Total pore-space estimations in freshly ploughed soil

H. KUIPERS and C. VAN OUWERKERK

Soil Tillage Laboratory, State Agricultural University, Wageningen, and Institute for Soil Fertility, Groningen, Netherlands, respectively

Summary

A method is described to measure the height of the soil surface at different times relative to level marks under the ploughed layer. These heights can be used to calculate pore space immediately after ploughing from its value before ploughing and the ploughing depth.

Three examples are given, from which can be seen 1. the compactive action of spring cultivations, 2. the large influence of rain on settling speed by natural forces, 3. the large influence of frost action and 4. the small influence of frost on soil surface roughness.

1. Introduction

One of the important aims of ploughing is to loosen the soil. The simplest way to characterize this action is to express it as an increase of the total pore space of the ploughed layer. However, pore-space determinations in a freshly ploughed soil are often very difficult and in many cases not practicable in view of the heterogeneity of the soil structure. As was pointed out previously (KUIPERS, 1959), one aspect of this heterogeneity can be expressed as a soil-surface roughness number. This index is calculated from the differences in height of the surface, which is measured in 400 places. If these height figures are measured before and after ploughing, relative to a reference level, it will be possible to estimate total pore space after ploughing from the pore space in the unploughed land (KUIPERS, 1960; ANDERSSON 1962). This method and some applications are described below.

2. Procedure and equipment

1. Before ploughing, samples for total pore-space determinations are taken in as many layers and replicates as necessary to get an accurate average for the entire layer to be ploughed.

2. The mean height of the soil surface is measured relative to level marks below the ploughed layer by means of a reliefmeter. This measurement is carried out in 5 places.

The reliefmeter (FIG. 1) (KUIPERS, 1957) consists of a vertical scale, 10 cm high, which is divided in cm and fitted in an aluminium frame [1]. In front of this scale 20

[1] Construction drawing available on request: Soil Tillage Laboratory, State Agricultural University, Wageningen, Netherlands.

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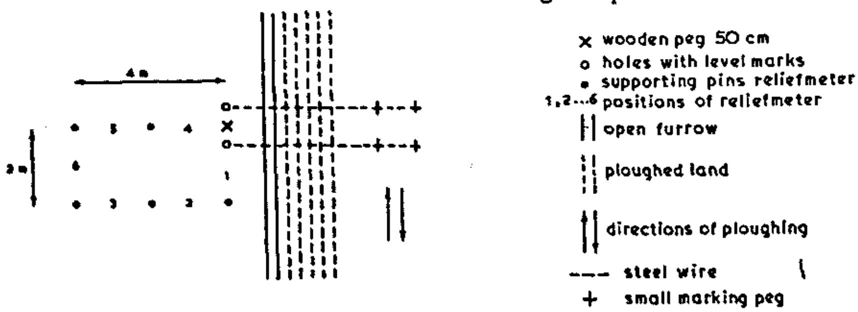
needles are placed with 10 cm interspace. The needles are held in their position by a spring-mounted bar. If this bar is pushed in, the needles slide down till their feet touch the soil surface. Each needle is divided in parts of 10 cm by means of differently coloured plastic hose pipe. This makes it easy to read the height figures over a wide scale. The reliefmeter is supported by pins which are pushed into the soil by means of detachable handgrips in which the reliefmeter can move freely. The pins have an adjusting screw by which the apparatus can be placed horizontal. For this purpose an accurate air level is attached to the reliefmeter.
As level marks cylindrical concrete blocks (7 cm diameter and 5 cm high) with flat top and bottom are used.
In 5 places along the open furrow and at some distance from it, a wooden peg is driven into the ground vertically. Each of the five pegs is regarded as a corner point of a rectangle of 4 × 2 m, of which the long sides are perpendicular to the direction of ploughing as indicated in FIG. 2. In position 1, one side of the reliefmeter rests on the peg, the other on a supporting pin with adjusting screw. After the apparatus has been placed horizontal no readings are taken, but the apparatus is brought in position 2, leaving the supporting pin in its place. This is done in each position, so 5 supporting pins should be available. In positions 2, 3, 4 and 5 the 20 needles are lowered onto the ground and the height of the soil surface is measured relative to the lower edge of the reliefmeter. In position 6 the level is checked. It should be accurate to 0,5 cm as the height figures are read in cm. If the accuracy was sufficient, the supporting pins are removed.

