ROTHAMSTED RESEARCH

Report for 1939-45

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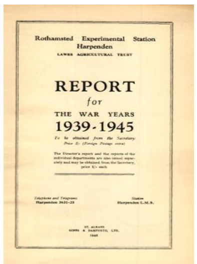
Rothamsted Experimental Station
Harpenden
REPORT
for
THE WAR YEARS
1939-1945

Physics Department

B. A. Keen

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DEPARTMENT OF PHYSICS

By B. A. KEEN

STAFF ACTIVITIES

Dr. Keen was President of the Royal Meteorological Society in 1938 and 1939, and Vice-President of the Institute of Physics. He was a member of the British Government Delegation to the Sofia University celebrations in May, 1939, and paid a second visit to Bulgaria in October-November, 1939, to report on problems of agricultural intensification and to select five agricultural scientists to come to England under British Council grants. In October, 1943, he was seconded as Scientific Adviser to the Middle East Supply Centre, Cairo, with the primary object of preparing a report and recommendations dealing with the agricultural development of some fourteen Middle East countries. The Report is now in the press, and will be published by the Stationery Office and the Oxford University Press. Dr. Keen also served on a Ministry of Supply committee on physical properties of explosives, and the soil stabilisation committees of the British Standards Institution and the Institute of Petroleum.

Dr. R. K. Schofield acted as Head of the Department in Dr. Keen's absence in the Middle East and replaced him on the above committees. He was appointed to the Ministry of Supply committee studying the mud-crossing performance of track-laying armoured fighting vehicles, and, at the request of the Meteorological Office, he also undertook with Dr. Penman special work on some problems of operational importance to the Royal Air Force. He was elected Chairman of the Physical Society Colour Group in 1945.

Dr. Russell was Chairman of the Hertfordshire County Garden Produce Committee.

Dr. Penman was seconded in September, 1941, for physical work in the Mine Design Department of the Admiralty. In April, 1944, he returned to Rothamsted at the request of the Air Ministry to join Dr. Schofield in special extensions of our work on transpiration and evaporation.

H. G. C. King, of the Assistant Staff, joined the Royal Air Force in May, 1941, and was commissioned as a pilot.

Besides the above activities, the departmental staff received a variety of requests for help and advice—usually involving rapid field or laboratory investigation—from organisations such as the Air Ministry and the Road Research Board.

For many years past, applications for admission to the Department as post-graduate voluntary workers have come from many different countries. The war drastically reduced the numbers, but the international aspect has been well maintained. Four voluntary workers obtained the Ph.D. degree of London University ; H. C. Pereira (England) : A. L. C. Davidson (Australia) : R. V. Tamhane (India) : and S. P. Saric (Jugoslavia). Others who spent a considerable period in the Department were : W. Balcerek (Poland) ; P. Boyanoff (Bulgaria), and A. Texeira (Portugal) ; the last two were in receipt of grants from the British Council.

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Crops, soils and weather

The large variations in crop yield and quality from season to season are primarily caused by weather variations (1). In spite of this intimate association, only broad general relationships emerge, such as the low yield in a consistently cold growing season. The infinite variety in weather sequences, the local effects of topography and the physiological responses of the plants to environmental changes constitute too complex a system for ordinary analyses. Superimposed on this system there is the further complexity of plant pests and diseases, whose incidence also depends in intricate ways on weather factors. For these reasons, meteorologists and others have devoted attention to local climate variations which they endeavour to relate to minor topographical features on the one hand and to vegetation on the other. Botanists have carried the problem a stage further to the micro-climate, i.e., the meteorological elements within the few centimetres of air surrounding the leaves and stems of vegetation, in the belief that plant responses are due to micro- rather than macro-climate.

There is another line of attack, the physical, to which the two just mentioned are complementary for they must draw on the results of the physical researches in order to put them on a quantitative basis.

In its broadest terms the physical attack relies on studying energy balances between the meteorological, soil and vegetation factors. Experimentally, this involves examination of radiation, temperature, humidity, evaporation, transpiration, drainage, diffusion, winds and their inter-relations. For many years past the equipment of the meteorological station at Rothamsted, which is in charge of the Physics Department, has been steadily extended, especially by providing continuous recording instruments, and used for this purpose. It possesses a unique series of drain gauges, or lysimeters, and large soil cylinders in which crops can be grown and the water table maintained at required depths. This part of the equipment is essential for the exact study of crop-weather relationships.

Considerable attention has been given in fallow or bare-soil conditions to drainage and evaporation in relation to other meteorological and soil factors (2, 3, 4, 5, 6, 7). Thanks to the use of continuous recording instruments it is possible to pick out from the mass of records a series of " natural periods " for detailed study. A natural period is the period between one cessation of flow of the drain gauge and the next cessation : its duration may vary from a day or so to several months. The advantage of a natural period is that evaluation of the influence of the factors over the period can be more precise as overlapping effects are reduced to a minimum. The conclusions can then be applied to interpreting the results of arbitrary regular periods—month, week, etc.—that are standard for meteorological records and tables of normals.

The results show that the normal air data of a meteorological station are inadequate to predict the behaviour of the natural air-soil system under drying conditions. However, the results from the Rothamsted equipment, covering both air and soil factors, have led to some important generalisations. Seasonal variations in drainage

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rate are almost wholly accounted for by the changes in viscosity arising from seasonal temperature changes. For a 20-in. depth of fallow uncultivated soil, the amount of water needed to cause waterlogging is about 0·3 in. in excess of the field capacity. During the rainless periods of a normal summer, the total water loss by evaporation (i.e., the deficit from field capacity) rarely exceeds 0·7 in. Thus there is a normal range of water content of only about 1·0 in. ; in other words, the maximum air content in midsummer is about $\frac{1}{20}$, or 5 per cent. by volume. The figure for a similar soil also fallow, but cultivated is about 15 per cent. Seasonal changes in evaporation have been studied in both field and laboratory conditions and an approximate interpretation has been given in terms of water movements, as vapour and as liquid, in the soil, and of diffusive flow of vapour through a still boundary layer of air above the soil surface into the turbulent air above.

