at the suggestion of M. B. Russell, the Yoder technique was used, but the wet sieving was continued for varying times and the weight retained on the sieve plotted against time. Russell found a linear relationship between log t and the weight retained, but this did not seem to apply to these soils. Since the break-up of aggregates on immersion in water takes place—due to compression of the air inside and to differential swelling—presumably after the time required to saturate the aggregate any further break-down is due to mechanical erosion.

For the second line of approach, the limited working range of the soil, the upper limit was determined by mechanically mixing powdered soil at increasing moisture contents and plotting the degree of aggregation. It was shown that aggregation suddenly commenced at 18 per cent moisture content and increased rapidly until the two soils attained a monolithic state at 24 per cent moisture content, the latter point being extraordinarily critical and much lower than the sticky point values of the two soils (about 35 per cent moisture content).

It was hoped to measure the lower working limit by determining the moisture content at which the cohesion of aggregates was sufficiently reduced to be broken up by a disc type harrow. A simple apparatus was made in which aggregates were crushed between two parallel plates. In the first experiment a highly significant difference in the load required to rupture 3-4 mm. air-dried aggregates was found, based on an average of twenty aggregates. This is the principal difference found between the two soils so far, but whether this will elucidate the very marked difference in structure visible in the field remains to be seen. Water stability does not seem to be an important factor, although up to the present only air-dry aggregates have been used, and it is possible that the variation of water stability with moisture content might yield interesting results.

Measurement of the volumes of solids, water and air in soils clods

The method introduced by Dr. E. W. Russell and modified by Dr. M. L. Puri has been further tested by Mr. W. W. Emerson. He has found it better to measure the volume of the water finally distilled from the clod under toluene than to run it off through a tap and weigh it. An interim report has been prepared and is available on request. A paper describing the method is being prepared for publication.

Effect of temperature on soil moisture

During a two months' visit Dr. L. Cavazza made a preliminary study in which a soil clod taken from the field in such a way as to preserve its natural structure was subjected to temperature changes between 5° and 40°C. The clod rested on a sintered glass membrane through which water could be withdrawn from or given to the clod, the suction (pressure deficiency) of the water under the membrane being measured by a manometer. In one series of measurements the suction was adjusted as the temperature was changed so as to prevent the water content of the clod from altering. In a second series of measurements the suction was maintained constant and the water content allowed to change with temperature.

Surprisingly large temperature effects were observed, the interpretation of which is greatly complicated by the fact that the same amount of water when held on the clod develops a greater suction at a given temperature when it has cooled to that temperature than when it has warmed to it.

Field measurements of suction

Mr. E. M. Clegg has been testing a form of tensiometer designed to give rapid indication of the low suction values developed in soil above a water-table. This form of instrument may help to demonstrate whether or not land drainage is desirable. The temperature effects have proved to be very troublesome unless the sintered glass membrane is placed deep enough in the ground to be within the "capillary fringe" above the water-table. This may extend less than one foot above the water-table. In spite of this difficulty this method of investigation appears promising enough to be worth pursuing further.

Vapour pressures of aqueous solutions

Accurate measurement or control of aqueous vapour pressure is fundamental to much of the work on water in soils and plants and in the atmosphere. Values of the vapour pressures of NaCl solutions calculated from the E.M.F. values of concentration cells were provisionally adopted as the standard, in spite of small systematic differences that appeared to exist between these values and those obtained by direct measurement. In the course of a critical study of these discrepancies Mr. G. H. Cashen obtained, through the courtesy of John Hopkins University, microfilm copies of the theses of W. R. Norris and S. S. Negus which describe their very accurate direct measurements made under the direction of J. C. W. Frazer of the differences of vapour pressure between NaCl solutions of different concentrations. It emerged that through a defect in the thermometer used to adjust the temperatures of the thermostats these measurements were made at 19·94°C. and 24·94°C. and not at 20°C. and 25°C. as had appeared from the only published account of the work. Vapour pressures are so sensitive to temperature, that even ·06°C. is of importance in accurate work, and it is

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very satisfactory to be able to report that there is, in reality, no serious discrepancy between these direct measurements and the E.M.F. measurements of Harned and Nims.

