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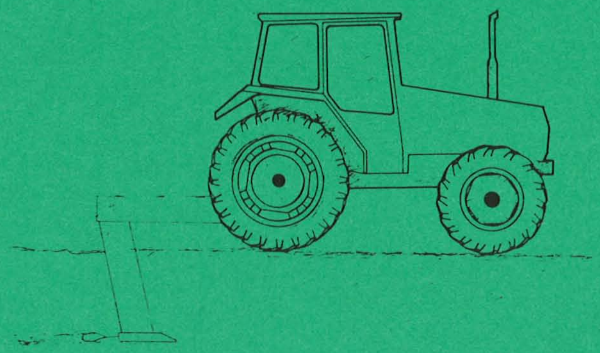
ASSESSING THE EFFECTS OF MOLE DRAINAGE ON PHYSICAL PROPERTIES OF A PEAT SOIL

Results from an experiment in mole drainage laid down in 1983

Mary Mc Afee



Institutionen för markvetenskap
Avdelningen för lantbrukets hydroteknik

Avdelningsmeddelande 84:2
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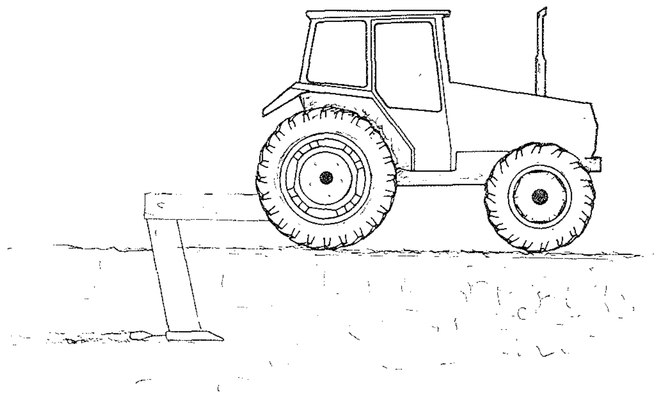

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PREFACE

This report describes results from an investigation of mole and tile drainage on a peat soil. The investigation was carried out in the year following drainage on a field trial laid out by the Experimental Division of Hydrotechnics and included field observations and field and laboratory analyses of important soil physical properties.

The report forms part of a Master of Science thesis.

FÖRORD

I denna rapport redovisas resultat från en studie rörande effekter av dränering genom tubulering och täckdikning på en torvjord. Studien har genomförts året efter dräneringens utförande i ett av de dräneringsförsök som f.n. finns vid Försöksavdelningen för hydroteknik. Den har omfattat observationer i fält samt mätningar i fält och på laboratorium av några viktiga markfysikaliska egenskaper.

Rapporten utgör en del i arbetet för en Master of Science examen.

Uppsala i december 1984

Waldemar Johansson

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INTRODUCTION

This report deals with methods of assessing the preliminary effects (after one year) of mole drainage on a peat soil. Various field and laboratory measurements are carried out to determine a number of soil physical characteristics, the results of which are reported here.

The experimental area where work for this report is carried out lies in Sörsalbo, Salbohed, Västmanlands län. A previous tile drainage system in the area had been unsuccessful. In an attempt to find a suitable drainage technique for this soil, two experimental plots were mole drained in July, 1983.

Layout is shown in Fig. 1 (appendix). Mole drains 10 cm in diameter were installed at 50-60 cm depth and 2.3 m spacing in two plots with an undrained (control) plot separating them. Mole channels were drawn directly into the open drains which border the field along both sides. No reinforcement of the mole outlets in the drain banks was made. The field immediately to the west was tile-drained in 1979. 2'' corrugated plastic pipes were installed at 1 m depth and 25 m spacing, opening into a catchment pipe running parallel to the road. This system proved unsuccessful from the start and in 1981 some short trenches were dug at various points to investigate the non-function of pipe drains.

Literature concerning the importance and effectiveness of mole drains in pea soils has been reported in Section I of this Master's work, "Drainage of Pea Soils - a literature review" (McAfee, 1984a). With regard to assessing peat physical properties, the analyses and calculations thought necessary by Galvin (1976) are: degree of humification, pH value, loss on ignition, specific gravity (= density of solids), void ratio, volume of pores, dry bulk density hydraulic conductivity and various moisture content determinations. Other volume/mass relationships considered important by Hillel (1980) are volume wetness, degree of saturation and air-filled porosity of the soil. In additi measurement of shrinkage after drying can illustrate another characteristic of the soil (Andersson, 1955). General descriptions of laboratory techniques used to measure physical properties of a soil are given in a separate paper (McAfee, 1984b). Therefore, only modifications of techniques to accommodate peat samples are described in this section.

The experimental work for this report consisted of field observation and fiel sampling for subsequent laboratory investigations. Three areas were sampled for comparison of their physical characteristics. These were: the moled area, which was sampled along lines 1, 4 and 5, the undrained area, which was sampl along line 2 and the tile drained area, sampled along line 3. Position of these lines is shown in Fig. 1.

A more detailed plan of individual lines is shown in Fig. 2 (appendix). Wate content determination samples were taken at points marked a, b, c etc. In lines 1, 2 and 3 these investigated the effect of distance from open or pipe drains and of depth below the surface on water content of the peat. In lines 4 and 5, samples were taken to investigate the effect of distance from the mole channel and of depth below the surface on the water content of the peat Fig. 2 shows the respective distances of sampling points from the reference drain (open, pipe or mole). In addition, points where augerholes were made and where cylinders were taken are shown.

Methods of laboratory investigations are described briefly before results ar presented, in table form wherever possible. Finally, results are discussed and the report ends with a short summary. All figures and tables are to be found in Appendix I.

PRACTICAL WORK

Field observations

The observations were carried out on June 12th, 1984. They included:

- measuring water levels in open ditches
- observing condition of mole channels and their outlets in the open drains
- observing surface condition and vegetation on all plots
- measuring hydraulic conductivity (augerhole method) at a distance from open drains
- measuring watertable levels at a distance from open drains
- observing and recording the nature of peat material in every 10 cm level

Results from field observations

Water levels in open ditches stood at 85 cm below the surface in the west ditch and at 83 cm below the surface in the east ditch. Mole channels opene directly into the open drains and though in many cases soil slip in the bank had obscured the mole opening, there was a flow of water from the mole drai Several mole channels were excavated at a distance from the open drains to check their condition. They proved to be full of a peat/water slurry but their walls were firm and showed no signs of collapse.

The field which has the moled plots had previously been cleared of vegetati It was apparent that the moled areas were already re-colonized by plants to a far greater extent than the undrained areas. The surface of the moled area was drier and firmer and cracks had developed above mole channels so that their position could be seen from the surface. The undrained areas of this field were almost bare of vegetation and were soft underfoot. No direct comparison of surface condition is possible with line 3 since that area had a full sward consisting chiefly of semi-aquatic perennial weeds and grass species. Watertable levels were measured on each of the lines using augerholes (points B, fig. 2). The following values were obtained from duplicates 3 m apart.

