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Physical properties of afforested former agricultural peat soils in western Finland

Metsitettyjen turvepeltojen maan fysikaaliset ominaisuudet

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The bulk density, organic matter content and soil water-retention characteristics of twenty-one afforested former agricultural peat soils were studied. Soil samples were collected from 5–10-cm, 15–20-cm, 25–30-cm and 35–40-cm soil layers. The studied soils' physical properties differed from those of undrained peatlands and peatlands drained for forestry mainly due to the mixing of mineral soil with the peat during cultivation. In the case of thick peat soils (peat layer > 30 cm), the bulk density was at a maximum (0.37 g cm^{-3}), and the organic matter content at a minimum (54%) in the uppermost soil layer. In the case of shallow peat soils (peat layer < 30 cm), bulk density increased and organic matter content decreased with increasing soil depth. In thick peat soils, total porosity and water retention at selected matric potentials were at their highest in the lowermost soil layer while in shallow peat soils, the uppermost soil layer possessed the highest total porosity and water retention. Most of the water was retained within the range – 100 to – 1 500 kPa in both soil types. This indicated that small pores were predominant. Air-filled porosity at – 10 kPa matric potential (about field capacity) was, on average, 16% in thick peat soils and 17% in shallow peat soils in the uppermost soil layer and decreased with increasing soil depth. The results suggest that the physical properties were generally rather unfavourable for adequate soil aeration and water availability as needed for satisfactory tree growth.

Key words: bulk density, organic matter, peat fields, soil aeration, water retention

INTRODUCTION

Agricultural lands afforested in Finland in the 1970s and 1980s have been typically organic or silty mineral soils of low agricultural value (Valtanen 1991, Hytönen & Ekola 1993, Rossi et al. 1993, Kinnunen & Aro 1996, Hynönen 1997, Hynönen & Saksa 1997a, b). Remoteness, small size, susceptibility to summer frosts, stoniness and poor drainage are characteristics of fields possessing low agricultural value and thus having high probability of being afforested (Selby 1980). Peat soils account for about 6% of the total area of arable land in Finland (Kähäri et al. 1987), but their proportion out of some 200 000 ha of afforested fields is about 40% (Valtanen 1991, Hytönen & Ekola 1993, Rossi et al. 1993, Kinnunen & Aro 1996, Hynönen 1997, Hynönen & Saksa 1997a, b).

Cultivation of agricultural crops, fertilization, liming, soil amelioration, and the use of cultivation machinery alter the physical and chemical properties of the soil. Cultivation affects particularly the plough layer causing a rise in pH and calcium content (Urvas 1985). In peat soils, the addition of mineral soil as a soil amelioration measure has been a common practice (Pessi 1953, 1962, Valmari 1983, Wall & Hytönen 1996), with a long-term effect on the chemical and physical properties of peat (Anttinen 1957, Pessi 1960, 1961a, b, Wall & Hytönen 1996). For example, the bulk density and ash content of peat in the plough layer increase (Pessi 1961a, Urvas 1985, Wall & Hytönen 1996, Hytönen & Wall 1997). Mineral soil application can also improve thermal and aeration conditions in peat soils (Pessi 1953, 1956, Alexeyenko 1988).

In Finland, the afforestation of former agricultural fields has, in general, been less successful in terms of seedling survival and growth on peat soils than on mineral soils (Valtanen 1991, Hytönen & Ekola 1993, Rossi et al. 1993, Kinnunen & Aro 1996, Hynönen 1997, Hynönen & Saksa 1997a, b). The trees planted on these soils have often suffered from growth disturbances related to nutritional imbalances. Deficiencies of potassium and boron, demonstrated through foliar analyses, have been particularly common (Hynönen 1992, Hytönen & Ekola 1993).

Improvement drainage is commonly required on afforested former agricultural peat soils in order to ensure forest growth (Valtanen 1991, Rossi et al. 1993, Hynönen 1997). The occurrence of high ground water tables can increase growth disturbances in stands of Scots pine established on abandoned peat fields (Paavilainen 1977). The physical conditions and properties of afforested peat soils and their effects on tree growth are, however, poorly known. Therefore, information about soil physical properties and their effects on soil water and aeration and the establishment success of forest plantations is needed.

The aim of this study was to: (i) determine the water-retention characteristics and related physical properties of afforested agricultural peat soils, and (ii) assess their significance from the viewpoint of plantation establishment on these soils.

MATERIAL AND METHODS

Soil samples were collected in 1992 from plantations of Scots pine (*Pinus sylvestris* L.) established on former agricultural lands in 1973–1974 and 1981–1982 in Keski-Pohjanmaa, western Finland. The study areas were randomly chosen from the archives of the District Board of Forestry. These stands have been examined previously in the context of the nutritional status of the soils and the tree crops (Hytönen & Ekola 1993, Wall & Hytönen 1996). Twenty-one stands situated on sites with underlying peat soils (organic matter content of the 0–20-cm soil layer > 40%) were used in this study.

As a rule, two circular sample plots of 100 m² in size were delimited within each stand. One sample plot was marked out in a location where the trees appeared to grow poorly and the other plot where the trees appeared to grow better. In cases where the area of the stand was small, or where differences in tree growth were slight, only one sample plot was established. The growth of trees is not analysed here, but will be done in another study.

The sample plots were divided into two classes according to the depth of peat layer. Where the thickness of the peat layer was over 30 cm, the sample plot was classified as thick peat soil. The sample plots with the organic layer less than 30 cm in depth were classified as shallow peat soils. The total number of sample plots was thirty-one, of which twenty-one were classified as thick peat soils and ten as shallow peat soils. Of all the sample plots, 86% were on *Sphagnum* peat soils and the rest on *Carex* peat soils. In the case of 75% of the thick peat soils, the depth of the peat varied between 30 and 100 cm.