Recently (May, 1944) at the request of the Meteorological Office, arising from a problem in war operational research, measurements of evaporation were made from open water surfaces, and short grass with a water table near the surface, in addition to those from bare soil. The results have shown that the total annual water losses from the short grass is about three-quarters of that from the open water. From the viewpoint of crop-weather relationships it is important to extend this work to tall crops. This cannot be done in the present soil cylinders, as it is not possible to have round them the broad guard-ring of the same tall crop to prevent unnatural exposure of the plants growing in the cylinders. A separate and rather costly equipment will be needed for this purpose. Meanwhile some encouraging results have been obtained by indirect methods based on the suction techniques for measuring moisture deficits developed in the Department. Representative soil clods are taken from below the field crops and placed on filters containing water at a controlled suction of 50 cm. Their gain in weight is a measure of the water removed from them by the crop roots. The results show that barley up to the time of ripening has removed from the soil an amount of water approximately equal to the excess of the evaporation from short grass in the cylinders over the rainfall of the same period. The indication is that evaporation from a tall crop may be about the same as that from short grass.

Attention has also been given to the diffusion of gases and vapours through the soil (8, 9). The relation of diffusion rate to soil porosity is of importance both in meteorological and plant physiological work, and also has a technical interest in problems of soil fumigation. It was shown that diffusion through soil is a modified form of free diffusion in air, the modification depending only on the pore space when diffusion is steady. In the unsteady state solvent action by soil water, adsorption and chemical action may affect the results. Anomalous results of other workers for carbon dioxide were traced to the neglect of adsorption effects. The results also show that gaseous diffusion is adequate to account for normal soil aeration, and that the influence of meteorological changes is unimportant. It is also clear that diffusion of water vapour by distillation down a soil-temperature gradient makes a negligible contribution to the change in moisture content at any point.

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In an analogous subject, the viscous diffusive flow of gases into plant tissues, a theoretical study was made of the porometer used by plant physiologists for the study of stomatal movements in leaves (10, 11).

Soil tillage

For a number of years past critical examinations of the effects of cultivation operations on the soil, soil moisture, plant growth and yield have formed an important section of the Department's work. The earlier results ran counter to certain of the traditions that have grown up around the subject, and, possibly for that reason, were received with scepticism. Later work, however, has confirmed the views set out in the previous investigations: crop yields are relatively insensitive to cultivation treatments; cultivations do not have the effects on soil-moisture control formerly attributed to them; weed control is most important in the early stages of crop growth. Since **1939** six papers have been published summarising various aspects of the results; two (**12**, **13**) for general and scientific readers, two (**14**, **15**) for agriculturists, and one (**16**) for horticulturists: the sixth paper (**17**) examines a large number of United States experiments on crop response to inter-row tillage, extending over many soils and seasons, and shows that they agree with our own results, in spite of the large differences in weather and soil and the use of different crops.

A three-year experiment in Surrey, on a loam soil overlaying sand and gravel, on the effect of inter-row tillage on potato yields was completed (18). Very low ridges were as effective as the standard high ridges in preventing green tubers and blight attack, and there was no difference in yields or in the relative proportions of ware, seeds and chats. In garden practice there seems no reason for ridging, but in commercial potato growing the present forms of implements for spraying and harvesting require high ridges for the reduction of haulm damage by wheels, and for ease in spinning out the tubers, especially in heavy soils. These experiments fell into line with the general conclusions already mentioned above; yields were insensitive to cultivation treatments but were appreciably reduced by even moderate weed competition in the early stages of crop growth.

The six-year cultivation experiment, begun in **1934**, was completed. This compared, in a three-course rotation of wheat, mangolds and barley, the effects of the following cultivation treatments: plough and harrow, cultivator and harrow, rotary cultivation, each at shallow (3-4 in.) and deep (7-8 in.) levels. The results of the first three-year course were given in the Report for **1936**, pp. **43-48**, and the full results have now been published (19). They show no yield difference between deep and shallow working, with the possible exception that maintenance of mangold yields may require an occasional deep cultivation. The ploughing treatment was better than the other two, for the probable reason that it showed the most efficient weed control.

Earlier work on inter-tillage of sugar beet suggested the importance of weed control in the early stages of crop growth, so experiments in **1939**, **1940** and **1941** were directed to this point, both on the sandy Woburn soil and the heavy stony Rothamsted soil. The results (20) show that on the Woburn soil the effect of weeding depends on the level of soil fertility. The yield of the manured plots was not improved by weeding, and a considerable infestation caused no decrease in crop, but the yield of the unmanured plots was increased by weeding provided it was done in the early stages of crop growth. In the heavier Rothamsted soil the effect of cultivation did not alter with the level of fertility. There was some indication that whereas hoeings after singling, above a modest minimum, produce either no effect or a reduction in yield, a cultivation before singling time could produce an increase.

A new cultivation-rotation experiment was begun in the autumn of 1943. The object of this experiment is to compare the effects of deep (about 12-in.) with shallow (about 6-in.) ploughing and the effectiveness of potash and phosphate applied in the spring in the seedbed with that of applications in the autumn just before ploughing. A six-course rotation—wheat, potatoes, oats, sugar beet, barley, seeds—is used and the deep-ploughing treatment is given in preparation for the wheat, potatoes and sugar beet, i.e., three times in six years, and the comparison of the method of incorporating the potash and phosphate is tested on the potatoes and sugar beet. The results of only two harvest years are so far available, and are in consequence provisional : but in the dry summer of 1944 the sugar beet seemed to do best on the deep-ploughed plots in which potash or phosphate were ploughed in, and in the moist summer of 1945 the potatoes seemed to respond well to the deep-ploughing.

Ever since the beginning of our cultivation studies we have been hampered by the absence of facilities for carrying out even simple experiments at other places besides Rothamsted and Woburn : indeed the only satisfactory outside experiment—the three-year one on potatoes in Surrey (18)—arose from the chance that a resident there was able to carry out work for a Ph.D. thesis on cultivations, under the writer's direction. As long as this unsatisfactory situation continued we were in no position to deal with the frequent statements of agriculturists and others that yields on their soils, unlike those at Rothamsted and Woburn, were responsive to cultivation. At the end of 1942 a full statement of the results to date was made to the Agricultural Research Council, and the need for further work was urged. Large numbers of heavy implements capable of deep work were in use, especially under the charge of the War Agricultural Executive Committees, and there was little or no evidence whether the extra call on limited fuel stocks needed by a deeper working of the soil would be justified by an increased crop yield. Eventually, the necessary implements were made available and a programme of work was authorised, the results of which are supplied to a joint sub-committee of the Agricultural Research Council and the Agricultural Improvement Council. The experiments are carried out in association with the County War Agricultural Executive Committees, usually through their Technical Officers, and the arrangement works very well. The work began in the autumn of 1944, and was confined to potatoes—a crop for which deep cultivation is considered very important—with the following four cultivation treatments : 7-8 in. ploughing ; the same, with subsoiling to a total depth of about 12 in. ; 13-15 in. ploughing ; the same, with subsoiling to a total depth of about 18-20 in. Fourteen centres were selected covering the following range of soil types : clay-with-flints, chalky boulder clay, boulder clay, London clay, clay fen, Lower Lias clay, sand over Lower Lias clay, old reclaimed gravel and sand heath, Old Red Sandstone alluvium. The results for the 1944-45 season were striking. The wide range of cultivation treatments produced no effect on yield, with the one exception of a very wet field where deep ploughing was beneficial. Nor were there any notable differences in the response to fertilisers with the different depths of cultivation. There is the possibility that in seasons like 1944-45, which was favourable for plant growth, cultivation differences, like manurial ones, will be smoothed out. The experiments will, therefore, be continued. A further set of deep-ploughing experiments on other sites and covering further soil types was begun in the autumn of 1945. Assistance has also been provided for a preliminary study of the root ranges of growing plants that may help to explain the effects of weeds already discussed above.

