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Waldemar Johansson
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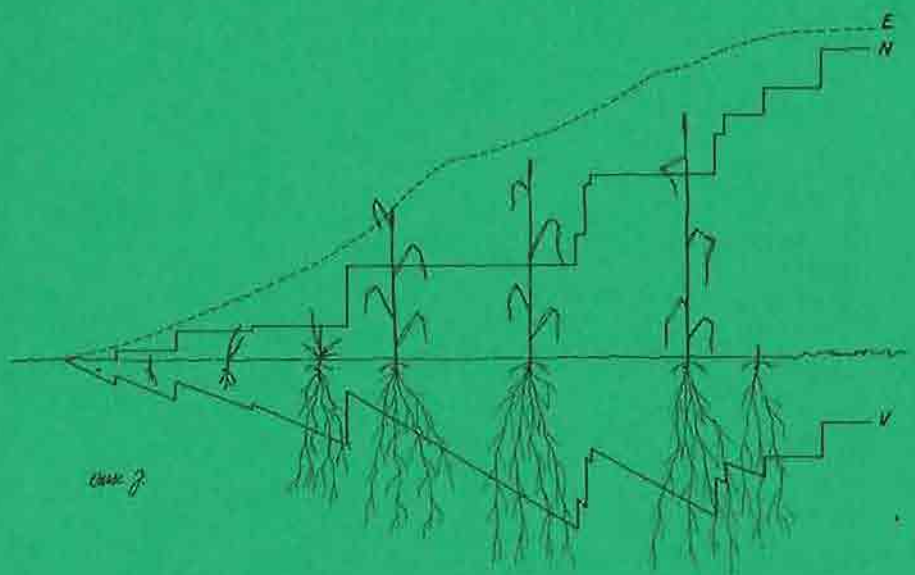

Institutionen för markvetenskap
Avdelningen för lantbrukets hydroteknik

Swedish University of Agricultural Sciences
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Division of Agricultural Hydrotechnics

Rapport 148
Report

Uppsala 1985
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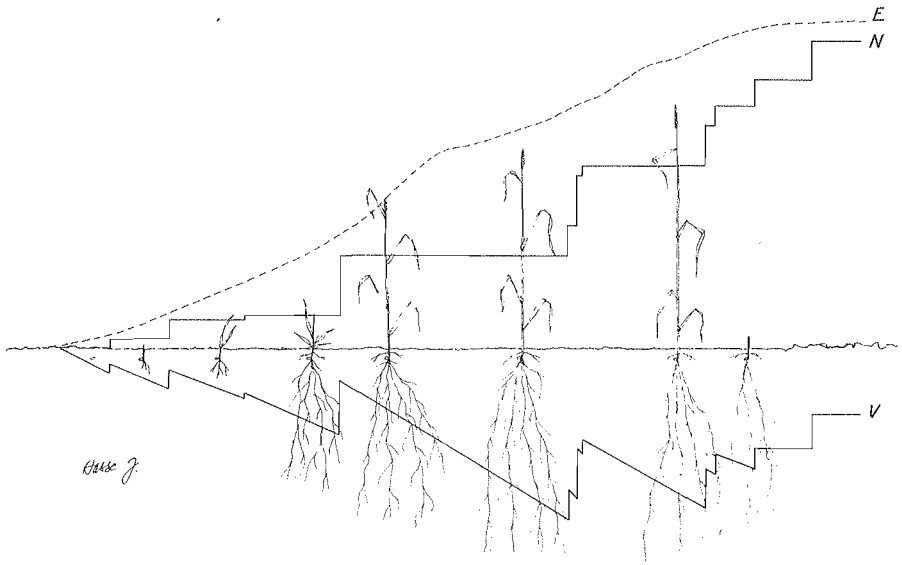

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PREFACE

This report presents physical characteristics of soils which have been the basis for two research projects. One project investigated the waterholding properties of drought-sensitive soils, the other investigated the effects of mulching on soil physical conditions and on moisture supply, root development and yield of cereals. Soil physical investigations formed a distinct section of these projects and are thus presented in a separate report. This allows comparison between the profiles described and with other profiles investigated and described previously.

Investigations were carried out in the soil physics laboratory at the Division of Hydrotechnics, using methods in routine use there. Many of the staff of the Division have assisted in field sampling, laboratory investigations and preparation of results. I wish to mention in particular Eva-Lou Gustafsson, Karin Södergren, Sven-Erik Karlsson, Tore Lindström and Christina Öhman. Jan Lindström took the photographs of profiles which are included in the report.

In compiling this report, I have had the assistance of Eva-Lou Gustafsson and Mary McAfee who prepared results and material for publication. M. McAfee also prepared most of the text.

This work was financed by the Swedish Council for Forestry and Agricultural Research and by the Experimental Division of Hydrotechnics at the Swedish University of Agricultural Sciences.

Uppsala i oktober 1985

Waldemar Johansson

FÖRORD

I denna rapport redovisas resultat från markfysikalisk karakteristik av jordar, vilka ingått som studieobjekt i två forskningsprojekt. Det ena av dessa projekt gäller torkkänsliga jordars vattenhushållande egenskaper, det andra inverkan av marktäckning på fysikaliska förhållanden i marken och på stråsäds rotutveckling, vattenförsörjning och avkastning. Den markfysikaliska karakteristiken har utgjort en avgränsad del av respektive projekt och redovisas därför också separat. Härigenom underlättas jämförelser mellan de olika profilerna och med andra markprofiler, som varit föremål för liknande undersökningar.

Undersökningarna har genomförts vid Avdelningen för hydrotekniks markfysikaliska laboratorium med de metoder som idag rutinmässigt användes där. Många personer vid avdelningen har medverkat vid provtagningen i fält, undersökningar i laboratoriet och bearbetning av primärmaterial. Här vill jag särskilt nämna assistent Eva-Lou Gustafsson, agronom Karin Södergren, försökstekniker Sven-Erik Karlsson, institutionstekniker Tore Lindström och laboratorieassistent Christina Öhman. Ingenjör Jan Lindström har tagit samtliga profilfoton.

Rapporten har utformats i samråd med Eva-Lou Gustafsson och M.Sc. Mary McAfee, vilka har svarat för slutbearbetningen av resultaten. M McAfee har skrivit huvuddelen av rapporten.

Arbetet har bekostats av Skogs- och jordbrukets forskningsråd samt av försöksavdelningen för hydroteknik vid Sveriges lantbruksuniversitet.

Uppsala i oktober 1985

Waldemar Johansson

CONTENTS

INTRODUCTION

This report describes the physical properties of twelve cultivated soils, sites pf current field investigations on the water holding capacity of mineral soils susceptible to drought and on the effects of mulching being carried out by the Division of Agricultural Hydrotechnics. Profiles are analysed and described using procedures developed at the Division and in routine use here. They are described in order of sampling year and county, with the lightest soil first within counties. Profiles from the same property sampled in different years are, however, placed together in this report.

During the last 30 years, many Swedish soil profiles have been investigated and described in a series of reports which also detail methods of investigation and presentation. Methods are described by Andersson (1955, 1962), Andersson & Wiklert (1970, 1972) and Johansson (1964). Other reports with results from soil physical investigations are listed after the references.

Since all previous reports have been in Swedish and only a few have an English summary, methods will be described briefly in the first part of this report. Diagrams and tables illustrate the characteristics of profiles so completely that written descriptions have been reduced to a minimum.

METHODS

Site description and sampling

Location of each sampling site is referred to property, urban district and county and details of site coordinates (system 2.5 gon V 1938) on the relevant topographical map are included. Details of site topography and geology are summarized according to FAO Guidelines for Soil Description (undated). Information on climate (nearest meteorological station) includes length of the growing season between $+5^{o}C$ and $+5^{o}C$ and the mean temperature and rainfall during this period (mean values 1931-60).

Extent of sampling is described for sampling using 10 cm high cylinders with 72 mm diameter. Four replicates are taken from each level of the profile down to 100 cm depth. In addition, metal cases are used to extract a full vertical profile and several horizontal sections of the soil. Cylinder samples (undisturbed) are used in subsequent laboratory determinations of physical properties of the soil, while sections are used for the photographs included in this report.

Determination of physical characteristics

Mechanical analysis is carried out using methods of sieving and pipetting to separate the fractions according to size classes shown in the table below. The Swedish system of textural classification was first proposed by Ekström (1927).

Group	Sub-group	Particle diameter (mm)	Abbreviation
block	-	> 200	-
stone	large	200 - 60	-
"	small	60 - 20	-
gravel	coarse	20 - 6	-
"	fine	6 - 2	-
sand	coarse	2 - 0.6	c. sand
"	medium	0.6 - 0.2	m. sand
fine sand	-	0.2 - 0.06	f. sand
" "	very fine	0.06 - 0.02	vf. sand
silt	coarse	0.02 - 0.006	c. silt
"	fine	0.006 - 0.002	f. silt
clay	coarse	0.002 - 0.0002	c. clay
"	fine	< 0.0002	f. clay

Furthermore, soils are classified according to their clay content thus:

clayless - slightly clayey	< 5 % clay by weight
clayey soils	5-15 % - " -
light clay soils	15-25 % - " -
medium clay soils	25-40 % - " -
heavy clay soils	40-60 % - " -
very heavy clay soils	> 60 % - " -

The class medium clay can be divided into two subclasses, light medium clay and heavy medium clay. A high content of sand or silt in a light or medium clay can be indicated by the adjectives 'sandy' amd 'silty' respectively. Note that these Swedish descriptions are used throughout this report since they are more specific than the classifications obtained from the standard textural triangle.

Results of mechanical analysis are presented in a standard diagram in which the horizontal axis represents 0 to 100 % by weight and the vertical axis represents 0-100 cm depth in the profile. Both axes have a linear scale. Mechanical composition of soil samples from each 10 cm level of the profile is entered on the diagram at the midpoint of each depth interval (5, 15, 25 ... cm below the surface). The proportion (% by weight) of each of the textural

fractions is entered in order of increasing particle size (clay, silt, fine sand etc.) with percentage loss on ignition bringing the total to 100 %. The loss on ignition value corresponds to the humus content of the sample when water of crystallization is corrected for by a factor. Ignition is carried out in a furnace at 550^0C for 2 hours.

The following determinations are carried out on undisturbed samples from every 10 cm soil level:

Moisture content at various soil moisture tensions. Known tensions are applied using methods described by Andersson & Wiklert (1972). Successively greater tensions are applied and the volume of water retained by a soil sample at each tension step is determined by weighing. Tensions are always referred to in metres of water column (mwc). Results are presented in tables (see Table 1), as soil moisture retention curves - also called soil moisture characteristic curves or soil moisture characteristics (see Fig. 2) - and as water tension (w_t-) curves (see Fig. 3). The relationships between moisture content and water retention are used to construct drainage equilibrium (w_{dr}-) curves (Johansson. 1964), see Fig. 4.

The soil moisture characteristic curve is constructed on a separate diagram and shows curves for levels of special interest in the profile. In such diagrams, the linear scale horizontal axis shows moisture content (volume %) and the logarithmic scale vertical axis shows tension (mwc), pF and equivalent pore diameter (mm).

Water tension curves show the relationship between applied tensions and water content in a soil profile. They are presented in standard diagrams where the horizontal axis shows volume from 0 to 100 % and the vertical axis shows depth below the soil surface from 0 to 100 cm. The diagram thus represents 100 % volume of a 1 m deep soil section which can be divided to show volume of pores and volume of solids.

Each tension curve shows the volume percentage of water (= mm water per 10 cm level) remaining in the pores of successive soil levels at the particular tension. It also shows the volume of air which enters the pores and provides an indirect picture of pore size distribution in the different layers of the profile.

In the diagrams, moisture content at biologically determined wilting point is also indicated (w_w-curve). The method used to determine wilting point is de-

scribed by Wiklert (1964). A nylon net is placed on top of the undisturbed soil sample and about 50 mm of rich topsoil applied above this. Sunflower and wheat seeds are then germinated and grown on the samples. Water is supplied until the seedlings are established, then the soil sample is allowed to dry out. At a point when the seedlings wilt permanently, and do not regain their turgor after 16 hours in a moist environment, the added topsoil is removed and the moisture content of the soil sample is determined.

Values of moisture content at a tension of 150 mwc are presented in tables for three silty light clay soils and a heavy gyttja clay.

Drainage equilibrium curves are constructed on a separate volume - depth diagram. These curves show the moisture content of the profile at matric tension equivalent to a certain drainage or watertable depth. Thus, if the watertable lies 1.0 m below the soil surface, the mean tension in the first 10 cm level (0-10 cm) will be 0.95 mwc, in the 10-20 cm level it will be 0.85 mwc etc. In the 90-100 cm level, tension will be 0.05 mwc. The values for w_{dr}-curves are interpolated from moisture characteristics or w_t-curves. In the following diagrams, w_{dr}-curves for 0.5, 1.0 and 3.0 m drainage (watertable) depth have been calculated for each profile.

Saturated hydraulic conductivity is determined on the 10 cm cylinder samples in a constant head apparatus described by Andersson (1955) and later modified in some respects. Results (means from measurements 1 hour and 24 hours after start) expressed in cm/hour are included in the table of physical characteristics for each profile. These tables also include values of materiality (= volume % of solids), porosity (= volume % of pores), moisture content at sampling (volume %), dry bulk density (g/cm^3) and density of solids (g/cm^3).

Moisture content at sampling is determined by weighing fresh samples, drying the samples at $105^{o}C$ (after all other determinations have been carried out) and reweighing. Loss in weight = mass of water in sample.

Dry bulk density = mass of dry matter/total volume of sample. This is calculated after drying of samples since sampling cylinders have a known volume.

Density of solids = mass of dry matter/volume of solids. A 5 g sample of dry soil is poured into a measuring flask and the volume of this dry soil is obtained by measuring the volume of ethyl alcohol (96 %) which must be added to bring the total volume of contents to 50 cm^3.

Results of dry bulk density (σ_t) and density of solids (σ_s) allow calculation of volume % of solids (= 100 σ_t / σ_s) and porosity (= 100 - 100 σ_t / σ_s).

DESCRIPTION OF PROFILES

Ultuna 1, 1979

Ultuna, Uppsala län. Topographical map 11I Uppsala NV. Coordinates 66336/16041. Sampling date: 16/11/1979.

Sampling site is located to the south of the Department of Ecology and Environmental Research, on a plain sloping down to the Fyris river in the east. The geological foundation is granite, covered by glacial and postglacial clay.

Climate (Ultuna recording station): 190 day growing season with mean monthly temperature = 11.1°C and mean total rainfall = 340 mm.

Cylinder samples (4 replicates) were taken from each 10 cm level down to 100 cm.

Soil profile description. Soil texture is shown by Fig. 1. The topsoil (0-30 cm) consists of a heavy clay (50 % by weight), the subsoil of a heavy clay with an even greater clay content (58 % by weight). The profile has, on average, 17 % fine silt and 11 % coarse silt throughout. The topsoil, which shows signs of compaction, has large, blocky aggregates. Aggregate form changes with depth, becoming more granular and fragmented. In the lower part of the profile, aggregates become more columnar. There are some large pores in all levels and a large number of roots throughout the profile. Saturated hydraulic conductivity is quite high in all levels of the profile, especially in the 40-80 cm level.

Porosity decreases somewhat with depth from 50 % in the topsoil to 45 % in the subsoil. Wilting occurs at around 25 % moisture and remains fairly constant for all levels. Available water storage capacity between full saturation of the pore space and wilting point is 468-269 = 199 mm. When the watertable lies 1.0 m below the surface, the following amounts of water can be retained by this soil:

Depth (cm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	Total (mm)
Moisture (vol.%)	44.9	45.1	39.9	37.2	36.6	36.0	38.3	37.4	39.1	43.1	397.6

Plant available water at this drainage depth is 398 - 269 = 129 mm, a reserve which should be adequate to supply the crop during normal dry periods in the growing season.

Table 1. Summary of the main physical characteristics of the profile Ultuna 1, 1979

Depth (cm)	Solids (vol%)	Pores (vol%)	Moisture content, volume %							Dry bulk density (g/cm^3)	Density of solids (g/cm^3)	Saturated hydraulic conductivity (cm/hour)
			tension, mwc						wilting point			
			0.05	0.5	1.0	2.0	4.0	6.0				
0-10	51.0	49.0	47.9	45.5	44.8	43.8	41.3	40.4	28.0	1.35	2.64	18
10-20	47.8	52.2	49.4	45.8	44.8	43.9	41.9	40.3	26.5	1.28	2.67	22
20-30	51.4	48.6	45.6	40.3	39.4	38.5	36.6	35.6	26.9	1.40	2.72	16
30-40	53.2	46.8	43.5	37.5	36.4	35.5	34.0	33.3	26.8	1.46	2.75	26
40-50	52.7	47.3	43.3	36.7	35.7	34.9	33.5	33.1	26.1	1.46	2.76	78
50-60	52.5	47.5	41.2	35.3	34.5	33.9	32.8	32.3	25.2	1.45	2.76	99
60-70	54.9	45.1	41.7	36.6	35.8	35.1	34.1	33.6	27.3	1.50	2.74	40
70-80	56.2	43.8	39.4	34.9	32.6	31.3	29.8	29.3	23.6	1.55	2.75	123
80-90	57.5	42.5	39.9	36.3	35.6	34.9	34.1	33.5	27.9	1.58	2.74	20
90-100	55.1	44.9	43.1	40.2	39.6	39.0	38.1	37.7	30.7	1.52	2.76	41
Total (mm)	532.3	467.7	435.0	389.1	379.2	370.8	356.2	349.1	269.0			

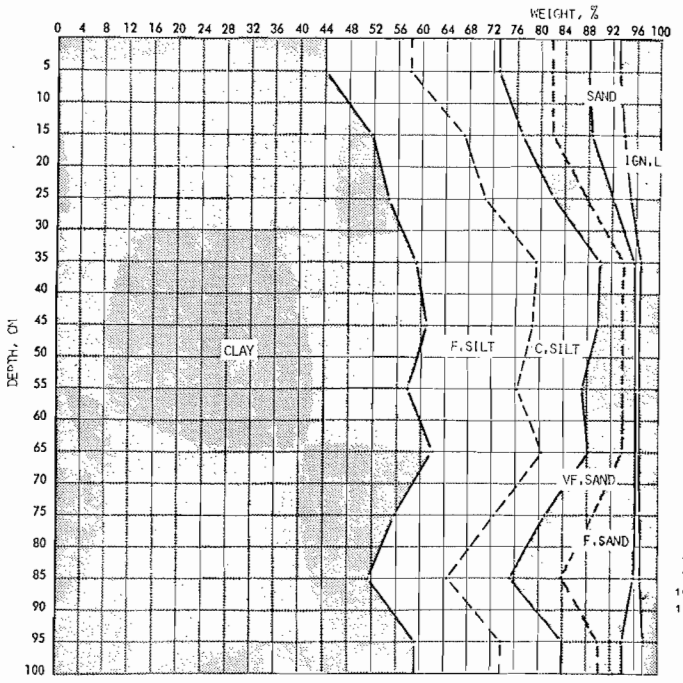


Fig. 1. Mechanical composition and loss on ignition. Ultuna 1, 1979.