Line	Point	Watertable (cm below surface)
1 (moled)	B1	62
	B2	58
2 (undrained)	B1	43
	B2	46
3 (tile drained)	B1	47
	B2	43

Field sampling

The following samples were taken:

Water content determination. Samples were extracted with an auger and placed immediately in air-tight containers for transport to the laboratory where they were weighed. Samples were taken at depths 0-10, 10-20, 20-40 and 40-60 cm from the surface at every point and at various distances from the referen drain as shown in Fig. 2. After weighing in the laboratory, samples were vacuum-dried at 55°C for 72 hours, then weighed again. Water content of each sample is expressed as a percentage of dry weight and results are shown in Fig. 3. Using values for dry bulk density obtained from points C, moisture content by volume is calculated and results are shown in Fig. 4. Galvin (1976) regards moisture content by volume as more meaningful for peat than moisture content by weight. Relationship between these two parameters for th peat is shown graphically in Fig. 5. As has been mentioned, bulk density values were extrapolated from points C to all other points. This, plus an erro due to losses during drying, leads to an unavoidable error in values obtaine for moisture content by volume, which in some cases is greater than 100 %.

Watertable levels and field measurement of hydraulic conductivity were made using auger holes at points marked B (Fig. 2). It was intended to carry out duplicate hydraulic conductivity measurements on each plot but water movement was so slow that the method was successful in only two cases, at one point on line 2 and at one point on line 3.

Cylinder samples were taken at points marked C (Fig. 2). Three replicates were taken from each 10 cm level down to 70-80 cm below the surface. Dimensions of cylinders and method of extraction are described in McAfee (1984b). The number engraved on each cylinder is used in field records. Full cylinder are sealed with filter paper and plastic lids and stored in cases for transport to the laboratory.

Peat material. Samples were removed from each 10 cm level down to 80 cm and placed in plastic bags, to be used in laboratory determination of pH, densit of solids, loss on ignition and humification status.

PHYSICAL PROPERTIES OF PEAT SAMPLES

Laboratory investigations

In general, the techniques described in McAfee (1984b) are used to determine physical properties of the peat samples. However, problems can arise in appl ing methods developed primarily for mineral soils to peat soils, and in some instances modification of standard procedures is necessary. Thus general descriptions of techniques are found in McAfee (1984b) and only modifications to suit peat samples are described here.

Water content determination. More accurate water content determinations (by mass and by volume) are made using samples extracted in cylinders which have known dimensions. Cylinders are weighed on return to the laboratory (water content) then left standing in water baths for some days until they are fully saturated with water. They are then weighed again (saturated water content) before being installed in a constant head apparatus for measurement of hydraulic conductivity. This apparatus is described in McAfee (1984b). Measurements are taken during a 60 minute period some hours after cylinders have been in the apparatus and during a further 60 minute period 24 hours later. Triplicates are used for each 10 cm level of peat. When cylinders are removed from the apparatus they are left to dry at 55°C under vacuum for 72 hours. Finally they are weighed again (dry matter mass). Mass of empty cylinders is obtained from records.

Shrinkage of samples. After drying, the remaining plugs of soil are measured and from values of height and diameter loss, the final volume can be calculated.

From data obtained, the following relationships can be calculated:

$$\text{Mass wetness, \%} = \frac{\text{mass water, g}}{\text{mass dry matter, g}} \times 100$$

$$\text{Volumetric water content, \%} = \frac{\text{volume water}}{\text{total volume, cm}^3} \times 100 = \text{mass wetness (\%)} \times \text{dry bulk density}$$

$$\text{Dry bulk density} = \frac{\text{mass dry matter, g}}{\text{total volume, cm}^3}$$

Density of solids determination. For peat soils, the method described in McAfee (1984b) is modified in that instead of oven-dried soil a sample of air-dried soil is used. Water content of the air-dried sample is determined on a replicate sample, dried at 55°C under vacuum. The subsequent calculation of density of solids is based on dry matter content of the sample. Results of this test are shown in Table 1.

Using density of solids values and mass/volume data obtained from cylinder samples, the following relationships can be calculated.

Void ratio (e), ratio of volume of pores to volume of solids. This can be ob tained from e = 100(1 - dry bulk density/density of solids) or from e = 100(mass wetness (%) at saturation x density of solids). The latter calculation is based on the knowledge that volume of pores = volume of water at saturation ≈ mass of water at saturation and is preferred for use in this work as it avoids any error in drying which may be present in measuring dry bulk density. Results are shown in Table 2.

Porosity (f), ratio of volume of pores to total volume, is obtained from voi ratio values using the relationship f = e/1 + e. Results (percentage form) are given in Table 2.

Moisture content by volume (θ), ratio of volume of water to total volume is obtained by dividing mass of water in the sample (at sampling) by total volume.

Degree of saturation (s) is obtained from s = θ/f and air-filled porosity (f from $f_a = f - \theta$. Values (percentage form) obtained for s and f_a are shown in Table 3.

Shrinkage. In a mineral soil, an approximation to shrinkage in volume (E_v) a a percentage of original volume is given by $E_v = 2\,E_d + E_h$, where E_d is decrease in diameter (%) and E_h is decrease in height (%) of the sample. For peat soils, where shrinkage is great, the following relationship must be use

$$E_v = 100\left(1 - \left(1 - \frac{E_d}{100}\right)^2 \left(1 - \frac{E_h}{100}\right)\right)$$

. Results are shown in Table 4.

pH determination. For each 10 cm level, a mixture of 2 g vacuum-dried peat and 10 ml distilled water was used and pH measured using a meter with a glass electrode. Results are shown in Table 5.

Loss on ignition was determined by igniting a 5 g sample of vacuum-dried peat at 500°C for 4 hours. Results expressed as final mass /original mass (%) are shown in Table 6.

Hydraulic conductivity. It was intended to carry out field measurement of hydraulic conductivity on all sites but, as mentioned previously, water movement was too slow to permit this in all but two cases. Thus for line 2, a single value of 0.0120 m/day and for line 3 a single value of 0.0360 m/day was obtained. No measurement was possible on line 1. Laboratory measurement of hydraulic conductivity (constant head apparatus) gave a range of values, as can be seen in Table 7. Some reasons for fluctuations in values will be discussed later in this report.

Humification degree of peat samples from every 10 cm level down to 80 cm was assessed according to the von Post scale and values for all levels are shown in Table 8. The von Post system is designed for samples of peat material from undrained bogs and it was necessary to modify the method for drier samples of peat by adding water to them and allowing it to soak in before squeezing the material in the hand.