A significant extension of the field work of the Department was an investigation of the relative efficiency and behaviour under normal farm usage of various types of pneumatic tyres and standard steel wheels, and the effects, in differing soil conditions, of various modifications such as loading, inflation pressure. The work was done at Rothamsted and Woburn at the joint request of the British Rubber Producers' Research Association and the British Rubber Publicity Association. At an early stage of the work it became necessary to devise a simple and accurate method of measuring the tractor performance over quite short runs, so that the field tests could be kept within a reasonable compass of time and area (21). The elaborate equipment used for testing tractor performance was unavailable, and in any case was inapplicable in the present work. By fitting an auxiliary small fuel tank, in which the fuel consumed could be accurately measured, a number of separate experiments can be made and statistically analysed, the length of run in each experiment being only between 50 and 175 yards. The recorded measurements of fuel consumed are corrected for certain variable factors, such as drawbar pull, gear ratio and speed of ploughing, and the corrected results give a measure of the tractor efficiency and, therefore, of the tyre performance in the particular experiment. The method has since been adopted by other investigators. Its use in the present investigation (22) brought out the following points.

Tyre performance depends more on adequate ballast than inflation pressure. Low pressures were useful only in wet conditions and when extra ballast is unavailable, and high pressures promote excessive slip. Extra ballast, especially over the landside wheel, whose load is reduced by the tilt of the tractor, improves the performance. Except for loose soil and wet turf, a large outside tyre diameter is more important than a wide section. Wheel slip, as usually measured, gives values higher than the real slip. The tyre casing and tread are compressed horizontally by the pressure that the treads must exert on the ground to move the tractor forward. The movement of the tyre on the ground is concertina-like, and this reduces the effective circumference of the tyre so that it appears to be slipping, although there may be little or no relative movement between tyre and soil. Measurements of plaster casts of the soil impressions left by a tractor running light and heavily loaded showed that practically all of a measured " slip " of 8 per cent. was accounted for by the apparent slip just described.

Soil structure and moisture relationships

Previous reports and published papers have developed the exact physical picture of the way water is held and moves in a soil. The theoretical and practical work of Haines* disclosed the hysteresis effect, i.e., there is no unique or single value for the soil-moisture content at a given equilibrium condition, and the actual value depends on how that equilibrium is approached. Haines's work was based on considerations of the geometry of the soil pore space and the curvature of the water films, and was therefore confined to coarse-grained material, such as sand and very light soils. Later, Schofield† gave a generalised treatment of hysteresis, based on energy considerations, and therefore applicable to all soils, and he also provided, over a wide range of suction values, experimental proof of its reality. Subsequent work in the Department has examined and extended the experimental techniques available for measuring the suction values corresponding to different moisture contents (23). It has been shown that an apparatus of the " filter " type, i.e., a porous pot or plate containing water and connected to a manometer, gives reproducible values for suctions up to about 400 cm. instead of up to one atmosphere, which is the theoretical maximum for these instruments. Measurements of suction by the freezing-point-depression method, on the other hand, are not reliable at suctions below about 4 atmospheres. The reason is that the freezing-point depression is due not only to suction but to the soluble salts in the soil moisture. The latter effect makes an appreciable contribution to the total depression at the soil-moisture contents corresponding to suction values below 4 atmospheres, and it is difficult to assess it accurately and so to arrive at the effect due to suction only. For use over the important suction range 400 cm. to 4 atmospheres, thin absorbent plates of Portland stone have been tried and found suitable. They are placed in contact with the soil and their equilibrium moisture content determined. They were calibrated up to one atmosphere by a suction technique, and from one to 4 atmospheres by vapour-pressure-depression measurements.

Problems of moisture distribution and movement concern not only agriculturists. They are of importance to water-works and irrigation engineers, to civil engineers and builders concerned with the pressure and stability of foundations, roads, etc. From an inspection of the considerable technological literature that has grown up around the engineering aspects of these subjects, under the name of " soil mechanics," and from the nature of the requests for help received by the Department from those concerned, it is

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* J. Agric. Sci. (1930), **20**, 97-118.
† Trans. Third Int. Congress Soil Sci. (1935), **2**, 37-48.

clear that the part played by moisture distribution and movement in their problems is not yet fully appreciated. A paper was, therefore, prepared, addressed especially to engineers, on the role of soil moisture in soil mechanics (24), setting out the mechanism of water distribution as it is now understood.

Soil structure, or the geometrical specification of particle arrangement, and its degree of permanence or impermanence are of basic importance in the study of soil tilth and the modifications produced by weather and cultivation operations. The experimental methods can be classed in two groups : (*a*) those which measure the size distribution of the clods and crumbs in the soil, and their degree of resistance to disintegration forces, (*b*) those which deal with the clod and crumb geometry—the volume of pore space, and of air and water in the pores.

Some methods in the first group have been examined (25). Simple passage through a nest of sieves gives information on size distribution of clods in field conditions, and on the effect of cultivation implements. For the smaller sizes of aggregates—the soil crumbs that characterise tilth—some measure of their stability is required. It is usually considered that tilth is related to the more resistant soil crumbs and, in default of any absolute definition of a resistant aggregate, the criterion taken is the ability to withstand slaking in water. Some degree of empiricism is inevitable, for the aggregates are not absolutely water-stable, and the results obtained will therefore depend on the way the slaking is carried out. The drastic method of slaking by sudden immersion in water was compared with the gentle ones of very slow wetting and wetting under a vacuum to avoid the disruptive effect of air evolution : the choosing of a particular method depends on the kind of information required, e.g., if stability under flood-irrigation conditions is the problem, the immersion technique would be the most suitable.