FIG. 2. Determination of zero level and marking the place of the level marks



Beside each peg two holes are dug with a special auger, to a depth exceeding 10 cm the expected ploughing depth. The two holes are situated on a line parallel to the direction of ploughing and at a distance of 50 cm from the peg (FIG. 2). A level mark is placed on the bottom of each hole and tapped into a horizontal position.
To measure the height of the upper side of the peg relative to the upper side of the two level marks, a special ruler is used. It consists of a pointed steel pin, of about 1 m length, with 10 cm marks. A well fitting block with a not too sensitive air level can slide along the pin and can be secured in any position. The ruler is placed vertically on top of the level mark and a long sensitive air level is placed with one side on top of the peg and with the other side on the block of the ruler. This block is now moved upwards or downwards until the long air level is horizontal. The height can be read on the ruler with the aid of an auxiliary scale which is divided in millimeters. Although good results are obtained in this way, it must be possible to improve the apparatus somewhat.

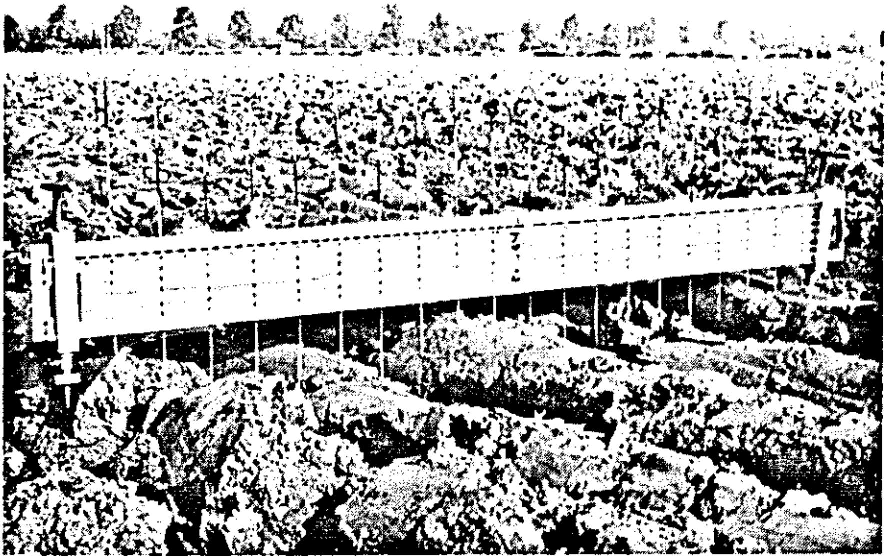


Fig. 1. Reliefmeter

After the measurements have been completed, the pegs are removed and the place of each level mark in the field is marked. With the aid of a steel wire, a straight line perpendicular to the direction of ploughing is set out (FIG. 2). Along the line small marking pegs are driven into the ground at distances of 4 and 5 m from the hole.

3. While the area is ploughed, the ploughing depth is measured in about 20 places by means of a special apparatus or by means of the reliefmeter. In the last case, some of the needles should be lowered onto the bottom of the open furrow, the others onto the unploughed land.

4. As soon as the land has been ploughed and at any other required time the measurements of the relative height of the soil surface are repeated in the same places as before ploughing.

Immediately after ploughing the place of the level marks is found by means of the steel wire and the ruler which is now used as a probe. The places are marked by willow twigs and the pegs are replaced in the middle between each pair of level marks.

It is assumed that the height of the level marks relative to the bottom of the ploughed layer is constant in the course of time. On the other hand the height of the pegs relative to the level marks may vary as the pegs may move up and down together with the soil of the ploughed layer. For this reason the height of the pegs relative to the level marks is measured at each repetition.

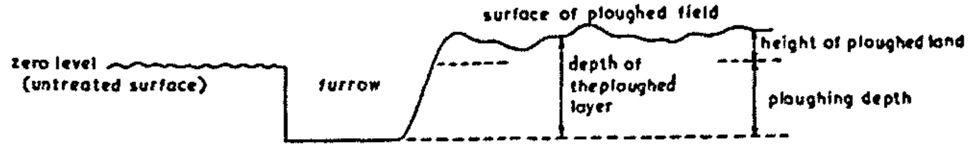
During seedbed preparations the pegs should be removed. The flexible twigs will remain in position during all tillage operations but ploughing and rotavating.