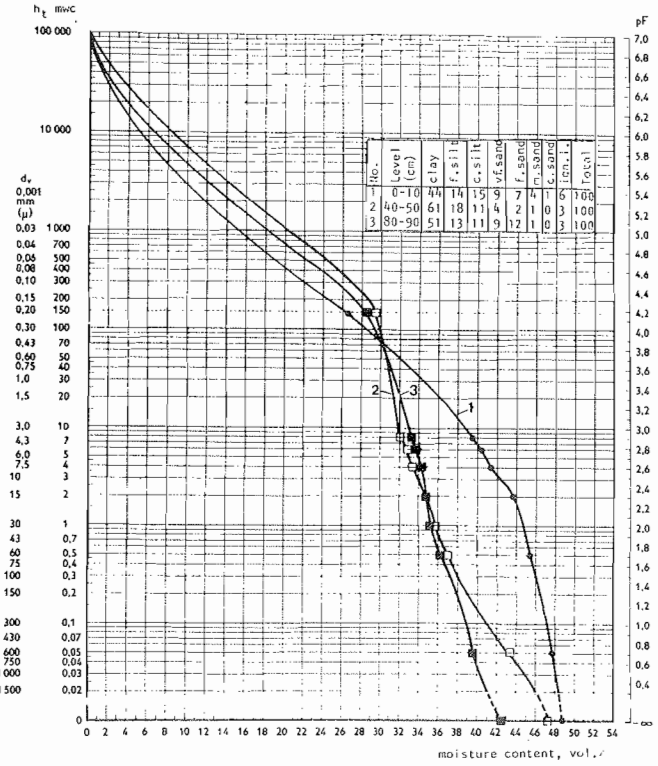


Fig. 2. Soil moisture retention curves. Ultuna 1, 1979.

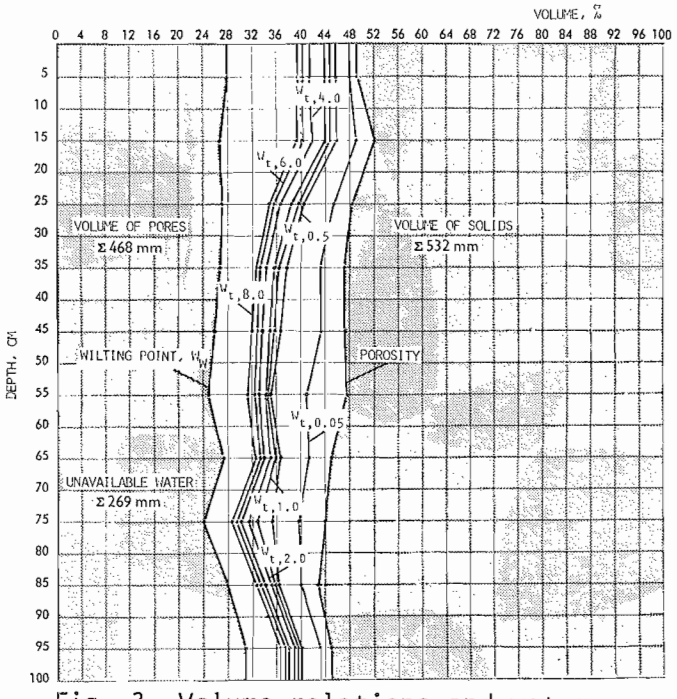


Fig. 3. Volume relations and water tension curves. Ultuna 1, 1979.

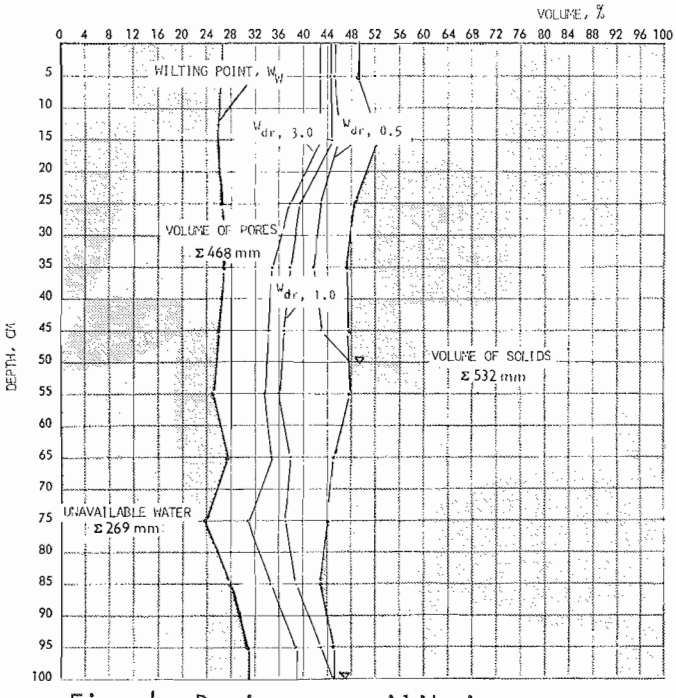


Fig. 4. Drainage equilibrium curves. Ultuna 1, 1979.

Ultuna 2, 1983

Ultuna, Uppsala län. Topographical map 11I Uppsala NV, coordinates 66340/16034. Sampling date: 20/9/1983.

Sampling site is located in the north-east corner of a field bordered to the east by Dag Hammarskjöld road and to the south by the road to Vipängen. The site lies on the western edge of a plain bordered by the Fyris river in the east and by a rock fault in the west. The geological foundation is granite, covered by glacial and postglacial clay.

Climate (Ultuna recording station): 190 day growing season with mean monthly temperature = 11.1°C and mean total rainfall = 340 mm.

Cylinder samples (4 replicates) were taken from each 10 cm level down to 100 cm. A full vertical profile was extracted and horizontal sections were taken at 15, 35, 55 and 80 cm below the surface (Plate 1).

Soil profile description. Soil texture is shown by Fig. 5. The topsoil consists of a heavy medium clay, the subsoil of a heavy clay. Proportions of clay, silt and fine sand in the topsoil are 39, 28 and 24 % respectively. These values remain fairly constant throughout the profile.

Structure of this soil is well developed and shows a characteristic change with depth. Aggregates in the topsoil are large and rather blocky, while in the subsoil they are granular, becoming columnar deeper in the profile.

Porosity is on average 45 % and remains fairly constant in all levels. Wilting occurs at an average of 27 % moisture for 0-100 cm. The moisture content at wilting for individual 10 cm layers increases with depth from 25 % (0-10 cm) to 33 % (90-100 cm). Available water storage capacity between full saturation of the pore space and wilting points is 450-275 = 175 mm down to 1 m depth. When the watertable lies 1.0 m below the surface, the following amount of water can be stored in the profile:

Depth (cm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	Total (mm)
Moisture (vol.%)	38.1	38.3	37.2	37.7	37.8	38.1	37.9	39.1	41.9	43.8	389.9

Plant available water at this drainage depth is 390-275 = 115 mm. This should be sufficient to supply the crop during normal dry periods in the growing season.

Table 2. Summary of the main physical characteristics of the profile Ultuna 2, 1983

Depth (cm)	Solids (vol%)	Pores (vol%)	Moisture content, volume %							Dry bulk density (g/cm^3)	Density of solids (g/cm^3)
			tension, mwc					wilting point	at sampling		
			0.05	0.5	1.0	2.0	6.0				
0-10	53.0	47.0	44.0	39.7	37.9	36.7	33.5	24.8	35.6	1.42	2.68
10-20	55.9	44.1	41.7	39.1	37.9	37.0	34.3	26.6	35.7	1.50	2.68
20-30	57.8	42.2	40.3	37.4	37.0	35.8	33.7	25.6	34.9	1.53	2.65
30-40	58.1	41.9	40.1	37.9	37.3	36.4	34.6	26.8	35.8	1.58	2.72
40-50	54.8	45.2	41.5	37.9	36.8	36.1	33.9	26.4	36.6	1.51	2.75
50-60	53.2	46.8	42.2	37.6	36.5	35.8	33.5	26.6	36.8	1.47	2.76
60-70	55.0	45.0	40.6	36.6	35.7	35.0	32.9	26.5	36.2	1.52	2.76
70-80	54.5	45.5	40.9	36.9	36.3	35.4	33.4	28.0	36.5	1.50	2.76
80-90	53.9	46.1	42.5	39.9	39.3	38.6	36.8	30.1	39.4	1.49	2.76
90-100	54.0	46.0	43.8	42.1	41.6	40.9	39.2	33.5	41.5	1.48	2.75
Total (mm)	550.2	449.8	417.6	385.1	376.3	367.7	345.8	274.9	369.0		

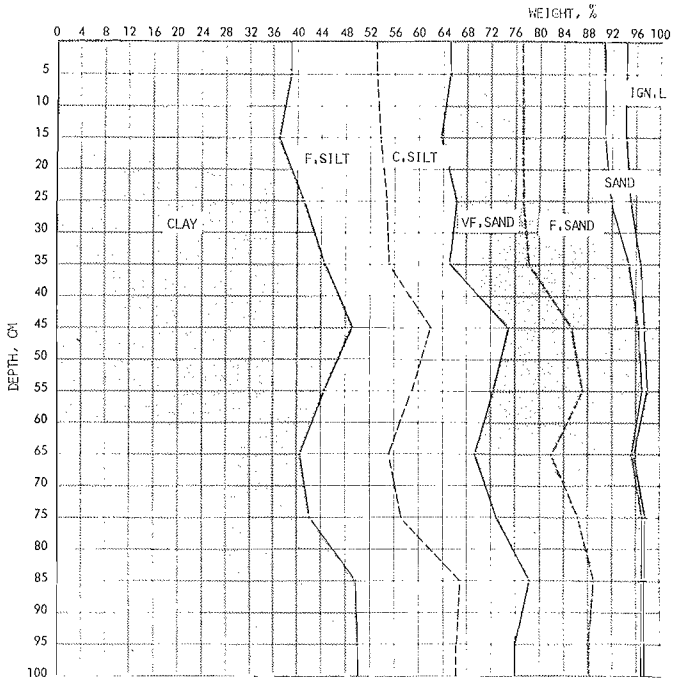


Fig. 5. Mechanical composition and loss on ignition. Ultuna 2, 1983.

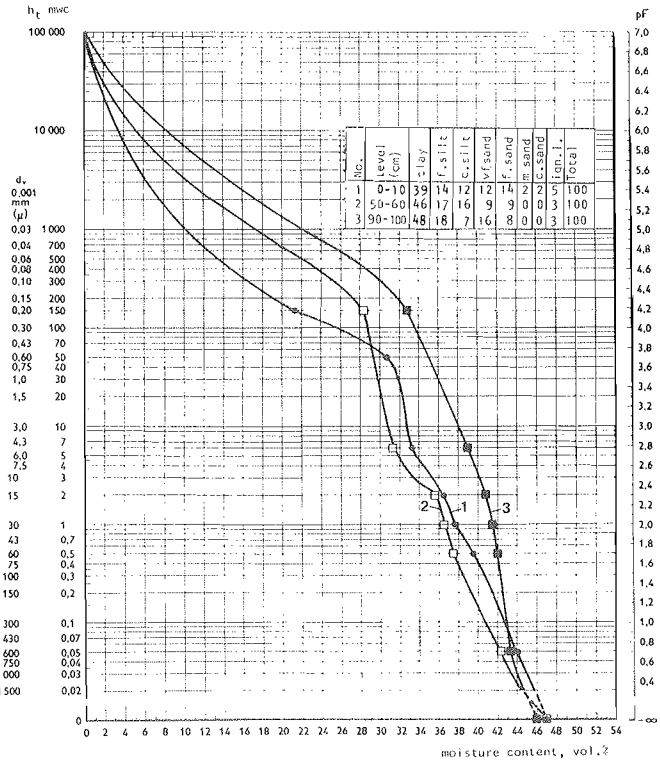


Fig. 6. Soil moisture retention curves. Ultuna 2, 1983.

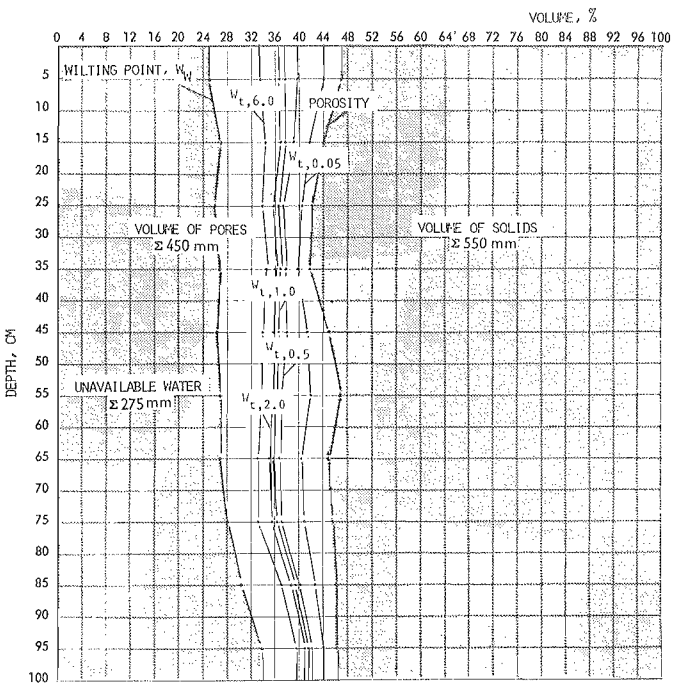


Fig. 7. Volume relations and water tension curves. Ultuna 2, 1983.

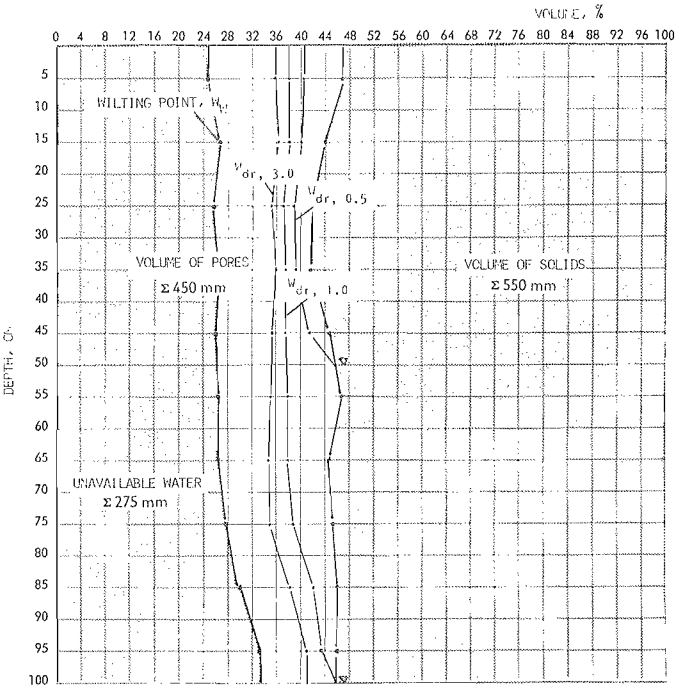


Fig. 8. Drainage equilibrium curves. Ultuna 2, 1983.

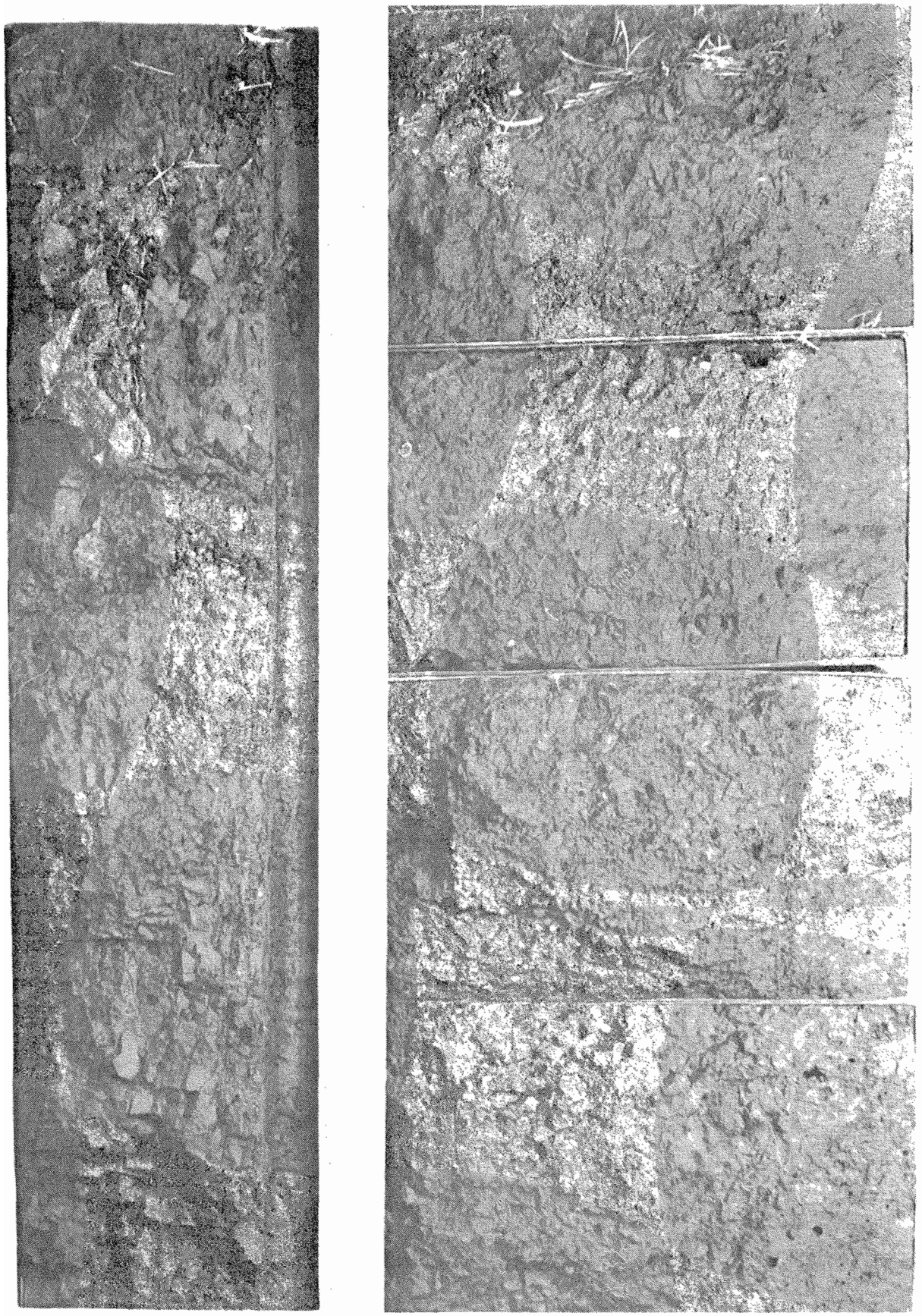


Plate 1. Vertical profile 0-100 cm and horizontal sections at 15, 35, 55 and 80 cm depth. Ultuna 2, 1983.

Wadsbro 1, 1979

Wadsbro, Malmköping, Södermanlands län. Topographical map 10H Strängnäs SV, coordinates 65609/15567.
Sampling date: 5/10/1979.

Sampling site is located on a convex slope in terrain with moraine outcrops surrounded by arable land. The geological foundation is gneiss, overlain by glacial and postglacial clay.

Climate (Eskilstuna recording station): 190 day growing season with mean monthly temperature = 10.2°C and mean total rainfall = 360 mm.

Cylinder samples (4 replicates) were taken from each 10 cm level down to 100 cm.

Soil profile description. Soil texture is shown by Fig. 9. The topsoil consists of a medium clay with a high silt content. Average proportions of clay, fine silt, coarse silt, very fine sand and fine sand in the topsoil are 26, 14, 20 and 11 % respectively. The subsoil consists of a heavy clay (40-80 cm) and a medium clay (80-100 cm). Fine silt content decreases with depth to 3 % while fine sand content increases to 32 %.

The 0-20 cm layer has 6 % loss on ignition and has an open structure, with many wormholes and large pores. The presence of layered or varved clay and silt below 50 cm impedes root development but does not inhibit it completely. The relatively high silt fraction and correspondingly low clay content mean that the structure is dense and has no permanent system of cracks.