In the second group of methods dealing with the volume measurements of pore space, air and water in the clod or aggregate, a variety of techniques is available for use with permeable stoneless soils, but for impermeable soils and, in particular, the stony " clay-with-flints " soil at Rothamsted no accurate method of a reasonable simplicity has hitherto been in use. Existing methods, based on forming an impervious coating around the clod of soil, either fail or have a low accuracy for damp clods. A method has now been developed (26) using a liquid that is immiscible with water and that is also non-polar, so that no appreciable swelling of the clod occurs. Paraffin was found to be suitable, after purification by shaking with finely divided damp soil and then with dry silica gel. The moist clod is weighed in air : then it is immersed under vacuum in paraffin which replaces the air in the clod and it is weighed in the paraffin : finally it is weighed in air when full of paraffin. A simple calculation from these three weighings gives the total clod volume, the volume of air and the volume of the soil particles plus the water, from which the water volume can be obtained by a subsequent determination of the volume of the soil particles. The accuracy of the field-volume and air-space measurements is at least 0·1 per cent. By bringing the clods to equilibrium with water at two definite suction values—the well-drained or field-capacity condition, and the wilting point— measurements of the water available to plants can be made. Tests of the soil from the farmyard-manure and unmanured plots of the classical field experiments at Rothamsted show that the long-continued applications of farmyard manure have increased the available water in the top 9 in. by about 35 per cent., although in the air-dry condition the air space in the clods of the manured soil is less than 2 per cent. greater than that of the unmanured soil. An interesting difference between the top soil and subsoil of the manured area is that the natural shrinkage on drying is much greater in the subsoil. The effect is not yet fully understood, as it cannot be entirely accounted for by the difference of organic matter content.

Properties of soil particles. Of the various fractions of soil, clay is the most interesting and important. It consists of all particles whose diameter, as calculated from Stoke's Law, does not exceed 2μ or $0{\cdot}002$ mm. It has long been apparent that sub-division of the clay fraction into groups of smaller diameter limits is desirable, because the properties are not distributed evenly over the diameter range : in general, the finer the particle the more marked are the properties. In the usual sedimentation method of mechanical analysis, impossibly long settling times would be needed for the sub-divisions if sampling were carried out at the normal depths. A study (27) has been made of the use of much shallower sampling depths with their correspondingly shorter sampling times. It was shown that the standard apparatus could be employed at a sampling depth of only 2 cm. instead of the usual 10 cm., without error, and that with special fine-point pipettes, e.g. a hypodermic needle, samplings as shallow as $2{\cdot}5$ mm. can be made. These factors, coupled with the use of a constant temperature enclosure to prevent convection currents, have made it possible to obtain sub-fractions down to a diameter of about $0{\cdot}1\mu$, which corresponds to a settling time of $11{\cdot}5$ days for 1 cm. In fact, the limitations to further sub-division lie more in difficulties with the dispersion than in the sampling technique itself. Using caustic soda as dispersion agent, the first effects are the desirable and necessary ones : adequate dispersion and stabilisation of the clay particles. But with increasing soda concentration the particles no longer settle independently, and the suspension behaves like a weak thixotropic gel, and, at a later stage, loses its homogeneity and practically flocculates.

In addition to the scientific aspects of subdividing the clay fraction, it is likely—to judge by some preliminary results—that there will also be agricultural aspects of significance. Size distributions in the clay fractions have been determined for clay soils from different formations. It appears, for example, that the Weald clay—which, although difficult to work cracks less than normal clays, such as the Gault—contains less clay in the finest fraction. Again, fruit soils on the Triassic and Old Red Sandstone formations, often have a lower proportion of the finest clay particles than pasture soils on this formation, although the total clay content is much the same.

Examination of clay particles by physico-chemical methods has shown by means of chloride-retention studies that positive charges as well as negative ones appear to be associated with the clay particle (28). The observation is of importance, because if, as seems possible, positive charges are present up to pH 7·5, they may affect the power of the clay to retain nutrient ions such as phosphate. Further, there is some suggestion that thixotropic effects are promoted by the positive charges, in which case they would have an important role in determining soil structure. The nature of these basis groups has yet to be worked out, in particular, whether they are an integral portion of the clay proper—in which case they should be related to the structure as revealed by X-ray analysis—or whether they belong to the small amount of amorphous material associated with the clay.

Organic matter. Physico-chemical studies of soil organic matter show that, like clay, it is a highly complex material. Considerable progress has recently been made. When measurements were first made of base uptake by soil as a function of pH, it was observed that more $Ca(OH)_2$ was taken up than $Ba(OH)_2$, and more $Ba(OH)_2$ than NaOH or KOH. This non-equivalence was used to combat the view that base uptake by soil was analogous to the neutralisation of an acid. It has now been shown (29) that solid substances, such as wood, peat and their constituents, exert buffer action simply by virtue of the dissociation of hydrion from specific chemical groups. It has also been shown that some relatively simple organic acids, such as acetylacetone, exhibit non-equivalence of alkali uptake or, more exactly, exhibit different dissociation constants according to the cation of the alkali used to neutralise them. The cause has been traced to the formation, by co-ordination, of a chelate compound with the ion. These compounds can only form when there is a particular molecular configuration, and it is quite reasonable to suppose that such configurations exist in soil organic matter. Thus a phenomenon that appeared to challenge the rational interpretation of buffer action in soil organic matter can now be used as a tool to assist in unravelling the details of the structure of these and similar complex materials.

Other work

Earlier studies on the measurement of soil colour directed attention to deficiencies in the standard colorimetric instruments, especially in the transformation of the experimental values to the international scale (C.I.E.). Dr. Schofield (30) has devised an addition to the Lovibond Tintometer—an instrument in wide use for measuring and recording colour—which overcomes this difficulty and, in addition, greatly simplifies the process of transformation to the C.I.E. scale. The device is now a standard feature of the instrument.

PUBLICATIONS

1. Keen, B. A. 1940. *Weather and crops.* Q. J. Roy. Met. Soc., **66**, 155-166.

Presidential address to the Royal Meteorological Society, 1940. A review of progress made in the study of the effects of seasonal weather variations on plant growth since 1900. The results of the closer mathematical examination of crop-weather relationships, originated and developed by R. A. Fisher, at Rothamsted, are briefly outlined. The possibilities and limitations of prediction formulae for yields are discussed.

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2. PENMAN, H. L. 1940. *Meteorological and soil factors affecting evaporation from fallow soil.* Q. J. Roy. Met. Soc., **66**, 401-410.

