Physics in Agriculture.[1]

By Dr. BERNARD A. KEEN.

THE study of the physical properties of soil has a fundamental place in the application of science to agriculture. It occupied an important position in the early days of agricultural science, and, after a lengthy eclipse in the latter half of the nineteenth century, when Liebig, Lawes and Gilbert, and others were establishing the modern agricultural chemistry and biology, it again came into prominence, owing to the recognition of the colloidal properties of the soil. The older concepts have been examined from this point of view, and it appears that the soil must be regarded not as a mass of comparatively inert grains over which water is distributed in a thin film, but as particles the surface of which is coated with colloidal material. The composition of this material is complex. It is a mixture of organic and inorganic substances derived from the decomposition of organic matter, and the weathering of clay, respectively, and it modifies very largely the deductions on the relations between soil and its moisture content made from the older hypothesis.

A soil can be easily divided into a few groups or fractions of different average size, depending on the velocity of fall in water. This process is known as mechanical analysis. It is a routine procedure in a soil survey and, combined with ecological and meteorological observations over the area, enables the expert to suggest improvements in the agriculture. In the case of undeveloped countries, this examination is essential if the agriculture is to be built up on sound lines. A striking example of the value of such a survey is afforded by the recent classification of Africa into areas according to agricultural potentialities, made by two American workers. The information was limited and the divisions are only approximate, but the very fact that it was possible to make them at all on such restricted information, shows the power and flexibility of the method.

In research investigations, the simple procedure of mechanical analysis must be replaced by more exact methods, in which the distribution of particles is expressed as a continuous function of the effective radius. One method depends on measuring the gradually increasing weight of particles settling on a pan immersed in a suspension of the soil in water, and from these data the distribution curve can be derived mathematically. The method is not yet perfect, because the settling particles that would eventually reach the liquid under the pan are naturally caught by the pan, whereas those in the annular space fall freely. In consequence, a density difference is established which sets up currents in the liquid, and the particles are deflected from their proper course.

For the purpose of this work, and for other studies, the Soil Physics Department at Rothamsted has developed an automatic and continuous recording analytical balance, illustrated in Fig. 1. A magnet is suspended from one arm, and the current through the solenoid is adjusted to keep the balance in equilibrium. The adjustment is automatic and is effected by using the motion of the balance beam away from equilibrium to complete subsidiary circuits which operate electromagnets controlling clockwork mechanism, that moves a sliding contact backwards or forwards along a slide wire. The current through the solenoid is, therefore,

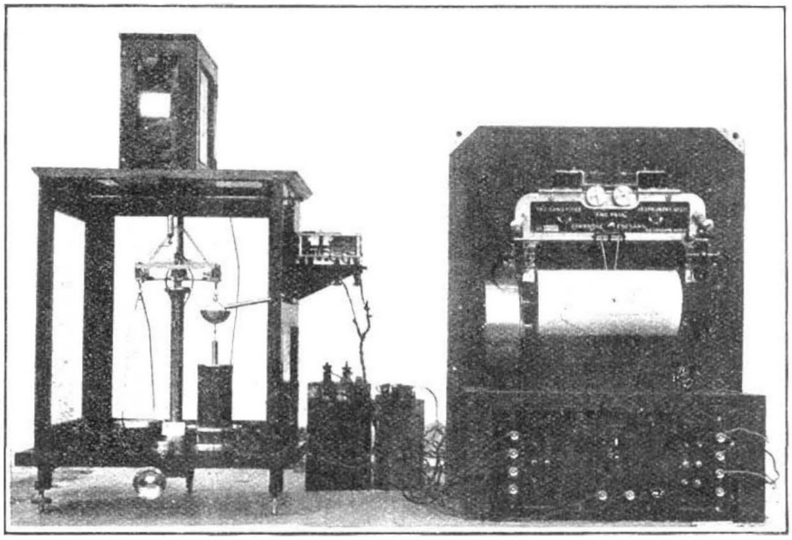

FIG. 1.—The Odén-Keen automatic recording balance.

changed by the requisite amount. When the contact reaches the end of the slide wire, a third circuit is completed, and a phosphor bronze ball of known weight is automatically added to the magnet arm. The sliding contact rapidly returns to its zero position and the cycle of operations recommences. The resistances are so arranged that the relation between weight and length of slide wire across which the solenoid is connected is practically linear. Hence a pan attached to the sliding contact and resting on a rotating drum, gives a continuous record from which the change in weight can be inferred.