Porosity is rather low below the 0-10 cm level and decreases further with depth. It is greatest (57 %) in the 0-10 cm level and least (39 %) in the 80-90 cm level. Wilting occurs at a moisture content of between 15 % (0-10 cm) and 33 % (60-80 cm). Available water storage capacity of the soil between full saturation of the pore space and wilting point is 441-245 = 196 mm down to 1 m depth. At a watertable depth of 1.0 m, the profile can retain the following amounts of water in its layers:

Depth (cm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	Total (mm)
Moisture (vol.%)	34.0	40.9	36.0	34.0	38.5	39.8	42.2	42.1	40.0	39.4	386.9

Plant available water at this drainage depth is 387-245 = 142 mm. However, crop rooting depth is usually restricted to the upper 50 cm of this profile which has a plant available moisture content of 183-100 = 83 mm at 1.0 m drainage depth. This amount of moisture will supply a growing crop for 15-20 days.
Permeability is high down to 80 cm depth but very low below this.

Table 3. Summary of the main physical characteristics of the profile Wadsbro 1, 1979

Depth (cm)	Solids (vol%)	Pores (vol%)	Moisture content, volume %								Dry bulk density (g/cm^3)	Density of solids (g/cm^3)	Saturated hydraulic conductivity (cm/hour)
			tension, mwc						wilting point	at sampling			
			0.05	0.5	1.0	2.0	4.0	6.0					
0-10	43.0	57.0	50.7	35.6	33.8	32.9	31.9	31.2	14.8	22.4	1.12	2.61	19
10-20	53.8	46.2	44.4	41.9	40.5	39.1	37.6	36.7	15.5	35.3	1.41	2.62	10
20-30	56.3	43.7	40.6	36.6	35.4	34.1	33.0	32.3	18.1	31.7	1.49	2.65	18
30-40	58.5	41.5	38.6	34.2	33.5	32.9	32.5	31.0	20.3	30.4	1.57	2.69	29
40-50	56.4	43.6	41.2	38.5	38.1	37.2	36.9	35.4	31.4	33.6	1.54	2.73	20
50-60	57.1	42.9	42.2	39.5	38.8	38.0	37.2	36.5	27.4	34.5	1.54	2.70	21
60-70	56.6	43.4	43.4	41.6	41.0	40.4	39.7	39.1	33.0	36.6	1.54	2.72	11
70-80	56.9	43.1	42.5	41.5	40.7	40.3	39.6	39.1	32.5	37.7	1.55	2.72	22
80-90	60.5	39.5	40.2	39.4	38.9	38.5	37.9	37.4	30.8	36.3	1.63	2.69	0.01
90-100	59.4	40.6	39.4	38.1	34.6	31.6	27.9	26.5	21.5	29.9	1.60	2.69	0.01
Total (mm)	558.5	441.5	423.2	386.9	375.3	365.0	354.2	345.2	245.3	328.4			

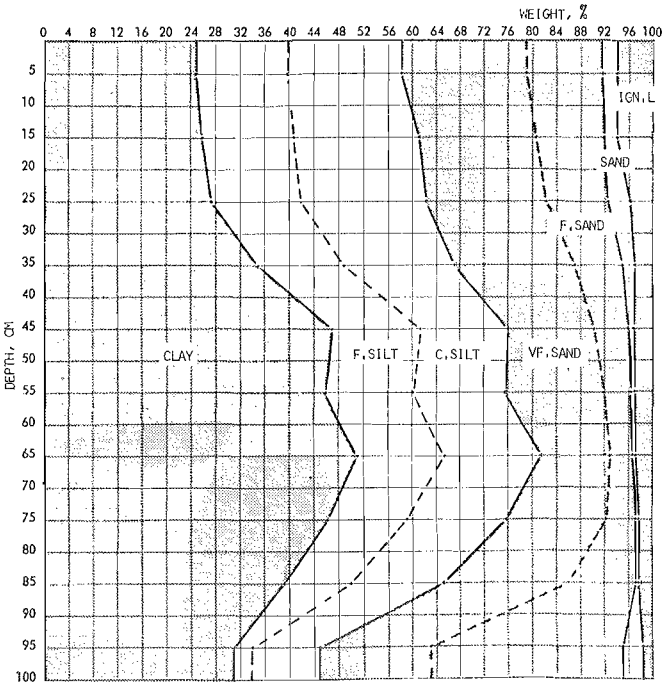


Fig. 9. Mechanical composition and loss on ignition. Wadsbro 1, 1979.

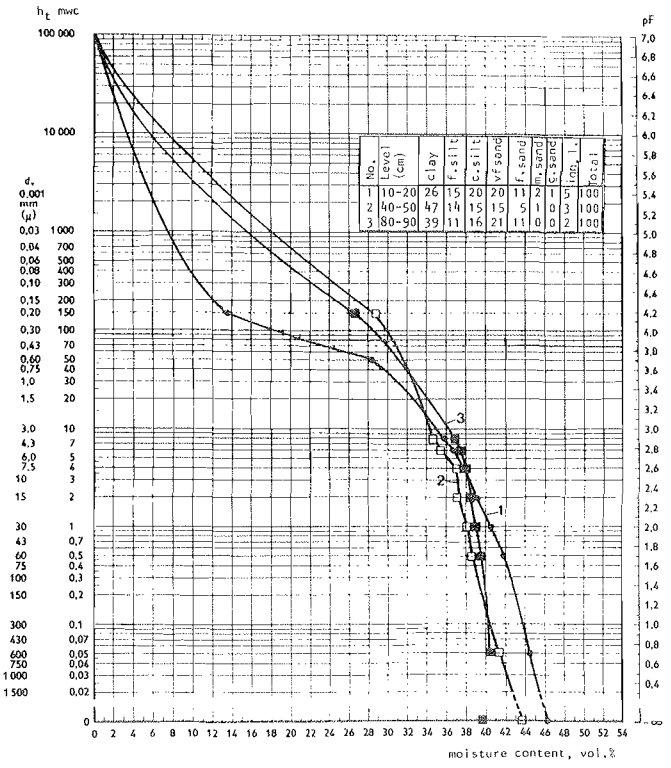


Fig. 10. Soil moisture retention curves. Wadsbro 1, 1979.

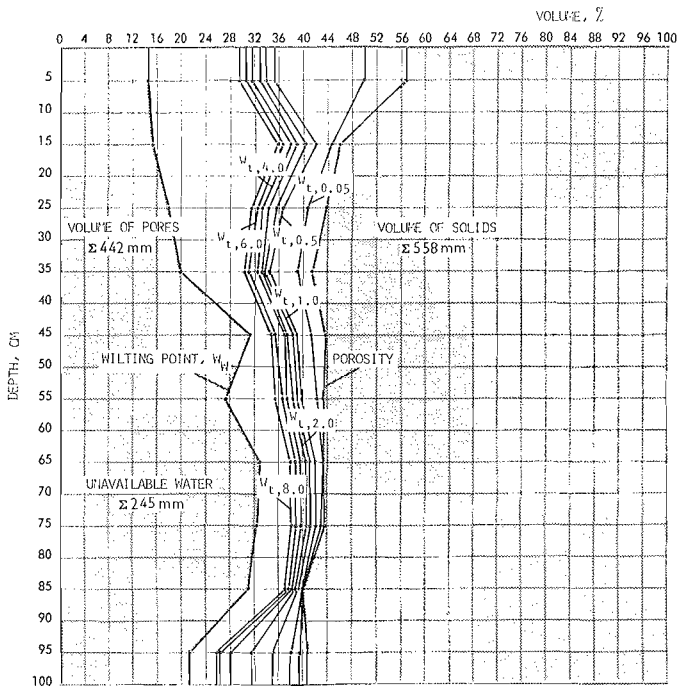


Fig. 11. Volume relations and water tension curves. Wadsbro 1, 1979.

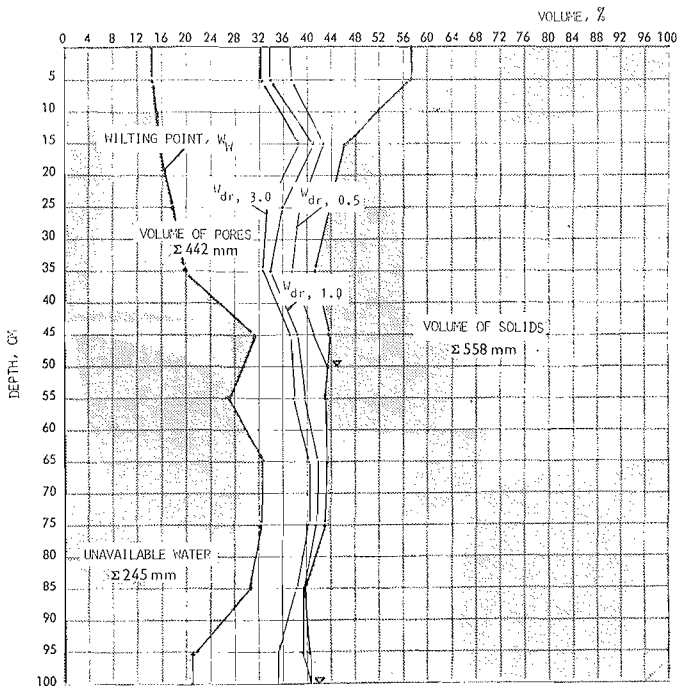


Fig. 12. Drainage equilibrium curves. Wadsbro 1, 1979.

Wadsbro 2, 1982

Wadsbro, Malmköping, Södermanlands län. Topographical map 10H Strängnäs SV, coordinates 65600/15577.
Sampling date: 16/11/1982.

Sampling site is located on a slight slope in an undulating plain with some moraine outcrops. The geological foundation is gneiss, covered by glacial and postglacial clay.

Climate (Eskilstuna recording station): 190 day growing season with mean monthly temperature = 10.2°C and mean total rainfall = 360 mm.

Cylinder samples (4 replicates) were taken from each 10 cm level down to 100 cm. A full vertical profile was extracted (Plate 2).

Soil profile description. Soil texture is shown by Fig. 13. The topsoil consists of medium clay containing approximately 30 % silt, 20 % very fine sand and 15 % fine sand. The subsoil consists of a heavy clay (30-60, 80-100 cm) and a medium clay (60-80 cm). A layer with a high content (25-30 %) of very fine sand occurs between 60 and 80 cm. This profile has a varved structure below 60 cm depth and this reduces root penetration but does not inhibit it completely. The clay content results in formation of a system of cracks in which roots can travel. The topsoil has a high number of wormholes and a good, open structure.

Porosity varies with mechanical composition of layers. It is, on average, 44 % (0-100 cm) and ranges from 48 % (0-10 cm) to 37 % (20-30 cm). Wilting occurs at increasing moisture content with depth, with the exception of the 60-80 cm level. Wilting occurs at 16 % moisture in the surface layer and at 39 % in the 90-100 cm layer. Available water storage capacity of the profile between full saturation of the pore space and wilting point is 444-261 = 183 mm. When the watertable lies at 1.0 m below the surface, the profile can retain the following amounts of water:

Depth (cm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	Total (mm)
Moisture (vol.%)	37.9	35.8	33.1	35.1	40.1	42.8	40.6	41.6	47.4	47.0	401.4

Plant available water at this drainage depth is 401-261 = 140 mm. In the 0-60 cm layer, the profile can retain 225-138 = 87 mm water at 1.0 m drainage depth. If root development is restricted to the 0-60 cm layer, available moisture will supply the crop for a period of 15-20 days.

Permeability is reasonably high in the 10-50 cm layer but rather low in all other levels.

Table 4. Summary of the main physical characteristics of the profile Wadsbro 2, 1982

Depth (cm)	Solids (vol%)	Pores (vol%)	Moisture content, volume %							Dry bulk density (g/cm^3)	Density of solids (g/cm^3)	Saturated hydraulic conductivity (cm/hour)
			tension, mwc					wilting point	at sampling			
			0.05	0.5	1.0	2.0	6.0					
0-10	51.9	48.1	42.8	39.2	37.7	36.5	33.9	16.5	35.5	1.38	2.65	2.4
10-20	55.7	44.3	39.8	36.4	35.5	34.6	32.4	17.5	32.8	1.47	2.64	19
20-30	63.4	36.6	35.5	33.4	32.7	32.0	30.2	20.9	30.8	1.70	2.68	36
30-40	60.0	40.0	38.0	35.2	34.9	34.4	32.2	25.8	32.0	1.64	2.73	6.2
40-50	54.5	45.5	44.4	40.1	39.6	38.8	35.9	28.1	32.4	1.50	2.76	12
50-60	53.1	46.9	46.3	42.4	41.9	41.2	38.2	28.9	33.4	1.47	2.77	4.3
60-70	55.8	44.2	42.8	39.5	37.9	36.3	30.5	22.2	23.3	1.53	2.74	1.9
70-80	56.3	43.7	43.0	39.9	39.2	37.7	35.5	27.0	29.8	1.54	2.73	3.5
80-90	52.4	47.6	47.8	45.8	45.3	43.6	42.9	35.8	39.6	1.45	2.76	1.8
90-100	52.9	47.1	47.0	45.4	45.0	43.7	43.2	38.6	41.4	1.47	2.77	1.5
Total (mm)	556.0	444.0	427.4	397.3	389.7	378.8	354.9	261.3	331.0			

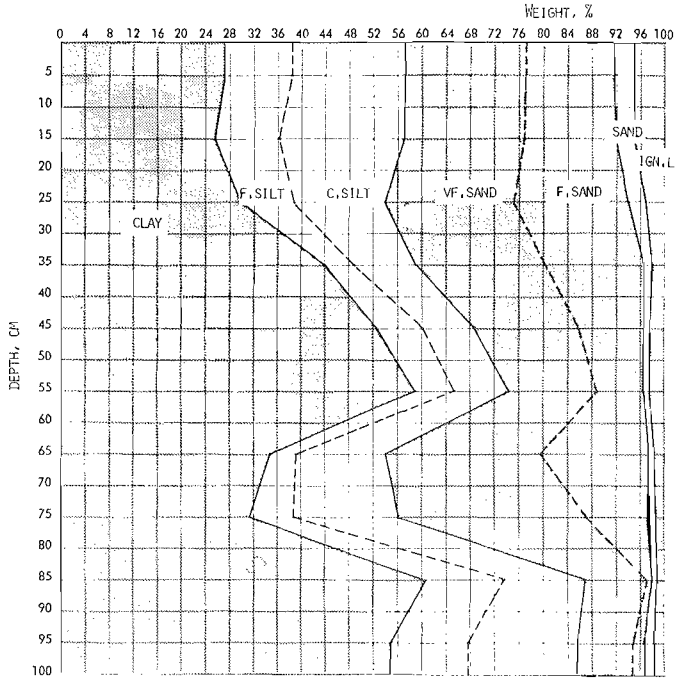


Fig. 13. Mechanical composition and loss on ignition. Wadsbro 2, 1982.

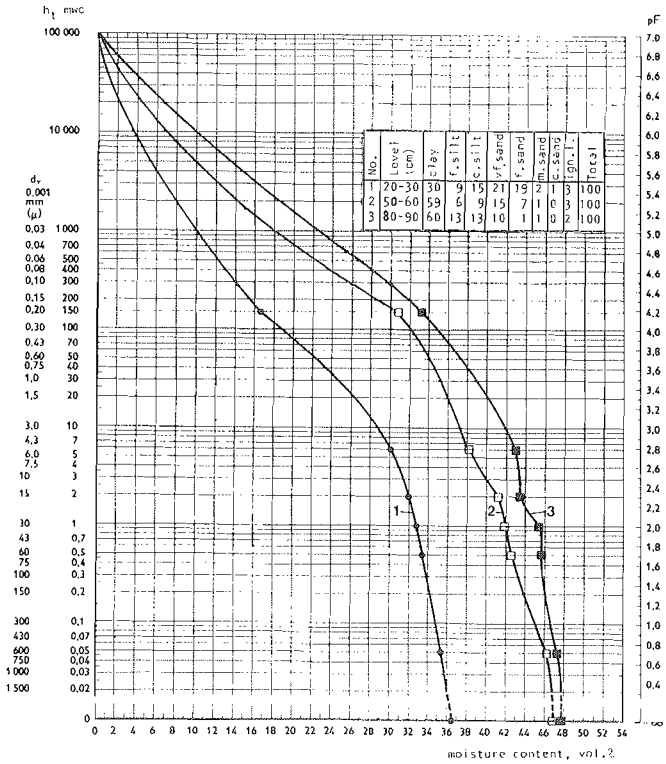


Fig. 14. Soil moisture retention curves. Wadsbro 2, 1982.

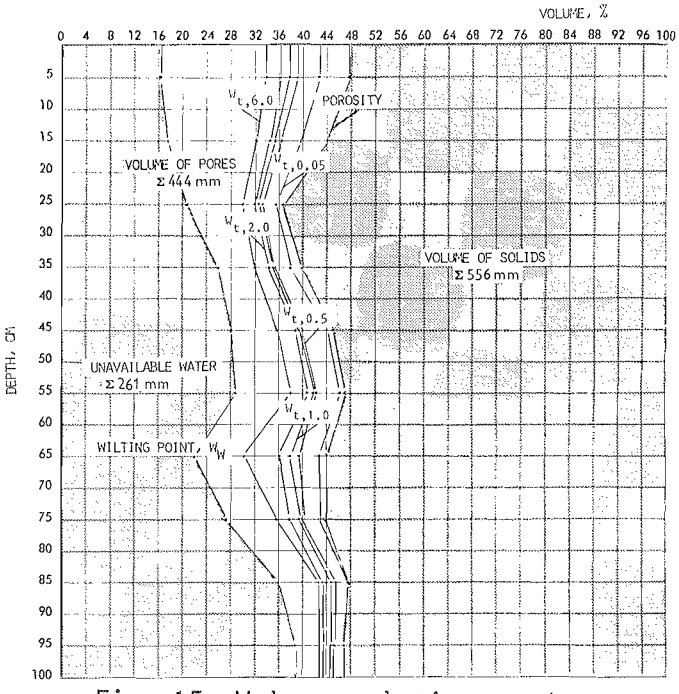


Fig. 15. Volume relations and water tension curves. Wadsbro 2, 1982.

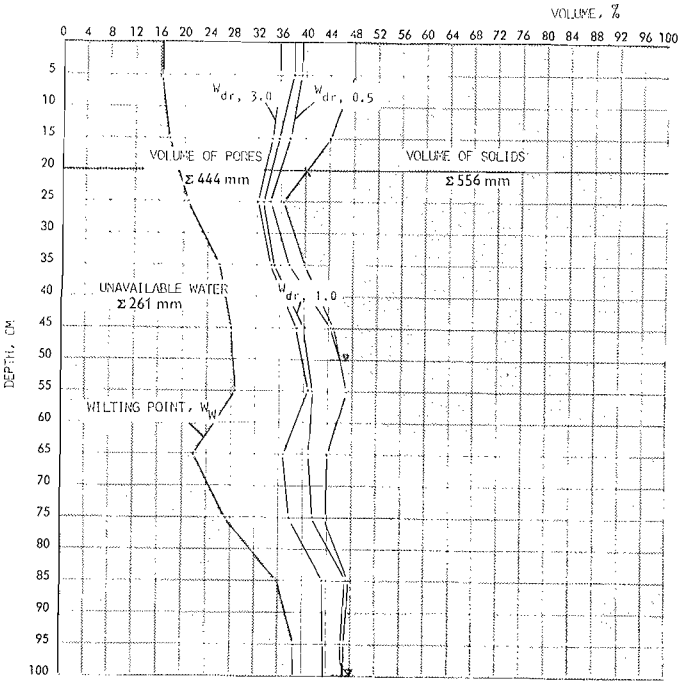


Fig. 16. Drainage equilibrium curves. Wadsbro 2, 1982.

