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STUDIES IN SOIL CULTIVATION.

I. THE EVOLUTION OF A RELIABLE DYNAMOMETER TECHNIQUE FOR USE IN SOIL CULTIVATION EXPERIMENTS.

By BERNARD A. KEEN and WILLIAM B. HAINES.

(*Soil Physics Department, Rothamsted Experimental Station, Harpenden.*)

(With Plate I and Three Text-figures.)

Introduction.

In most countries that have a long agricultural history, and especially in Great Britain, the cultivation of the soil has been raised to a fine art. The mass of empirical and traditional details that has grown up around the various operations is reflected in the variety of implements now available. The majority of such details centre around the operation of ploughing as being the basic cultivation process, and the one on which the ultimate success of the seed bed largely depends. For this reason, in the field experiments which form the subject of the present series, attention has so far been confined to the operation of ploughing.

There are two main groups of factors involved in this operation, which may be separated for convenience in presentation and discussion, although they are very closely inter-related in actual practice; these groups comprise the implemental and the soil factors respectively. The former includes all problems of plough design such as the evolution of the best shape of mouldboard for different kinds of work—unbroken or broken furrows, one way or turn-wrest ploughing, etc.; the relation between design and draught for different speeds, depths and similar variables; together with questions connected with the materials used in construction, methods of attachment, etc., that lie within the province of agricultural engineering. The second group, the soil factors, contains those properties of the soil that are more or less permanent, such as its mechanical analysis, together with variable factors, of which moisture content, organic matter content, fertiliser treatment are obvious instances. Actually the soil factors exert their influence indirectly through such properties as soil cohesion, plasticity and surface friction. These important properties of soil are susceptible to study under laboratory conditions, and the results are being described in a separate series of papers[1].

During the operation of ploughing all the implemental and soil factors combine to determine the resistance that must be overcome by the applied tractive force in drawing the implement through the soil. This draught can be measured and recorded as a continuous trace by the dynamometer described below, and from the records thus obtained it is possible to draw deductions of economic, practical, and scientific value. Comparisons may be made of the draught of different implements on the same soil, the resistance offered by different soils, the effect of moisture content, climatic conditions, cultural variations and so on.

No systematic and fundamental study of this aspect of soil cultivation appears to have been made up to the present. In addition to the numerous traditional and empirical details already referred to, which are in themselves evidence of the complexity of the subject and the importance of scientific investigation therein, a considerable amount of scattered literature exists. But the greater part of the latter work, when examined in the light of the results recorded in this and the next paper in the present series, shows that the technique employed was unreliable. This is distinctly unfortunate, since many of the experiments were supposed to have answered definite economic and practical questions. For instance, a direct comparison of the draught required by different ploughs presupposes that the soil used for the test was uniform and would have shown a reasonably constant resistance to the standard plough, so that the differences observed with the different ploughs are therefore to be attributed entirely to variations in implement design. The second paper of this series is devoted to a test of this fundamental assumption; the results show that gross errors may be made by assuming that because a field looks reasonably uniform to visual inspection the resistance it offers to ploughing is equally uniform over the area.

Such considerations point to the necessity for careful planning of all field experiments in ploughing draught and cautious interpretation of the results. Since the factors concerned are so complex it is essential that the dynamometer record should be as reliable as possible, and in the present paper a description is given of the technique that has been developed for this purpose, together with the results of preliminary investigations of the effect of variations in speed of ploughing and similar factors that have a direct bearing on the interpretation of the results.

[1] Haines, W. B. "Studies in the physical properties of soil, I." This *Journal*, **15** (1925), p. 178.

A tractor has been used in preference to horses for several reasons: a greater range of speed is obtainable, and a number of other factors can be kept under control more easily. Further, in horse ploughing, the character of the work done is largely under the control of the ploughman, who will ease or hold the plough in accordance with variations in the nature of the land, and in our own work it seemed advisable to defer the examination of these additional complications until later. They are of course of considerable importance and are instanced by many practical men as points in which the quality of tractor ploughing still falls short of horse ploughing.

Description of Dynamometer.

The dynamometer used throughout the field measurements is one designed by Mr G. W. Watson, Past President of the Institution of Automobile Engineers. In its essentials, this instrument is a self-recording pressure gauge, indicating the pressure produced in an oil system by the pull between the two points to which the instrument is hitched. The chart consists of a continuous strip on which parallel records are given of drawbar pull (hereafter written D.B.P.), time intervals and of the depth of ploughing. Referring to Plate I, *A* and *B* are the holes for hitching the instrument to the tractor drawbar and to the plough respectively. Two pairs of holes are supplied, the leverage provided by one pair being double that of the other. This gives a choice of two degrees of sensitiveness in the instrument. The pull is applied to the lever which transmits it as a thrust at *C* through a hardened steel ball bearing against a piston head. The pressure on this piston is taken up by an oil system and transmitted to a cylinder and piston of reduced size. This arrangement has the double advantage of reducing the total thrust while increasing the total movement. The smaller piston bears against a calibrated spring enclosed at *D*, whose contraction is recorded on the chart by stylus *E*. Further ranges of sensitivity are obtained by taking out this spring and inserting another of lighter or heavier calibration value. All the styluses are of brass working on a paper with a specially prepared slightly abrasive surface. A perfectly legible mark is left without a heavy pressure of the stylus, though it is found advisable to ink in the trace by hand afterwards for the sake of greater legibility and permanence. Certain records which had been exposed to light for some months were found to be no longer legible owing to the bleaching of the trace made by the brass stylus. A special type of linkage causes the stylus *E* to move in an approximately straight line across the chart.

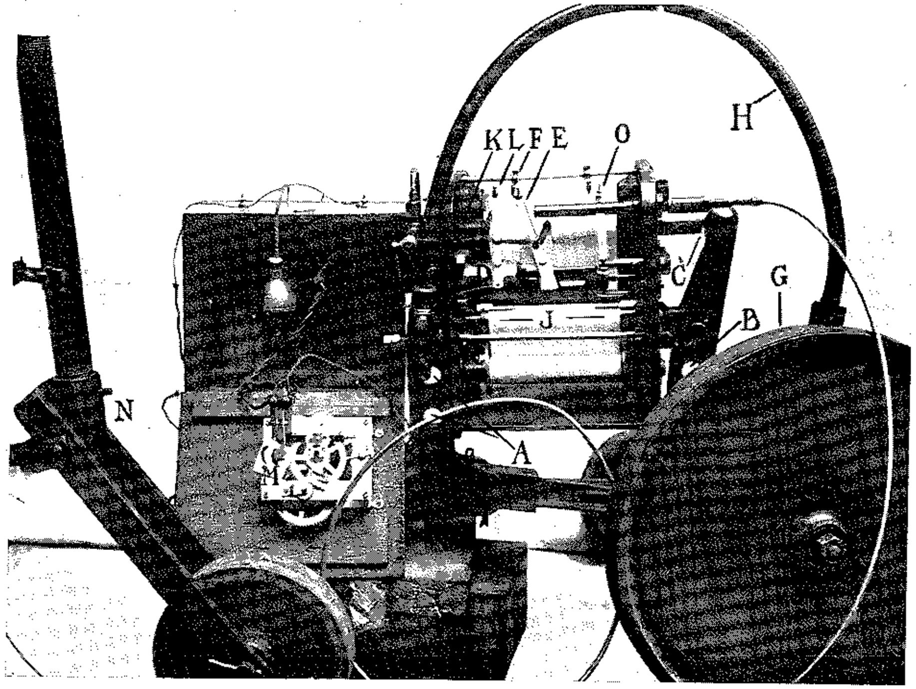
Stylus F is fixed at the appropriate point to record a straight line on the chart representing zero pull.

The motion of the chart through the instrument is governed by the movements of the carriage wheel G. The rotation of this wheel is suitably geared through the flexible shaft H to a roller J, which has two rows of pointed pins to engage the chart by piercing it and thus drawing it forward. Thus the chart starts and stops in accordance with the movements of the dynamometer and plough. The pin-pricks are about 1 cm. apart and represent 25 feet of travel over the land. The spools which feed and receive the chart can contain enough paper for many hours' continuous working.

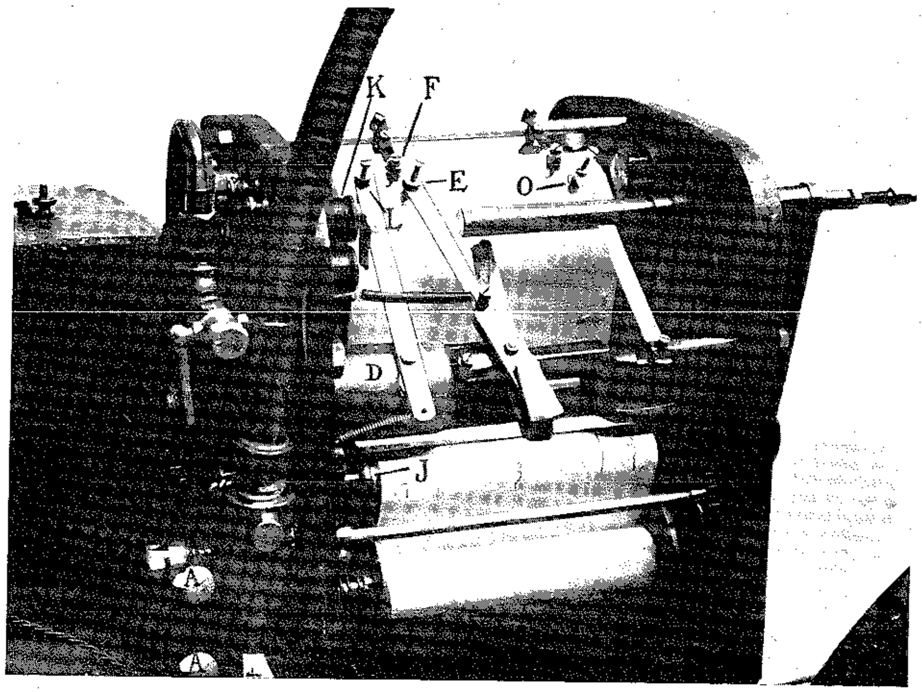
The time record is made by means of a clock which actuates the electro-magnet K every 10 seconds, causing it to draw the stylus L momentarily to one side. This periodic closing of the circuit is obtained by the cam seen at M which replaces the second hand of an ordinary clock.