Using the conception of natural periods, for which the difference between rainfall and drainage can be equated to the evaporation, the mean daily rates of evaporation from a block of fallow soil at Rothamsted are examined for 94 periods varying in length from 13 to 45 days. In seeking correlations with single daily meteorological observations two types of treatment are employed. 1. The year is considered in three seasons of four months each—summer, winter and two equinoctial pairs of months—and it is shown that an almost complete description of evaporation can be obtained in terms of rainfall only, the nature of the correlation varying from season to season. 2. A general treatment is attempted in physical terms, considering evaporation as due to diffusion across a non-turbulent boundary layer whose thickness is determined by wind velocity, the soil surface being assumed to be continuously at 100 per cent. relative humidity (R.H.). The general agreement between observed and predicted values is very good in winter. The summer data are shown to lie between the theoretical limits imposed by the assumptions of (i) continuous 100 per cent. R.H. at the surface, and (ii) a steady retreat of the 100 per cent. R.H. layer into the soil, i.e., no upward movement of *liquid* during the evaporation process.. The considerable scatter in the data is attributed partly to the inadequacy of single daily meteorological observations but chiefly to the lack of knowledge of the conditions existing at the soil surface.

3. SAHNI, P. N. 1941. *The relation of drainage to rainfall and other meteorological factors.* J. Agric. Sci., **31**, 110-115.

Natural drainage periods, i.e., periods between consecutive cessations of flow of the Rothamsted 20 in. drain gauge, were selected for the months of June, July and August. All periods of from 2 to 13 days were taken.

A curvilinear relationship between the difference of rainfall and drainage (deficit) and rainfall was established.

Residuals from this curve showed no appreciable correlation with the mean air temperature, but there was some slight evidence that the deficit was increased by a decrease in relative humidity or an increase in wind velocity.

The residuals showed little correlation with drainage during the previous three weeks.

4. PENMAN, H. L. and SCHOFIELD, R. K. 1941. *Drainage and evaporation from fallow soil, at Rothamsted.* J. Agric. Sci., **31**, 74-109.

There is a seasonal change in the drainage response after rain which can be almost wholly ascribed to viscosity changes arising from seasonal changes of soil temperature.

Natural periods can be chosen over which the difference between rainfall and drainage can be equated to the evaporation. Good approximations are : periods of a year, six months, or long series mean of individual calendar months. A single calendar month will rarely approximate to a natural period.

Summer evaporation is two to three times as great as winter evaporation ; the former is dependent and the latter independent of rainfall. Consideration of the physical basis of evaporation in relation to the vapour pressure gradient in the air immediately above the soil surface brings out the following points :

(*a*) In winter the soil does not dry at the surface. Winter evaporation is, therefore, much the same as would be obtained from a water surface and extra rainfall does not affect it.

(*b*) In summer the surface remains moist only for a short time after rain has fallen ; the air gradient is then much steeper than in winter. For the rest of the time the surface is drier and there is also a vapour pressure gradient in the soil. Hence (i) there is more rapid evaporation while the surface is wet ; (ii) the total amount of evaporation is dependent upon both total rainfall and on its distribution in time ; (iii) the later stages of evaporation are more dependent upon soil conditions than on air conditions, and (iv) the total evaporation is much less than from open water.

(*c*) An adequate description of evaporation in all seasons may be obtained from knowledge of the difference in the partial pressures of the water vapour of the air in and above the soil surface. In the general evaporation equation this term is the most important, and the impossibility of representing changes in it in terms of changes of rainfall and mean air temperature alone accounts for the apparent anomalies in the results of previous statistical treatments.

5. PENMAN, H. L. 1941. *Laboratory experiments on evaporation from fallow soil.* J. Agric. Sci., **31**, 454-465.

Laboratory experiments on evaporation from freely drained soils are described. Under "isothermal" conditions (i.e., the soil is kept at air temperature, apart from surface cooling, produced by evaporation) characteristic *winter* field behaviour is obtained, even when the air drying power is greater than its normal English midsummer value. Characteristic *summer* field behaviour is obtained when the rapid drying of a thin surface layer is achieved either by using an extremely high air temperature under "isothermal" conditions, or by raising the surface temperature by means of radiation—the normal method in nature. The effect of a high salt concentration in the soil water is shown to lead to greater evaporation losses and to a tendency for the salt to concentrate in the more salty patches.

It is suggested that mulching will only be beneficial during the isothermal part of the year, i.e., when soil surface and air temperature are approximately equal, and that it will have little effect on water conservation where the soil will be self-mulched by the action of summer sunshine. The cause of this self-mulching action is briefly considered in the light of our limited knowledge of soil water dynamics; it appears to depend on the existence of a dual mechanism of water movement in soils—as liquid and as vapour—the rates of movement being very different functions of moisture content and moisture gradient.

6. PENMAN, H. L. 1943. *Daily and seasonal changes in the surface temperature of fallow soil, at Rothamsted.* Q. J. Roy. Met. Soc., **69**, 1-16.

A method of obtaining continuous records of soil surface temperature is described and 15 months' records are discussed.

The relations between surface and sub-surface temperatures are briefly considered, and then, in more detail, the inter-dependence of soil surface and air temperatures is examined. At all seasons the soil temperature is in phase with solar radiation whereas the maximum air temperature is delayed; for air maxima below 52°F. the daily range of soil surface temperature is approximately the same as that of the air temperature. Above this threshold the soil surface maximum increases twice as rapidly as the air maximum. Using this value of the air maximum, 52°F., to divide the year into two seasons, it is found that the winter and summer periods so separated are the same as those previously obtained from the criterion: seasonal evaporation is equal to or less than that from an open water surface. Interest is primarily centred on the summer season, in which the soil surface temperature exceeds that of the air for a considerable part of the day, and for a rainless summer period of t days an anticipated relation of the form $\Sigma E = at^{\frac{1}{n}}$ where $n = 3$, a is a constant and ΣE = the total evaporation, is confirmed from the Rothamsted records.

The effect of the diurnal oscillation of surface temperature on germinating seed is briefly discussed.

7. SCHOFIELD, R. K. 1940. *Note on the freezing of soil.* Q. J. Roy. Met. Soc., **66**, 167-170.

A short paper dealing with the cold weather of early 1940, and explaining the soil temperature observations in terms of the water movement within soil interstices of differing sizes that occurs when ice forms, and the latent heat of thawing.

8. PENMAN, H. L. 1940. *Gas and vapour movements in the soil. I. The diffusion of vapours through porous solids.* J. Agric. Sci., **30**, 437-462.

The dependence of the coefficient of diffusion, D, upon the porosity, S, of a granular solid is investigated experimentally. For steady state conditions, using carbon disulphide and acetone vapours, it is shown that a curve connecting D/D_0 and S can be drawn which is independent of the nature of the solid, its moisture content and, within limits, its texture. For a limited range of values of S ($0{\cdot}0 < S < 0{\cdot}7$) a good approximation is $D/D_0 = 0{\cdot}66S$ and over this range the diffusion coefficients are larger than those found by Buckingham for carbon dioxide.