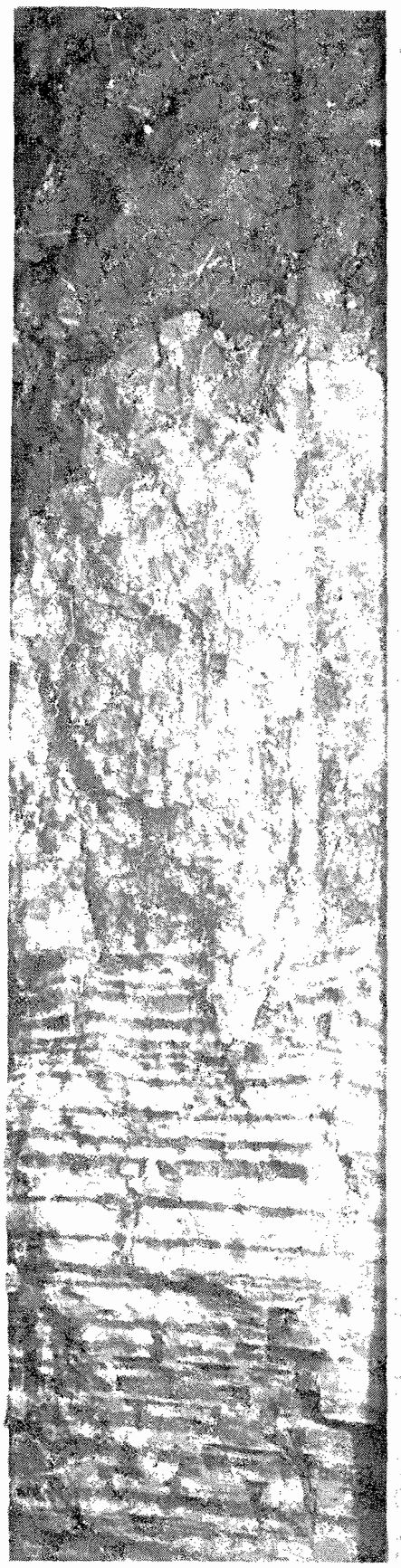


Plate 2. Vertical profile 0-100 cm. Wadsbro 2, 1982.

Ålbo 1, 1979

Ålbo, Västerfärnebo, Västmanlands län. Topographical map 11G Västerås NO, coordinates 66457/15282.

Sampling date: 9/10/1979.

Sampling site is located in a slight depression on a gentle convex slope. The geological foundation consists of gneiss and this is covered by moraine and varved glacial clay. Some postglacial clay occurs in the area but not at this site.

Climate (Västerås recording station): 190 day growing season with mean monthly temperature = 12.6°C and mean total rainfall = 340 mm.

Cylinders samples (4 replicates) were taken from each 10 cm level down to 100 cm.

Soil profile description. Soil texture is shown by Fig. 17. The topsoil consists of a silty light clay with low (3 %) loss on ignition, the subsoil of a silty medium clay (30-60 cm) and a silty light clay (60-100 cm). The mean proportions of clay, fine silt, coarse silt, very fine sand and fine sand in the total profile are 24, 25, 37, 8 and 2 % respectively. The coarse silt fraction increases with depth from 23 to 55 %. The silt content means that the structure of this soil is unstable, the surface tending so smear in wet periods and to form a crust in dry. A rather high capillary flow can occur in the unstratified topsoil and cause dessication and pan formation.

The presence of varved silt and clay in the subsoil restricts root depth to 50-60 cm. Porosity is relatively low (mean 43 % for 0-100 cm) and remains fairly constant below the 0-10 cm level. Wilting occurs at between 13 and 23 % moisture, reflecting fluctuations in the clay content (Fig. 19). In all levels, there is a rather large difference between wilting point and the moisture content at a tension of 150 mwc, which means that roots have difficulty in making full use of water which should be available physically. Available water storage capacity of this soil between full saturation of the pore space and wilting point is 434-195 = 239 mm down to 1 m depth. When the watertable lies 1.0 m below the surface, the profile can retain the following amount of water:

Depth (cm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	Total (mm)
Moisture (vol.%)	36.4	35.7	36.6	37.9	38.4	40.4	41.3	44.0	42.6	43.5	396.8

Since root depth is restricted to the upper 60 cm of the profile, the maximum amount of available water at 1.0 m drainage depth = total (0-60) - unavailable (0-60). From the values given above and in Table 5, this is 225-115 = 110 mm. This represents a moderate moisture reserve during dry periods.

Permeability under the 50 cm level is very low, which can lead to waterlogging and low aeration of the topsoil after heavy rain.

Table 5. Summary of the main physical characteristics of the profile Ålbo 1, 1979

Depth (cm)	Solids (vol%)	Pores (vol%)	Moisture content, volume %										Dry bulk density (g/cm^3)	Density of solids (g/cm^3)	Saturated hydraulic conductivity (cm/hour)
			tension, mwc								wilting point	at sampling			
			0.05	0.5	1.0	2.0	4.0	6.0	50	150					
0-10	51.5	48.5	44.1	37.7	36.3	34.9	34.1	33.6	19.0	10.8	13.2	36.1	1.35	2.61	6.8
10-20	57.5	42.5	39.4	36.4	35.4	34.5	33.9	33.4	23.6	13.2	18.7	35.9	1.51	2.62	2.4
20-30	59.3	40.7	39.3	37.0	36.2	35.5	34.9	34.4	22.3	13.2	15.8	36.1	1.57	2.64	4.2
30-40	57.7	42.3	40.6	38.1	37.6	36.5	35.7	35.0	28.2	19.7	23.2	36.8	1.54	2.66	10
40-50	57.5	42.5	40.1	38.5	37.9	37.1	36.2	35.5	24.9	16.9	22.8	37.6	1.53	2.67	25
50-60	57.9	42.1	41.4	40.3	39.9	39.4	38.6	38.1	24.8	17.7	21.4	39.4	1.56	2.69	0.02
60-70	57.0	43.0	41.9	41.0	40.5	40.0	39.4	39.0	17.1	12.7	20.7	40.3	1.54	2.70	0.003
70-80	55.3	44.7	44.6	43.2	42.8	42.4	41.8	41.3	22.8	16.1	22.7	42.5	1.49	2.69	0.02
80-90	55.8	44.2	43.0	41.3	40.7	40.3	39.7	39.1	18.0	12.8	16.4	40.2	1.50	2.69	0.80
90-100	56.1	43.9	43.5	42.8	42.4	42.2	41.8	41.3	22.0	15.0	20.5	42.0	1.50	2.68	0.03
Total (mm)	565.6	434.4	417.9	396.3	389.7	382.8	376.1	370.7	222.7	148.1	195.4	386.9			

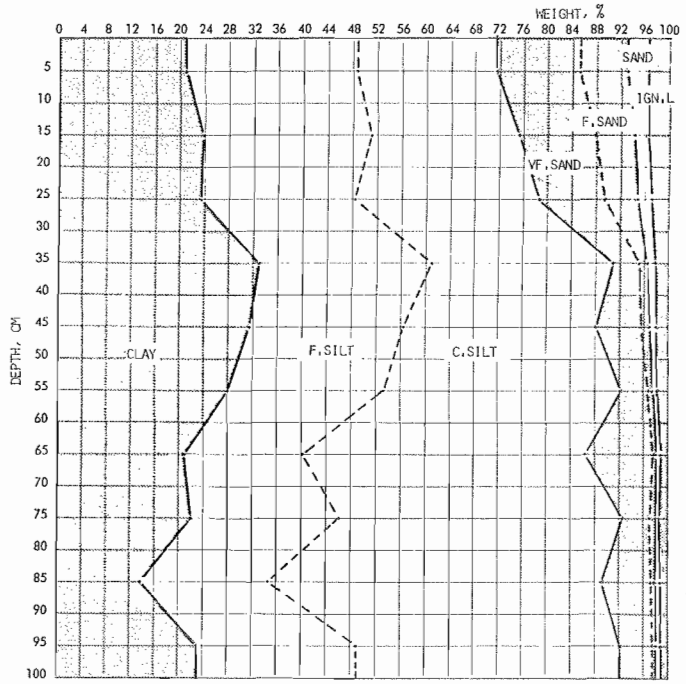
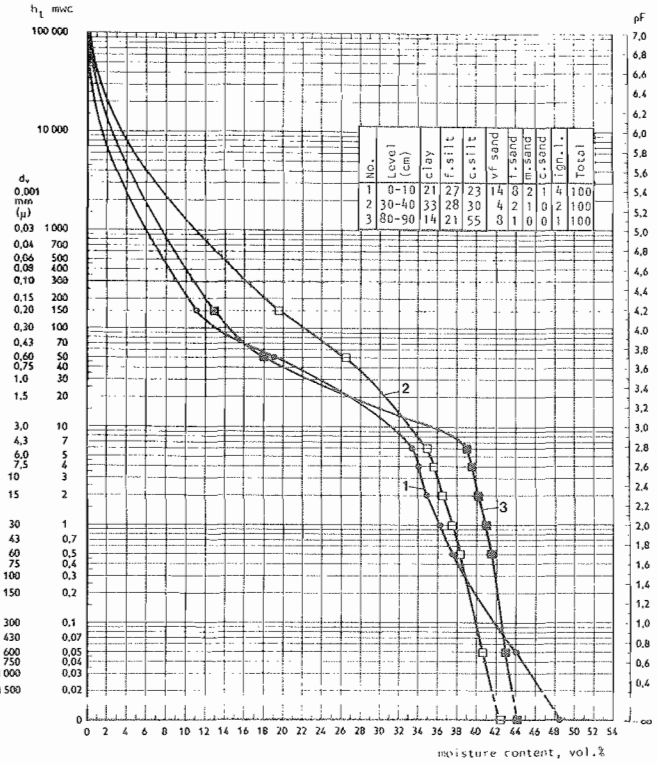


Fig. 17. Mechanical composition and loss on ignition. Ålbo 1, 1979.



No.	Level (cm)	clay	f.silt	c.silt	vf sand	f.sand	m.sand	c.sand	Ign.l.	Total
1	0-10	21	27	23	14	8	2	1	4	100
2	30-40	33	28	30	4	2	1	0	2	100
3	80-90	14	21	55	3	1	0	0	1	100

Fig. 18. Soil moisture retention curves. Ålbo 1, 1979.

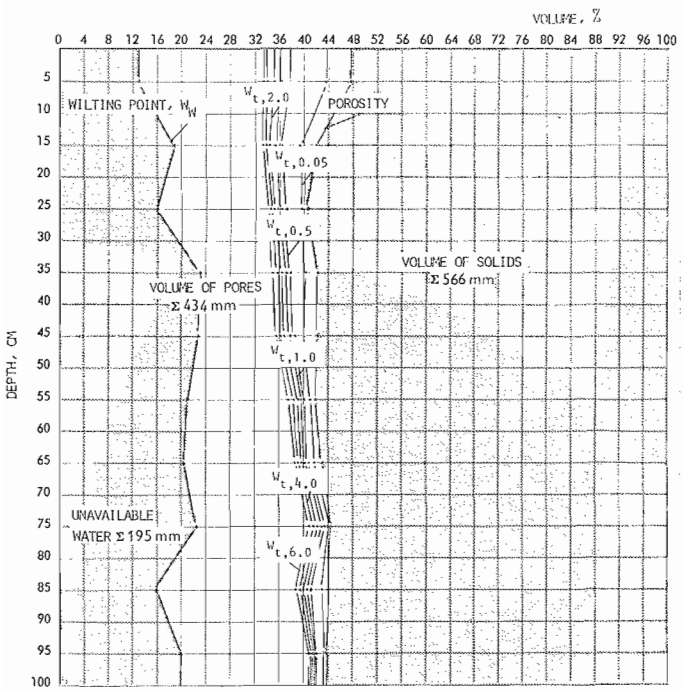


Fig. 19. Volume relations and water tension curves. Ålbo 1, 1979.

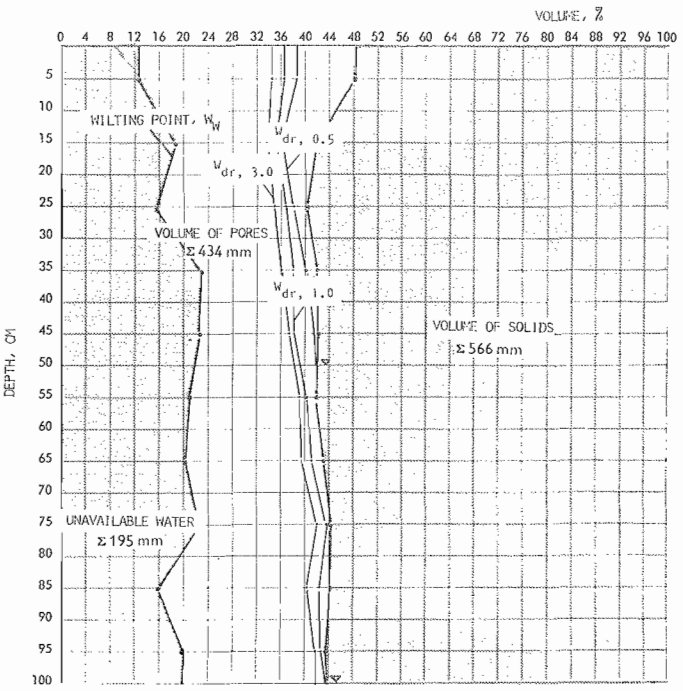


Fig. 20. Drainage equilibrium curves. Ålbo 1, 1979.

Ålbo 2, 1984

Ålbo, Västerfärnebo, Västmanlands län. Topographical map 11G Västerås NO, coordinates 66457/15283.
Sampling date: 10/10/1984.

Sampling site lies approximately 50 m from the Ålbo 1, 1979 site. Details of geology, environment and climate are thus similar to those described for Ålbo 1. Cylinder samples were taken from each 10 cm level down to 100 cm. A full vertical section was extracted and horizontal sections were taken at 10, 25, 55 and 80 cm below the surface (Plate 3).

Soil profile description. Soil texture is shown by Fig. 21. The topsoil is a light silty clay with, on average 23 % clay, 28 % fine silt, 22 % coarse silt, 11 % very fine sand and 8 % fine sand. The subsoil consists of a medium clay (40-50 cm) and a silty light clay. In the lower half of the profile, the coarse silt fraction increases to 54 % (70-90 cm). The profile has a very dense structure, with alternate layers of silt and clay in the subsoil. Smearing and crust formation in the surface layer and dessication and pan formation in the topsoil occur often in the spring and early summer when rain falls on the bare soil surface and is followed by dry periods. Roots are restricted to the upper 50-60 cm and permeability of the soil is very low below this level (Table 6). In hydraulic conductivity tests on the 70-80 cm samples, two cylinders gave very high values and two gave very low values.

Porosity is on average 45 % and remains relatively constant from one layer to the next. Wilting (150 m water tension) occurs at an average moisture content of 16 %, with variations due to mechanical composition between layers so that it is lowest (11 %) in the 0-20 cm level and highest (24 %) in the 40-50 cm level. Available water storage capacity between full saturation of the pore space and 150 mwc is 450-157 = 293 mm. When the watertable lies 1.0 m below the surface, the following amount of water can be stored in the profile:

Depth (cm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	Total (mm)
Moisture (vol.%)	37.8	36.2	37.2	35.5	40.1	39.7	41.4	41.6	42.6	43.3	395.4

Since root depth is restricted to the upper 60 cm of the profile, maximum available water = total (0-60) - unavailable (0-60) at 150 mwc = 227-89 = 138 mm. The corresponding amount calculated from biologically determined wilting point should be 110-115 mm. During longer dry periods in the growing season, water is likely to be limiting for the crop on this soil.

After heavy rain, the topsoil can remain waterlogged and poorly aerated for some time.

Table 6. Summary of the main physical characteristics of the profile Ålbo 2, 1984

Depth (cm)	Solids (vol%)	Pores (vol%)	Moisture content, volume %							Dry bulk density (g/cm^3)	Density of solids (g/cm^3)	Saturated hydraulic conductivity (cm/hour)
			tension, mwc						at sampling			
			0.05	0.5	1.0	2.0	6.0	150				
0-10	54.1	45.9	42.6	38.8	37.7	36.1	34.8	11.5	38.8	1.42	2.63	26
10-20	52.6	47.4	42.2	37.0	35.9	34.2	33.1	10.9	37.4	1.38	2.62	51
20-30	55.9	44.1	40.7	37.7	36.7	35.5	34.3	13.6	37.4	1.49	2.67	59
30-40	56.3	43.7	39.5	35.7	35.0	34.5	33.0	14.4	34.6	1.51	2.69	72
40-50	55.2	44.8	42.6	40.2	39.4	38.7	36.9	23.7	39.0	1.49	2.69	12
50-60	56.2	43.8	42.0	39.4	38.6	38.0	37.0	14.9	38.6	1.51	2.68	0.88
60-70	55.4	44.6	42.5	40.8	39.9	39.5	38.9	16.8	40.0	1.50	2.70	0.55
70-80	54.2	45.8	42.6	40.4	40.0	39.7	38.8	17.5	39.6	1.47	2.72	19
80-90	54.5	45.5	42.9	41.7	41.4	41.2	40.9	16.9	41.1	1.47	2.69	0.08
90-100	56.1	43.9	43.3	42.3	42.0	41.8	41.3	16.3	41.7	1.50	2.68	0.13
Total (mm)	550.5	449.5	420.9	394.0	386.6	379.2	369.0	156.5	388.2			

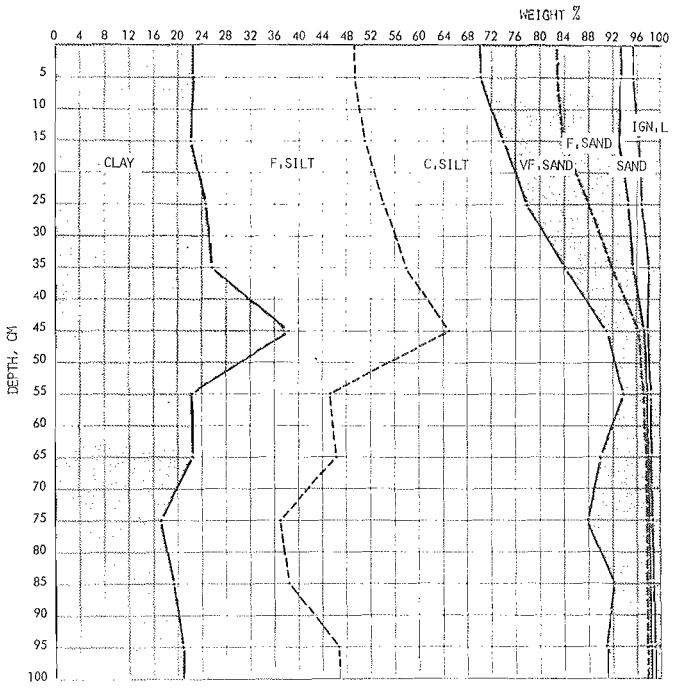


Fig. 21. Mechanical composition and loss on ignition. Ålbo 2, 1984.

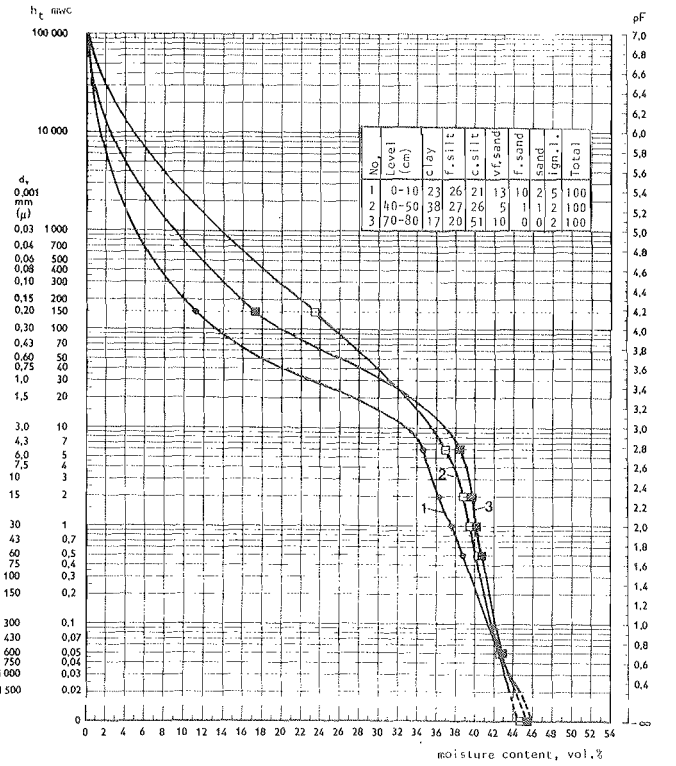


Fig. 22. Soil moisture retention curves. Ålbo 2, 1984.