The treatment of the flow of water through soil, in an analogous manner to the flow of heat or electricity through conductors, presents considerable difficulties, because the quantities corresponding to conductivity and potential (which for heat and electricity are practically independent of external conditions and current density) are not independent of the moisture content, the state of packing and the colloidal content of the soil. Although the difficulties of theoretical and practical investigation are great, much attention has

[1] Based upon a lecture on "The Physicist in Agriculture, with Special Reference to Soil Problems," being the ninth of the public lectures on physics in industry, arranged by the Institute of Physics, and delivered on November 25.

been devoted to the problem because of the practical applications, especially in areas under irrigation, where it is essential to make the best use of the available water, and yet to avoid the concentration of deleterious "alkali" on the soil surface resulting from an excessive upward movement of soil moisture. In regions with adequate rainfall, recent experiments at Rothamsted indicate that the depth from which water can ascend by capillary action, and thus become available for plant growth, is not very great. This emphasises the value of those cultivation operations designed to conserve the moisture in the upper regions of the soil.

The importance of the soil water relationships resulted in many additions to the original broad divisions of soil moisture into gravitational, capillary, and hygroscopic moisture. They were based on the assumption that the soil grains could be regarded as inert, but the recognition of the colloidal properties of soil has destroyed the validity and physical significance of these additions. Further, it has been shown that the vapour pressure of moist soil reaches its saturation value at a moisture content well below the values obtained for the so-called "equilibrium points" of soil moisture. This suggests that the moisture relationships are best expressed by other properties of moist soil, such as cohesion and plasticity, because variations in these factors are to be expected at moisture contents above the value for saturation vapour pressure. These properties have the further advantage that they are closely related to the behaviour of the soil under the action of cultivation implements, and they can be readily interpreted on the assumption that the colloidal material in soil forms a coating over the larger inert grains. Thus, the shrinkage of a plastic mass of kaolin, which normally follows a different course from that of soil, can be made closely to simulate the latter if a small amount of silica gel is previously precipitated on the surface of the kaolin particles.

In the field, the integrated effect of plasticity, cohesion, and surface friction between soil and a metal surface may be measured by a dynamometer in the hitch between the implement and the horse, or tractor. The drawbar pull thus recorded is found to vary considerably even on areas that to visual inspection are quite uniform. In a comprehensive field test, variations of more than 30 per cent. were found, even when the average drawbar pull of plots 66 ft. × 33 ft. was considered. For individual furrows the differences were much greater. The results are well illustrated by Fig. 2, where the "contours" of equal drawbar pull have been mapped from the results on a scale plan of the field. This variation is of obvious importance in competitive or comparative implement trials, for which, as an essential preliminary, a dynamometer survey should be made of the selected area. Other experiments show that the variations from point to point persist unchanged from season to season, and are not sensibly affected by manuring, with the exception of organic