For the purpose of recording the ploughing depth a wheel carried on an elbow joint N is attached to the plough frame. The wheel rides upon the uncut land by its own weight and the angle of the elbow fluctuates with the depth at which the plough is working. These fluctuations are transmitted to the third stylus O by means of a Bowden wire fixed at the joint in such a way that it is pulled in and out by the movements of the arm. Another fixed stylus is required to record the zero depth. A calibration of this part of the record is easily carried out after the equipment is set ready for work by lifting the wheel a measured height and marking the corresponding position of the stylus O.

The apparatus has been found to work well subject to careful attention and adjustment, but the connection between chart length and distance travelled is not sufficiently exact for some purposes. Two causes introduce error in this respect: (1) the slipping of the carriage wheel and (2) what is more important, the sporadic adhesion of soil clods to the wheel rim, which effectively increases the wheel diameter. To overcome this difficulty a further attachment was devised consisting of a parallel circuit to the timing arrangement, with a bell-push which could be carried in the hand. This circuit is closed when the plough reaches any given point in the field and a mark is obtained on the time record. This can be distinguished from the time marks proper by holding the contact for a longer period (see Fig. 1), or by making three contacts in sharp succession. In this way the chart can be divided up to correspond accurately to the dividing lines separating the features of interest in the field itself.



Assembled components of Watson Drawbar Dynamometer.



Detail of Recorder.

TREATMENT OF CHARTS.

A facsimile of a portion of a ploughing record is shown in Fig. 1. The first process in measuring up a chart is to draw across it the lines which correspond to the boundaries of the field plots. A mean value of D.B.P. (or of ploughing depth) is then obtained by integrating the area of the inclosed figure by means of a planimeter. The instrument used for this work is a rolling type made by Coradi of Zurich. This instrument rolls on two heavy wheels which are geared to a shaft having at its

SPECIMEN OF DYNAMOMETER CHART

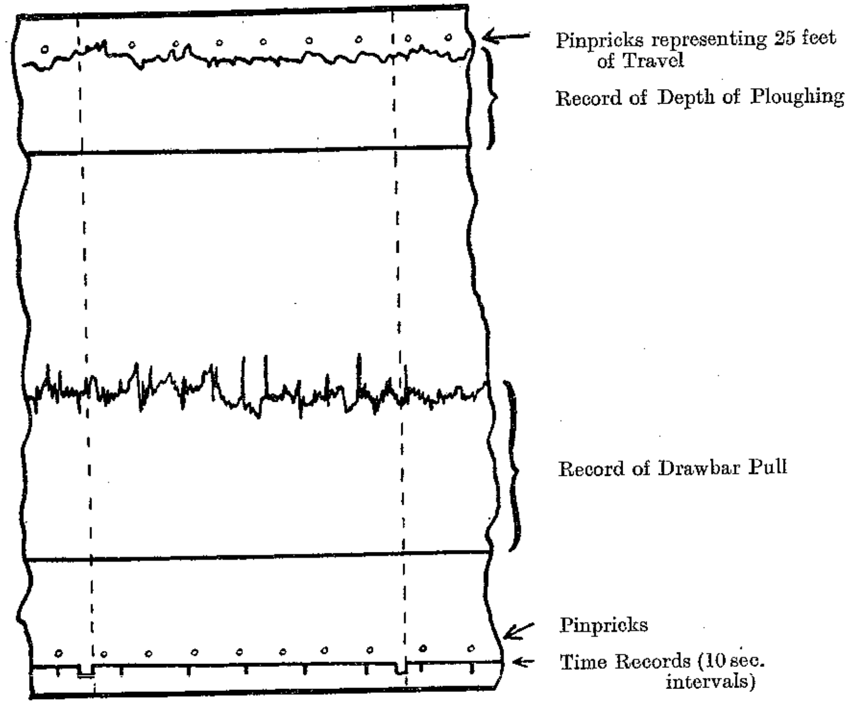


Fig. 1.

end a portion of a true sphere. A cylinder attached to the planimeter arm rolls on this sphere round a circle whose size is determined by the angle at which the arm is held. The usual fixed point in the plane of the paper is thus replaced by the rolling contact between the wheels and the paper, which gives the advantage that any required length of chart can be integrated with one movement. The degree of accuracy attained in measurement was two or three parts per thousand, even with the smallest areas. As the lines of division could scarcely be drawn with this accuracy the areas were always divided by the base length as measured on the chart, even where the plot lengths were the same.

The D.B.P. figures thus obtained are those upon which all comparisons of draught are based. As already mentioned, this depends upon soil resistance and plough design. It represents the useful work done by the tractor, which is less than the total output of energy, since a certain portion is absorbed in moving the weight of the tractor itself against frictional forces and in losses due to slip in the land wheels. Therefore the dynamometer gives no direct measure of the total power exerted by the engine; it gives information as to what is happening behind rather than in front of it. However, an indirect measure can be obtained by suitable treatment of the charts, as explained on p. 384, that is in all probability sufficiently accurate, pending direct determinations by measurements of fuel consumption under specified conditions of working. This question is now being examined as it is obviously one of the most important sections of the work from the economic aspect.

Preliminary Tests.

The actual calibration of the dynamometer can be dismissed in a few words. The D.B.P. values were calculated from calibration data supplied by the National Physical Laboratory and the inventor. Tests of the time values on the chart with those taken by means of a stop-watch agreed to one part in a thousand. The correspondence between distance travelled and chart length was not good, but the reasons for this and the method of overcoming it have already been described.

In order to use the D.B.P. figures for comparisons of soils or implements (the remaining factors being constant) they must first pass certain tests of validity. The charts show a very irregular line corresponding to fluctuations in pull, and only a close examination can show how far these are due to a purely chance occurrence of stones and similar obstacles, and how far they represent significant differences in the soil which would always re-appear in operations over the same spot. It is also necessary to know how sensitive the D.B.P. is to changes in speed, depth of ploughing, manner of hitching and all those implemental factors which cannot be maintained at an exactly constant value during a test.

In regard to the significance of small variations in D.B.P. the evidence afforded in Fig. 2 seems conclusive that these are produced by soil variations and that they reappear in successive furrows over the same

locations. The diagram was prepared by placing side by side the chart records of a number of contiguous furrows so that a direct comparison could be made. In such a case chance variations like those due to stones will not be reproduced from one furrow to the next, but significant variations should be the same for such near neighbours. The mean level of D.B.P. represented on the chart is about 1200 lb. with a range of fluctuation of 310 lb. In the upper half of the figure even small fluctuations in D.B.P. will be seen to be reproduced each time the same point is reached. There is also the same drift from end to end, from a higher D.B.P. on the left to a smaller one on the right. Exact parallelism in the sense of equal spacing between the lines is not to be expected, since the setting of the plough was not the same in all cases. The case was specially selected for the purpose of comparison, as it was a cross-ploughing of weathered furrows. The first ploughing had been done in

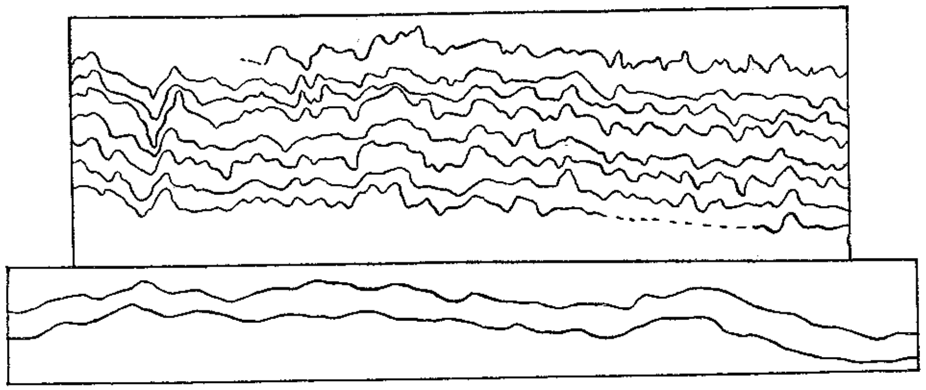


Fig. 2. D.B.P. traces of parallel furrows compared.

sections at various times so that the degree of weathering varied across the field, and gave rise to differences along the cross furrows. In addition the presence of the furrows and ridges between the ploughing lands affects the pull at regular intervals in a manner which can be picked out easily in the figure. The lower part of the figure shows two parallel furrows on another occasion when the gross variations down the furrow were larger but the smaller variations were not so noticeable. In this case the actual traces were smoothed somewhat in reproducing them, but the essential similarity in the two is quite apparent. There will be occasion in a later paper of the series (III) to show similar comparisons for furrows ploughed over the same places not on the same day, but in successive years.

The effect of maladjustments in the hitch and "set" of the plough was to produce bad work but had little effect on the D.B.P., except in so far as the depth of ploughing was affected. If the adjustment resulted in the plough working deeper there was a corresponding increase in pull. Tests on adjustments of depth alone were confined to the region of ordinary ploughing conditions, *i.e.* between the limits of 4½ and 6 in. Over this region the D.B.P. could be taken as bearing a linear relationship to the depth.

The mean of eight readings taken over the range indicated can be well represented by a straight line drawn through the values 1150 lb. for a depth of 4½ in. and 1460 lb. for 6 in. depth. For depths greater than 6 in., the greater resistance of the "plough-sole" results in a rapid increase of draught.