If we assume, as it seems we must, that the similar measurements of Lovelace, Frazer and Serase on KCl solutions were made at 19·94°C., and not at 20°C., their results are found to support the conclusion that satisfactory values for the vapour pressures of KCl solutions are obtained by combining the values provisionally adopted for NaCl with the concentrations of NaCl and KCl solutions of equal vapour pressure (isopiestic concentrations) which have been accurately determined by several workers. Distinctly different values are obtained by calculation from the available data for the E.M.F. values of KCl concentration cells, and these must be rejected.

Mr. Cashen has obtained further evidence pointing in the same direction by calculating from the heats of solution of several solutes in their saturated solutions and their temperature coefficients of solubility the rate of change of vapour pressure with concentration at saturation. Measurements of isopiestic concentrations enabled him to obtain the corresponding change with concentration of the vapour pressure of NaCl and KCl solutions. Again there is very satisfactory agreement with the NaCl standard but not with the KCl E.M.F. data.

We now feel that the values adopted for the vapour pressure of NaCl solutions must be very close to the truth, and we believe them to be a distinct improvement on tabulated values in current use. A detailed account of this work is in preparation, and we hope that the results will be useful in other laboratories.

Aluminium ions in acid soils

Mr. Taylor has been extending the work already done on the simpler ions –Ca^{++}, Mg^{++}, K^{+} and H^{+} to aluminium ions which are known to be present in acid soils. As a first step a study was made of the products of the reaction between $AlCl_3$ and $Ca(OH)_2$ at high dilution. He has shown that aluminium can exist in true solution at a concentration of 2×10^{-5} molar when the pH is as high as 5·3, the solution then containing both Al^{+++} and $AlOH^{++}$ ions, in proportions governed by an equilibrium constant which he has determined at three temperatures. The minimum solubility occurs at about pH 6, above which aluminium occurs in solution almost entirely as aluminate ions –$Al(OH)_4^-$.

When samples of an acid soil are shaken with solutions of $CaCl_2$ of concentrations ranging from M/100 to M/1,000, the concentrations of aluminium found in the filtrates do not fall off so much with decrease in the concentration of $CaCl_2$ as would be the case if all the aluminium in solution existed as triply charged ions. The proportion of $AlOH^{+}$ can be calculated from the pH, and is quite insufficient to account for the observed behaviour. It appears that much of the aluminium dissolved in the soil solution is not present as simple Al^{+++} or $AlOH^{++}$ ions, but as complex ions carrying one or two unit charges or even as uncharged molecules. Further tests are being made to verify this deduction and get further information about these complexes.

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Equilibrium concentration of phosphate ions

Dr. H. C. Aslyng has shown that when a soil sample is shaken up with a dilute $CaCl_2$ solution, a small but definite concentration of phosphate ions is found in the solution after separation from the soil by filtration. The more dilute the $CaCl_2$ solution the greater is the phosphate concentration, and it has proved convenient to standardize the $CaCl_2$ concentration at M/100, which is about the upper limit of the salt concentration of natural soil solutions in normal soils and is strong enough to ensure flocculation of clay soils so that a clear filtrate is easily obtained for colorimetric estimation.

If soil samples are dried before they are brought in contact with the $CaCl_2$ solution higher phosphate concentrations are generally found than when the soil is examined fresh. Some soils are more sensitive in this respect than others, and the higher the temperature of drying the greater the disturbance. The ratio of soil to solution has only a small influence on the result : 25 gm. of soil in 50 ml. of solution are generally convenient.

Proof that we are dealing with a reversible equilibrium between the phosphate ions in solution and those "sorbed" on the soil particles has been obtained from physico-chemical studies in which it has been possible, on the one hand, to exchange the soil cations without altering the value of $pH + pH_2PO_4$ and, on the other hand, by adding lime to increase the pH without materially altering pH_2PO_4 in M/10 $CaCl_2$. The equilibrium concentrations found in the calcareous soils of Broadbalk and Hoosfield, which receive superphosphate, correspond with the solubility obtained by Bjerrum for the metastable calcium phosphate $Ca_4H(PO_4)_3.2H_2O$.