The peat material encountered in the profiles is described in the Appendix. The peat sequence is rather similar in all three profiles. The upper layers are dark and well humified, the middle layers are less well humified and consist of tree, shrub and reed residues. The lower layers of the profile show a gradual change over to gyttja.

DISCUSSION OF RESULTS

Watertable levels are an important parameter, the influence of which is apparent in other results. On the moled plot, the watertable was 15 cm lower than on either of the other two areas. The effects of low watertable were apparent in the improved surface condition and trafficability of the moled area.

Gravimetric water content (GWC) increased with depth in all cases. Values on line 1 were in the range 161 to 454, on line 2 in the range 194 to 734 and on line 3 the range was 180 to 628. However, when moisture content was expressed as volume percent (VWC) the difference between treatments disappeared (compare Figs 3 and 4). For volumetric water content, the range for line 1 was 60 to 154, for line 2, 60-132 and for line 3, 36-126. This change is due to differences in bulk density between the three lines. Moisture content values over 100 vol. % are a result of error described earlier. As a result of higher bulk density in drained peat samples, Fig. 5 shows a higher VWC at a given GWC for line 1. Lines 2 and 3 show similar values although those for line 3 may be marginally higher. Actual values of moisture content by volume and bulk density are given in Table 1. As can be seen, water content of the soils depend on the depth to the watertable. Bulk density of peat soil is increased by drainage, at least above the watertable, as can be seen from the values obtained. Variation within each line is due to differences in composition.

Density of solids ranged from 1.49 to 1.92 on line 1, 1.44 to 1.72 on line 2 and 1.42 to 2.07 on line 3.

Void ratio and porosity (%) are comparable in all treatments for layers above the watertable 3-4 and 78 % respectively and for layers below the watertable, 7 and 87-88 respectively.

Degree of saturation in the upper 50 cm is lower in line 1 (81.2 %) than in line 2 (82.4 %) and line 3 (86.4 %).

Air-filled porosity in line 1 is higher at levels between 40 and 70 cm below the surface, presumably as a result of the lower watertable in this plot.

Shrinkage in volume was lower for samples from line 1 at all levels, especially in layers above the watertable. This is to be expected if drainage has already led to compaction of the peat on line 1.

pH measurements did not show any variation between plots.

Loss on ignition values reflect three aspects of the soil profile at this site - the highly undecomposed layer at 30-50 cm depth, the inclusion of gyttja below the 50-60 cm level and, finally, the effect due to drainage on the upper layers. Exposure of the peat material to air by drainage causes oxidation of organic matter and reduces the organic matter proportion of the peat, with a corresponding decrease in loss on ignition. Thus the upper 40 cm of the moled plot have a lower content of organic matter (lower loss on ignition) than the other two plots. The lower loss on ignition values for levels around and below 60 cm in all plots reflect the gyttja content of the lower layers.

Hydraulic conductivity is notoriously difficult to measure on peat soils, especially in the laboratory. Slight shrinkage of the sample causes leakage between the soil plug and the cylinder wall and gives misleadingly high k-values (Boelter, 1965). Values obtained in this study gave a large range 0-29.4 cm/hour. However, disregarding extreme high and low values and k_2 readings, the range of values obtained was 0.6-4.7 (cm/hour) on line 1, 0.2-7 on line 2 and 0.2 to 7 on line 3. A trend towards lower hydraulic conductivity with depth and with drainage (line 1) was shown.

The range of values obtained can be compared to figures produced by Boelter (1965) who tested vertical hydraulic conductivity of peat in the laboratory and found k-values of 32.4 cm/hour for undecomposed peats, 0.2 cm/hour for partially decomposed peat with wood inclusions and 0.014 cm/hour for herbaceous peat.

Galvin (1976) tested a range of Irish peats and found laboratory values of 0.2 cm/hour for reed fen peat, 0.03-0.76 cm/hour for woody fen peat and 0.87 cm/hour for younger Sphagnum peat.

Dasberg & Neuman (1977) found vertical k-values of 0.15-29 cm/hour in samples of peat from 40 cm depth and 0.002-0.8 cm/hour in samples from 55 cm depth.

CONCLUSIONS

At this early stage mole drainage appears to be a successful drainage technique for the peat soil investigated in this project. Evidence of this can be seen first from surface condition and trafficability, as compared to the other two areas. A further indication of mole success is seen in control of watertable level in the moled plot to a depth of 60 cm below the surface.

This peat has particular drainage problems because of its extremely low permeability as seen in augerhole tests. In addition, a dense layer of undecomposed material at and above drain depth is a feature of this profile. The formation of cracks above the mole channel allows precipitation falling on the surface passage through the impermeable material to the drain.

Laboratory measurement of hydraulic conductivity in the constant head apparatus does not appear suitable for a peat sample. In some cases, slight shrinkage of the peat plug in the cylinder results in too high a k-value. In other cases (compare line 1) results reflect only a decrease in k-value due to drying and compaction of material after drainage and take no account of the vertical cracks which contribute to the success of this technique. A method to make continuous measurements of infiltration in the field and to observe the effects of precipitation on groundwater levels would be more appropriate to the assessment of drainage on peat soils.

Problems arise when tests of soil physical characteristics which have been designed for mineral soils are applied to peat samples. Such problems arise from

a) low density of peat material which makes it impossible to use a 10 g sample as is done with mineral soils. Because of the greater volume, a 10 g peat sample is too bulky for the standard equipment,

b) shrinkage of peat, especially irreversible shrinkage brought about by glutinous humic acids produced from the oxidation of lignin (Puustjärvi, 1982). This process occurs naturally in drained soils and is seen as increased bulk density and decreased volume shrinkage of the peat (compare line 1, tables 1 and 4). When this shrinkage occurs in samples taken for laboratory analyses, results may be distorted. For this reason, density of solids determinations mus be performed on air-dried samples.

Loss of material through oxidation of organic matter to carbon dioxide and wate is known to occur fairly quickly, especially in pure Sphagnum peats (Puustjärvi, 1982). If this process has already taken place in samples of peat from a drained area, then weight/volume comparisons with samples of undrained peat are not correct.

Although mole drainage is effective at present in the area investigated, long term studies to establish the service life of mole channels on this peat must be made, for in practice the cost of moling to the farmer is offset by increase returns from the drained area for the number of years the mole channels are functional.

Since the main improvement of surface was due to the vertical cracks which formed over the mole channels and since peat permeability decreases with drainage, there may be a case for future experiments with high intensity slit drainag on peat soils.

SAMMANFATTNING - Tubuleringseffekter på en torvjord

Här redovisas resultat från ett tubuleringsförsök på en torvjord i Sörsalbo, U-län, utlagt 1983. Laboratorie- och fältundersökningar utfördes för att bestämma några viktiga markfysikaliska egenskaper och samband hos torvjord.