The effect of variations in slope over the area being worked was examined by comparing the D.B.P. of furrows going up and down the same slope. The results show that no measurable difference occurs in D.B.P. for gradients of less than 1 in 40. This result may seem at first surprising. The extra work on the tractor going uphill is very obvious, but this is mainly due to raising its own weight, and is not reflected in the dynamometer record. The only extra pull imposed by the plough is that required to lift its weight against gravity, which is very small in comparison with the pull due to the soil. Thus a plough weighing 300 lb. drawn up a slope of 1 in 40 would impose only an extra 7 lb. to a D.B.P. of about 1000 lb.

The remaining factor, and the most important, is the effect of speed. Davidson[1] and Collins[2] in Iowa, U.S.A., have carried out tests upon the connection between draught and speed of ploughing. Taking the draught at 1 mile per hour as 100, Davidson finds that an increase of speed to 4 miles per hour raises the draught to 126 or 142 according to the heaviness of the soil. Collins experimented with two types of plough, the long-breasted "general purpose" pattern and the short "breaker" pattern. The former pattern increased in draught from 500 to 600 lb. over a range of speed from 2 to 5 miles per hour, while the latter pattern gave a much larger increase from 400 to 700 lb. In our own experiments we were not able to attain quite such a range of speeds, but gained greater experimental accuracy than these workers by dividing up the furrow into short lengths and making a number of comparisons between the neighbouring plots so formed. Fig. 3 shows the results of the speed tests after taking means in this way (about nine comparisons for each point). The D.B.P. figures have been reduced so that the one for normal speed—2·5 ft. per sec.—is represented by 100. The results are comparable with those of Collins for the general purpose plough, this type being the one used in all our experiments. The small change in the D.B.P. for considerable change in speed is remarkable. For an increase in speed which would mean a 50 per cent. greater area ploughed in a given time, the increase in D.B.P. is only 7 per cent., and it is highly improbable that the extra fuel required to raise the pull by this amount would be anything like enough to outweigh the saving of 50 per cent. in time. The saving in labour costs per acre would be additional to this. Hence, as the speed of ploughing is increased, there should be a very considerable saving in expense. Practically, a limit is set by two new factors which come in, viz., the bad work performed by a plough moving too fast and the shattering wear and tear to the tractor at high speeds. Both of these difficulties could be met to a large extent by adaptation in the design of the machinery. It is evident therefore that there is a promising future for implements and tractors designed for work at higher speeds than those we have become accustomed to in using horses. Such an advance was made many years ago in steam cultivation, which has made speeds up to 6 miles per hour quite usual in certain operations.

[1] J. B. Davidson. *Agrimotor*, U.S.A. Jan. 1920. [2] G. V. Collins. *Ibid.* April, 1921.

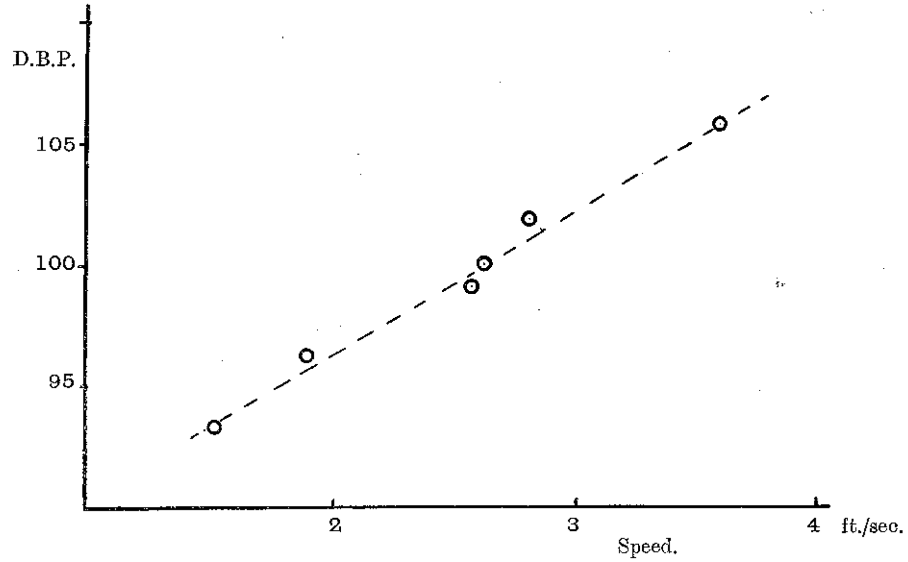


Fig. 3. Relationship between speed of ploughing and drawbar pull.

The Power Factor.

The conclusions discussed in the preceding paragraph have important economic bearings and it is highly desirable to have some quantitative method of assessing or comparing results from the point of view of costs under different conditions. The simple expression for work done—D.B.P. times the distance ploughed—is not suitable since it takes no account of the special way in which the D.B.P. is produced by the prime mover (tractor engine) nor of such factors as losses due to slip and the effect of the speed of ploughing. Consider, for instance, the plough brought to rest by an obstacle which offers a resistance higher than the maximum D.B.P. obtainable. If the source of energy were a falling weight this D.B.P. would be maintained without any loss since there is no movement, but the expenditure of energy by a tractor engine must be continuous in order to maintain the pull even though the plough itself remains stationary. Or, as another instance, take the case of ploughing up and down the same slope, all controls being kept at a constant setting. The D.B.P., and hence the work done by the plough, is practically the same in both directions (p. 382). But the total power output of the tractor for a given distance of ploughing is very different, and shows up unmistakably in the slower speed of ploughing uphill. We conclude therefore that the desired measurement is better made on a time, rather than a distance basis, and we have employed the product of the D.B.P. and the time (in seconds) taken to plough a 1 ft. length of furrow, under the name of the "power factor," as a measure of the output or fuel consumption. The assumptions involved in taking this figure as a measure of consumption are (1) that, so long as the tractor engine runs within the range of speed for which it is designed, a given pull developed at the drawbar corresponds to a certain rate of fuel consumption and (2) that this rate is simply proportional to the D.B.P. The "power factor" is then an integral expressing the amount of fuel consumed. The factor is of help in comparing results given by the same tractor and plough in any one series of experiments, especially where the D.B.P. does not vary very much from one experiment to another; the adaptation which takes place in speed as the D.B.P. changes makes the power factor a more sensitive measurement in some cases than the D.B.P. Similarly when different series of experiments are being compared (*e.g.* different soils, or manuring, or different implements), where the D.B.P. will vary from one series to another, the power factor can be used for making comparisons of the

relative costs, provided that the assumptions mentioned are valid. We hope to make tests of this and related matters at an early date in order to ascertain the measure of agreement between the indirect treatment of the dynamometer results—the power factor—and the direct measurements of fuel consumption, etc., needed for economic comparisons. In the meantime the assumptions made above are very simple and do not appear unreasonable.

As an example the results of a test on a plough and furrow-press may be recorded. The test was made with a two-furrow Ransome plough drawn by an Austin tractor, and for part of the time a furrow-press, consisting of three heavy wheels, was attached to the plough. Three journeys to and fro in the field (800 ft. long) were recorded on the dynamometer with press attached and three more without. The mean D.B.P. in the first case was 1109 lb. and the speed 2·84 ft. per sec. When the press was detached the D.B.P. fell to 802 lb. and the speed increased to 2·95 ft. per sec. Making a comparison on the D.B.P. alone, therefore, the ratio of work done with the press to that done without it was 1·38; while a comparison of the power factors in the two cases, taking account of the gain in speed as well as the fall in the draught, gave the ratio 1·50. There can be little doubt that the latter ratio is a truer expression of the additional cost imposed by the furrow-press than is the former value.

Conclusion.

The general conclusion can be drawn from the whole of the results that during a steady run with tractor and plough the variations in drawbar pull can be entirely ascribed to variations in soil texture, or soil resistance. Chance changes in the implemental factors will not produce large effects, and as far as these occur the data are available from which to calculate the necessary corrections. The unit consisting of tractor—dynamometer—plough should therefore prove to be useful for making field surveys of soil conditions and characteristics. Tests of such a nature are dealt with in the following papers of the series.

Summary.

An account is given of a reliable technique that has been evolved for making dynamometer measurements in the field. It has been shown that quite small variations in the trace of the drawbar pull are significant, and correspond to actual variations in the resistance of the soil. No significant change in drawbar pull is produced by imperfect adjust-

ments in the hitch or set of the implement within the limits met with in ordinary ploughing, except in so far as the depth of working is affected. The drawbar pull bears a linear relationship to ploughing depth within the region of ordinary ploughing. The slope of the land is without appreciable effect on the drawbar pull up to gradients of 1 in 40.

The effect of changes of speed has been examined in some detail. Although the drawbar pull increases with speed the percentage increase is relatively so slight that considerable saving in labour and other costs should result if the speed of ploughing were increased. The ordinary expression for work done (the product of drawbar pull and distance) is shown to be unsuitable as a measure of the power output, and pending direct determinations of fuel consumption, the "power factor" (defined as the product of drawbar pull and time taken to plough unit length) has been employed. The assumptions involved in the choice of this unit are discussed, and shown to be simple and not unreasonable.

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STUDIES IN SOIL CULTIVATION.

II. A TEST OF SOIL UNIFORMITY BY MEANS OF DYNAMOMETER AND PLOUGH.

By WILLIAM B. HAINES and BERNARD A. KEEN.

(*Soil Physics Department, Rothamsted Experimental Station, Harpenden.*)

(With One Text-figure.)

Introduction.