3. Calculations

Each measurement gives 80 height figures relative to two level marks. The mean value of the 80 height figures before ploughing, is regarded as the zero level for each place. The height of the whole field is calculated as the mean of the heights measured in each of the 5 places relative to zero level.

The mean ploughing depth is calculated from the observations in the open furrows. The sum of the ploughing depth and the height of the soil surface relative to zero level equals the depth of the ploughed layer (FIG. 3). If the mean pore space before ploughing is known, it can easily be calculated at any other moment, as the volume percentage of the solid phase times the depth of the ploughed layer will be constant.

FIG. 3. Cross section through ploughed field



4. Accuracy

The estimation of pore space in a freshly ploughed soil from height measurements should have about the same accuracy as the determination of pore space in a settled field with the aid of core samples. Experience in this type of pore-space determina-

tions shows that under favourable sampling conditions and a reasonable homogeneity, a difference of 1 vol. % can be measured sufficiently accurate. A significant difference of 2 vol. % will be regarded generally as reasonable, while under poor conditions one will have to be content even with a significant difference of 5 vol. %.
Taking these differences of 1, 2 and 5 vol. % respectively as tolerated deviations of pore space, and assuming that pore space before ploughing and ploughing depth are known, the required accuracy of the height measurements can be calculated.
As d.s. = constant, where d = depth of the ploughed layer in cm and s = vol. % of solids, it follows that $(d - \alpha)(s + \beta) = d.s.$, where β is the tolerated deviation of s and α the induced deviation of d. Thus $\alpha = \frac{d \cdot \beta}{s + \beta}$ or about $\frac{d}{s} \cdot \beta$, as β is small relative to s.
Therefore, if d is great and s is small, which means a high pore space, α will be great. For example, if d = 15 cm and s = 60 vol. %, it follows that for β = 1, 2 or 5 vol. %, α = 0,25; 0,50 and 1,25. If d = 30 cm and s = 40 vol. %, α = 0,75; 1,50 and 3,75 cm respectively.
The depth of the ploughed layer (d) is calculated as the difference of the mean height of the soil surface before ploughing and that on the moment under consideration, added to the ploughing depth. As the surface before ploughing generally will have a much lower roughness than after ploughing, the error in the determination of the soil-surface level before ploughing will be small relative to the error in this determination after ploughing. Therefore the accuracy of the determination of the mean height of the soil surface after ploughing will be conclusive.
As mentioned above the height of the soil surface is calculated as the mean of $5 \times 80 = 400$ height figures. The standard deviations S (in cm) of these 400 figures is used in the calculation of soil-surface roughness, according to R = 100 log S (KUIPERS, 1957). It appeared experimentally that soil-surface roughness after ploughing will range from about R = 30 to R = 100, therefore S ranges from 2 cm to 10 cm.
The standard error of the mean will be $\sqrt{400} = 20$ times smaller than the standard deviations S. This means that the standard error of the mean ranges from 0,1 to 0,5 cm and the significant difference α from about 0,3 to 1,5 cm.
From this it appears that if a soil with a high pore space is ploughed to a great depth, the height measurement will give an accuracy comparable with a rather good pore-space determination even when the surface is very rough as α derived from soil-surface roughness will not be higher than 1,5. If soils with a low pore space are ploughed shallow, the required accuracy of the height measurements is more critical. Very rough surfaces will then give results only comparable with a rather poor pore-space determination. However, experience shows that these very high roughnesses generally only occur at moderate or great ploughing depths.
It stands to reason, that the accuracy of the difference in height between the pegs and the level marks should not become the limiting factor. Therefore it will be necessary to aim at an accuracy of 1 mm in this measurement. By using 2 level marks for each peg it is possible to check this.

5. Applications

1. In an experiment on the time of fall ploughing (KUIPERS *et al.*, 1961) measurements were made on 4 fields in 1958—1959 and in 1959—1960 and on a fifth field in the last mentioned period only. The soils were 4 medium-textured marine

soils and 1 heavy sea-bottom soil. There were two ploughing dates on each field, in most cases about 1 month after each other. The height measurements were made just before and immediately after ploughing and in spring just before and after seedbed preparation. On the early ploughed parts a fifth measurement was made at the time of late ploughing.