Syftet med undersökningen var att uppskatta dräneringsteknikens effektivitet. Jämförelser gjordes mellan tubulering, täckdikning och odikat (öppna diken med 50 m avstånd). Försökets uppläggning visas i fig. 1 (se bilaga). Tubuleringen

gjordes med 2,3 m avstånd och 0,5-0,6 m djup, tubuleringsgångarna var 10 cm i diameter. Gångarna mynnar i öppna diken som avgränsar fältet. Fältet väster om det tubulerade området täckdikades 1979 med 2 tums plaströr med 25 m avstånd och 1 m djup. Täckdikningen har aldrig fungerat tillfredsställande.

Provtagningen i fält utfördes i juni 1984, enligt fig. 2. Provtagningarna i det tubulerade ledet gjordes längs linjerna 1, 4 och 5, i det odikade ledet längs linje 2 och i det täckdikade ledet längs linje 3. I fält mättes vattennivåerna i de öppna dikena, grundvattennivåerna och genomsläppligheten enligt borrhålsmetoden i de 3 försöksleden. Vattenhaltsprover togs vid punkterna a-f (enl. fig. 2) och cylinderprovtagningarna gjordes vid punkt C i försöksleden. Resultaten visas i fig. 3 och 4.

I laboratorieundersökningarna bestämdes bl.a. humifieringsgrad, pH, kompaktdensitet, porvolym, torr skrymdensitet, krympning och genomsläpplighet. Resultaten redovisas i fig. 5 och i tab. 1-8 (se appendix).

Enligt resultaten är tubulering en lämplig dräneringsteknik på denna jord. Dräneringseffekten visas främst av att grundvattennivån i det tubulerade ledet var 15 cm lägre än i de andra leden. Markbärigheten och ytförhållandena i det tubulerade försöksledet är bättre än i de andra försöksleden.

Denna torvjord har vissa dräneringsproblem p.g.a. dess mycket låga genomsläpplighet. Det var omöjligt att mäta genomsläppligheten i fält enligt borrhålsmetoden, förutom i två fall, på grund av att vattenrörelserna var för långsamma. Profilen har ett skikt låghumifierat material på 30-50 cm djup, men detta har ingen avgörande betydelse för genomsläppligheten.

I det tubulerade ledet hade det bildats sprickor över tubuleringsgångarna och det har lett till att nederbörden nådde dikena snabbt trots den låga genomsläppligheten. Det har visat sig att mätning av genomsläpplighet på laboratoriet är en olämplig metod för torvjordar. Det går ofta inte att undvika krympning av jorden i cylindern, ett mellanrum uppstår mellan cylinderväggen och jordpelaren och de k-värden som uppmäts blir icke representativa. I andra fall (t.ex. linje 1) tar cylinderproven ingen hänsyn till de vertikala sprickorna som finns och k-värdena blir för låga.

En metod att mäta infiltration i fält och att mäta effekterna av nederbörden på grundvattennivån vore lämpligare för att bedöma dräneringseffekter på torvjordar. Problem uppstår när man försöker applicera den vanliga markfysikaliska undersökningsmetodiken (som har utvecklats för mineraljordar) till torvjordar. Problem orsakas av: a) den låga skrymdensiteten, som hos torvjordar gör att den vanliga föreskrivna mängden 10 g inte ryms i behållaren i kompaktdensitet- och glödningsförlustundersökningar, b) krympningen, speciellt den permanenta krympningen som orsakas av att lignin oxideras och producerar klibbiga biprodukter (Puustjärvi, 1982). Denna process förekommer naturligt i dränerade torvjordar och visar sig som ökad torr skrymdensitet och minskad krympning av torven (jämför linje 1, tabell 1 och 4).

Materialförluster genom oxidation av organiskt material till CO_2 och vatten sker ganska snabbt, speciellt i ren vitmosstorv (Puustjärvi, 1982).

Tubulering har visat sig vara en effektiv dräneringsteknik i det undersökta området. Det behövs fortsatta studier för att bestämma livslängden hos tubuleringsgångarna, eftersom detta är mycket avgörande för tubuleringens lönsamhet.

De vertikala sprickorna över tubuleringsgångarna är betydelsefulla för dräneringseffekten. En teknik som bör undersökas är slitsdränering på torvjordar i samband med annan dränering.

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APPENDIX

List of figures and tables included in the report

Fig. 1. Map of the experimental site

Fig. 2. Plan showing all sampling points

Fig. 3. Water content (mass %) at sampling points a-f

Fig. 4. Water content (volume %) at sampling points a-f

Fig. 5. Relationship of moisture content by mass to moisture content by volume.

Table 1. Water content, bulk density and density of solids of samples

Table 2. Void ratio and porosity of samples

Table 3. Degree of saturation and air-filled porosity

Table 4. Shrinkage in volume during drying

Table 5. pH values

Table 6. Loss on ignition

Table 7. Hydraulic conductivity, k-values

Table 8. Degree of humification, von Post scale

Profile desription of peats from line 1, 2, and 3.