A measurement of the degree of variation of soil characteristics over any area on which variety, or manurial, or implement trials are being made, would be of the greatest value. In implement trials, especially those of a competitive nature, it is usually only feasible to divide up the area into long parallel strips, one of which is allotted to each implement. Any comparison of the implements made on the actual records of drawbar pull so obtained would be unfair unless those physical properties of the soil on which the drawbar pull (D.B.P.) depends were themselves reasonably constant over the whole experimental area; on the other hand, if a preliminary test of these variations be made, the results can be used as the standard basis for comparing the D.B.P. records of the different competing implements. Such a survey is also a necessary preliminary before any valid deductions can be drawn as to the effects of different manuring, etc., on the D.B.P.

It should also be of value in connection with the modern developments of plot technique, that are based on a statistical treatment of the yields from replicate plots of the various treatments under test, distributed at random over the experimental area. It is well known that yields vary from one small plot to the next, even on an area where the conditions have been made as uniform as possible[1]. In so far as the variations in soil characteristics are reflected in variations of yield, it is possible to allow for them in the statistical analysis and thus to improve the reliability of the results. As a corollary to the soil uniformity investigation described in the present paper, studies of crop growth are being made, and yields will also be measured.

[1] W. B. Mercer and A. D. Hall. This *Journal*, 4, 1911, p. 107.

The technique of field measurements with plough and dynamometer described in the preceding paper of this series affords a sufficiently manageable and sensitive means of measuring the degree of uniformity. Any other method of conducting a survey, such as making physical and chemical analyses of soil samples taken at regularly spaced intervals, would involve a prohibitive amount of labour. Further, in the present state of our knowledge, it would not be possible to make more than a very general inference as to the degree of uniformity of field characteristics from the measurement of selected factors such as plasticity, or mechanical analysis. The recorded D.B.P., on the other hand, is in effect an integration of all these factors, and by virtue of the large amount of soil dealt with the usual difficulty due to errors of sampling is eliminated. It is easily possible to arrange in a single day's ploughing to cover an entire field with measured furrows at short intervals, and to secure sufficient replication to smooth out experimental irregularities. Although the measurement of the considerable length of chart obtained is laborious it is not prohibitively so, and it is comparatively simple. A test of this kind was therefore deemed to be of such importance as to claim an early place in the programme of dynamometer investigations.

Experimental.

The site chosen for the test was a portion of a field known as Sawyer's, covering about 6¼ acres, which had recently been taken into the area covered by the experimental farm at Rothamsted. The field was quite level except for one slight dell and showed no obvious irregularities of any kind. Also, as far as is known, the field has received uniform treatment for many years. At the time of ploughing the land was in clover, and a small irregularity (mainly expected to affect the moisture content) was introduced at one corner by the fact that the clover there had been left uncut for some weeks after the rest.

The field was laid out in square plots of 1 chain (66 ft.) side, and the boundaries in one direction were marked as ridges in setting out the ploughing "lands." As a preliminary, rather less than half of each "land" was ploughed before the test furrows were cut. The plots could thus be divided into half in the direction of the ploughing, and the measured work gave furrows running down the middle of these half-plots. The actual test was carried out within the course of a single day in September, 1924, the field being worked across twice, so as to equalise the effect of changes, such as drying out of the soil, taking place during the course of the day. Such changes were a minimum as the day was dull throughout, with

a steady breeze and no precipitation. The plough was a Ransome two furrow, drawn by an Austin tractor.

Table I brings together the final results for mean D.B.P. values along each half-plot. Each figure represents the mean of three to six values, *i.e.* the records covered from three to six journeys along each half-plot, and represented contiguous furrows in each group. The results of moisture determinations taken on samples from alternate (whole) plots are also shown in the table. These are remarkably uniform; the two high values F 6 and J 1 being largely attributable to shading, in the one case by trees in the hedge and in the other by the patch of clover already mentioned, which was only cut just prior to the ploughing.

Table I. *Drawbar pull values (lb.) and moisture contents (per cent. on dry weight) on Sawyer's field. Ransome two-furrow plough. Austin tractor.*

Plot		1		2		3		4		5		6		7	8
A.	Down	1236	20·0	1258		1260	18·1	1282		1301	20·4	—		—	—
	Up	1233		1260		1275		1277		1335		1383		—	—
B.	Down	1293		1296	19·2	1282		1304	20·4	1409		1428	21·5	—	—
	Up	1231		1331		1275		1262		1340		1380		—	—
C.	Down	1257	19·5	1285		1282	17·9	1270		1375	19·7	1375		—	—
	Up	1342		1287		1328		1337		1456		1419		—	—
D.	Down	1380		1337	20·8	1345		1470	18·4	1529		1475	20·4	—	—
	Up	1363		1374		1356		1464		1638		1712		—	—
E.	Down	1315	20·0	1363		1349	22·1	1493		1665	20·5	1575		—	—
	Up	1378		1386		1444		1544		1513		1537		1500	—
F.	Down	1296		1333	21·8	1368		1384	24·0	1477		1507	28·8	—	—
	Up	1263		1269		1292		1317		1579		1428		1441	—
G.	Down	1275	22·2	1288		1317	20·4	1366		1526	20·5	1370		1259	—
	Up	1236		1249		1294		1333		1522		1394		1265	—
H.	Down	1232		1246	22·2	1275		1382	21·3	1329		1359	19·5	1273	—
	Up	1208		1241		1265		1335		1362		1382		1342	1310
J.	Down	1158	29·6	1250		1243		1263		1288		1353	19·7	1328	1291
	Up	—		1082		1171		1220		1250		1190		1238	1209
K.	Down	—		1174		1215		1218		1225		1242		—	—

In order to produce the best graphical presentation of the results lines have been drawn on a scale plan of the field so as to indicate regions of equal D.B.P. (Fig. 1). The figure thus has the appearance of an ordinary contour map, the "hills" and the "valleys" representing regions of high and low D.B.P. respectively. We propose to adopt the term "isodyne[1]" as a convenient description of these contour lines. The convention followed in drawing was to consider that the mean D.B.P. value arrived at for each plot was the true one for the centre of the plot, and that the D.B.P. gradient to the contiguous plots was quite smooth. The result is a considerable smoothing out of the slighter

[1] The derivation of this word is obvious; Mr P. H. H. Gray, of this station, kindly made an exhaustive search for a possible alternative, but nothing more suitable was found.

variations. The comparisons between parallel furrows cited in the previous paper indicate that highly localised variations are faithfully reproduced by the dynamometer so that, if much smaller plots were taken, the isodynes could be followed with greater detail as to local irregularities, and these details would be perfectly legitimate deductions

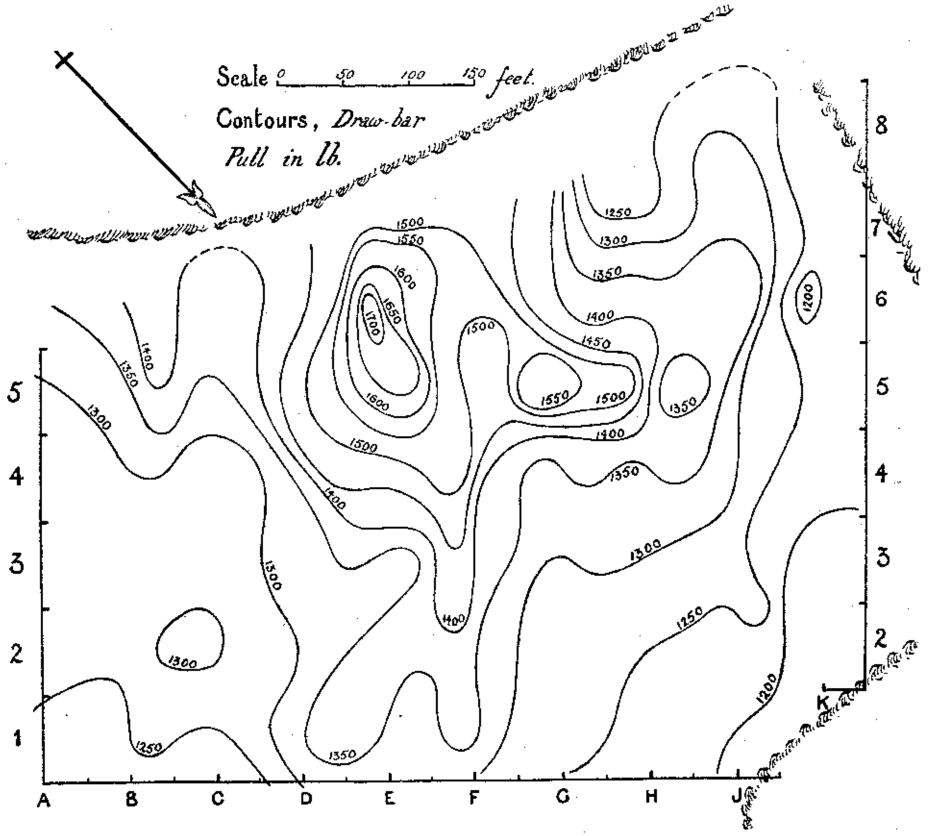

Fig. 1. N.B. Strip A extends between the points A and B, strip B between the points B and C, and so on. The left half of each strip is the one denoted in Table 1 as ploughed "down," and the right half "up."

from the chart data. But it is preferable to produce a bolder effect by smoothing, in order to throw the really vital differences into greater relief. The chart readings from which the mean values of D.B.P. were taken were examined statistically for significance. The probable error for the values of the D.B.P. gradient from one plot to the next was calculated for a number of cases taken at random. That is to say, the

calculation was made on differences in D.B.P., not on absolute values. The values range around 10 or 20 per cent. with only a few higher values in exceptional cases (such as plots representing the beginning of a furrow where irregularities are always greatest). It may therefore be inferred that the direction of the D.B.P. gradient is always significant, and that its value between contiguous plots is correct to about one part in five. When a gradient over a series of plots is considered the degree of accuracy is much greater.

Discussion.