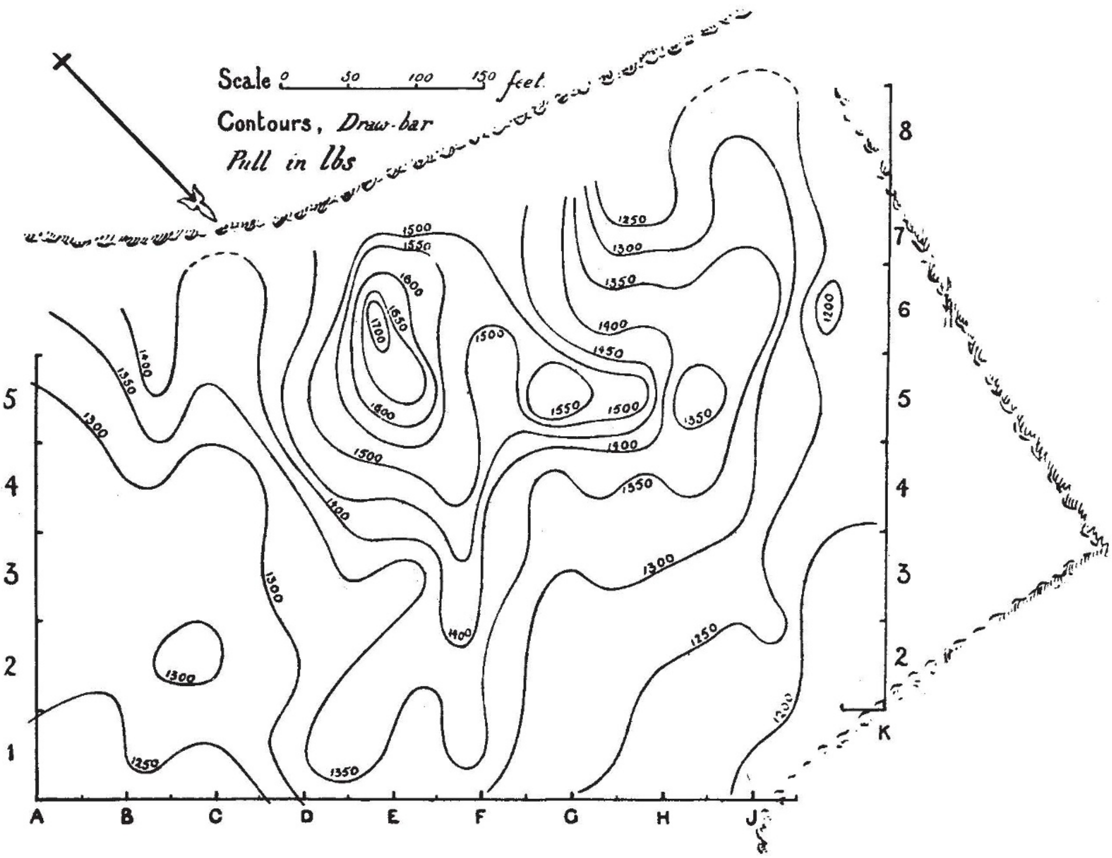

FIG. 2.—Lines of equal draw-bar pull over a supposedly uniform field.

manures. The variations in drawbar pull figures are also closely related to the amount of drainage and to the early stages of plant growth.

It is found that the drawbar pull is comparatively unaffected by speed of cultivation. Thus for tractor ploughing, an increase from $2\frac{1}{2}$ to 4 miles per hour, which would mean a 60 per cent. greater area ploughed in a given time, only involves a 7 per cent. increase in drawbar pull. It is improbable that the cost of the extra fuel necessary to give this increased pull would be more than a small fraction of the saving in labour costs due to increased speed of work. The design of tractors run at higher speeds without undue wear and tear, and of implements to perform satisfactory work at high speeds, should present no insuperable difficulties.

The Geology of the New Mersey Tunnel.

By Prof. P. G. H. BOSWELL, University of Liverpool.

ON December 16 H.R.H. Princess Mary inaugurated the work of excavation for the new tunnel under the River Mersey, sanctioned by Parliament last August. As is well known, a railway tunnel of invert form and 26 ft. in width has long been in existence; it was begun in 1881 by the Mersey Railway Company and completed some years later. The new tunnel is to be a highway and will be the largest of its kind. The major part of the tube will be circular in section, with an internal diameter of 44 ft., the road-way being constructed so as to take fullest advantage of the width. It will thus provide a four-way road for slow and fast two-way traffic, with side-walks of about 4 ft. for purposes of traffic control, etc. The cost of the tunnel is to be 4,750,000*l*., half of which will be provided by the Ministry of Transport in view of its highway character.