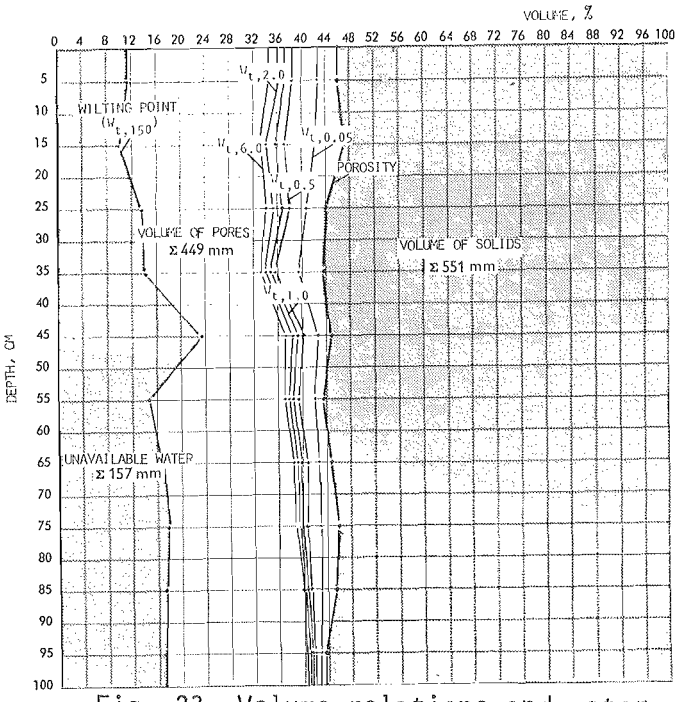


Fig. 23. Volume relations and water tension curves. Ålbo 2, 1984.

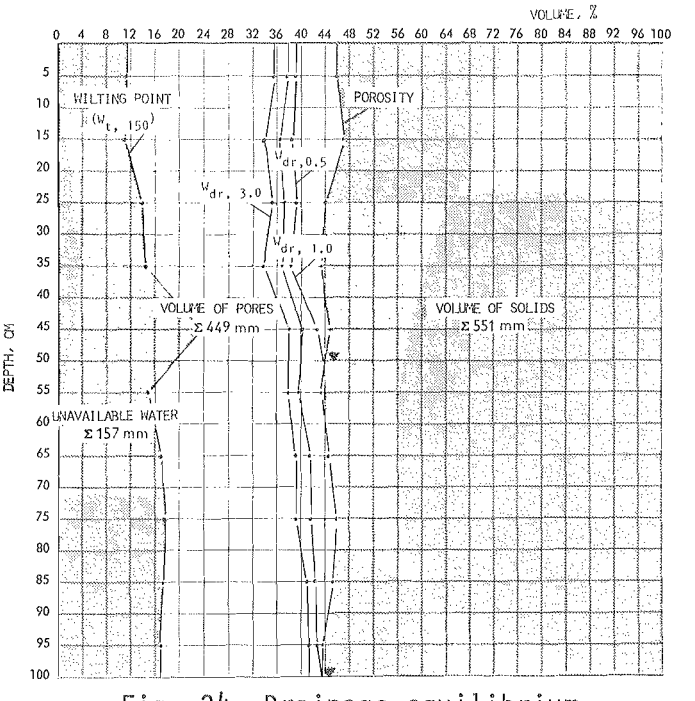


Fig. 24. Drainage equilibrium curves. Ålbo 2, 1984.

Plate 3. Vertical profile 0-100 cm and horizontal sections at 10, 25, 55 and 80 cm depth. Älbo 2, 1984.

Igelsta 1979

Igelsta, Västerås, Västmanlands län. Topographical map 11G Västerås SO, coordinates 66193/15489.
Sampling date: 4/9/1979.

Sampling site is located on a slight slope surrounded by an undulating plain. To the west lies an esker, to the north a drained marsh. The geological foundation is granite, overlain by glacial and postglacial clay at this point.

Climate (Västerås recording station): 190 day growing season with mean monthly temperature = 12.6°C and mean total rainfall = 340 mm.

Cylinder samples were taken from each 10 cm level down to 100 cm. A full vertical profile was extracted and horizontal sections were taken at 5, 25, 45 and 70 cm below the surface (Plate 4).

Soil profile description. Soil texture is shown by Fig. 25. The topsoil consists of a heavy clay with 6 % loss on ignition, the subsoil of heavy clay. There is a fairly high silt content throughout the profile, in which the average proportions of clay, silt and fine sand are 51, 30 and 13 % respectively.

The upper part of the profile has a very dense structure and although roots are found throughout the profile, they are very fine and poorly developed. The clay in the lower layers (60-100 cm) is varved and this acts as a barrier to the capillary movement of moisture.

Porosity is, on average, 47 % for the profile and is fairly constant from one level to the next. Wilting occurs at around 29 % moisture, so much of the water retained in the profile is unavailable to plants (Fig. 27). Available water storage capacity of this soil between full saturation of the pore space and wilting point is 470-292 = 178 mm down to 1 m depth. When the watertable lies 1.0 m below the surface, the profile can retain the following amount of water in its layers:

Depth (cm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	Total (mm)
Moisture (vol.%)	42.3	41.1	37.6	39.0	42.3	42.2	42.0	44.0	44.6	45.4	420.5

Plant available water at this drainage depth is 421-292 = 128 mm. The presence of layered clay in the profile restricts upward movement of moisture to the roots. This means that less moisture than 128 mm can be available to the crop and the moisture content of the profile may be insufficient during dry periods. Furthermore, the soil has a tendency to smear and form a crust which can inhibit crop establishment and reduce soil aeration.

Permeability is rather high in the 20-70 cm layers but very low below this.

Table 7. Summary of the main physical characteristics of the profile Igelsta 1979

Depth (cm)	Solids (vol%)	Pores (vol%)	Moisture content, volume %							Dry bulk density (g/cm^3)	Density of solids (g/cm^3)	Saturated hydraulic conductivity (cm/hour)
			tension, mwc					wilting point	at sampling			
			0.05	0.5	1.0	2.0	6.0					
0-10	52.1	47.9	44.6	43.2	42.2	40.7	38.1	24.3	43.7	1.38	2.65	2.5
10-20	53.5	46.5	44.2	41.8	40.8	39.2	36.9	24.3	41.7	1.42	2.66	3.6
20-30	54.9	45.1	41.6	38.0	37.2	36.1	34.2	26.0	37.3	1.48	2.69	12
30-40	53.1	46.9	42.4	39.3	38.4	37.4	35.3	26.4	39.4	1.45	2.74	9.0
40-50	52.2	47.8	44.8	42.4	41.5	40.4	38.4	30.0	42.1	1.44	2.75	10
50-60	52.3	47.7	44.5	41.9	40.9	39.8	37.0	30.8	42.8	1.44	2.75	5.6
60-70	53.9	46.1	43.5	41.3	40.5	39.8	37.8	31.2	40.7	1.48	2.75	15
70-80	52.9	47.1	44.7	43.1	42.2	41.6	39.6	32.8	42.8	1.46	2.77	0.09
80-90	52.9	47.1	45.0	43.3	42.6	42.1	40.2	32.4	42.7	1.46	2.76	0.09
90-100	52.7	47.3	45.4	43.9	42.7	41.8	40.8	34.2	44.4	1.44	2.74	1.8
Total (mm)	530.5	469.5	440.7	418.2	409.0	398.9	378.3	292.4	417.6			

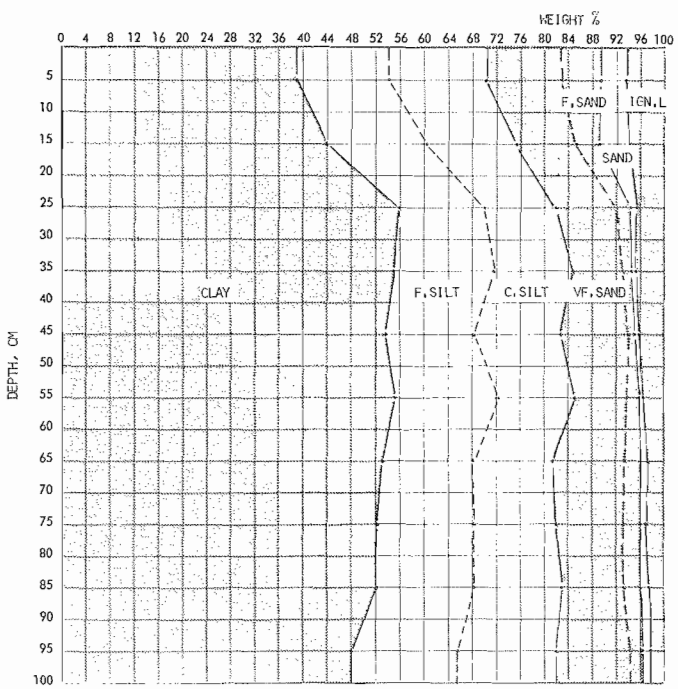


Fig. 25. Mechanical composition and loss on ignition. Igelsta 1979.

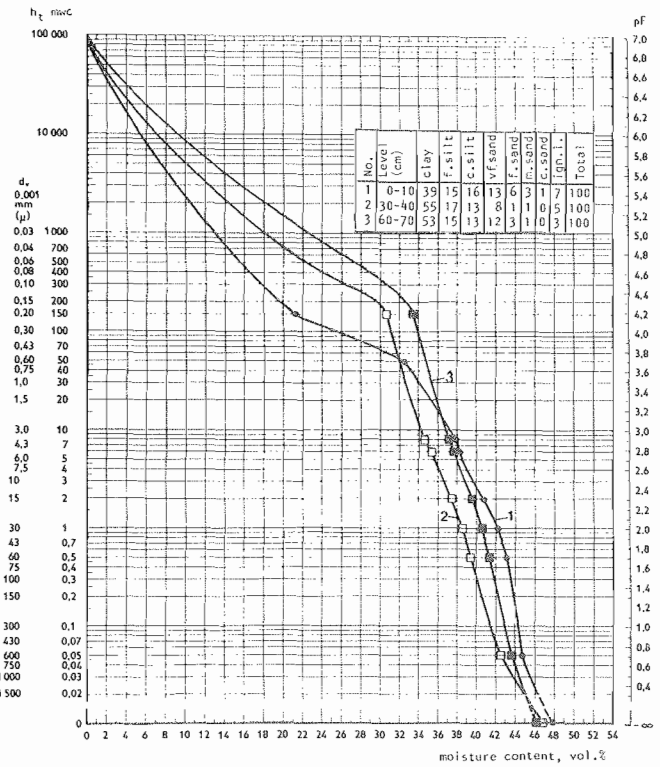


Fig. 26. Soil moisture retention curves. Igelsta 1979.

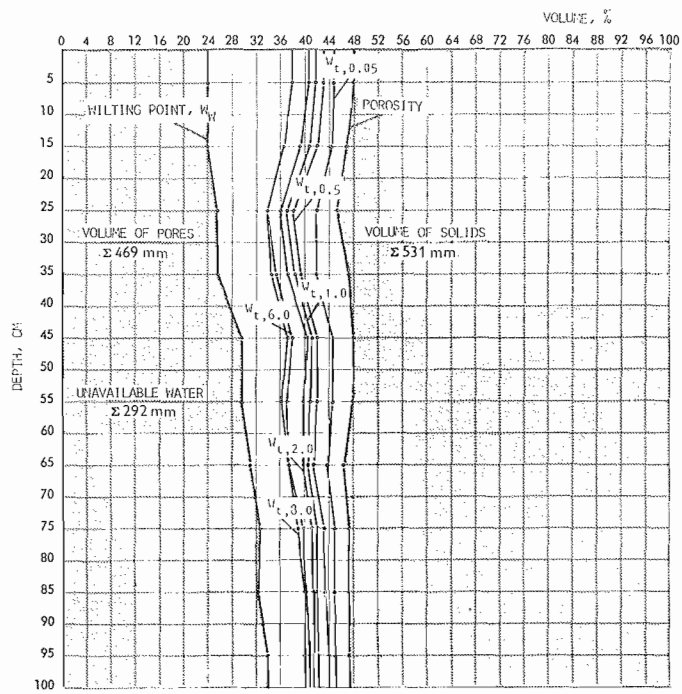


Fig. 27. Volume relations and water tension curves. Igelsta 1979.

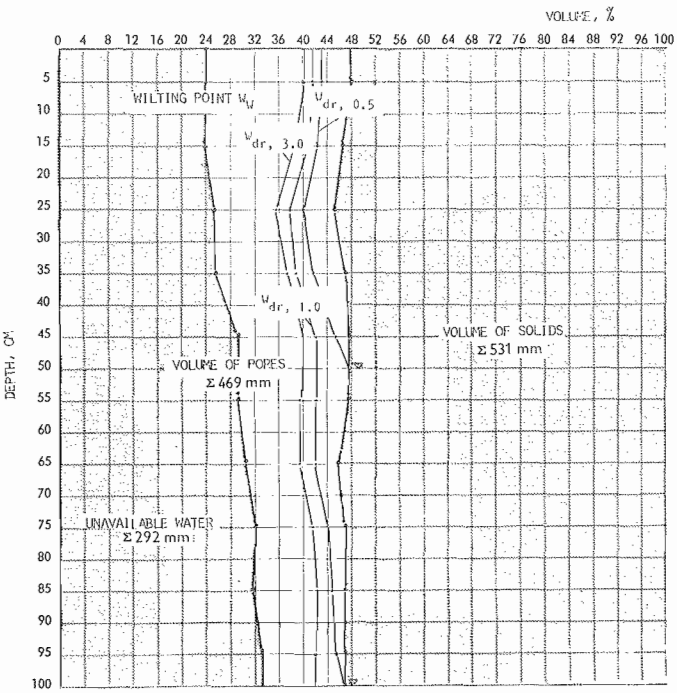


Fig. 28. Drainage equilibrium curves. Igelsta 1979.

Plate 4. Vertical profile 0-100 cm and horizontal sections at 5, 25, 45 and 70 cm depth. Igelsta 1979.

Kurö 1979

Kurö, Ängsö, Västmanlands län. Topographical map 11H Enköping SV, coordinates 66050/16522.

Sampling date: 31/8/1979.

Sampling site is located in an area which was once a bay of the lake Mälaren and which has been drained with embankments and pumps. Sampling site lies 30 m from the embankment. The geological foundation here is grey gneiss, covered by glacial and postglacial clay. On this former lake bottom, however, there is a gyttja or mud inclusion in the clay.

Climate (Västerås recording station): 190 day growing season with mean monthly temperature = 12.6°C and mean total rainfall = 340 mm.

Cylinder samples (4 replicates) were taken from each 10 cm level down to 100 cm.

Soil profile description. Soil texture is shown by Fig. 29. The soil is a heavy clay, very heavy in the 40-50 and 70-80 cm levels. Increased clay content corresponds to decreased fine sand content. Loss on ignition, which is on average 6 % by weight throughout the profile, indicates the presence of organic matter in all levels. The mean proportions of clay, silt and very fine sand in the entire profile are 54, 23 and 10 % respectively.

This profile has a well developed structure and good drainage conditions have led to formation of a permanent system of cracks, even in lower levels. Roots follow these cracks down to 50-60 cm, above which level pH is between 4 and 5. Below 60 cm depth, pH decreases rapidly from 3.8 (60-70) to 3.1 (80-90 cm) and root growth is inhibited.

Porosity is high (65 % for 0-100 cm) and increases slightly with depth (see Fig. 31). Biological wilting point could not be determined for samples below the 60-70 cm level, since low pH inhibited seedling growth. For the 20-30 to 60-70 cm levels, the very high wilting point values in relation to the moisture content at a tension of 150 mwc reflect the influence of pH. Wilting point in Figs. 31 and 32 show water retained at a tension of 150 mwc. Available water storage capacity of the soil between full saturation of the pore space and wilting point is 653-255 = 398 mm down to 1 m. When the watertable lies at 1.0 m below the surface, the following amount of water can be retained:

Depth (cm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	Total (mm)
Moisture (vol.%)	43.9	46.8	49.7	47.6	49.4	48.7	57.0	55.4	64.1	66.7	529.3

Plant available water at this drainage depth (from 150 mwc) is 529-255 = 274 mm. For 0-60 cm, the corresponding value is 286-156 = 130 mm. The soil has thus good reserves of available water during dry periods but despite this, is often low yielding. The reason for this may be chemical rather than physical conditions.

Table 8. Summary of the main physical characteristics of the profile Kurö 1979

Depth (cm)	Solids (vol%)	Pores (vol%)	Moisture content, volume %									Dry bulk density (g/cm^3)	Density of solids (g/cm^3)	Saturated hydraulic conductivity (cm/hour)
			tenslon, mwc								wilting point			
			0.05	0.5	1.0	2.0	4.0	6.0	50	150				
0-10	38.2	61.8	55.7	45.6	43.7	41.6	40.2	39.2	31.0	23.3	22.3	1.01	2.64	22
10-20	41.9	58.1	52.8	47.7	46.4	45.0	43.6	42.5	34.6	25.4	25.3	1.11	2.64	17
20-30	39.1	60.9	58.7	50.3	49.0	48.0	47.1	46.5	34.9	25.5	37.0	1.07	2.74	1.9
30-40	34.8	65.2	60.4	47.9	47.0	46.2	45.3	44.9	36.2	29.6	43.4	0.95	2.72	31
40-50	33.5	66.5	56.6	49.4	48.9	48.3	47.7	47.3	33.1	27.9	53.6	0.91	2.72	98
50-60	35.2	64.8	54.6	48.0	47.2	46.5	45.7	44.7	31.2	24.0	58.7	0.96	2.73	72
60-70	32.6	67.4	59.8	55.6	55.2	54.7	53.9	53.1	31.2	23.9	60.1	0.90	2.77	57
70-80	31.9	68.1	57.7	52.5	51.9	51.4	50.7	49.9	32.8	26.2		0.88	2.77	54
80-90	30.6	69.4	65.0	60.9	60.4	59.8	59.0	58.3	31.2	24.4		0.84	2.75	17
90-100	29.5	70.5	66.7	63.7	63.3	62.8	62.0	61.5	31.7	24.7		0.82	2.79	40
Total (mm)	347.3	652.7	588.0	521.6	513.0	504.3	495.2	487.9	327.9	254.9				

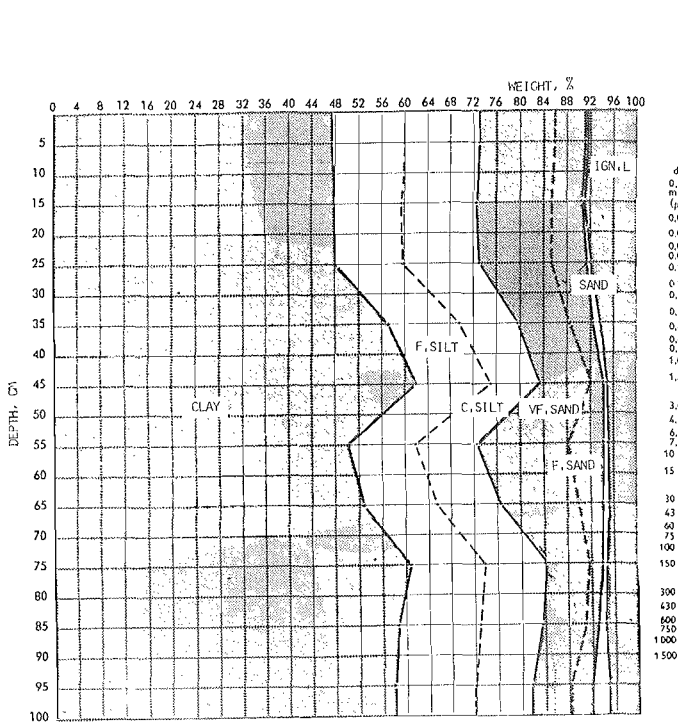


Fig. 29. Mechanical composition and loss on ignition. Kurö 1979.