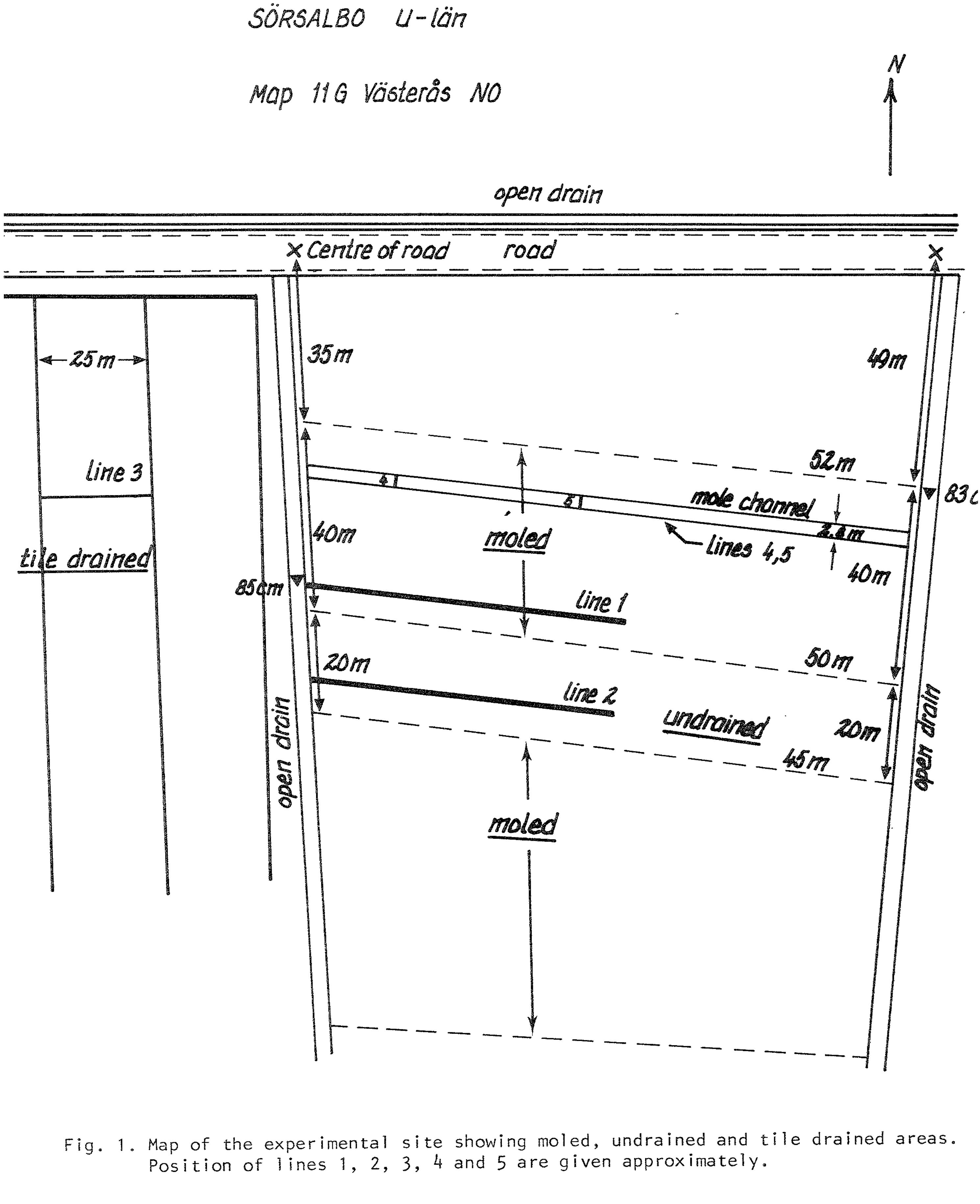

Fig. 1. Map of the experimental site showing moled, undrained and tile drained areas. Position of lines 1, 2, 3, 4 and 5 are given approximately.

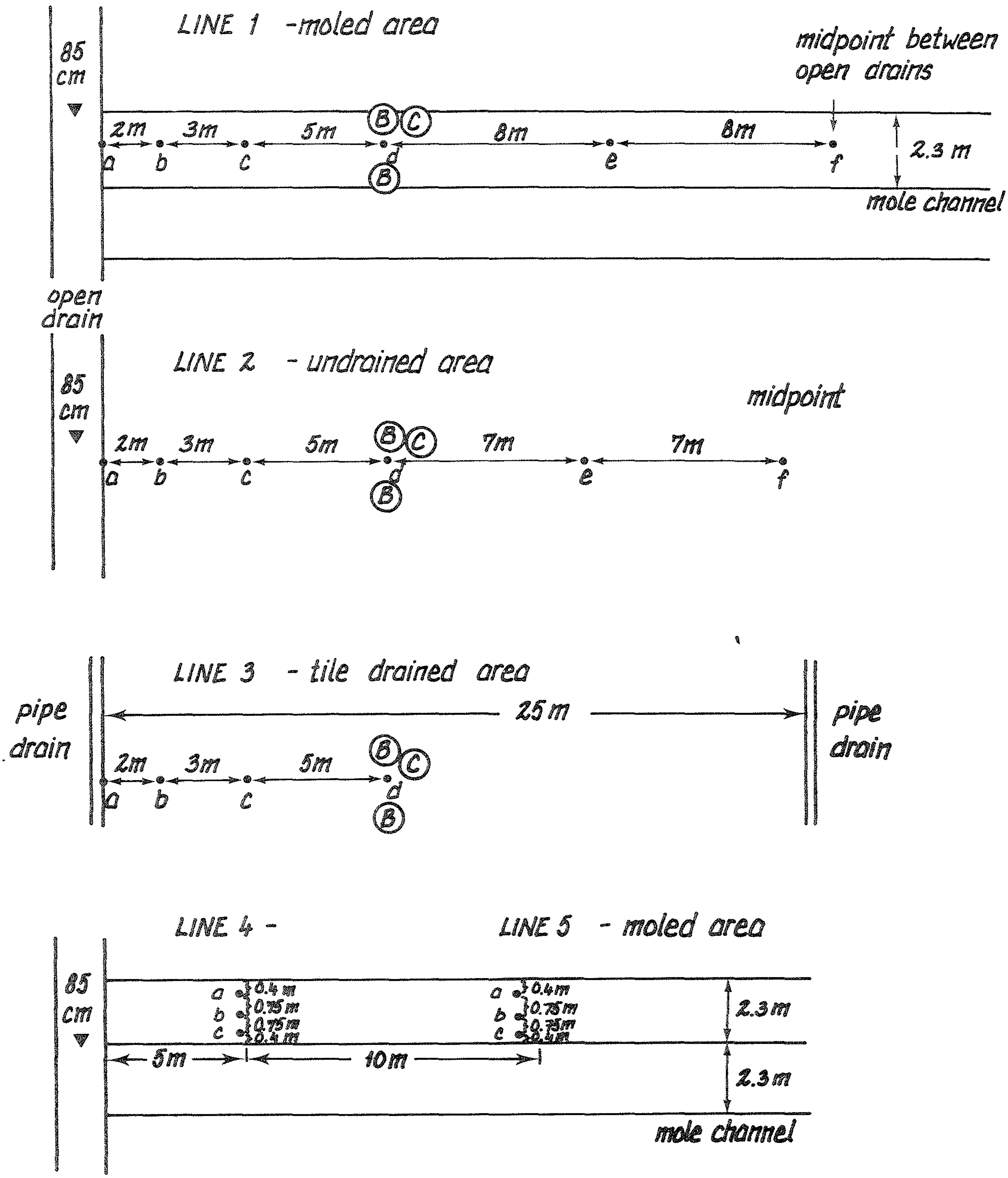

Fig. 2. Plan showing all sampling points in the experiment. Symbols given are:

a, b, c, d, e, f: water content determination points. Samples taken at 0-10, 10-20, 20-40 and 40-60 cm depth at every point.

B : augerholes bored to 120 cm depth for determination of watertable levels and field measurement of hydraulic conductivity.

C : cylinder samples taken, 3 from every 10 cm level down to 80 cm.