The results shown in the table and figure are very significant. Taken as a whole they present overwhelming evidence that, for the physical properties at any rate, an assumption of soil uniformity would have been far from correct. The range of variation in the D.B.P. is about 40 per cent. It would be possible to select patches of fair uniformity, and to reject patches showing large variation, but that fact only reinforces the argument for a uniformity test as a preliminary to other experimental work.

The ease with which the isodynes can be drawn is itself good evidence of the constancy of the implemental factors, *i.e.* all questions concerning the running of the tractor and setting of the plough which might alter the draught. Any variation in these factors from furrow to furrow would show up as a tendency of the isodynes to run to and fro in a direction parallel to the ploughing. But it would be difficult to infer from the diagram the direction of the ploughing. Only in one case was there a break in the smoothness of the ploughing, when the implement pulled out of its work and had to be re-adjusted. This upset a few of the readings and the result is shown about the middle of the plan, where the lines tend to be suddenly displaced between the up and down furrows of the F strip. Measurements of depth of ploughing, however, showed no change after this slight mishap.

The situation of the dell already mentioned is about G–H 5, and is indicated plainly by the isodynes showing a somewhat heavier pull than on the immediately adjacent areas.

It is very instructive to see what would have been the result of using this field for a competitive implement trial. This can be done by comparing the average D.B.P.'s for strips taken right across the field, *i.e.* by comparing the averages of either the columns or the rows in Table I. These are given in Table II.

Table II. *Average drawbar pull for strips across the whole area.*

Strip	A	B	C	D	E		
Average drawbar pull, lb.	1267, 1297	1335, 1303	1307, 1345	1423, 1485	1460, 1479		
Strip	F	G	H	J	K		
Average drawbar pull, lb.	1394, 1370	1343, 1328	1299, 1306	1272, 1194	1215		
Strip	1	2	3	4	5	6	7
Average drawbar pull, lb.	1276	1279	1297	1343	1428	1417	1337

It is at once evident that, in spite of the additional smoothing of the values introduced by averaging the D.B.P. for the whole length of a strip, considerable differences still remain. If the lowest D.B.P. in each of the two sets of strips be taken as the standard, the increase in D.B.P. rises to a maximum of 12·2 per cent. for strips running up and down, and 11·2 per cent. for strips running across the field.

It is evident that no reliance could be placed on a comparison of the D.B.P. given by the competing implements if the inherent resistance of the soil itself varied by over 10 per cent. from one strip to another, unless these variations were first of all surveyed and allowed for in the comparisons. The necessity for such a survey is further emphasised when one remembers that even in the present stage of development of power drawn implements, a reduction of 10 per cent. in D.B.P. by improvement in design is hardly to be expected, and the improvement immediately attainable is more likely to be of the order of 5 per cent. as a maximum.

The significance of the differences in D.B.P. as an expression of differences in the physical properties of the soil is being followed up in various directions, and a number of preliminary results have been obtained. Although there is a tendency for the higher moisture figures to be associated with the heavier plots, there is no really consistent relationship, which is perhaps not surprising, since such differences would level up considerably in the winter months when the moisture samples were taken.

The question as to what degree these differences are permanent, or affected by seasonal factors, is dealt with in the next paper (III) of this series.

There is a definite correlation between the D.B.P. and clay content, as shown by the following typical results from areas covering considerable range in drawbar pull:

Clay per cent. (oven-dry, not ignited)	23·6	30·0	33·1	34·3
Drawbar pull (lb.)	1280	1400	1500	1550

Similar results will be found in the third paper of this series. This correlation would of course be expected from general experience, since "heavy" soils almost invariably contain considerable quantities of the clay fraction. On the other hand the correlation would not be exact, because the physical properties of the clay also vary.

The D.B.P. variations have also a very important correlation with the early stages of plant growth.

After the dynamometer measurements were made the land was prepared and sown to winter wheat. Measurements made by Messrs. T. Eden and E. J. Maskell on the number of plants present on the plots (*i.e.* the number surviving the winter) show that the less the average D.B.P. the greater was the number of plants. The correlation coefficient was $-0·75 \pm ·08$. A similar relationship held for the percentage of plants that had tillered, the correlation coefficient in this case being $-0·77 \pm ·10$. There is thus an unmistakable relationship between plant-growth and D.B.P., since such high correlations are not, in general, obtained under field conditions.

Counts will be made at intervals over the growing season, and the yields also measured. It will be of considerable interest and importance to see how far these striking early differences level up as growth proceeds and how far the fertility or yield "contours" over the area are a reflection of the isodynes.

The necessity of first determining the isodynes of any area in order to obtain a valid basis for subsequent experiments and deductions is brought out in the present paper. The conclusions of earlier workers have been invalidated, or at the best, rendered less reliable through the omission of this essential preliminary. The recent paper by Davies[1] on the draught of horse ploughs may be cited in this connection. In one section of his work, for instance, the recorded D.B.P. was used to estimate the state of consolidation of the ground after different crops. The results were obtained on different fields and the differences in draught attributed to the effect of the previous crop. There is no reference to the degree of uniformity of the soil beyond the statement that "an examination of soils...shows a considerable uniformity of texture in every field." The recorded values of clay content, however, vary between 10·8 per cent. and 15 per cent., a degree of variation relatively as great as those recorded in this paper for Sawyer's field. Such differences must have had an important effect on the draught and in view of the fact that Davies attempted no correction for this, the conclusions drawn are by no means fully supported by his data.

[1] This *Journal*, **14** (1924), p. 370.

SUMMARY.

Measurements are recorded of soil resistance to ploughing, taken with a view to testing the uniformity of a soil over a single field. The results have been examined for significance and indicate large variations over short distances. The differences have been represented by means of isodyne contours (*i.e.* lines of equal drawbar pull), drawn on a map.

The importance is emphasised of assuming and allowing for such variations before drawing conclusions from the drawbar pull recorded by different implements.

Preliminary work is described showing that the variations are correlated with clay content and also with the growth of a crop in its early stages.

(*Received* 21*st May*, 1925.)

STUDIES IN SOIL CULTIVATION.

III. MEASUREMENTS ON THE ROTHAMSTED CLASSICAL PLOTS BY MEANS OF DYNAMOMETER AND PLOUGH.

BY WILLIAM B. HAINES AND BERNARD A. KEEN.

(*Soil Physics Department, Rothamsted Experimental Station, Harpenden.*)

(With Plate II and Six Text-figures.)

DURING the course of several seasons of ploughing, dynamometer measurements of the type described in the previous papers of this series have been made, as opportunity offered, upon the classical plots at Rothamsted. These include fields permanently under wheat, barley and mangolds respectively. The earlier results were analysed on the assumption of an originally uniform soil, so that the differences shown between plots were attributed to the effect of manurial treatment and its secondary influence through the crop. Such comparisons gave results which appeared very confusing and difficult to reconcile with one another or with other known facts. As soon, however, as the uniformity test (described in Paper II) had been made, the reason for the difficulty was clear. The results have therefore been worked up in the same way as in the uniformity trial, *i.e.* by drawing a drawbar pull (D.B.P.) map of the field. In this way the actual differences existing are brought out, and inferences can be made from the shape of the isodynes as to whether these differences are to be attributed to manurial treatment or to pre-existing heterogeneity of the soil. When the contours show a sharp gradient associated with the lines dividing different plots then the effect is clearly referable to the plot treatments, while contour lines which run across irrespective of the plot boundaries indicate a natural drift in the soil properties and an absence of artificially induced variations. Where measurements are available for different years observations can also be made to discriminate between differences which persist from year to year and those which may be ascribed to seasonal variations.

BROADBALK PERMANENT WHEAT.

Broadbalk field is divided into narrow plots running the whole length of the field. For purposes of ploughing the boundaries of the plots separate the "lands," the ridges and open furrows alternating each year.

Table I. *D.B.P. values for Broadbalk Field Wheat Plots.*

	Mean values for seasons 1923, 1924																Mean plot-values lb.
2. Farmyard manure	945	978	936	961	947	966	999	965	926	911	936	959	996	974	979	1008	964
3. Unmanured	991	1003	1022	1001	1013	1036	1121	1112	1070	1003	1034	1030	1047	1042	1114	1146	1049
5. Complete mineral manure	1040	1027	1099	1090	1068	1075	1083	1033	1045	1070	1051	1053	1105	1123	1180	1213	1085
6. As 5, and single amm. salts	1047	1103	1170	1200	1161	1143	1190	1124	1120	1078	1112	1103	1130	1309	1351	1192	1158
7. As 5, and double amm. salts	1060	1056	1040	1030	997	1079	1067	1011	965	916	966	1010	1043	1170	1317	1152	1055
8. As 5, and treble amm. salts	1037	1037	1027	1027	1050	1043	1055	1107	1057	1034	1053	1070	1089	1163	1290	1207	1079
9. As 5, and single nitrate of soda	1089	1074	1057	1039	1079	1087	1150	1137	1099	1058	1058	1040	1043	1167	1271	1260	1107
10. Double amm. salts alone	989	1032	980	1034	1081	1045	1117	1122	1115	1049	1031	1039	1043	1072	1152	1171	1067
11. As 10, and super-phosphate	(1068)	1110	1103	1120	1114	1073	1124	1140	1140	1105	1078	1068	1108	1151	1160	1178	1115
12. As 10, and super. and sulph. of soda	995	1064	1108	1149	1187	1161	1150	1111	1175	1133	1119	1095	1062	1098	1147	1177	1123
13. As 10, and super. and sulph. potash	1091	1113	1157	1183	1198	1193	1180	1128	1128	1139	1111	1107	1116	1091	1193	1232	1148
14. As 10, and super. and sulph. magnesia	1068	1122	1210	1278	1318	1307	1226	1181	1178	1175	1150	1125	1091	1178	1267	1304	1199
15. Double amm. salts in autumn and minerals	1060	1141	1167	1203	1173	1178	1156	1131	1077	1079	1070	1079	1108	1197	1218	1273	1144
16. Double nitrate and minerals	1059	1046	1107	1137	1216	1188	1140	1146	1157	1159	1111	1092	1183	1380	1361	1432	1182
17. Minerals alone, or double amm. salts alone in alternate years	1090	1087	1128	1219	1266	1240	1262	1265	1262	1220	1241	1197	1312	1520	1580	1595	1280
18.	1116	1080	1119	1178	1198	1200	1184	1183	1149	1098	1128	1149	1213	1417	1560	1525	1218
19. Rape cake alone	1140	1083	1148	1171	1172	1220	1130	1138	1139	1103	1090	1172	1433	1460	1378	1219	1200
20. Mineral manure (without super.) and amm. salts	—	—	—	—	—	—	—	—	1040	994	956	990	1045	1155	1333	1268	1098