Investigation of the non-steady state shows that in soils the attainment of pressure equilibrium is retarded by adsorption, and it is suggested that Buckingham's low values for steady-state conditions can be attributed to premature observations of the diffusion rates; the steady state had probably not been attained when his measurements were made.

9. PENMAN, H. L. 1940. *Gas and vapour movements in the soil. II. The diffusion of carbon dioxide through porous solids.* J. Agric. Sci., **30**, 570-581.

Apparatus for measuring the rate of diffusion of carbon dioxide through granular solids is described and the results obtained with it are shown to conform to the curve connecting D/D_0 and S previously obtained for carbon disulphide and acetone. The equation $D/D_0=0{\cdot}66S$, which it is suggested should replace Buckingham's equation $D/D= S$-, is applied to a discussion of soil aeration, and it is shown that at all porosities the rate of diffusion of carbon dioxide from the soil is sufficient to account for normal respiration without invoking the assistance of meteorological changes. A further application of the equation to water vapour movement in soils is briefly discussed.

10. PENMAN, H. L. 1941. *Theory of viscous flow porometers.* Appendix to paper by O. V. S. Heath. Ann. Bot., **5** (New Series), 455-500.

11. PENMAN, H. L. 1942. *Theory of porometers used in the study of stomatal movements in leaves.* Proc. Roy. Soc., B., **130**, 416-434.

The mathematical theory of porometers, as used by Gregory and his collaborators for the study of stomatal movements in leaves, is given for viscous and diffusive flow of gases. It is shown that under certain conditions the theory applies to both kinds of gas movements ; a correction is included for those cases in which the basic assumptions for diffusion are not realised. From determinations of the total leaf resistance to gaseous flow the conductance of the stomata can be found if the mesophyll resistance is known. The importance of this quantity is discussed and demonstrated, methods of measuring it are suggested, and possible checks upon the reliability of the results are described.

As an illustration, the theory is applied to some hitherto unpublished data on two pelargonium leaves ; the treatment gives results that are internally consistent, and deduced rates of assimilation are found to be of the same order of magnitude as those observed in practice.

12. KEEN, B. A. 1942. *Soil physics : theory and practice.* J. Roy. Soc. Arts, **90**, 545-579.

The Cantor Lectures to the Royal Society of Arts, 1942, dealing with (*a*) soil physics ; its scope in agriculture ; (*b*) soil cultivation—art or science ? (*c*) cultivation and crop yields.

13. KEEN, B. A. *Progress in the fundamental study of soil, soil moisture, and soil tillage,* 1912-1945. (In the press.)

A paper contributed to the Prasolov Jubilee Scientific Session of the Dokuchayev Soil Institute, Moscow.

14. KEEN, B. A. 1938. *Are cultivations overdone ?* J. Min. Agric., **45**, 645-652.

A summary of the Rothamsted work on cultivation up to 1938 on subsoiling, extra ploughings, seed-bed consolidation, intensive inter-row cultivation of root crops, rolling and harrowing, depth of tillage and rotary cultivation.

15. RUSSELL, E. W. 1945. *What are the minimum cultivations necessary for high farming ?* Proc. Inst. Brit. Agric., Eng., **3**, 99-111.

A summary of the cultivation work up to 1944 showing that agricultural crops are far more sensitive to weeds than to tilth, and hence that early hoeing (and possibly deep ploughing also), by giving good control of weeds, is very important. It is further suggested that the crop itself can become an excellent cultivator of the soil, for a crop sown in good time and given really adequate dressings of manure and fertiliser, will prevent weeds developing and will forestall the intensive cultivation programme that patchy and half-starved crops need.

16. KEEN, B. A. 1942. *Hoeing.* J. Roy. Hort. Soc., **67**, 323-328.

A review of the results on hoeing of farm crops with reference to their application to horticultural practices and ideas.

17. Pereira, H. C. 1941. *Crop response to inter-row tillage.* Emp. J. Exp. Agric., **9**, 29-42.

Inter-row tillage of crops has been tested in the U.S.A. by many simple field trials with maize, and by several well-replicated modern trials with market-garden vegetables. The results have shown the maintenance of a soil mulch between plant-rows to be of little importance in the absence of weeds. The experiments emphasised the importance of weed-destruction. British evidence on inter-row tillage is scarce, but the data available confirm the findings of the American workers.

18. Pereira, H. C. 1941. *Studies in soil cultivation.* IX. *The effect of inter-row tillage on the yield of potatoes.* J. Agric. Sci., **31**, 212-231.

The experiments conducted in the years 1937, 1938 and 1939, indicate that for a well-drained sandy loam, under a considerable range of moisture-supply conditions, main-crop potatoes do not respond in the absence of weeds to ridging-up, or to deep or frequent inter-row grubbings, by any increase in yield or in the percentage of ware. The crop showed successful powers of adaptation to a range of contrasting inter-row tillage treatments.

The potato crop showed considerable sensitivity to weed competition in the early stages of growth. This indicates that it is of great importance to maintain the crop in a weed-free condition during this early period.

Inter-row tillage operations on this type of soil should, therefore, be designed to destroy weeds and to provide moderate cover for the tubers. Intensification of such tillage beyond these limits is not of direct benefit to the plants.

No moisture-conservation effect of any importance was produced by a 3-in. soil mulch during dry weather, even when the water-table lay within 4 ft. from the surface.

19. Russell, E. W. and Keen, B. A. 1941. *Studies in soil cultivation.* X. *The results of a six-year cultivation experiment.* J. Agric. Sci., **31**, 326-347.

The results of a six-year cultivation rotation experiment are given. The rotation used was wheat-mangolds-barley and the seed-beds for these were prepared either by ploughing, using a rotary cultivator or a tractor-drawn grubber.

The yields of these crops were barely influenced by the depth of ploughing, a 4 in. depth giving throughout the six years just about the same yield as an 8 in. depth. The mangold crop was possibly a little larger on the deeper ploughed plots.

The mean yields of the seed-beds prepared with the tractor-drawn grubber or cultivator followed by harrows, etc., were lower than the ploughed seed-beds for all the crops, and this was particularly so on those seed-beds prepared by only one grubbing down to 4 in. depth.

The mean yields on the seed-beds prepared by the rototiller were lower than on the ploughed seed-beds for wheat and mangolds. If the seed-bed was prepared by rototillage to a depth of 8 in. by going over the land twice, the yield of barley was the same as on the ploughed seed-beds, but was definitely less on the seed-bed rototilled only once to 4 in.