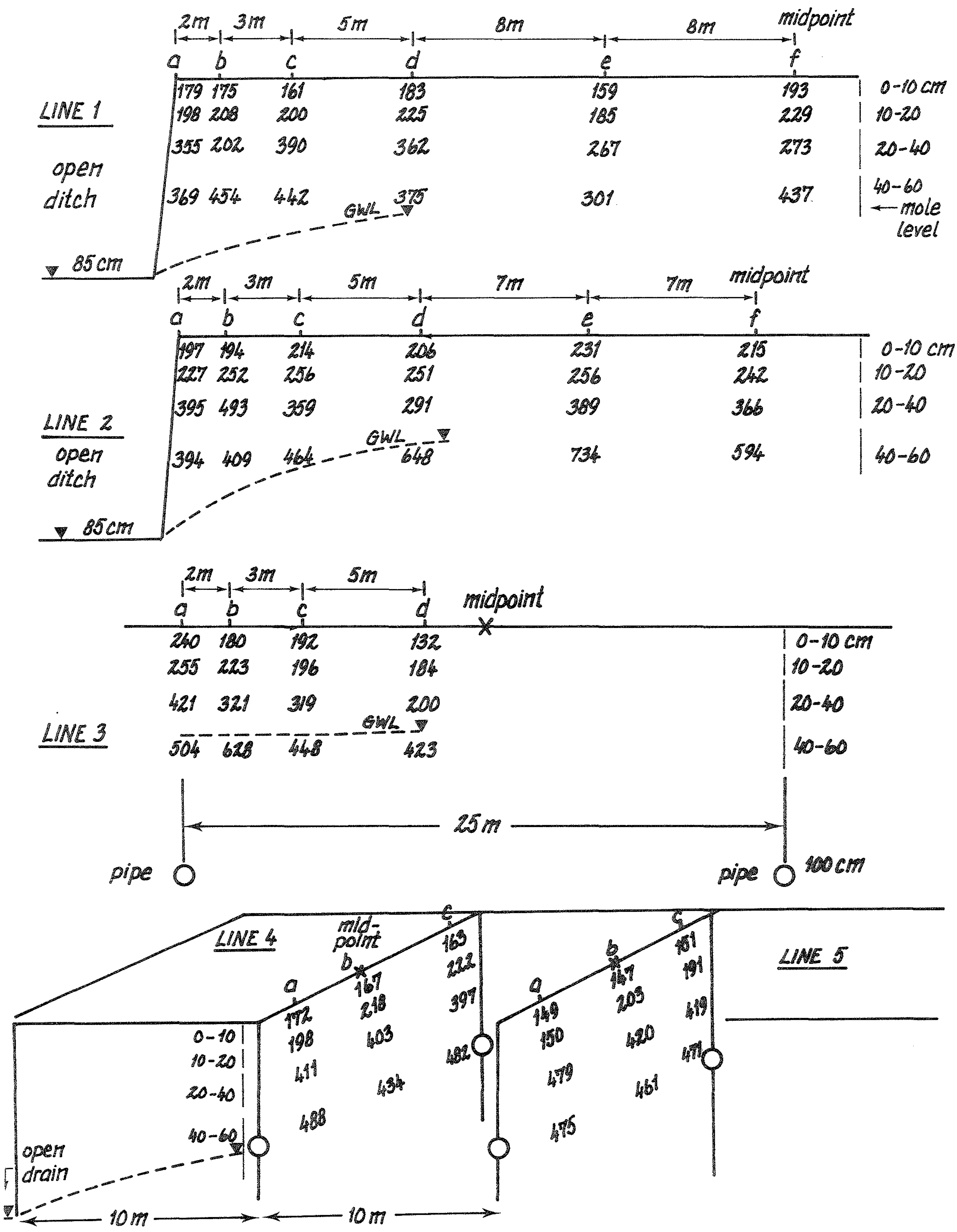

Fig. 3. Water content (mass %) shown in relation to sampling depth, watertable level and position of existing drains. Position of lines 1-2 and points a-f are as shown in Fig. 2. GWL = Groundwater level.

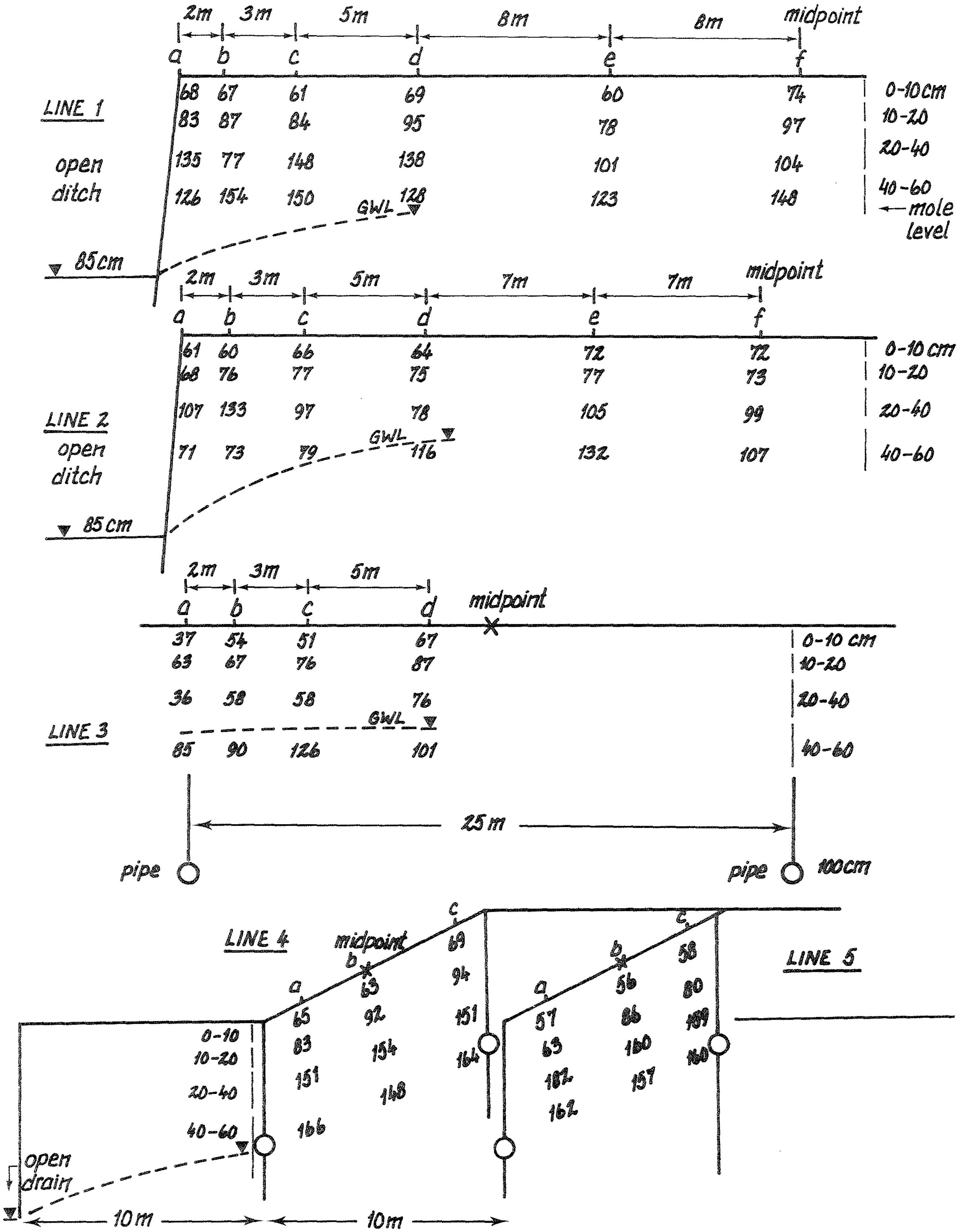

Fig. 4. Water content (volume %) shown in relation to sampling depth, watertable depth and position of existing drains. Position of lines 1-5 and points a-f are as shown in Fig. 2.