There is a considerable slope across the middle of the field, the plots running straight up and down it. The ploughing of any one plot therefore runs up the slope one year and down it the next, which enables the effect of the slope to be cancelled out by taking means. For purposes of measurement, sixteen equal divisions were made down the length of

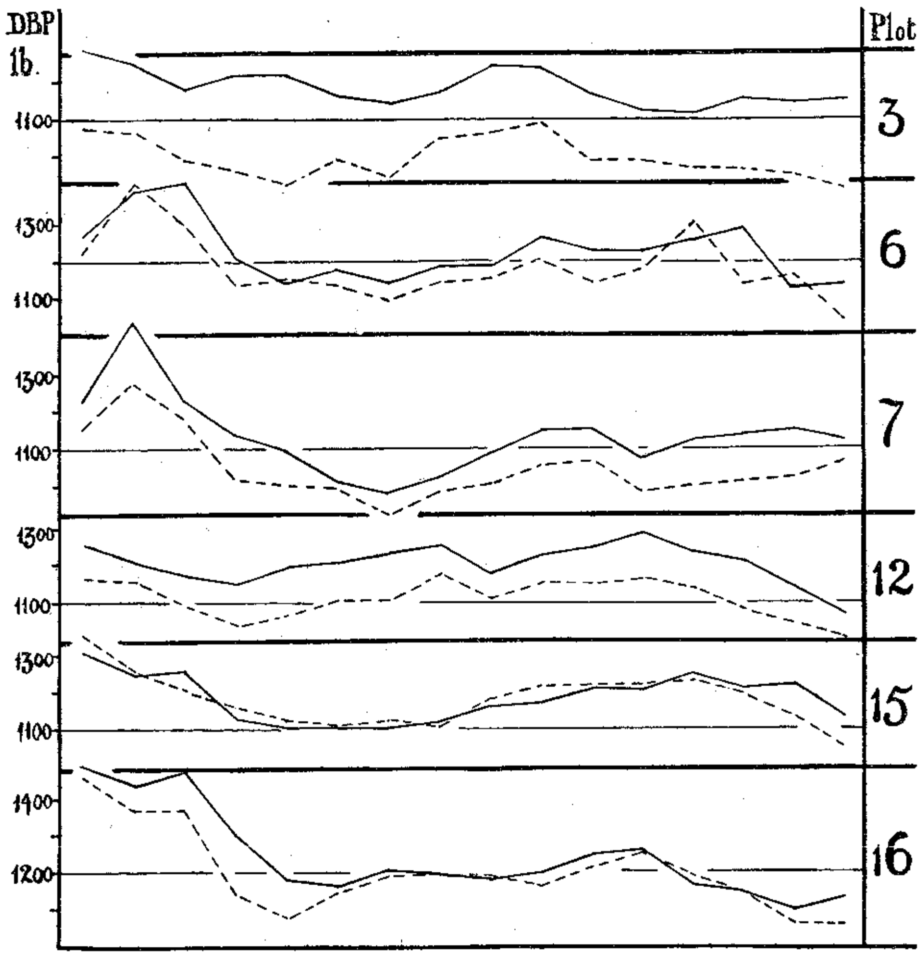

Fig. 1. Parallel readings of D.B.P. in successive years, Broadbalk.

the plots, giving about 300 values of D.B.P. over the field from which to draw the isodynes. Records covering the whole field were available for the two years 1923 and 1924; the mean values are given in Table I. The figures for the two years for certain plots are shown in Fig. 1, set out side by side, to afford a comparison. The curves shown were directly derived from the dynamometer chart for the furrows along the plots. It will be seen that in almost every case the fluctuations agree in the two years, showing that the soil differences which they indicate are permanent ones. Although one year's figures were for ploughing up the slope and the other year's for ploughing down there is no discernible difference due to this cause. The agreement between the absolute values, or the "level" of D.B.P., is not so good. In some cases the curves for the two years almost coincide, but in others they are separated by a considerable gap. There is no *a priori* reason to expect the same values of D.B.P. in the two years, since in 1923 the plough had 3 furrows working at $4\frac{1}{2}$ in. depth while in 1924 it was reduced to 2 furrows working at $5\frac{1}{2}$ in. depth. But the fact that the values coincide in some plots and not in others indicates that there are seasonal effects which bear more on one plot than on another. The incidence of such effects is probably accentuated on Broadbalk, as, owing to its abnormal manurial and cultural treatment, some of the plots will be more susceptible than others to climatic influences. For a field in ordinary cultivation such differential responses would not be expected, and the influence of climatic factors is likely to be smaller, and distributed more uniformly over the area.

The isodyne map for Broadbalk is shown in Fig. 2. The interval between the lines is 100 lb., with the addition, in broken line, of the half-way 50 lb. interval in cases where the gradient is small. Pl. II shows a raised model of this map in which the height of the surface above the table (*i.e.* including the legs of the stand) represents the D.B.P. at any point. This model brings out very effectively the large variations which occur.

The salient features of the map are the two patches of heavy land at the top of the field, of which the one on the left covering Plots 16 to 20 is by far the heavier. The D.B.P. rises at this place to 1600 lb. while the general level for the field is between 1100 and 1200 lb. There is another heavy patch lower down with its highest point on Plot 14, while Plot 7 is signally light over almost the whole of its length. Plot 2, farmyard manure, has a much lower D.B.P. than the rest of the field. This is the only case, with the exception of the sharp contrast between Plots 6 and 7, where a variation in the D.B.P. is clearly attributable to manurial treatment.

The major variations then, are to be ascribed to the natural soil heterogeneity, modified perhaps by certain artificial influences such as

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Solid model showing variation of Drawbar Pull on Broadbalk.

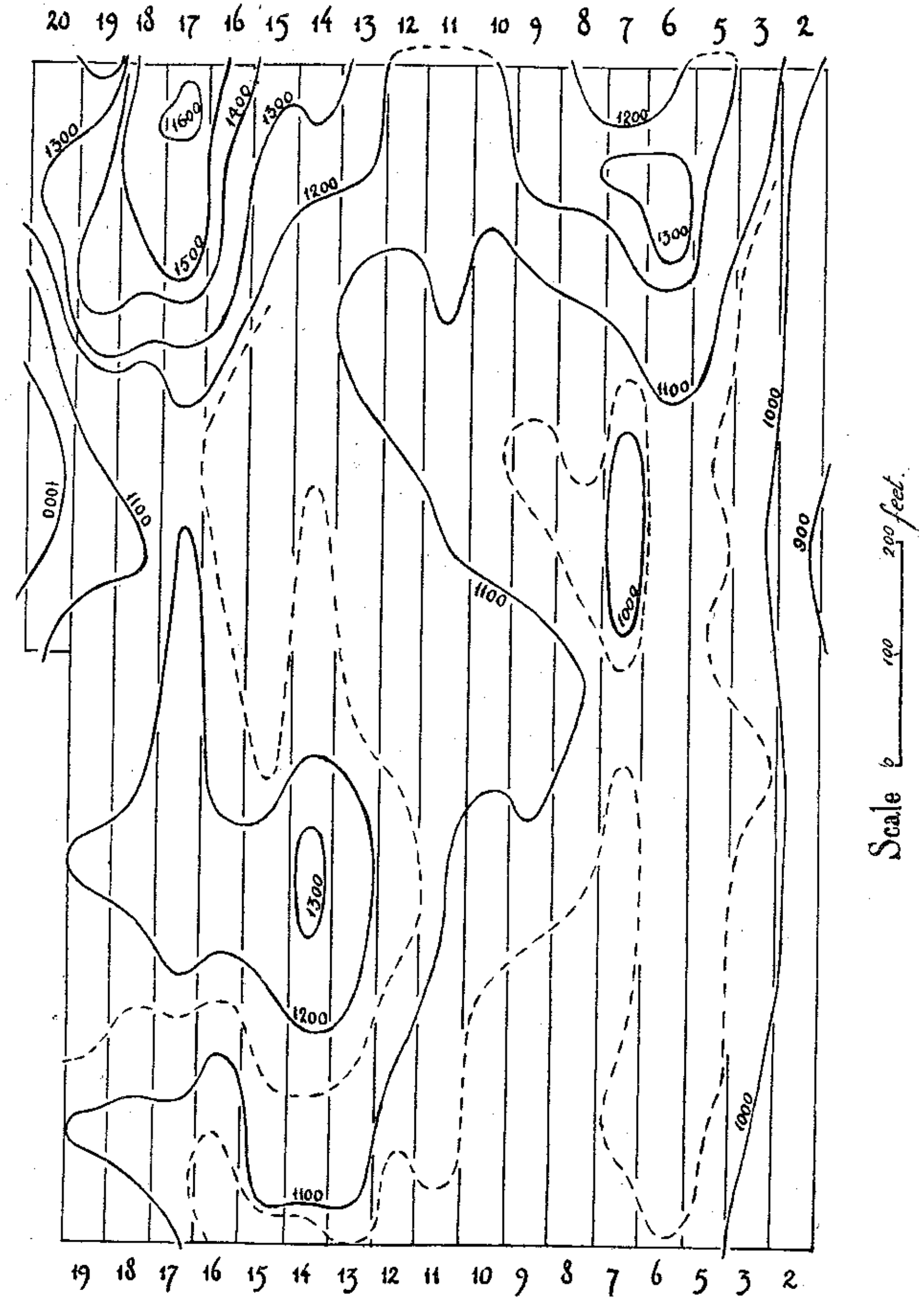

Fig. 2. Broadbalk permanent wheat, Contours, D.B.P. in lb.

the drainage system or the dells produced by digging for chalk in earlier times. There are a number of dells, which were recorded in 1851 soon after the field was laid out for experiment, and a later one near the top end of Plot 6 produced during the Great War by a bomb. An examination of their positions in conjunction with the isodynes did not indicate any relationship between D.B.P. and these changes in the contour of field level.