As the method described above was being developed at that time, the accuracy was not always quite satisfactory. Therefore only the mean results of the 8 measurements in the first season, and of the 10 in the second are shown in TABLE 1.

TABLE 1. Mean height of the soil surface relative to the level before ploughing in cm

Period	At ploughing	After about one month	Before spring cultivation	After seedbed preparation
1958—1959	7,5	3,9	3,7	1,7
1959—1960	6,1	4,1	3,7	0,4
Total mean	6,7	4,0	3,7	1,0

Thus on the average, the depth of the ploughed layer was increased by about 7 cm. The decrease by natural forces amounted to 3 cm, of which 90 % occurred in the first month. It is therefore not to be expected, that early ploughing on these soils will give a smaller pore space in consequence of the longer period in which the soil can settle.

Before spring cultivation 55 % of the depth increment of the ploughed layer was left. It is remarkable that this figure was reduced to 15 % by the seedbed preparation. What this means can be best demonstrated by calculating the influence on pore space. It is assumed that the mean ploughing depth is 24 cm, as indeed it was, and that pore space before ploughing was 45,0 vol. %, with a moisture content of 42,0 vol. %. This means that only 3 % air space is left in the soil which is a rather normal condition in the heavier soils of the Netherlands (KUIPERS, 1961). TABLE 2 demonstrates the influence of the changes in height on pore space.

TABLE 2. Influence of changes in depth of the ploughed layer on pore space

	Depth of ploughed layer (cm)	Vol. percentages of		
		Pore space	Water content	Air content
Before ploughing	24,0	45,0	42,0	3,0
Immediately after ploughing	30,7	57,0	32,8	24,2
One month after ploughing	28,0	52,8	36,0	16,8
Before seedbed preparation	27,7	52,4	36,4	16,0
After seedbed preparation	25,0	47,2	40,3	6,9

In this example the water content as a percentage of dry weight is assumed to be constant. The final decrease in pore space by seedbed preparations reduces the air content from a favourable to a critical level. Therefore, it will be very important to investigate the possibilities of reducing this compaction, *e.g.* by minimum-tillage methods.

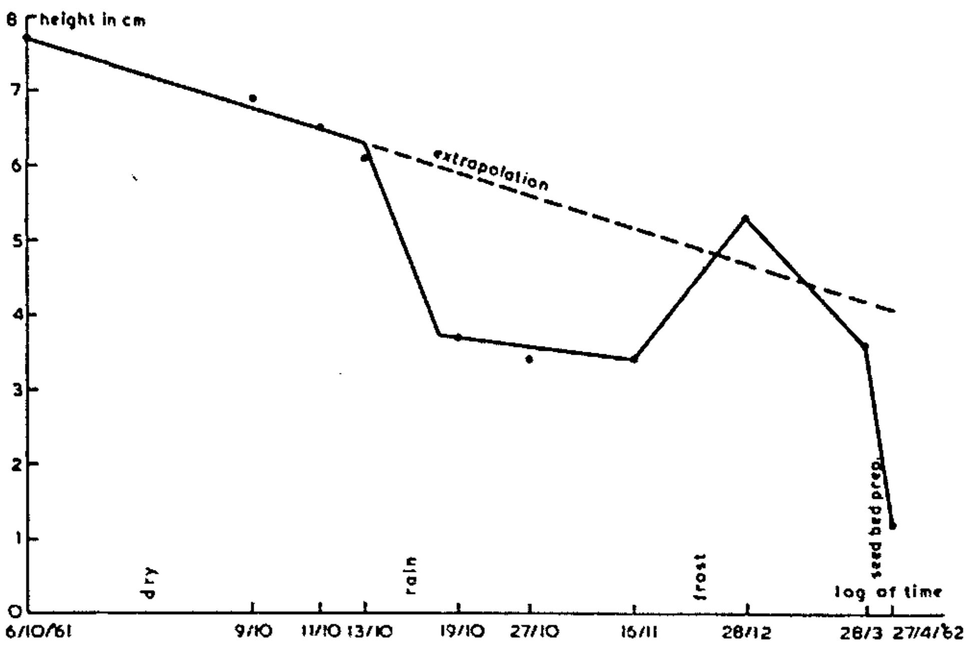
2. The decrease of the depth of the ploughed layer by natural forces was investigated in more detail in two experiments in 1961—1962.