Seed-beds prepared by the rototiller or grubber have only a small residual effect on the crop yields in the following year.

It is concluded that the primary function of ploughing is weed control, and that it is only advisable to omit ploughing either if the land is already fairly clean or if the crop will be hoed very early on in its development.

For wheat and mangolds differences in weed infestation of the seed-bed were probably of greater importance than differences in tilth in so far as the crop yield was concerned. The reverse may have been true for barley.

20. Russell, E. W., Keen, B. A. and Mann, H. H. 1942. *Studies in soil cultivation.* XI. *The effect of inter-tillage on the sugar beet crop.* J. Agric. Sci., **32**, 330-337.

Experiments on the effect of inter-row cultivation of sugar beet, carried out in the three years 1939-41 on a sandy loam, led to the following results :

(1) If the soil nutrients are in short supply hoeing or hand-weeding increases the yield of the beet, provided these operations are carried out before or shortly after singling.

(2) Hoeing is more effective than hand-weeding, but it cannot yet be said with certainty whether this is due entirely to more efficient weed destruction, or whether there is some additional effect, such as mulching.

(3) If adequate quantities of soil nutrients are present, inter-row cultivation has little effect on yield, and the crop can tolerate a considerable weed infestation without any effect on yield.

The results for sugar beet on the heavy clay-with-flints soil at Rothamsted show :

(1) Additional hoeings after singling, above a modest minimum, have either no effect on yield or else depress it.

(2) On the one occasion when pre-singling cultivations were given, the yield was increased.

(3) In contrast with the Woburn results the effect of cultivation does not vary with the level of manuring.

21. Russell, E. W. and Hine, H. J. **1941.** *On measuring the efficiency of a tractor by its fuel consumption.* Emp. J. Exp. Agric., **9**, 98-110.

An investigation has been made on how accurately the fuel consumed by a tractor running over distances of 2 to 8 chains (44 to 176 yards) can be measured. It has been shown how the crude measurements can be corrected for certain variable factors, and that when this has been done it is comparatively easy to measure the fuel consumed to about 3-5 per cent. per run.

Examples are given of the kind of results that can be obtained and the precautions that must be taken to ensure that the results are correctly interpreted.

22. Russell, E. W., Hine, H. J. and Keen, B. A. 1942. *The efficiency of pneumatic tyred tractors under farm conditions.* J. Agric. Sci., **32**, 1-42.

(1) Increasing the ballast on pneumatic tyres, up to a certain weight, improves the tractor performance as judged by its speed, fuel consumption and wheel slip. Further increases beyond this point continued to decrease the wheel slip without having any marked effect on its speed or fuel consumption. No certain evidence was obtained that too heavy a ballast decreased the tractor's efficiency.

(2) The tyre load affects the maximum pull the tractor can exert while working reasonably efficiently, but this pull does not depend markedly on the speed of work. Wheel weights of about 12-13 cwt. seem to be the minimum required for optimum performance of the 36 or 28 in. tyres at pulls of 1,800 lb. under fairly good ground conditions, and possibly a greater weight may be required by the 24 in. tyre.

(3) If the tractor is ploughing it is usually running tilted, and this tilt transfers sufficient weight on to the furrow wheel for it to work efficiently under most conditions. Additional ballast is, however, often necessary for the lighter land-side wheel.

(4) Tyre performance is much less dependent on inflation pressure than on ballast. Pressures below 10 lb./sq. in. were only of use in wet conditions when small amounts of additional ballast were not available. Pressures above 12 lb./sq. in. may allow excessive slip to take place and probably only need be used on the furrow wheel of a well-loaded tractor ploughing.

(5) The effect of pneumatic tyres and standard steel wheels on tractor and wheel performance depends on both tyre diameter and tyre section, and varies also with the type of soil and its condition. In general, a large outside diameter for a tyre appears to be more important than a wide section for all except loose soil conditions and possibly wet slippery turf.

(6) The fuel consumption per acre was higher for the tractor working in bottom than in second gear, and this effect can account for about half the difference in fuel consumption between the 36 and 24 in. tyres. This is not an effect of speed of work, for the fuel consumption was independent of the speed of work within this range if the speed was varied by altering the governor setting on the tractor engine but keeping the tractor in second gear.

(7) The tractor fitted with pneumatic tyres was able to plough or cultivate as well as when fitted with steel wheels under all soil conditions with only a few exceptions, none of which could be examined in detail owing to the transitory existence of the unfavourable soil conditions.

23. DAVIDSON, A. L. C. and SCHOFIELD, R. K. 1942. *Measurement of the suction of soil water by Portland stone absorbers calibrated by a new method for determining vapour pressures near to saturation.* J. Agric. Sci., **32**, 413-427.

(1) A filter apparatus cannot be relied upon to give a correct reading of the suction of soil water when this exceeds about 400 cm. of water.

(2) Owing to the contribution of dissolved matter to the freezing-point depression the suction in a soil of normal low salt content can only be obtained from the freezing-point depression with reasonable accuracy when it exceeds about 4,000 cm. of water (freezing-point depression greater than 0·3°C.).

(3) Suctions in the range 400 to 4,000 cm. have been measured with the aid of calibrated absorbers consisting of thin plates of Portland stone.

(4) The plates were calibrated up to 1,000 cm. by the application of suction through a filter, and above 1,000 cm. by measuring the vapour-pressure depression by a new technique.

(5) When applied direct to soil, the new vapour-pressure technique is more reliable than the freezing-point method, and can be applied to materials which do not exhibit a well-defined freezing-point.

(6) A suitable soil was washed free from salts and brought to 1,000 cm. suction on a filter. Measurements of the vapour-pressure depression and the freezing-point depression checked well with the thermodynamic formulae.

24. SCHOFIELD, R. K. 1943. *The role of moisture in soil mechanics.* Chem. Ind., **62**, 339-341.

This paper is addressed to engineers concerned with soil problems. It outlines the present-day conceptions on water distribution and movement, and its relation to soil properties such as pore space, base-exchange, and the bearing of these on practical problems.

25. RUSSELL, E. W. and TAMHANE, R. V. 1940. *The determination of the size distribution of soil clods and crumbs.* J. Agric. Sci., **30**, 210-234.

(1) It is possible to determine the size distribution of clods in the field by simple sieving of the soil without any pre-treatment provided the soil is not too wet. There is a personal factor involved in the sieving, but with care and training this will not affect comparisons of results obtained by that person.