Several preliminary tests on soil samples from the field have been made and the clay content is the factor which has so far shown the closest relationship with the D.B.P. The samples were taken at spots chosen so as to cover the full range of D.B.P. and estimations made of clay content and moisture content. The clay measurements were made by means of Robinson's method[1], but the fraction was not ignited. The moisture figures showed only small variations, which were not correlated with D.B.P. At the time of sampling there was a fine seed-bed on the field, saturated after a very wet spell, so that the comparative uniformity of the moisture content is not surprising. The correlation between clay and D.B.P. was quite clearly marked and is brought out in the diagram (Fig. 3) where the two sets of values are plotted against each other.

The drainage system of Broadbalk includes a drain running down the centre of each plot, with one or two ramifications caused by dells or obstacles, and short subsidiary drains for the lower headland and path. When wet weather sets the drains running the farmyard manure plot is always noticed to yield the least drainage and is the first, by a long lead, to stop running. An opportunity was taken, after a rainfall of 1 in. in a single night, to make some measurements on the rate of efflux from the drains. The time at which these measurements were taken was about 11 a.m. the next morning, when the rate of flow was already falling off, and the drain to Plot 2 (farmyard manure) had quite ceased to flow. In Fig. 4 the mean D.B.P. for each plot is shown graphically along with the rate of efflux from the respective drain. A very close relationship obviously exists, though it gives the surprising result that the heaviest plots were flowing the fastest. The last few plots of the series, numbers 17 to 19, fall out of step for two reasons. In the first place Plot 19 gets a large amount of extra drainage from the side of the field, which has a ditch along part of its length, and in the second place the D.B.P. figures for Plots 17 and 18 are unduly weighted by the existence of a very heavy patch of land extending at the top end over only a small portion of the plots. Since the D.B.P. figures have

[1] This *Journal*, **12**, 1922, p. 306.

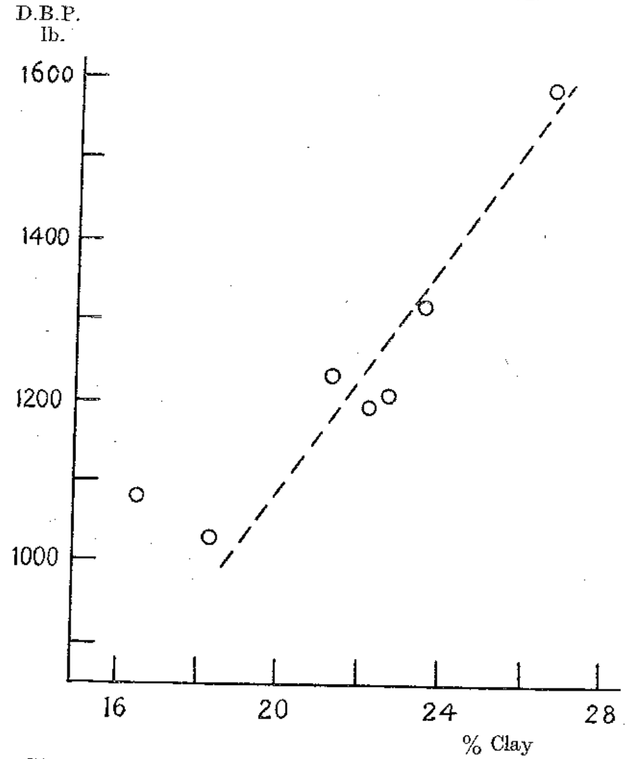

Fig. 3. Correlation of D.B.P. and clay content, Broadbalk.

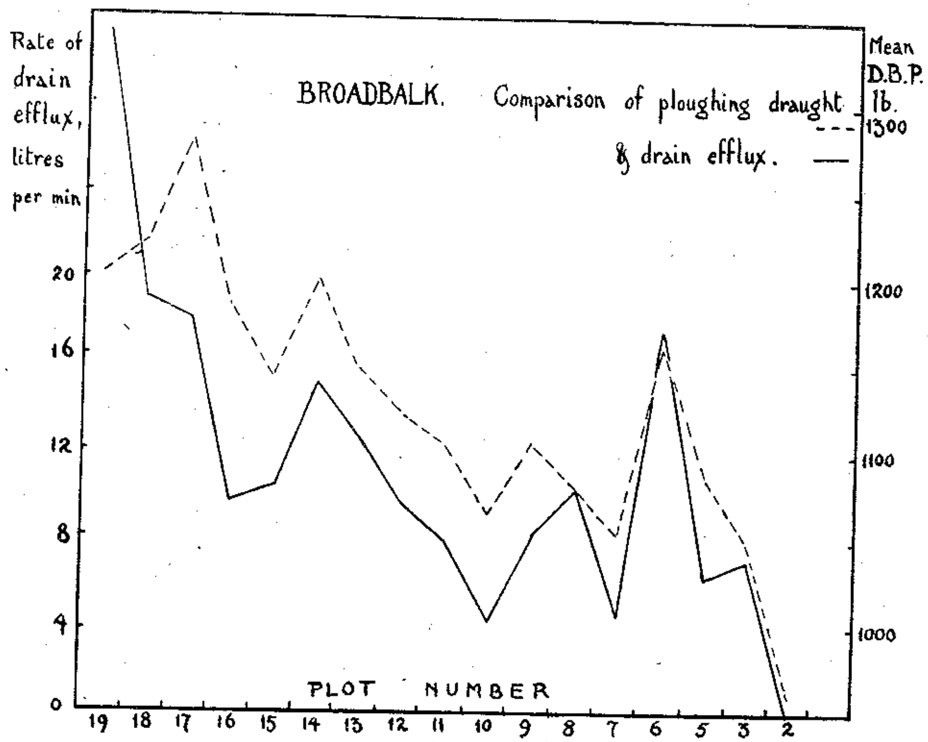

Fig. 4.

already been shown to follow the clay content closely, it is plain that the drainage rate (at the time of measurement) is not governed by the permeability of the soil *per se*. Observations made several hours earlier than the actual measurements led to the estimate that all drains were flowing at about an equal rate. Apparently, therefore, the soil differences show up as retentiveness rather than as simple permeability. It is suggested that as the values were obtained towards the end of the flow, the less permeable plots had held back the water and so had a reserve which caused them to flow for a longer period. A second effect which would influence the flow in the same way is the difference in the rate of drainage to the subsoil. A simple calculation shows that if the whole inch of rain (which fell on to already sodden ground) had come through the drains, they would have continued to run for at least 40 or 50 hours, while they actually ran for a small fraction of this (six to eight hours). Hence the drainage water is only the balance of the water which does not get right through to the subsoil. This means that the least permeable subsoils will cause a greater proportion of the water to be side-tracked into the drains, enabling the drains of the heavier plots to flow for a longer time than the others. The problem is a highly important one which will require more extended measurements for its full elucidation.

Hoos permanent barley.

In the case of the Hoos barley plots complete data were available for three years, so that seasonal variations were smoothed in the mean values (Table II). These values were used for the preparation of Fig. 5,

Table II. *D.B.P. values for Hoos Field Barley Plots in lb.*

			1 Unmanured	2 Superphosphate	3 Alkali salts	4 Complete minerals
		N Nitrate soda only	1259	1309	1355	1306
		C Rape cake	1235	1244	1341	1305
			1266	1246	1272	1271
6–2	7–2					
Furnace ashes	Farmyard manure	AAS Nitrate of soda	1299	1270	1278	1269
		AA ,,	1273	1260	1281	1245
1225	1187	A Ammonium sulphate	1274	1236	1235	1230
1208	1221		1286	1267	1213	1239
1241	1325	O Unmanured	1352	1303	1297	1260
1380	1376		1370	1288	1301	1293
6–1 Unmanured	7–1 Unmanured					

which shows the isodyne map for this field. Each plot was halved for purposes of calculation, giving plots about 24 yards square. The map

shows much greater uniformity in the soil than the other cases so treated. The interval between the lines has been reduced to 50 lb., with broken lines showing 25 lb. intervals. Especially over the middle of the field there is great uniformity. Patches covering several plots occur whose mean values of D.B.P. do not vary by more than two or three parts per thousand. Several of the plots show marked differences due to cultural treatment. Plot 7–2 receiving farmyard manure is lighter than any other plot of the series. The unmanured plot, 1–0, is distinctly heavier to work. The remaining unmanured plot, 6–1, is not so