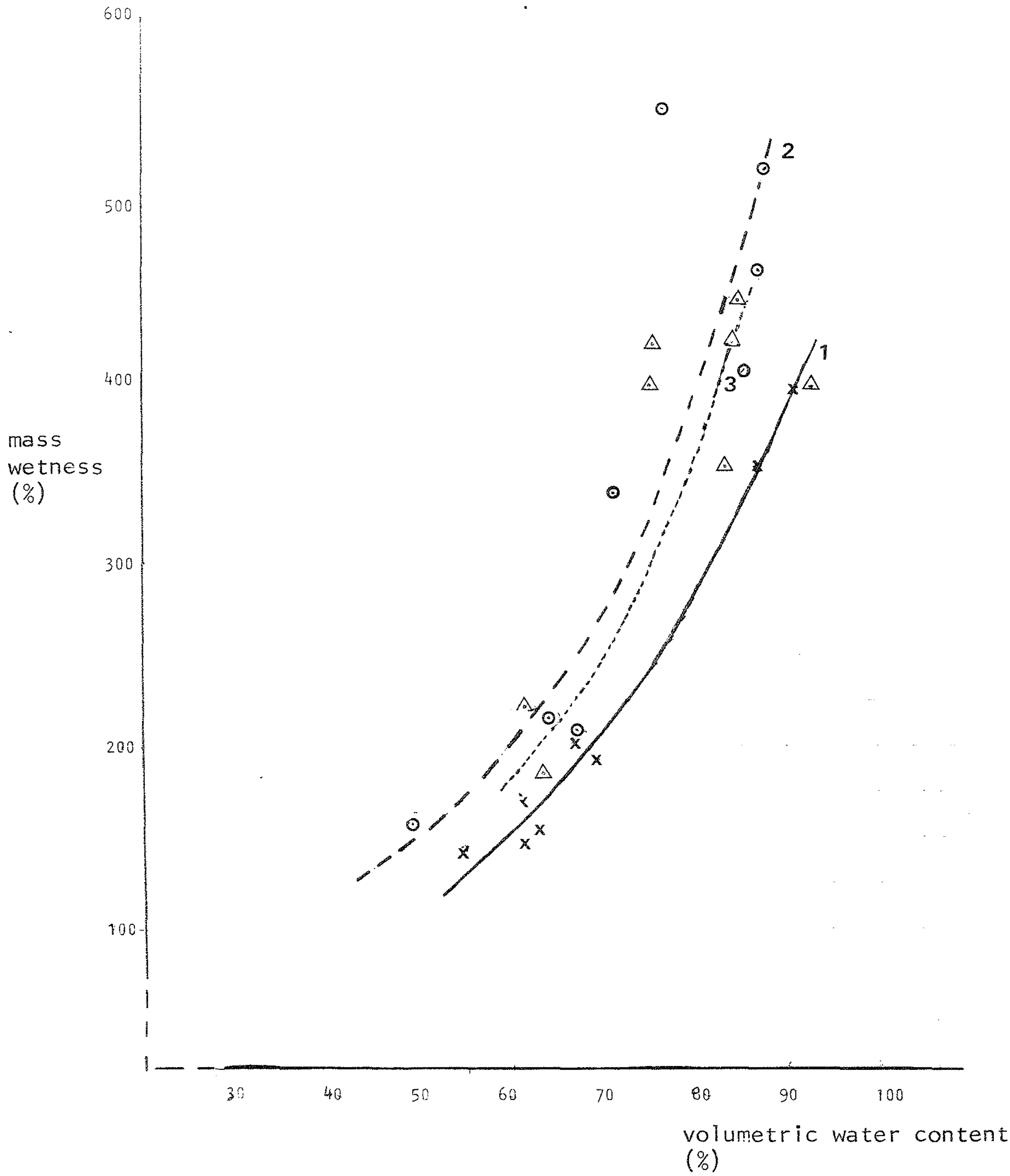

Fig. 5. Relationship of mass wetness (%) to volumetric water content (%), lines 1, 2, 3 (moled, undrained, tiled).

Table 1. Water content (vol. %), dry bulk density and density of solids at 10 cm intervals, lines 1, 2, 3.

Level (cm)	Water content, (vol. %)			Dry bulk density (g/cm^3)			Density of solids		
	1	2	3	1	2	3	1	2	3
0-10	54.7	49.6	62.1	0.38	0.31	0.28	1.60	1.51	1.50
10-20	61.8	64.5	63.6	0.43	0.30	0.34	1.54	1.46	1.55
20-30	62.1	67.6	75.4	0.41	0.33	0.19	1.65	1.44	1.42
30-40	69.4	71.0	75.9	0.36	0.21	0.18	1.49	1.45	1.50
40-50	61.2	76.7	84.5	0.36	0.14	0.19	1.71	1.47	1.49
50-60	66.9	85.3	84.1	0.33	0.21	0.20	1.79	1.69	1.74
60-70	90.8	87.0	84.6	0.23	0.20	0.24	1.91	1.62	1.76
70-80	86.8	97.9	91.7	0.23	0.17	0.23	1.92	1.72	2.07

Table 2. Void ratio (e) and porosity (f, %) at 10 cm intervals, lines 1, 2, 3.

Level (cm)	line 1		line 2		line 3	
	e	f (%)	e	f (%)	e	f (%)
0-10	3.17	76.0	3.59	78.3	3.96	79.8
10-20	2.59	72.1	3.53	78.2	3.35	77.0
20-30	2.81	73.6	3.50	77.8	6.18	86.1
30-40	3.59	78.1	5.93	85.6	6.76	87.1
40-50	3.25	76.4	8.70	89.7	6.88	87.3
50-60	4.29	81.9	7.21	87.9	7.59	88.4
60-70	7.89	88.8	7.31	88.0	6.41	86.5
70-80	7.41	88.1	7.18	90.2	8.92	89.9

Table 3. Degree of saturation (s, %) and air-filled porosity (f_a, %) at 10 cm intervals, lines 1, 2, 3.