In the first experiment on a heavy river-clay soil near Wageningen the height was measured at short time intervals immediately after ploughing and subsequently at much longer intervals.

In FIG. 4 the height relative to the surface before ploughing is plotted against time on a logarithmic scale as from experiences in soil mechanics a straight-line relationship could be expected. In the first week after ploughing this linearity seemed to be a rather good approximation, predicting, that in the next spring about half of the depth increase of the ploughed layer should be lost. This indeed turned out to be true, but this loss was obtained in a much more complicated manner.

In the second week heavy rains gave a rapid fall of nearly 2,5 cm, bringing the total decrease to 4 cm, or somewhat more than 50 % of the initial increase in depth of 7,7 cm. Thus the condition expected in spring was reached within a fortnight, which clearly demonstrates the great influence of weather on the process.

FIG. 4. Mean height of the soil surface in relation to log of time after ploughing a river clay soil

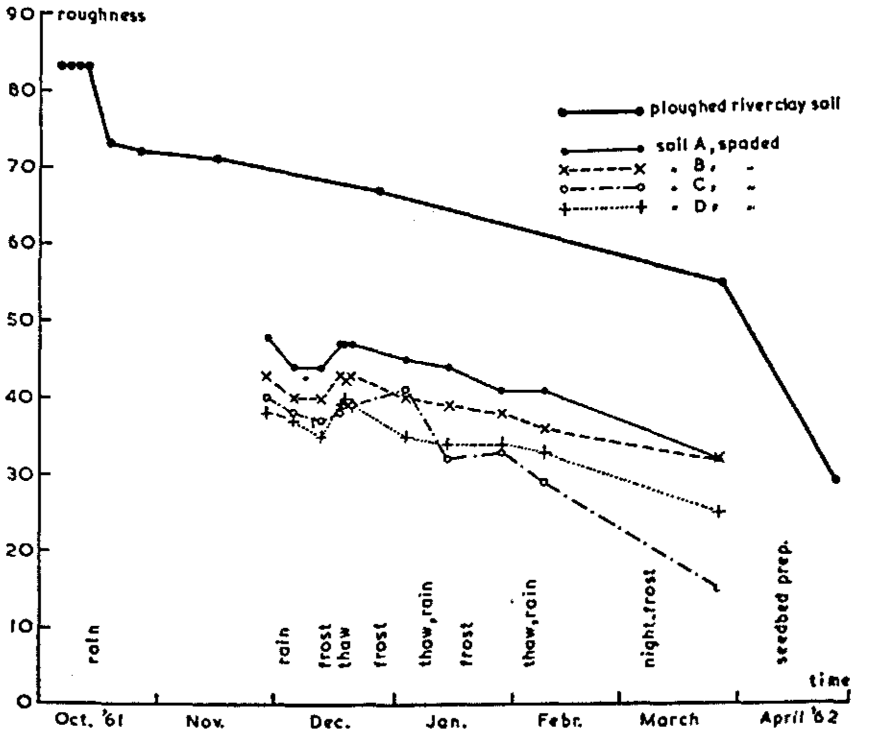


After this the rate of settling was so much slower, that the question arises whether the rains only changed the speed of the settling process and perhaps not the final state. Between the 16th of November and the 28th of December the soil surface rose at least about 2 cm by frost action. This rise did not entirely disappear in the next 3 months. This suggests that frost action can indeed change the final state. The large decrease in the last month is due to spring cultivations.

Soil-surface roughness was constant in the first week, but showed a sharp decline during the rainy period in the second week (FIG. 5, top curve). Subsequently the roughness decreased rather linearly with time till the seedbed preparation.

TABLE 3 shows the results of the pore-space estimations of this soil.