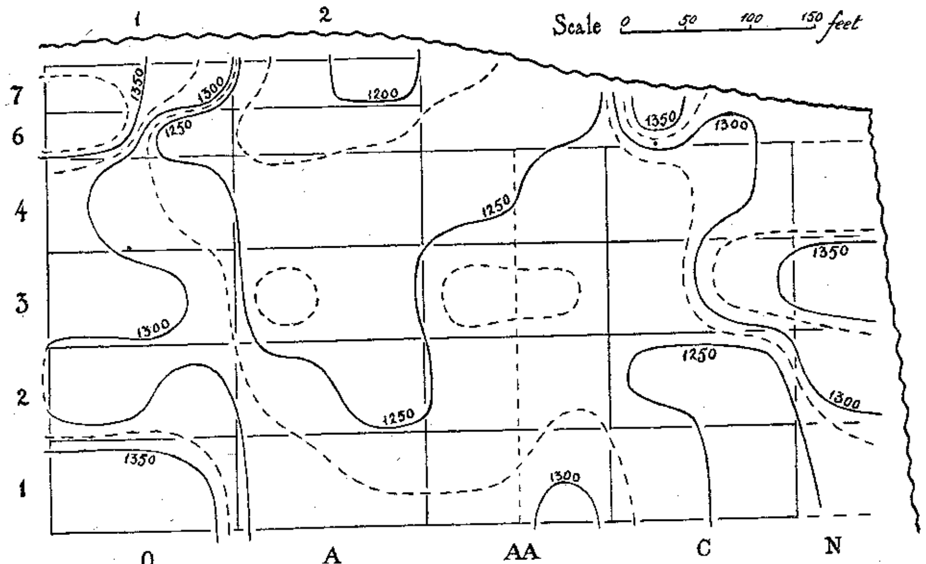

Fig. 5. Hoos permanent barley, Contours, D.B.P. in lb.

heavy on the average as 1–0. The results for Plot 7–1 should be noted. This plot received 14 tons of farmyard manure annually from 1852 to 1871, since which date it has been unmanured. The yield however is still persistently above that of the adjacent plot, 6–1, and this is usually ascribed to a residual effect of the earlier manuring. The dynamometer results show that no residual physical improvement can be attributed to the organic manuring. The AAS plots which receive silicate of soda show, on strips 1 and 4, an increase over the AA portion, but the tendency to higher values is barely perceptible in the others. For the rest of the field the uniformity is such that no certain effects can be ascribed to cultural treatment. The map has been examined in the light of other known facts such as the higher calcium carbonate content on strip 4[1], but no further conclusions seem to emerge.

BARNFIELD PERMANENT MANGOLD PLOTS (Fig. 6).

Owing to the lateness of the season when Barnfield comes into the farm programme it is often impossible to get the tractor on to the land, so that only one occasion has so far arisen on which a set of dynamometer readings could be taken. It is proposed to adapt the dynamometer to work with horse traction, but the change has not yet been effected. The width of the plots allows both up and down ploughing to take place

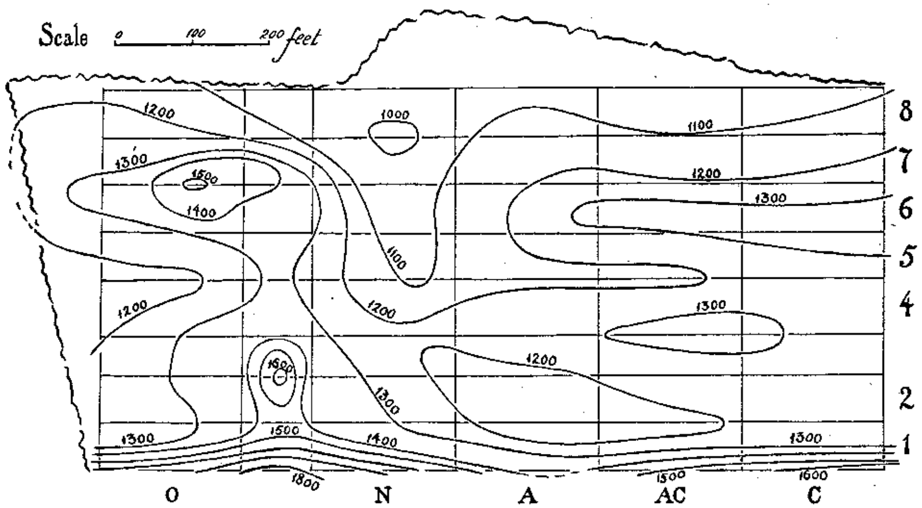

Fig. 6. Barnfield permanent mangolds, Contours, D.B.P. in lb.

on every plot. As the measured furrows were taken immediately after the work was opened up they gave values of D.B.P. for each side of the plots (one up and one down the field). When these were placed in their appropriate position on a plan of the field the values came together in pairs on either side of the plot boundaries. Each pair were for the most part (*i.e.* except on the slope) very similar, as they should be for parallel furrows. This is further evidence that the differences due to cultural treatment are small compared with the "natural" differences.

Barnfield has a more marked slope than any of the other fields. The slope is downward over the A and N plots to the valley, with a value of 1 in 22, and there is also a slight fall over the N plots from Plot 1

[1] A. D. Hall and N. H. S. Miller. *Proc. Roy. Soc.* B. **77** (1905), p. 10.

to Plot 8. The isodyne of lowest value (1000 lb.), forming a ring on Plots N 7 and 8, corresponds exactly to the lowest part in the dip of the field, while the next line (1100) shows a great tendency to follow the same direction as the contour of level.

A ridge of high values runs along the plots known as the "Valley," which receive no manurial dressing. The bad state of the soil was probably the original reason for leaving this strip out of the experiment; this has been enhanced by the low level of cultivation resulting. The values of D.B.P. along strip 1 (14 tons farmyard manure annually) present interesting features. They are very much higher than would be expected in view of the manuring. At the outer edge of this strip (which is bounded by a bank marking a sudden rise in ground level of a foot or so) the depth of soil overlying the clay is very small. With horse ploughing the depth of furrow had always been adjusted by the ploughman according to the thickness of the soil layer. The present occasion was the first on which a tractor plough had been used and the furrow slice was cut at a uniform depth. Thus where the soil was thin the ploughshare at times went well into the subsoil clay, so giving rise to a large increase in D.B.P. Even when allowance is made for this, the values over the whole plot give rise to the suspicion that the ameliorating effect of farmyard manure is by no means shown as it is on the corresponding plots of Broadbalk and Hoos field. This suspicion has been confirmed by observation on the cultivation operations carried out in the past few months. Owing to the abnormal conditions, ploughing had to be deferred until after the winter. When the field was ploughed in March, strips 1 and 2 receiving farmyard manure behaved in a strikingly different manner from the rest of the field. The freshly turned furrows were of a cheese- or putty-like consistency, and some days after ploughing contained 25·9 per cent. of water as against 15·3 per cent. on the strips receiving a complete artificial manure, an excess considerably greater than normally expected from the difference in organic matter content on the two plots. Reference to the experiments on surface friction of moist soil already published in this Journal[1] will show that increased draught in ploughing would be expected at a moisture content of 18 per cent. The increased draught on these plots was unmistakable and an extra horse had to be added to the team. A further indication of the heavy state of the farmyard manure strips was obtained from observation of the furrows as they dried out. The rest of the field dried out normally

[1] W. B. Haines. "Studies in the physical properties of soil (I)." This *Journal*, **15** (1925), p. 197.

and the crumbly furrows were comparatively easily pulled down and shattered by the cultivator. The farmyard manure furrows on the other hand passed through no such stage: the sticky furrow slices remained intact and dried out into iron-hard clods. Several alternations of wetting and drying were insufficient to produce more than a moderate ameliorating effect, and, in the end, a tilth had to be forced. It is difficult to give the exact reason for these abnormal effects. The manure is of course applied annually in large quantities, the impervious clay subsoil has prevented proper aeration and drainage, especially in the past two wet seasons, and it is possible that under these conditions the manure has not followed a normal decomposition process. The normal products, which by their mechanical and physico-chemical effects turn the soil into a friable and easily ploughed condition, may have therefore been absent or considerably reduced. A close examination of the furrows showed that some of the manure applied 12 months previously was only partly decomposed, a fact which lends some support to the possibility suggested above.

Summary.

Maps of soil resistance to ploughing have been drawn up from the dynamometer readings over several seasons for the Rothamsted classical plots, carrying wheat, barley and roots respectively.

The conclusions as to the effect of manurial treatment are only of a general nature at the present stage of the work. Such differences are certainly small in comparison with the natural variations in the soil.

In the case of the Broadbalk wheat plots the drawbar pull values have been shown to have a close relationship with the clay content of the soil and with certain aspects of the soil drainage.

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ALKALI INVESTIGATIONS IN THE SUDAN.

By A. F. JOSEPH.

(*Wellcome Tropical Research Laboratories, Khartoum.*)

(With One Text-figure.)

1. *Introduction.* In a paper recently published on the soils of this country (1), reference is made to the area known as the Gezira where important developments in cotton growing are now taking place: the area under cultivation will shortly be increased owing to the completion of the Sennar Dam, which will command several million acres[1]. The soil consists of a brown heavy clay rather high in water-soluble salts and possessing considerable alkalinity, and the irrigation programme has necessitated large and small scale agricultural experiments which have been carried out for over ten years and have provided material for the investigations on soil alkali which form the subject of this paper.

The origin of the soil is aeolian, but that of the soil salts has not yet been determined, as they might be formed by decompositions *in situ*, or have been brought with the deposited soil, or deposited from solution of the water of the Nile. A general description of the area with mechanical and chemical analyses was given in 1911 by Beam (2): the ultimate analyses of the various soil fractions will be found in the first paper referred to. Additional data for the mineral composition of the whole soil are given below: these have been calculated from the results published previously for the typical first foot sample for which the actual analysis is given in (1):

Table I.

Silica SiO_2	48·28
Aluminium Al_2O_3	14·97
Iron Oxide Fe_2O_3	9·91
Titanium Oxide TiO_2	2·31
Manganese Oxide MnO	0·28
Lime CaO	7·33
Magnesia MgO	1·37
Potash K_2O	0·31
Soda Na_2O	0·41
Phosphoric Oxide P_2O_5	0·12
Carbonic Acid CO_2	4·71
Volatile matter (H_2O etc.)	9·44
Total	99·44

[1] The area lies near the west bank of the Blue Nile between parallels 14° and 15° North.