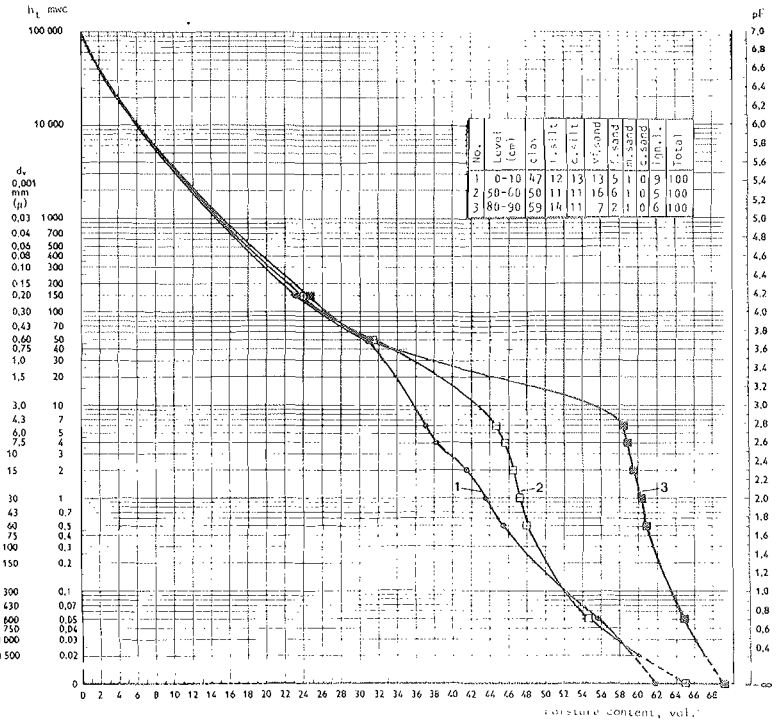


Fig. 30. Soil moisture retention curves. Kurö 1979.

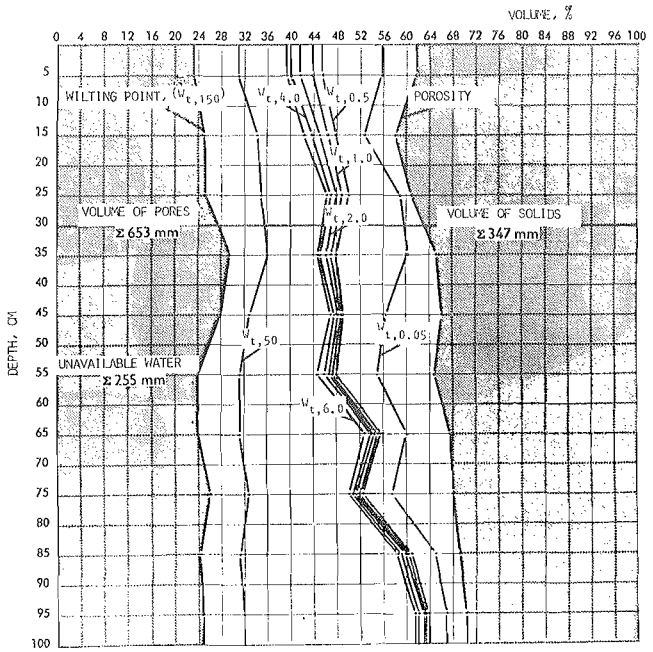


Fig. 31. Volume relations and water tension curves. Kurö 1979.

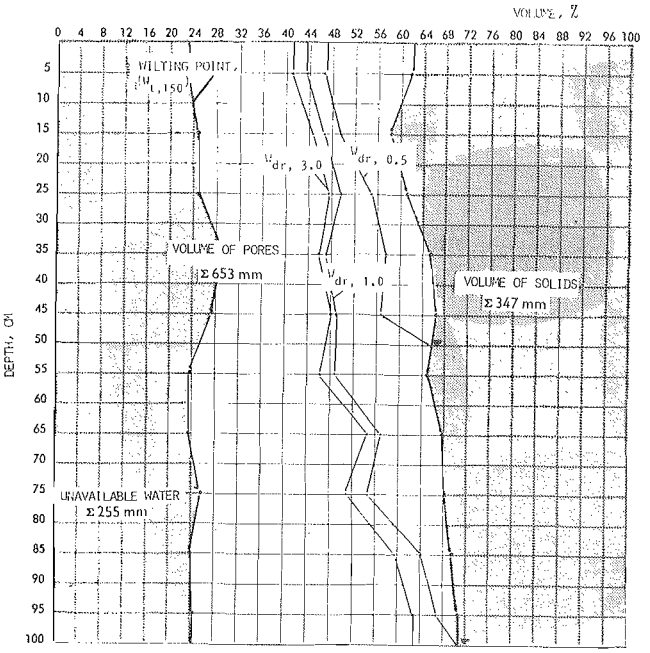


Fig. 32. Drainage equilibrium curves. Kurö 1979.

Limsta 1982

Limsta, Ransta, Västmanlands län. Topographical map 11G Västerås NO, coordinates 66323/15441.
Sampling date: 9/11/1982.

Sampling site is located on the upper part of an open plain which slopes gently towards a river in the south-east. The geological foundation is gneiss, overlain by glacial and postglacial clay.

Climate (Västerås recording station): 190 day growing season with mean monthly temperature = 12.6°C and mean total rainfall = 340 mm.

Cylinder samples (4 replicates) were taken from each 10 cm level down to 100 cm. A full vertical section was extracted and horizontal sections were taken at 10, 30, 55 and 80 cm below the surface (Plate 5).

Soil profile description. Soil texture is shown by Fig. 33. The topsoil consists of heavy clay, the subsoil of very heavy clay. Respective proportions of fine and coarse silt increase from 12 and 5 % (30-40 cm) to 17 and 15 % (90-100 cm). The topsoil contains 9 % very fine sand and 16 % fine sand but in the subsoil these fractions decrease to 3 and 1 % respectively.

The upper layers of this profile have a very compact structure with large, blocky aggregates and a dense plough pan. Hydraulic conductivity is very low (Table 9) and water in the upper layers is prevented from reaching the drains.

Porosity increases from 45 % in the topsoil to 52 % in the subsoil. Wilting occurs at between 29 % moisture (0-30 cm) and 37 % (30-100 cm). Available water storage capacity of this soil between full saturation of the pore space and wilting point is 491-350 = 141 mm. When the watertable lies 1.0 m under the surface, the following amounts of water can be retained by the profile:

Depth (cm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	Total (mm)
Moisture (vol.%)	41.8	42.2	44.4	48.4	47.4	47.6	48.0	48.0	49.3	50.2	467.3

Plant available water at this drainage depth is 467-350 = 117 mm. This represents a reasonably good moisture reserve for the crop during dry periods, provided that roots have penetrated the plough pan. The main problem with this soil tends to be waterlogging of the upper layers during wet periods.

Table 9. Summary of the main physical characteristics of the profile Limsta 1982

Depth (cm)	Solids (vol%)	Pores (vol%)	Moisture content, volume %							Dry bulk density (g/cm^3)	Density of solids (g/cm^3)	Saturated hydraulic conductivity (cm/hour)
			tension, mwc					wilting point	at sampling			
			0.05	0.5	1.0	2.0	6.0					
0-10	54.7	45.3	43.5	42.6	41.7	40.4	38.7	27.6	41.8	1.45	2.66	0.12
10-20	54.7	45.3	43.5	42.7	42.0	40.9	38.5	27.7	41.8	1.45	2.66	0.01
20-30	53.5	46.5	45.1	44.7	44.1	43.3	41.4	32.6	42.9	1.45	2.71	0.02
30-40	48.8	51.2	48.7	48.5	48.0	47.4	45.8	36.4	46.6	1.35	2.76	0.11
40-50	49.2	50.8	48.6	47.5	46.7	45.9	44.5	36.7	45.2	1.36	2.76	0.34
50-60	48.2	51.8	49.9	47.3	46.4	45.7	44.2	35.4	45.8	1.34	2.78	6.9
60-70	49.8	50.2	48.9	47.6	46.9	46.4	45.1	36.7	46.1	1.37	2.75	0.04
70-80	50.9	49.1	48.5	47.3	46.8	46.4	45.3	39.4	45.7	1.41	2.76	7.2
80-90	49.8	50.2	49.5	48.6	48.4	48.0	47.0	38.4	47.3	1.38	2.77	0.37
90-100	49.8	50.2	50.2	48.5	48.2	48.1	47.2	38.6	47.2	1.38	2.78	0.10
Total (mm)	509.4	490.6	476.4	465.3	459.2	452.5	437.7	349.5	450.4			

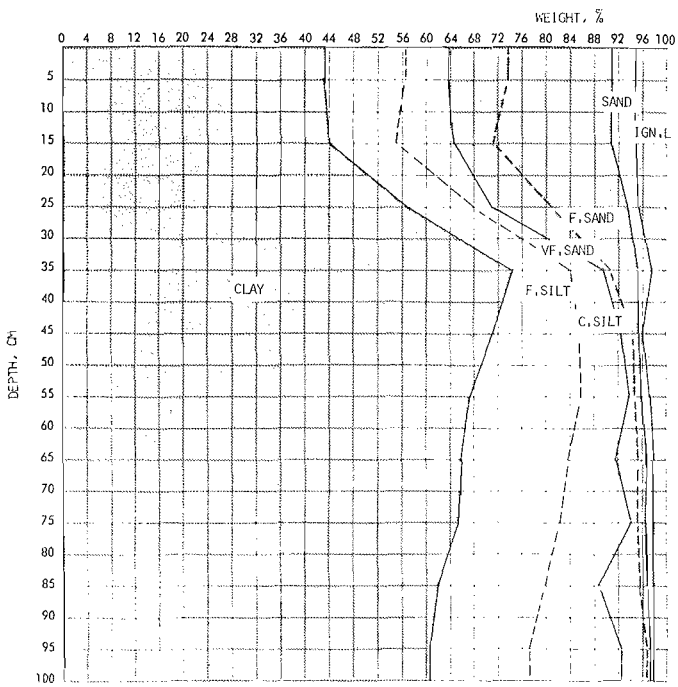


Fig. 33. Mechanical composition and loss on ignition. Limsta 1982.

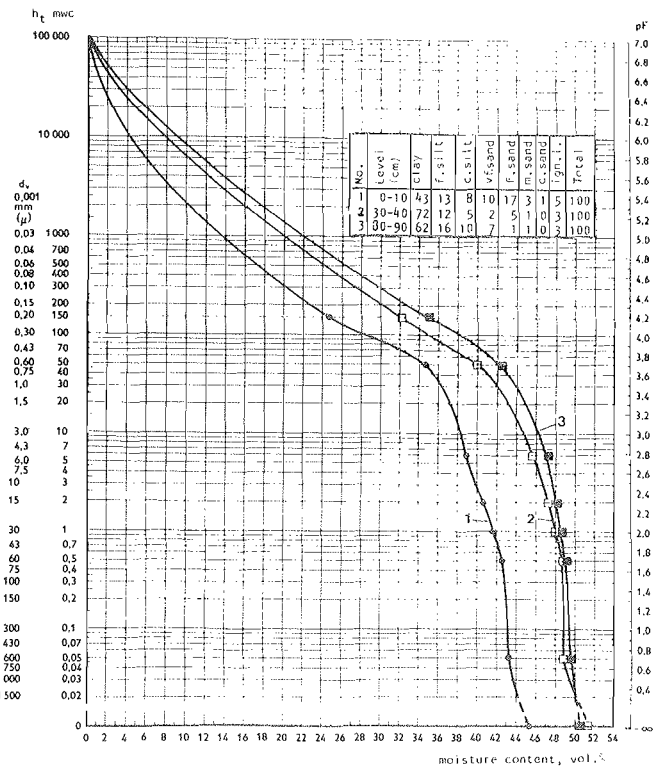


Fig. 34. Soil moisture retention curves. Limsta 1982.

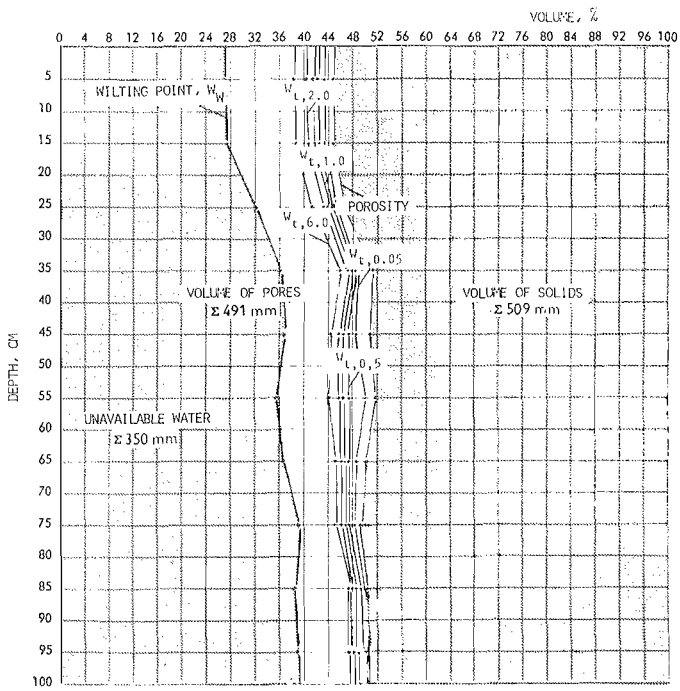


Fig. 35. Volume relations and water tension curves. Limsta 1982.

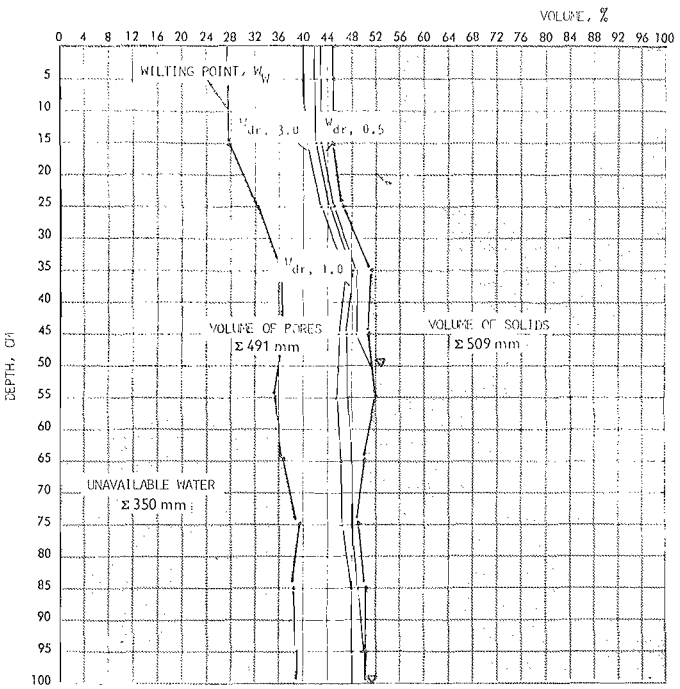


Fig. 36. Drainage equilibrium curves. Limsta 1982.

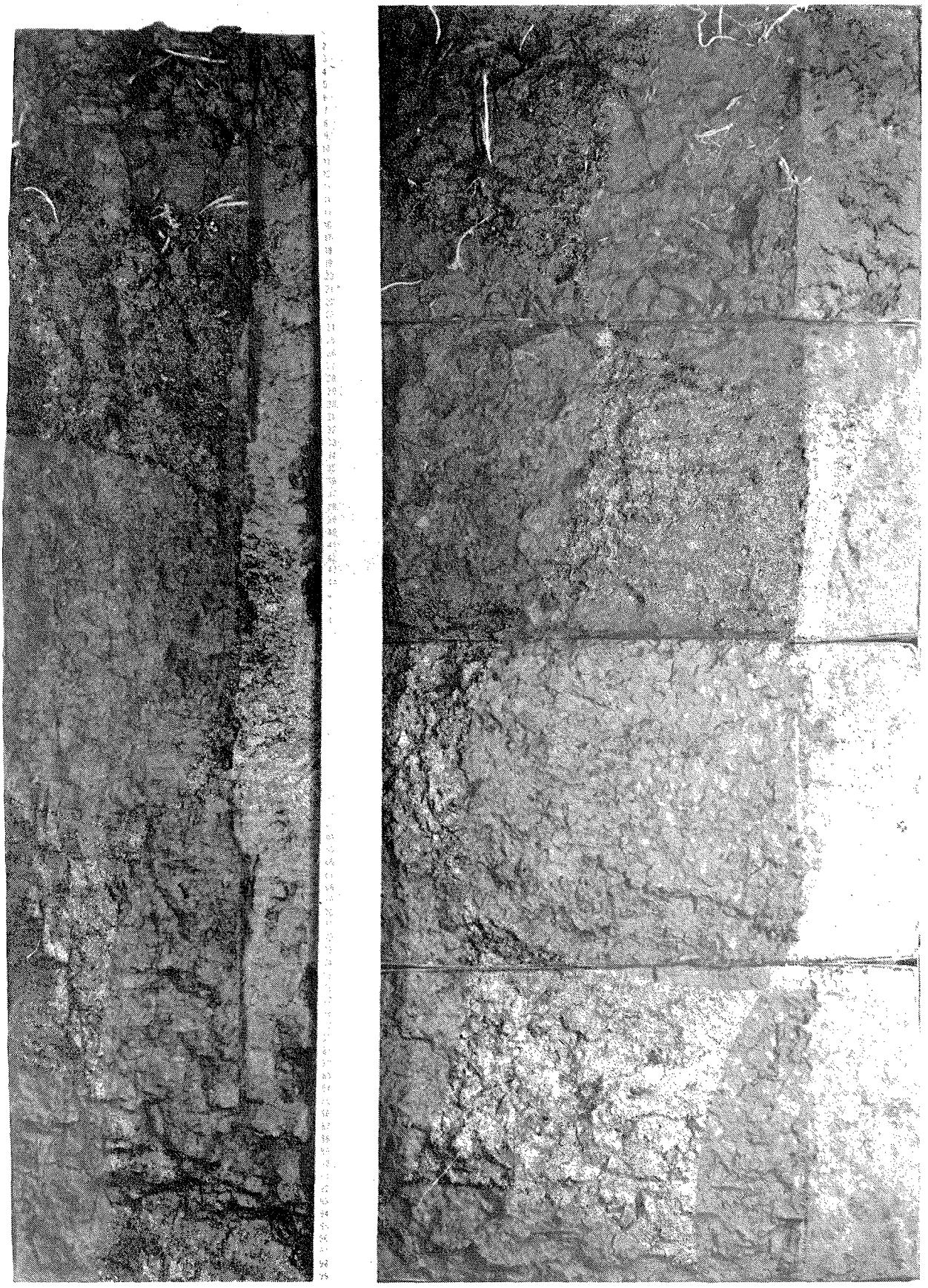


Plate 5. Vertical profile 0-100 cm and horizontal sections at 10, 30, 55 and 80 cm depth. Limsta 1982.

Ugerup 1981

Ugerup, Kristianstad, Kristianstad län. Topographical map 3D Kristianstad SO, coordinates 62052/13948.
Sampling date: 28/8/1981.

Sampling site is located in a field surrounded by trees planted to form a windbreak. The surrounding area is a wide, flat plain which is subject to wind erosion. The foundation of Cretaceous rock is overlain by sand and fine sand deposited by melting land ice.