FIG. 5. Soil surface roughness after cultivation



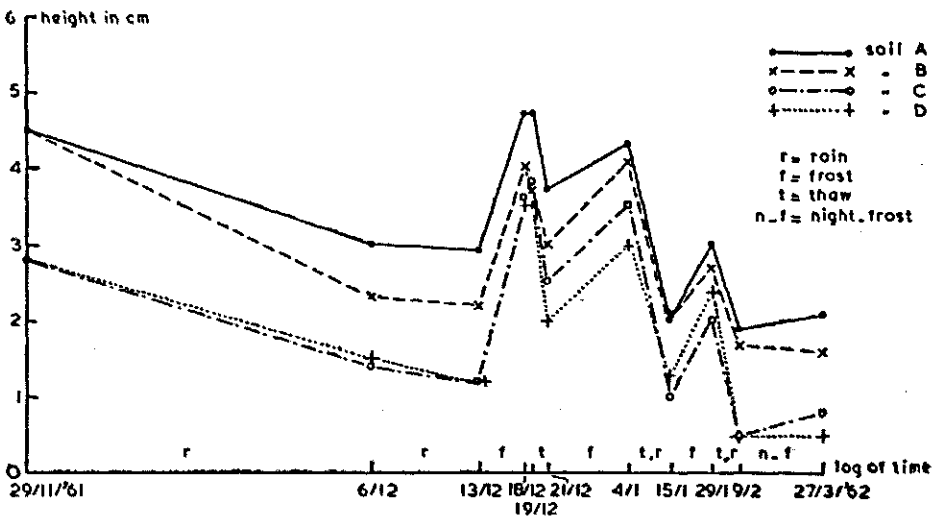
Before ploughing the soil was practically at field capacity where it contained only 4,6 % of air. Until seedbed preparation the air content at pF 2 remained at a very satisfactory level but after that it was much lower. Here again the dangerous aspect of soil compaction during spring cultivations is demonstrated. A check with core samples after seedbed preparation proved, that the estimation of pore space from the height figures was rather large. This is to be expected because the loose top layer, that is the seedbed itself, is included in the height measurements. From the core samples, taken at 3—8 and 18—23 cm depth a mean pore-space percentage of 46,8 % was found, with a water content at pF 2 of 28,2 % of dry weight, corresponding with an air content of 6,6 %. This difference can reasonably be explained by assuming a depth of the seedbed of 3 cm with a pore space of 60 %.

TABLE 3. Influence of time on the depth of the ploughed layer, total pore space and vol. percentage of water and air at pF 2

Time	Depth of ploughed layer (cm)	Vol. percentages of		
		Pore space	Water content at pF 2	Air content at pF 2
Before ploughing				
5/10	23,8	45,4	40,8	4,6
After ploughing				
5/10	31,5	58,8	30,8	28,0
9/10	30,7	57,7	31,6	26,1
11/10	30,3	57,0	32,2	24,8
13/10	29,9	56,5	32,5	24,0
19/10	27,5	52,8	35,3	17,5
27/10	27,2	52,3	35,7	16,6
16/11	27,2	52,2	35,7	16,5
28/12	29,1	55,4	33,3	22,1
28/3	27,4	52,6	35,4	17,2
After seedbed preparation				
27/4	25,0	48,1	38,8	9,3

3. On four plots of different clay soils at the Institute for Soil Fertility, Groningen, the height of the soil surface was measured after spading the soil to as rough a tilth as could be obtained after the potato harvest. The clay soils range from 40 to 70 % particles < 16 micron. A and B are non-calcareous, C has 10 % of $CaCO_3$ and D about 1 %. A, B and C are marine soils, D a river clay soil.
In FIG. 6 the height relative to the unspaded soil is plotted against the logarithm of the time. The increase in height at spading was highest in the two non-calcareous soils, and lower in the others where more crumbling was obtained. In the first week,

FIG. 6. Mean height of the soil surface in relation log of time after spading four soils



all the soils lost about half of this increase except soil A for which it was one third. In this first week there was rather much rain and, therefore, the result is quite in accordance with that of example 2 (FIG. 4). Here too, after the rain, the decrease was much slower. After the second week the soil surface moved up and down irregularly by the action, at different periods, of freezing and thawing. In spring about half the depth increase of the cultivated layer was lost on soil A, and only one fifth remained on soil D, the others having intermediate positions.
As is shown in FIG. 5, soil-surface roughness was here also far less sensitive to frost action, as it decreased rather linearly with time.

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