Level (cm)	Degree of saturation (%)			Air-filled porosity (%)		
	1	2	3	1	2	3
0-10	69	61	78	23	30	18
10-20	85	85	84	11	12	12
20-30	83	87	88	13	10	11
30-40	89	91	90	8	8	9
40-50	80	88	92	15	11	7
50-60	90	93	94	8	6	5
60-70	92	98	97	7	2	2
70-80	99	96	95	1	3	3

Table 4. Shrinkage after drying, reduction in sample volume (E_v, %) at 10 cm intervals, lines 1, 2, 3.

Level (cm)	line 1	line 2	line 3
0-10	69.3	76.0	76.1
10-20	65.9	78.0	74.5
20-30	70.9	76.1	80.3
30-40	76.2	78.0	77.3
40-50	76.4	85.8	84.9
50-60	82.0	87.5	86.0
60-70	84.3	87.4	86.9
70-80	83.8	89.9	87.4

Table 5. pH values at 10 cm intervals, lines 1, 2, 3.

Level (cm)	line 1	line 2	line 3
0-10	5.5	5.5	5.3
10-20	5.5	5.5	5.3
20-30	5.6	5.6	5.4
30-40	5.6	5.6	5.4
40-50	5.6	5.5	5.5
50-60	5.6	5.5	5.5
60-70	5.6	5.7	5.7
70-80	5.7	5.7	5.7

Table 6. Loss on ignition (% dry matter) of peat at 10 cm intervals, lines 1, 2, 3.

Level (cm)	line 1	line 2	line 3
0-10	71.4	75.2	78.6
10-20	58.8	67.6	72.6
20-30	56.6	68.6	81.2
30-40	70.0	74.3	75.8
40-50	74.2	87.0	64.6
50-60	60.4	62.6	47.0
60-70	35.0	44.6	34.6
70-80	30.2	45.8	33.8

Table 7. Hydraulic conductivity (k-values[1], cm/hour) after 1 hour (k_1) and after 24 hours (k_2) in 10 cm intervals, lines 1, 2, 3.

Level (cm)	line 1 k_1	line 1 k_2	line 2 k_1	line 2 k_2	line 3 k_1	line 3 k_2
0-10	4.68	5.01	23.76	27.60	8.70	5.40
	13.20	11.04	2.64	1.08	3.60	2.64
	3.36	5.08	29.40	23.04	6.66	8.63
10-20	2.73	2.40	0.24	0.24	3.48	2.94
	1.85	3.64	0.96	2.34	7.08	10.02
	1.22	0.84	1.50	2.52	3.12	7.26
20-30	0.39	0.39	1.32	2.82	1.56	6.18
	0.99	0.22	0.90	1.20	1.50	4.92
	0.14	0.39	1.62	1.86	1.28	3.66
30-40	2.57	2.26	0.04	0.04	7.38	19.00
	0.84	0.76	5.76	5.56	4.14	14.10
	1.70	2.53	0.04	0.06	1.26	5.88
40-50	2.40	3.46	7.32	10.26	12.12	15.60
	0.60	0.60	0.42	0.54	14.88	18.96
	2.11	3.04	2.34	3.48	6.00	7.50
50-60	0.00	0.00	6.54	6.12	2.64	9.30
	0.00	0.08	4.92	0.96	0.08	0.06
	0.00	0.00	10.80	5.28	2.04	4.32
60-70	0.84	0.16	2.82	0.90	1.50	1.38
	0.79	0.22	0.18	4.32	0.00	0.00
	0.50	0.09	1.92	2.16	1.14	3.34
70-80	0.00	0.00	0.60	1.14	0.24	2.99
	0.00	0.00	0.04	0.24	2.16	1.38
	0.00	0.00	1.92	4.32	2.52	1.14

[1] k-values were calculated from measurements of water volume and time by an application of Darcy's law

$$k = \frac{l}{A} \times \frac{1}{h} \times \frac{Q}{t}$$

where k = hydraulic conductivity (cm/hour), Q = volume of water which passes through the sample (cm^3), A = cross-sectional area of the sample (cm^2), t = time (minutes), h = height of head in the apparatus (cm) and l = length of sample (cm). Since we know A = 40.7 cm^2 and h = l = 10 cm, the equation becomes

$$k = 1/40.7 \times 1 \times \frac{Q}{t} = 0.02 \frac{Q}{t} \text{ (cm/min)}$$

Table 8. Degree of humification (von Post scale) at 10 cm intervals, lines 1, 2, 3.

Level (cm)	line 1	line 2	line 3
0-10	H4	H4	H3
10-20	H3	H3	H3
20-30	H3	H3	H3
30-40	H2-H3	H2	H3
40-50	H2	H2	H4
50-60	H5[1)]	H5	H4
60-70	H5	H5	H5
70-80	H6	H6	H6

1) below this level, some gyttja was included in the profile. Auger samples below 90-100 cm had a blue-grey colour.

Profile description of peats from lines 1, 2, and 3

LINE 1

0-10 cm	peat resembles dry, black crumbs with some small fragments of woody material present
10-20	black, dryish crumbs, some fine roots and wood fragments present
20-30	brownish peat containing much poorly decomposed plant stems, roots and woody fragments
30-40	solid, brownish black mass which flakes apart in layers to show inclusions of wood fragments and reed remains
40-50	layer of poorly humified material consisting of wads of fibrous plan material such as reeds and roots. Yellowish colour, wetter
50-60	brownish black, homogenous, well humified and with inclusion of gytt
60-70	brown, homogenous, lighter in feel, gyttja present
70-80	wet, smooth, brown, well humified peat with a high proportion of gyt

LINE 2

0-10 cm	fine crumbs, hard, black, some fine roots
10-20	coarser crumbs, black, woody fragments present
20-30	black, less well humified with plant material present, many fine roots and wood fragments present
30-40	black, much larger crumbs, high proportion of wood fragments and ree debris
40-50	brownish-yellow wads of humified material
50-60	brownish black solid mass, flakes apart to show layers, gyttja prese
60-70	wet, homogenous mass of brown peat with some gyttja present
70-80	brown, very wet paste-like mass, gyttja inclusion

LINE 3

0-10 cm	much dense root material, black peat crumbs with wood fragments prese
10-20	very hard, black crumbs in a matrix of roots and fibres
20-30	crumbs as above, large unhumified fragments present
30-40	black, wet mass with much unhumified plant material present
40-50	brownish wet mass, somewhat humified reed and root remains present
50-60	brown, soft wet mass with some gyttja present
60-70	light brown material, gyttja present
70-80	as above

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