Climate (Kristianstad recording station): 220 day growing season with mean monthly temperature = 12.7°C and mean total rainfall = 390 mm.

Cylinder samples (4 replicates) were taken from each 10 cm level down to 100 cm.

Soil profile description. Soil texture is shown by Fig. 37. The topsoil consists of fine to medium sand with a low humus content, the subsoil of a somewhat coarser sand. Proportions of fine, medium and coarse sand in the topsoil are 56, 29 and 5 % respectively. In the subsoil, these fractions form 43, 36 and 15 % (40-70 cm) and 29, 61 and 5 % (70-100 cm). The upper 30 cm of the profile contains an average of 3 % clay, the subsoil 0.7 % clay.

The profile has a very poorly developed, almost single grained, structure and root depth is limited to the topsoil. Permeability is high in all levels and increases somewhat with depth.

Porosity is on average 42 % for the entire profile. Because of the coarse texture of the soil, wilting occurs at very low moisture contents. At wilting, the topsoil contains 6-7 % moisture and the subsoil contains even less (Table 10). Available water storage capacity of the profile between full saturation of the pore space and wilting point is 415-47 = 368 mm down to 1 m depth. Moisture is easily removed from the soil by application of even low tensions (Fig. 39). When the water table lies at 1.0 m below the surface, the following amount of water can be retained by the soil layers:

Depth (cm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	Total (mm)
Moisture (vol.%)	17.7	21.8	19.1	16.5	13.4	19.3	24.7	30.3	35.8	42.4	241.0

Plant available water at this drainage depth is thus 241-47 = 194 mm. Since root development is restricted to the topsoil, maximum amount of water available in the 0-30 cm layer is 59-17 = 42 mm. This represents a poor moisture reserve and irrigation is normally required to ensure crop yields on this sandy soil.

Table 10. Summary of the main physical characteristics of the profile Ugerup 1981

Depth (cm)	Solids (vol%)	Pores (vol%)	Moisture content, volume %							Dry bulk density (g/cm^3)	Density of solids (g/cm^3)	Saturated hydraulic conductivity (cm/hour)
			tension, mwc					wilting point	at sampling			
			0.05	0.5	1.0	3.0	6.0					
0-10	56.7	43.3	42.3	26.6	16.7	12.6	11.0	6.6	15.7	1.45	2.55	9.5
10-20	55.6	44.4	42.9	28.6	18.9	14.1	12.6	5.9	18.3	1.42	2.56	8.0
20-30	58.4	41.6	40.9	25.1	13.1	10.1	8.9	4.1	13.6	1.51	2.58	11
30-40	62.3	37.7	35.8	20.0	8.4	5.9	4.7	3.4	11.6	1.60	2.57	11
40-50	62.0	38.0	34.3	14.0	8.0	6.1	4.9	4.3	10.8	1.59	2.57	18
50-60	62.8	37.2	34.2	17.4	11.1	8.5	7.6	4.4	14.0	1.62	2.58	11
60-70	59.2	40.8	36.6	18.8	12.3	9.8	8.4	4.3	15.2	1.54	2.60	17
70-80	56.2	43.8	40.9	17.0	10.3	7.7	6.5	5.0	15.3	1.46	2.59	29
80-90	56.3	43.7	41.5	15.7	10.2	8.4	7.3	5.1	17.1	1.45	2.58	37
90-100	54.9	45.1	42.4	17.2	11.8	9.5	8.5	4.3	26.4	1.42	2.58	30
Total (mm)	584.4	415.6	391.8	200.4	120.8	92.7	80.4	47.4	158.0			

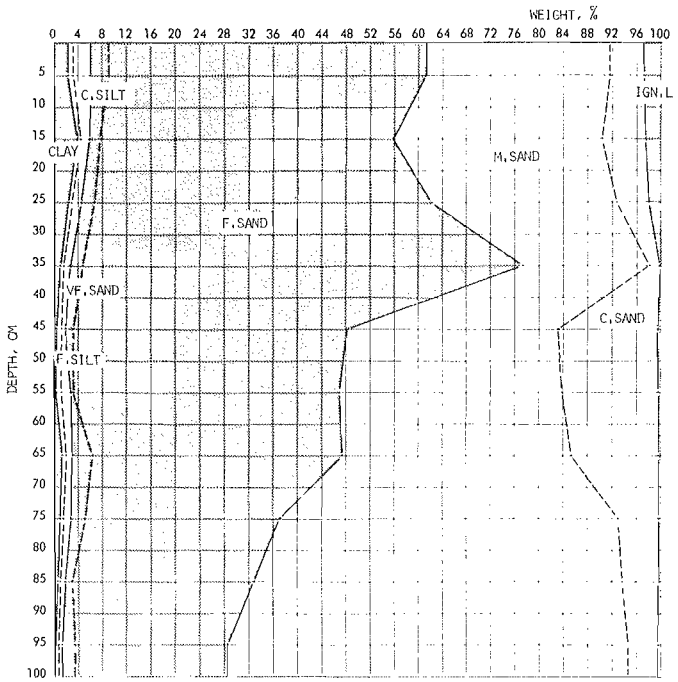


Fig. 37. Mechanical composition and loss on ignition. Ugerup 1981.

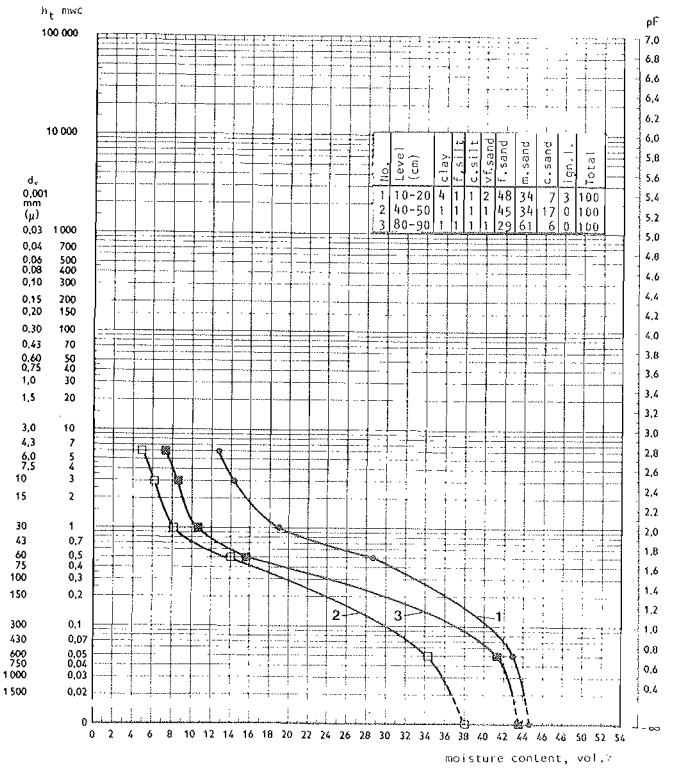


Fig. 38. Soil moisture retention curves. Ugerup 1981.

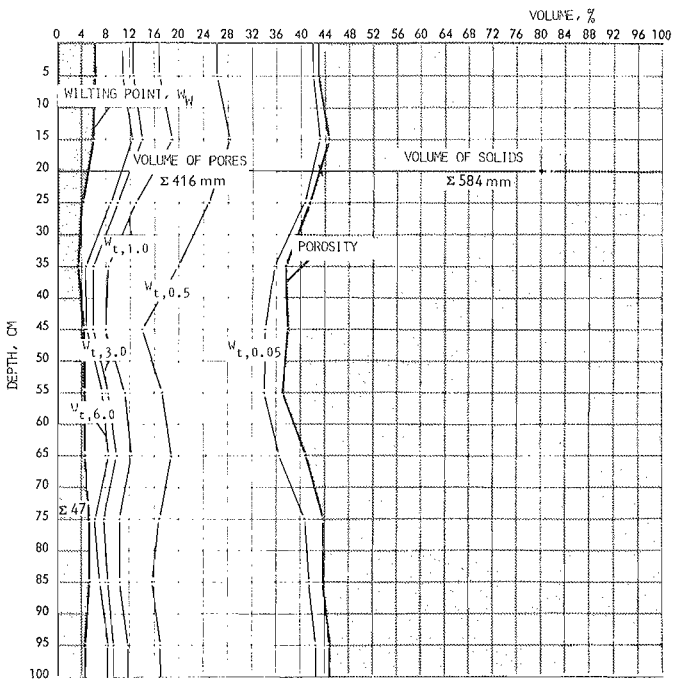


Fig. 39. Volume relations and water tension curves. Ugerup 1981.

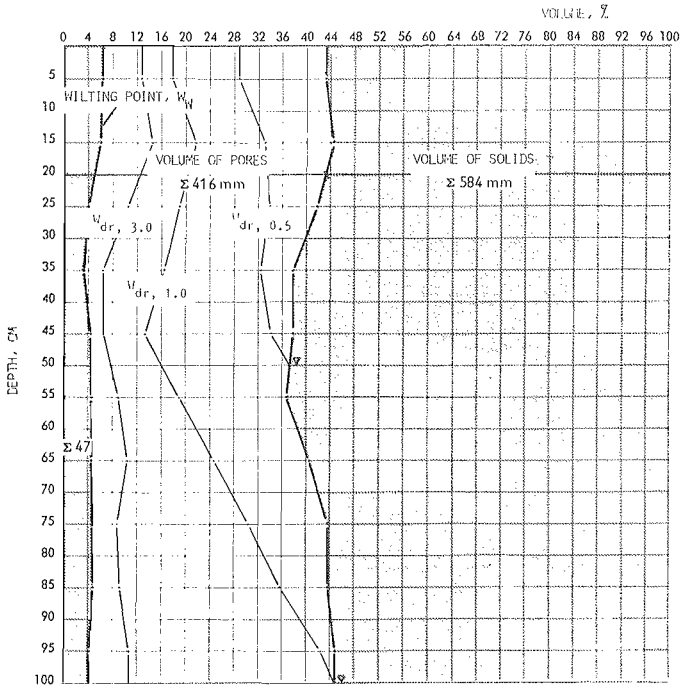


Fig. 40. Drainage equilibrium curves. Ugerup 1981.

Sveden 1982

Sveden, Stora Tuna, Kopparbergs län. Topographical map 13F Falun SO, coordinates 67050/14824.
Sampling date: 3/11/1982.

Sampling site is located on a wide fluvial plain where the geological foundation consists of granite covered in places by blocky moraine and at the sampling site by silt deposits.

Climate (Falun recording station): 165 day growing season with mean monthly temperature = 11.7°C and mean total rainfall = 340 mm.

Cylinder samples (4 replicates) were taken from each 10 cm level down to 100 cm. A full vertical section was extracted and horizontal sections were taken at 10, 25, 50 and 85 cm below the surface (Plate 6).

Soil profile description. Soil texture is shown by Fig. 41. The topsoil consists of a silty light clay, the subsoil of a silty light clay (40-60 cm) and a silty medium clay (60-100 cm). The clay content increases from 16 to 35 % with depth. The fine silt and coarse silt fractions make up 25 and 37 % of the profile and these values remain constant in all levels except the 50-70 cm level. The proportion of fine sand ranges from 5 % in the 20-30 cm level to 23 % in the 50-60 cm level.

The soil has a weak structure which is very unstable. There are few pores and no roots occur below 55 cm, where the profile becomes layered. Alternating clay layers (2 mm thick) and silt layers (1 mm thick) begin at 55 cm and continue below 100 cm depth.

Apart from the 0-10 and 10-20 cm levels where the values are 55 and 54 % respectively, porosity in the profile is low (average 42 % for 20-100 cm). Wilting occurs at between 9 and 23 % moisture or at an average of 16 % for the full profile. Available water storage capacity of this soil between full saturation of the pore space and wilting point is 441-157 = 284 mm down to 1 m depth. When the watertable lies at 1.0 m below the surface, the profile can retain the following amount of water:

Depth (cm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	Total (mm)
Moisture (vol.%)	38.6	38.8	34.2	34.0	33.0	34.5	37.5	40.8	42.2	45.0	378.6

Root depth is effectively restricted to the upper 55 cm of the profile by the varved structure below. Plant available water at 1 m drainage in the 0-60 cm layer is 213-73 = 140 mm, so the soil has adequate water reserves. Problems with this soil are its low permeability under 20 cm depth and its tendency to smear during spring rain and to form a crust during subsequent drying.

Table 11. Summary of the main physical characteristics of the profile Sveden 1982

Depth (cm)	Solids (vol%)	Pores (vol%)	Moisture content, volume %									Dry bulk density (g/cm^3)	Density of solids (g/cm^3)	Saturated hydraulic conductivity (cm/hour)
			tension, mwc							wilting point	at sampling			
			0.05	0.5	1.0	2.0	6.0	50	150					
0-10	45.0	55.0	43.5	39.7	38.5	35.8	34.2	14.0	8.1	12.1	39.5	1.17	2.61	8.6
10-20	46.3	53.7	44.8	39.4	38.5	36.1	34.9	14.0	8.1	10.9	38.8	1.22	2.64	24
20-30	59.2	40.8	36.7	34.5	33.8	32.9	32.2	12.6	6.5	9.4	34.0	1.59	2.68	0.40
30-40	58.5	41.5	36.9	34.3	33.3	32.8	32.0	16.4	8.8	10.9	33.2	1.57	2.68	7.4
40-50	61.6	38.4	35.4	33.1	32.3	31.9	31.1	18.0	10.3	13.4	32.5	1.65	2.68	0.35
50-60	59.5	40.5	36.2	34.3	33.6	33.1	31.9	21.6	12.5	16.5	34.1	1.60	2.69	0.07
60-70	59.3	40.7	38.6	36.9	36.2	35.6	34.5	25.7	13.9	22.8	35.6	1.60	2.70	1.4
70-80	57.3	42.7	41.2	40.4	39.8	39.2	37.9	31.1	16.1	20.1	38.8	1.55	2.71	0.03
80-90	57.4	42.6	42.3	41.7	41.3	40.9	39.8	38.7	17.6	18.5	40.4	1.56	2.72	0.02
90-100	55.0	45.0	45.3	44.9	44.7	44.5	43.8	38.6	17.5	22.6	44.0	1.50	2.72	0.02
Total (mm)	559.1	440.9	400.9	379.2	372.0	362.8	352.3	230.7	119.4	157.2	370.9			

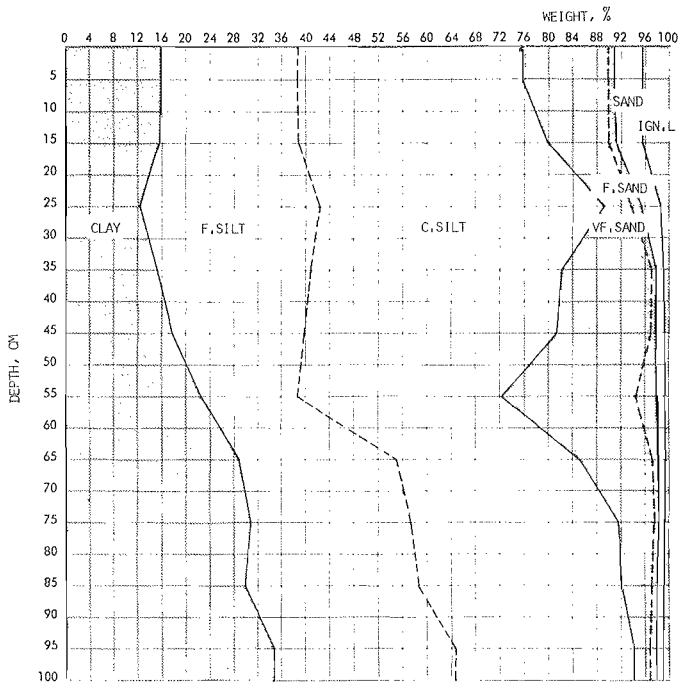
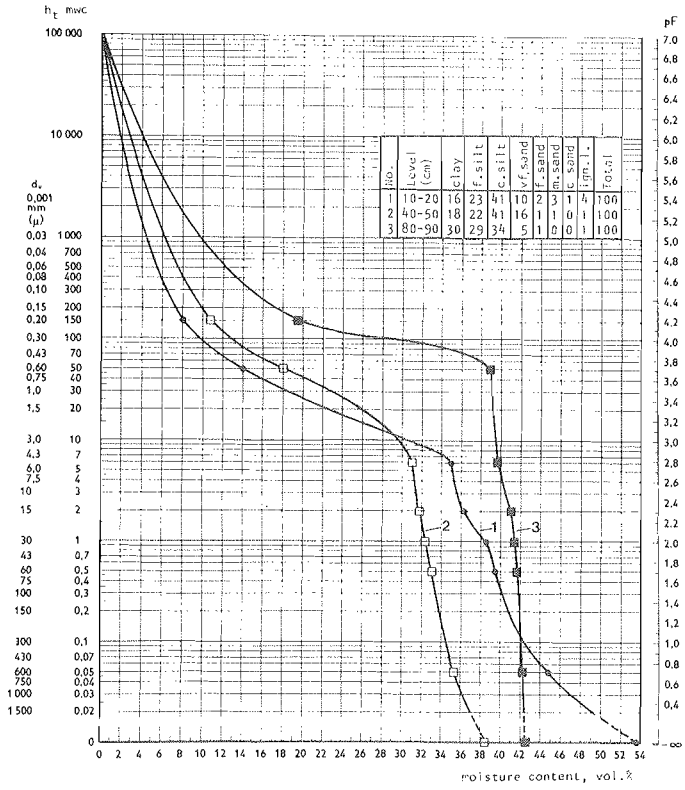


Fig. 41. Mechanical composition and loss on ignition. Sveden 1982.



No.	Level (cm)	Clay	F.silt	C.silt	Vf.sand	F.sand	m.sand	c.sand	Im.l.	Total
1	10-20	16	23	41	10	2	3	1	4	100
2	40-50	18	22	41	16	1	1	0	1	100
3	80-90	30	29	34	5	1	0	0	1	100

Fig. 42. Soil moisture retention curves. Sveden 1982.

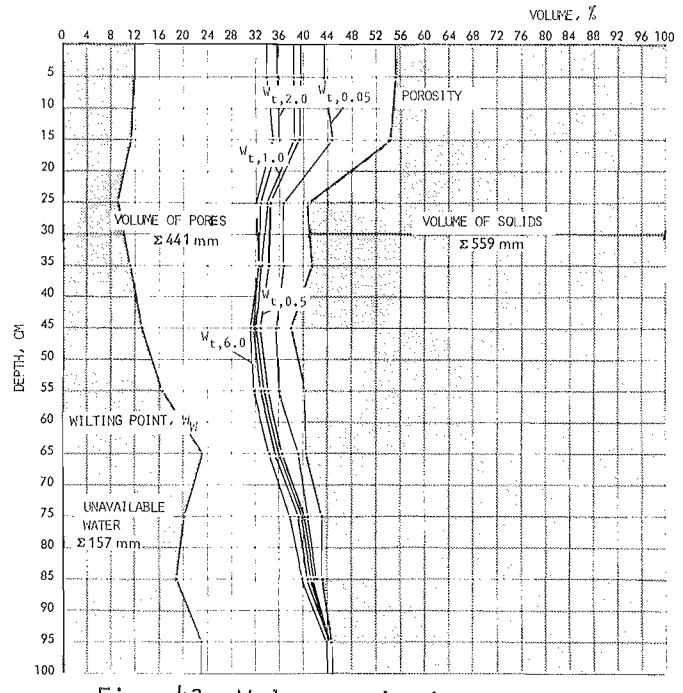


Fig. 43. Volume relations and water tension curves. Sveden 1982.