The line of the tunnel is to be roughly parallel to and about 150 yards north of the existing tunnel, its direction being about N.E.-S.W. The total length of tunnel will be rather more than two miles, of which about three-quarters of a mile will lie beneath the river.

At the Birkenhead end the entrance is to be near the Birkenhead Woodside Railway Terminus, and thus close to the docks. A suitable gradient of 1 in 30 will be obtained by a spiral descent. On the Liverpool side the tunnel will bifurcate, the northern branch ascending by a spiral gradient of 1 in 30 to the docks north of the pier-head, and the southern branch by a fairly straight stretch, of gradient 1 in 20, to an entrance in the heart of the city.

Throughout its course the tunnel will lie in Triassic sandstone and the overlying glacial deposits. On the Birkenhead side, under the River Mersey and for about 550 yards from the dock-walls on the Liverpool side, the rock belongs to the Middle Bunter Sandstone (or "Pebble-beds," though pebbles are scarce in the district). The beds dip at a low angle eastwards. The last 330 yards of the southern branch on the Liverpool side may be expected to lie in the Upper (Soft) Mottled Sandstone of the Bunter, which is here thrown down by a fault against the Middle Sandstone.

The latter is a firm, well-bedded rock, excellent for purposes of excavation, for it will stand well; the Upper Sandstone is rather soft. Both rocks, however, are renowned for the copious water-supply yielded by them.

It will be remembered that the Mersey estuary narrows considerably where Birkenhead and Liverpool are situated. Indeed, a rock-bar is responsible for the consequent ease of communication between those ports. Higher up the river, the overburden of glacial drift thickens, and, as the late T. Mellard Reade demonstrated, a deep channel of drift occurs at Widnes. As a result of his study of minor channels of drift in the area of the Liverpool and Birkenhead docks, Mellard Reade declared, before the Mersey railway tunnel was cut, his belief that they drained into the main buried channel, which would thus extend down the Mersey estuary, through the rock-barrier to the sea. He claimed, with good reason as the sequel showed, that geologists could previse, and warned the engineers that the channel of drift must be expected in the course of their operations. The channel was struck on the down-grade portion of the tunnel about 90 yards from the Liverpool side, and 44 ft. below the present bed of the Mersey, its base being closely 95 ft. below O.D. An unavailing attempt was made to avoid it, but fortunately the lowest 6 ft. of the channel (which was cut into for a length of about 66 yards) proved to be a stiff purple Boulder Clay. This clay yielded an excellent roof, and, unlike the sandstone, gave no trouble from water.

Another prediction, even more puzzling to those to whom the geology was not familiar, was that of the late G. H. Morton of Liverpool, who drew a geological section across the Mersey estuary and inferred the presence of a north-south fault with a westerly downthrow, under the bed of the river. This fault was struck in due course near the place assigned to it by Morton.

Trial-borings in the roof of the railway tunnel under the middle of the river proved a thickness of at least 15 ft. of Bunter Sandstone. The level of the top of the new tunnel in the part beneath the river will be nearly the same as that of the existing tunnel (approximately 106 ft. below O.D.). With the information made available by Mellard Reade and Morton, and the precision given to it by the excavations for the railway tunnel, and with the knowledge which has accumulated since (the officers of H.M. Geological Survey having re-surveyed the area just before the War), the engineers of the new enterprise will be fully forewarned of possible difficulties. But nobody, least of all a geologist, would care to predict the exact course, changes in depth, or lithological variation from clay to sand or gravel in a buried channel of glacial drift. There is no reason to doubt, however, that the new undertaking will prove successful.