(2) There appears to be no best method for determining the size distribution of the soil crumbs, i.e., of the water-stable aggregates in the soil. The method and the technique must be chosen so as to give the maximum amount of useful information. If an appreciable proportion of the crumbs are larger than ½ mm., a water-sieving method is practically essential.

(3) The method of wetting to be used can only be chosen from a consideration of what information is wanted. If possible it would be desirable for general purposes to use both a very slow or a vacuum wetting technique and a very rapid wetting technique such as wetting the soil by immersion in water.

(4) The decision whether air-dry or field-moist soil should be used depends entirely on the information needed. For general purposes the use of air-dry soil is recommended.

(5) It has been found possible to separate the crumb fractions of Rothamsted soil into crumbs and sand particles by carefully dispersing them in a bromoform solution of the correct density. The crumbs float and the sand particles sink.

(6) A rapid method of overcoming this difficulty of distinguishing between crumbs and sand particles in a crumb fraction is to determine the proportion of the total base-exchange capacity of the soil that is in each crumb fraction. Schofield's potassium carbonate method for doing this is described.

26. RUSSELL, E. W. and BALCEREK, W. 1944. *The determination of the volume and air space of soil clods.* J. Agric. Sci., **34**, 123-132.

A method is described for determining the field volume and the air space of a clod of any shape by filling its pores with a hydrocarbon oil, such as paraffin or tetralin, and determining its weight in the oil and in air before and after impregnation. The method appears to work well for clods of any moisture content.

This method is shown to give values of these volumes entirely comparable with those given by the other accurate methods described in the literature.

Its accuracy for clods of Rothamsted soil, weighing between 20 and 500 g. was probably 1 part per thousand, i.e., 0·1 per cent.

The method has been applied to the determination of the available water held by a soil and has been used to illustrate the effect of long-continued applications of farmyard manure to a soil in increasing the amount of available water it can hold.

27. RUSSELL, E. W. 1943. *The sub-division of the clay fraction in mechanical analysis.* J. Agric. Sci., **33**, 147-154.

An examination has been made of the possibility of extending the routine mechanical analysis of soils down to finer particles than the conventional clay. The main conclusions reached are :

(1) Sampling depths of only 2 cm., using standard mechanical analysis apparatus, appear to introduce no new sources of error.

(2) If a constant temperature room is available, sampling times of 7 days seem to be allowable.

(3) Using special pipettes and settling vessels, sampling depths of only 2½ mm. seem to be allowable.

(4) The amount of caustic soda to be added to a soil for proper dispersion depends on the soil, and this dependence limits the accuracy with which the mechanical analysis of the clay fraction can be carried out. There are no certain criteria available for deciding how much should be added, though Robinson's suggested 8 c.c. of N. NaOH per 20 g. of soil dispersed in 1 litre is probably rather too high for most English soils.

(5) Robinson's suggestion that the settling velocities of particles rather than their conventional size should be used has been adopted, and the symbol $pv = -\log v$ has been used throughout the paper.

(6) Routine mechanical analysis can be extended, by the simple methods here described, to clay particles with a conventional diameter of about $0 \cdot 1\mu$.

28. SCHOFIELD, R. K. 1940. *Clay mineral structures and their physical significance.* Trans. Brit. Ceram. Soc., **39**, 147-161.

It is shown how the atomic structure of the clay minerals as revealed by X-ray analysis accounts for the presence of positively and negatively charged zones on the crystals. Measurements of ionic retention enable these charges to be measured and their variations with pH studied. In the presence of sufficiently concentrated salt solutions cations and anions are retained in equivalent amounts. Firmness of binding varies widely amongst both cations and anions. Support is found for the view that a network tends to form in clay suspensions through attraction between the positive and negative zones of neighbouring crystals. It is suggested that a condition in which the cations and anions leave equal amounts of positive and negative charge " uncovered " is particularly favourable for the formation of a network.

29. SARIC, S. P. and SCHOFIELD, R. K. 1946. *The dissociation constants of the carboxyl and hydroxyl groups in some insoluble and sol-forming polysaccharides.* Proc. Roy. Soc. A., **185**, 431-447.

In order to establish the conditions under which the buffering of insoluble substance may most usefully be studied, suspensions of fibre cellulose, hemicellulose and xylan have been examined to determine the relationship between pH and the degree of dissociation of their carboxyl groups. The materials were suspended in normal potassium chloride solution, in order to confine local gradients of hydrion concentration to the immediate vicinity of each charged buffer group. Under these conditions the dissociation curves are all of the simple Henderson type with a common constant $pK = 2 \cdot 95$ (N/100 hydrochloric acid in normal potassium chloride being taken as pH 2).

Sols of arabic and pectic acid follow the same dissociation curve, showing that the dissociation of the carboxyl groups is not necessarily influenced by the state of aggregation. Within the accuracy of these measurements, uronic and gluconic carboxyls have the same pK. The dissociation of pectic acid departs from the Henderson curve in the same general way as the dissociation curve of maleic acid differs from that of fumaric acid. It is suggested that some of the carboxyls in pectic acid are linked by hydrogen bridges. To a less extent such linkage may also occur in alginic acid below pH 3 when a gel is formed.

The pK for the first stage of acid dissociation of the hydroxyl groups in wheat starch is close to 13·3. The same value was obtained whether potassium hydroxide, calcium hydroxide or barium hydroxide was used. The alkalis were made up in normal solutions of the corresponding chlorides. The same constant holds for alginate within the limits of experimental error. The dissociation in cellulose up to pH 13·5 is much less than in starch.

Using a new method based on a determination of the ratio of chloride ions to hydroxyl ions, the dissociations of starch and cellulose were measured in 5 N. alkali (approximately pH 14·7). The second pK of starch is estimated at roughly 15·0. The cellulose, largely mercerized at this pH, exhibited a dissociation not much less than that of starch, and agreeing closely with the prediction of Neale.

An insoluble buffer substance suspended in an electrolyte solution is a two-phase system. The hydrion dissociation can be determined in two-phase systems over a greater pH range than is possible in one-phase systems.

30. SCHOFIELD, R. K. (1939). *The Lovibond Tintometer adapted by means of the Rothamsted device to measure colours on the C.I.E. system.* J. Sci. Instr., **16**, 74-80.

The Rothamsted device is an obturator vane by which the observer, when matching a specimen by a combination of Lovibond glasses, can make the two surfaces he is viewing look equally bright. This device greatly reduces the number of combinations required for colour matching. Conversion graphs give the C.I.E. co-ordinates for these combinations in Standard Illuminant B. The C.I.E. co-ordinates of matched colours are thereby obtained.

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