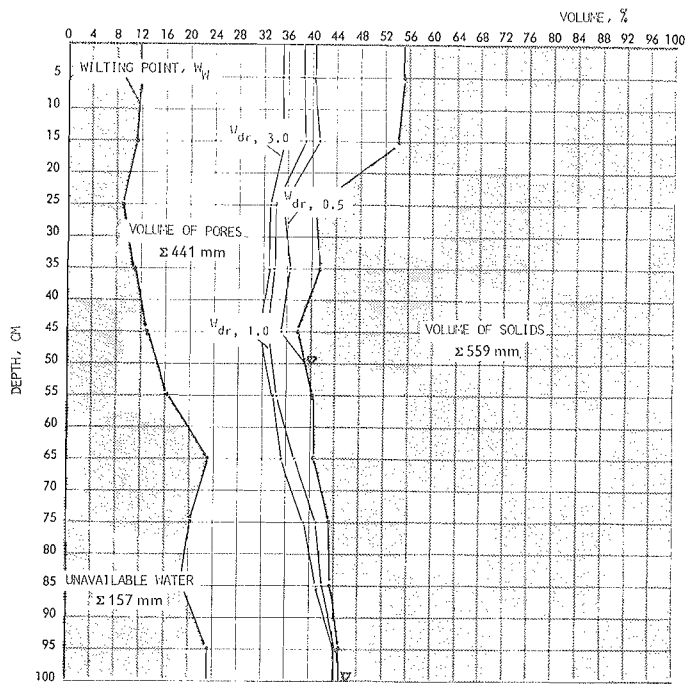


Fig. 44. Drainage equilibrium curves. Sveden 1982.

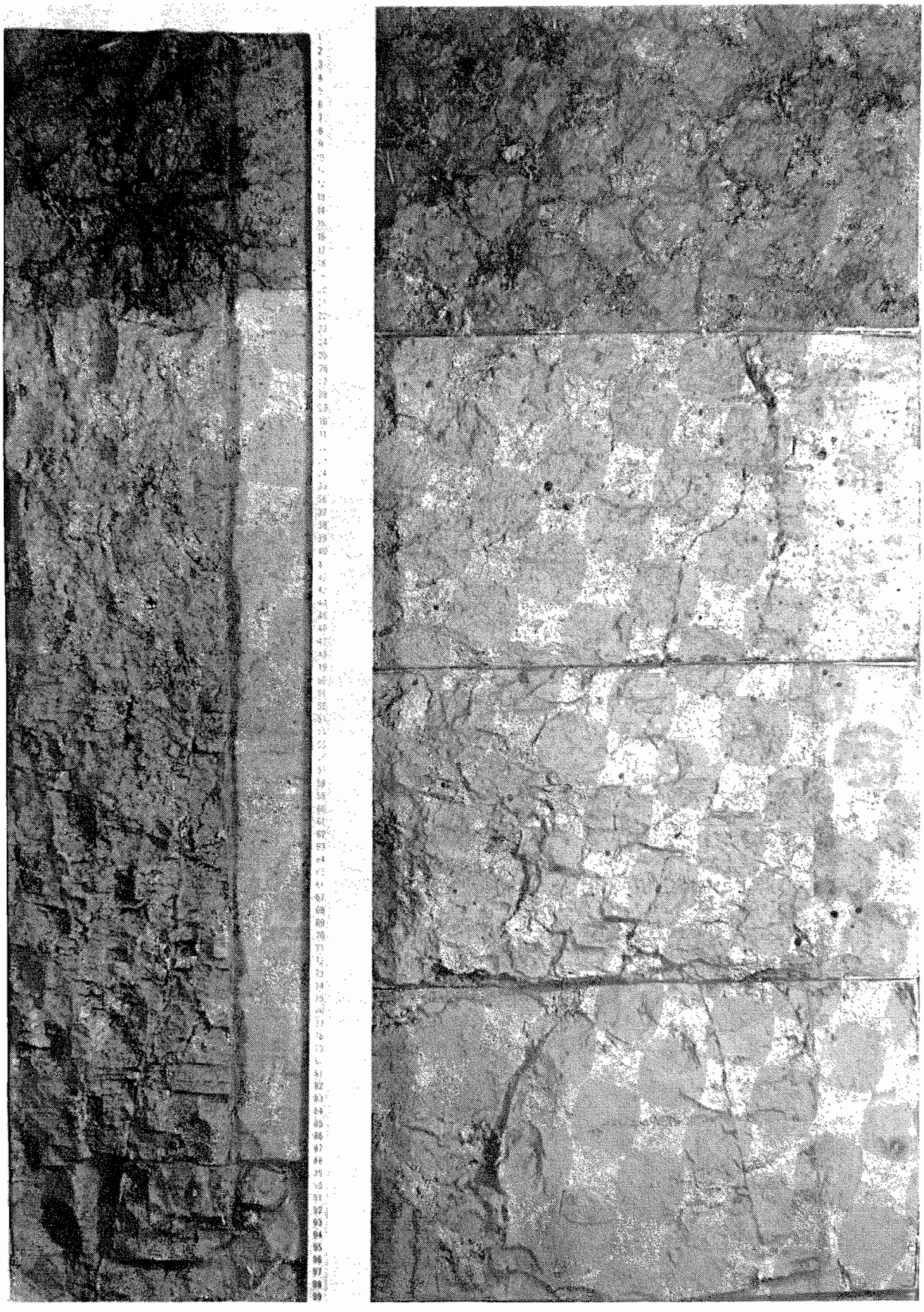


Plate 6. Vertical profile 0-100 cm and horizontal sections at 10, 25, 50 and 85 cm depth. Sveden 1982.

Värmlands Säby 1983

Värmlands Säby, Kristinehamn, Värmlands län. Topographical map 10E Karlskoga SV, coordinates 65515/14033.
Sampling date: 17/11/1983.

Sampling site is part of a large flat area drained by embankments and pumps. The area is part of a peninsula formed between two inlets in the north-west corner of Lake Vänern. The geological foundation is granite, covered with a thin layer of glacial clay and postglacial clay with sand layers. The latter were deposited in varying thicknesses by wave action.

Climate (Karlstad recording station): 200 day growing season with mean monthly temperature = 11.4°C and mean total rainfall = 380 mm.

Cylinder samples (4 replicates) were taken from each 10 cm level down to 100 cm. A full vertical section was extracted and horizontal sections were taken from 10, 25, 60 and 80 cm below the surface (Plate 7).

Soil profile description. Soil texture is shown by Fig. 45. The topsoil consists of a sandy medium clay with a low humus content and a high silt content. A very thin layer of fine sand occurs at 20-30 cm. The subsoil consists of a heavy clay (30-60 cm) and a layer containing 80 % very fine and fine sand (70-80 cm).

Structure of the soil is dominated by the presence of the sandy layers, which present a textural barrier to root growth and capillary movement of water.

Porosity varies with the mechanical composition of the layers (Fig. 47). It is on average, 43 % in the topsoil and 49 % for the full profile. It is lowest (39 %) in the sand layer at 70 cm and highest (61 %) in the 80-100 cm layer. Wilting point also varies throughout the profile. It occurs at 26 % moisture in the topsoil, at 36 % in layers with a high clay content (30-40, 60-70 cm) and at 8 % in the sandy layer (70-80 cm). Water holding capacity in individual levels varies accordingly, especially at tensions greater than 2 m water column (Fig. 47). Available water storage capacity of the soil between full saturation of the pore space and wilting point is 487-276 = 211 mm. When the watertable lies 1.0 m under the surface, the profile can retain the following amount of water:

Depth (cm)	0-10	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	Total (mm)
Moisture (vol.%)	37.2	40.4	36.3	46.4	43.9	49.0	50.0	37.9	58.9	60.3	460.3

Since root depth is restricted to above the sand layer at 70 cm, plant available water at 1.0 m drainage depth in the 0-70 cm layer is 303-207 = 96 mm. This is adequate to supply the crop only during shorter dry periods.
Permeability is rather low in all layers except 60-70 and 80-100 cm.

Table 12. Summary of the main physical characteristics of the profile Värmlands Säby 1983

Depth (cm)	Solids (vol%)	Pores (vol%)	Moisture content, volume %							Dry bulk density (g/cm^3)	Density of solids (g/cm^3)	Saturated hydraulic conductivity (cm/hour)
			tension, mwc					wilting point	at sampling			
			0.05	0.5	1.0	2.0	6.0					
0-10	54.3	45.7	40.2	38.5	37.1	36.2	34.1	23.5	36.3	1.43	2.64	1.0
10-20	56.9	43.1	41.9	41.0	40.2	39.4	37.3	29.1	39.5	1.50	2.64	0.02
20-30	59.9	40.1	37.7	36.8	35.8	33.9	28.8	24.4	35.9	1.59	2.65	0.04
30-40	52.0	48.0	47.4	46.6	46.0	45.6	43.8	35.5	45.4	1.41	2.72	0.22
40-50	53.1	46.9	46.3	44.0	42.8	40.9	35.8	25.6	41.9	1.45	2.73	0.03
50-60	49.6	50.4	49.9	48.9	48.3	47.8	45.6	31.4	47.9	1.35	2.73	0.08
60-70	48.3	51.7	51.1	49.4	48.5	47.7	42.1	37.3	48.6	1.31	2.71	3.5
70-80	60.7	39.3	38.3	37.3	36.6	32.9	15.6	7.9	37.5	1.63	2.68	0.12
80-90	39.2	60.8	59.2	58.0	57.3	56.7	53.9	29.5	58.1	1.06	2.71	52
90-100	38.5	61.5	60.5	59.2	58.4	57.8	54.3	32.2	60.0	1.05	2.73	14
Total (mm)	512.5	487.5	472.5	459.7	451.0	438.9	391.3	276.4	451.1			

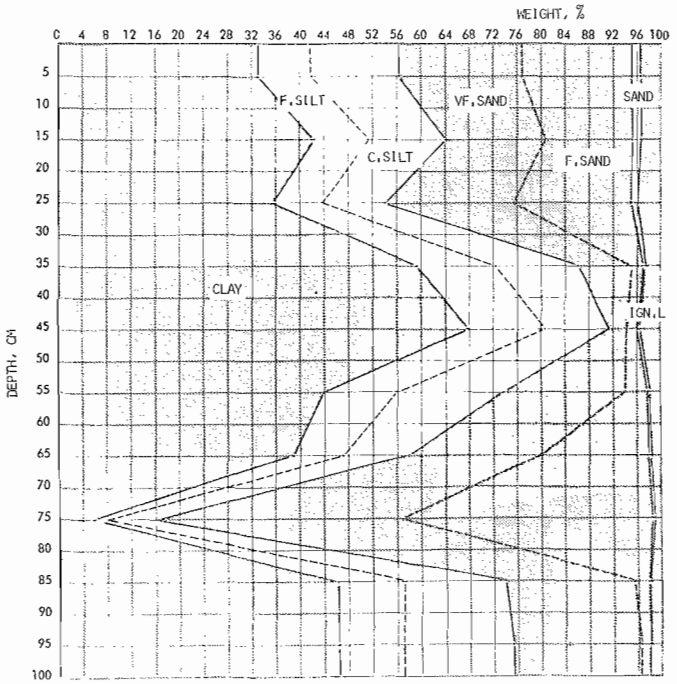


Fig. 45. Mechanical composition and loss on ignition. Värmlands Säby 1983.

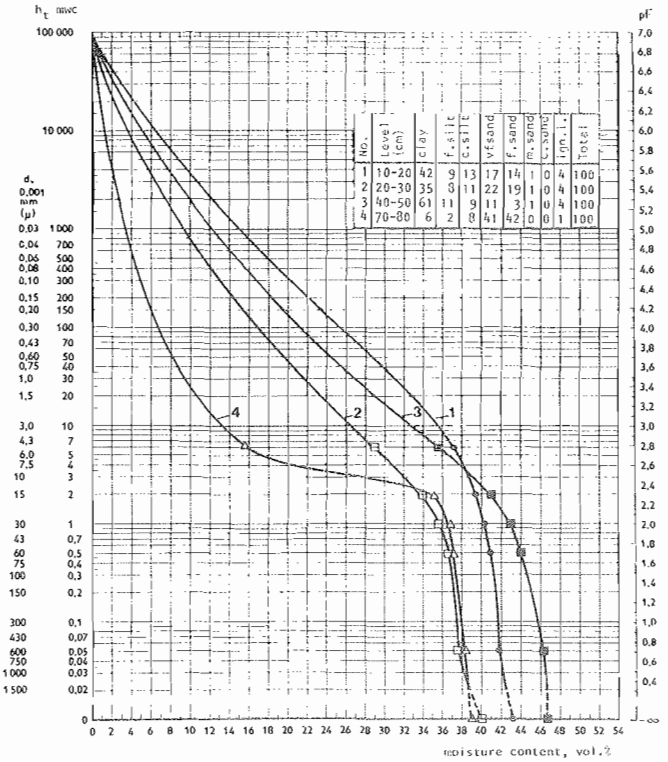


Fig. 46. Soil moisture retention curves. Värmlands Säby 1983.

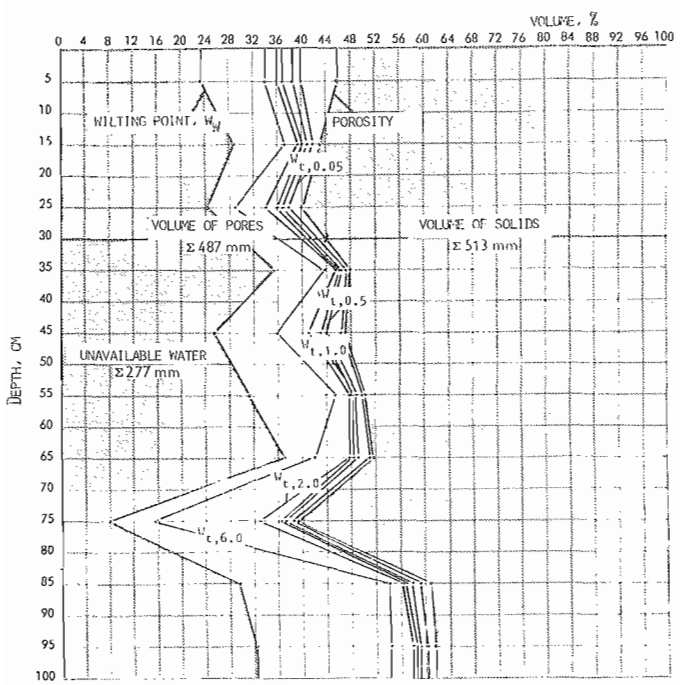


Fig. 47. Volume relations and water tension curves. Värmlands Säby 1983.

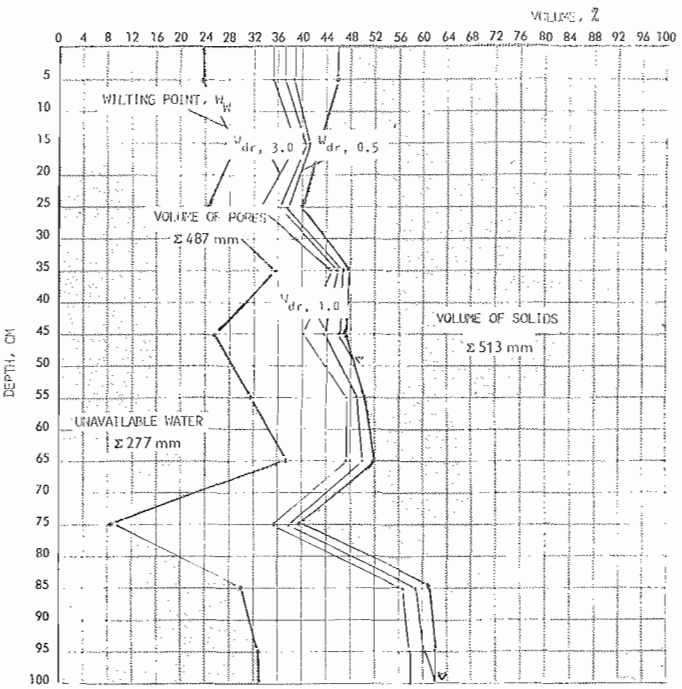


Fig. 48. Drainage equilibrium curves. Värmlands Säby 1983.

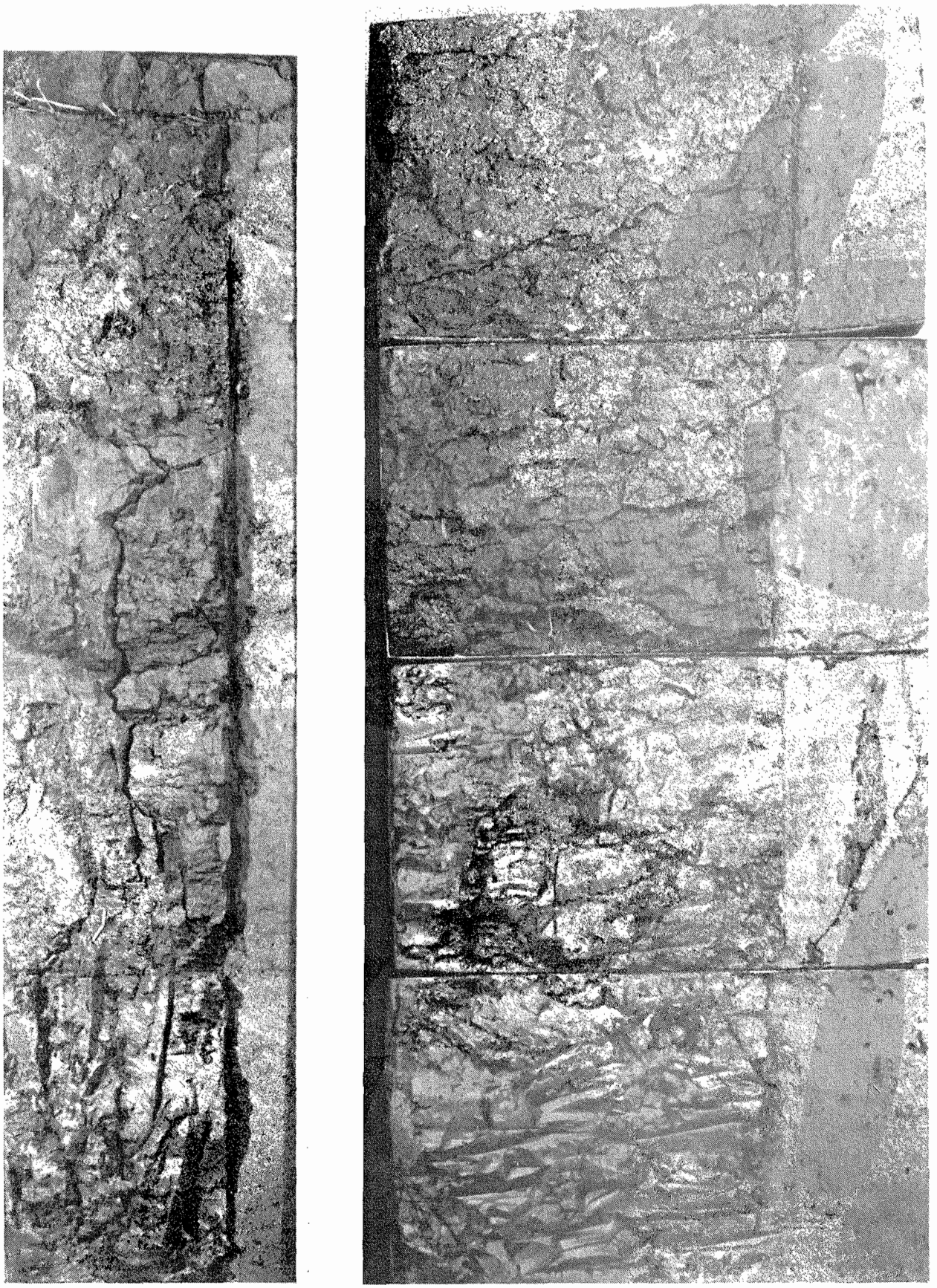


Plate 7. Vertical profile 0-100 cm and horizontal sections at 10, 25, 60 and 80 cm depth. Värmlands Säby 1983.

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