Undisturbed soil samples 162 cm³ in size were taken using open-ended metal cubes (5.7 * 5.7 * 5.0 cm) from the centre of the sample plots. One sample per soil layer (5–10-cm, 15–20-cm, 25–30-cm, 35–40-cm layers) was taken from each sample plot. In some cases, these volumetric samples could not be taken from deeper soil layers due to the hardness of the mineral soil. The total number of soil samples was 111. The samples were weighed after saturation with water and their volume at saturation was measured with a ruler. The measured volume was used to calculate bulk density (Db, g cm^{-3}), which was estimated as the ratio of dry mass (dried at 105°C) to the volume at saturation. The organic matter content (Om, %) was determined as a percentage of the mass loss of ignition at 550°C. Particle density (Dp, g cm^{-3}) of a randomly chosen 100 samples was measured using liquid pycnometers, with water as the filling liquid, and a water bath (Heiskanen 1992). The fitted equation for estimating the Dp of all the samples from the Om was:

$$Dp = 2.681 - 0.012\ Om\ (R^2 = 0.935,\ RMSE = 0.117) \quad (1)$$

The density of organic matter (Do, g cm^{-3}) was estimated using the equation:

$$Do = Db^*(Om/100) \quad (2)$$

and the density of mineral matter (Dm, g cm^{-3}) using the equation:

$$Dm = Db^*(100 - Om)/100 \quad (3)$$

Thus,

$$Db = Do + Dm \quad (4)$$

The total porosity (TP, %) was calculated from the estimated Dp and Db as:

$$TP = ((Dp - Db)/Dp)^*100 \quad (5)$$

The air-filled porosity (AFP, %) was estimated from TP and water content at – 10 kPa matric potential (WC10, %) as:

$$AFP = TP - WC10. \quad (6)$$

The water-retention characteristics (WRC, %) were measured at desorption after saturation using a pressure-plate apparatus (Soilmoisture Equipment Corporation, USA). Matric potentials of – 1, – 5, – 10 and – 100 kPa were applied successively over the cube samples until water had ceased to flow from the pressure chambers. Water retention at – 1 500 kPa matric potential was measured from separate samples. These procedures are described in detail by Heiskanen (1993). The volumetric shrinkage of the samples at – 100 kPa matric potential was on average 2.3% and at higher matric potential it was negligible. Water retention was reported based on the saturated volumes of the samples. Water retention within the selected matric potential ranges (0...– 1, – 1...– 10, – 10...– 100 and – 100...– 1 500 kPa) was determined for the purpose of assessing the volumes of the different pore size classes in the soil.

The soil colour was measured with a tristimulus colour analyser (Minolta Chroma Meter CR-300). The soil samples were mechanically crushed and mixed prior to colour measurements. Color was measured from both air-dried and moistened samples. Moistening was done by adding distilled water until the samples were thoroughly wet. CIE tristimulus values were converted to the Munsell notations using a computer program (Macbeth Conversion Program). The Munsell color system describes all possible colors in terms of its three co-ordinates, Munsell hue, Munsell value and Munsell chroma (Munsell ... 1990). These three variables are related to the colour characteristics of dominant wavelength, lightness and color saturation, respectively (Melville & Atkinson 1985).

The effect of sampling depth and soil class on the WRC was tested with repeated measures analyses of variance, using matric potential as a repeated factor. Tukey's test was applied to evaluate the differences in the variables for the various sampling depths. Correlation and regression analyses were used for estimating the linear relationships between the variables.

RESULTS

Soil density, organic matter content and colour

The Db of thick peat soils varied between 0.19 and 0.68 g cm^{-3} in the studied soil profile (0–40 cm). The Db and Dp decreased and Om increased with increasing soil depth (Fig. 1, Table 1). The Om varied between 16% and 87% indicating that some samples as such would have belonged to the soil group of mull (organic matter content 15–40%). The change in Db with soil depth accompanied mainly the change in Dm because the Do remained relatively unchanged within the soil profile. The mean soil colour of dry samples expressed as Munsell notations was 9.0YR 3.7/0.4. The soil colour was rather constant and variation was small within the studied soil profile. The Munsell hue values of the moist samples were generally 0.5 units lower than those of dry samples.

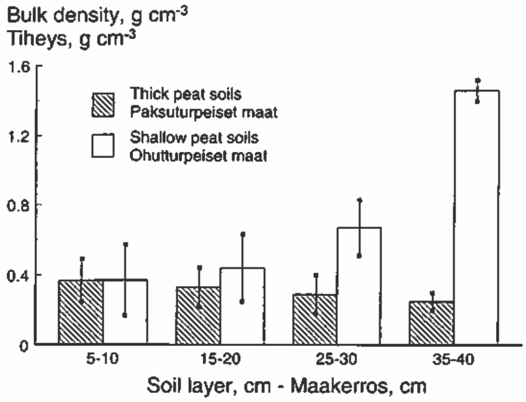

Fig. 1. The bulk density of peat soils by soil layers. Vertical lines in bars indicate standard deviation.

Kuva 1. Turvemaiden maan tiheys maakerroksittain. Keskihajonta on merkitty pylväisiin janoilla.

Respective values for the decrease in Munsell value was 0.1 units and Munsell chroma 0.5 units.

In shallow peat soils, the Db, Dp and Dm increased and Om decreased with increasing sampling depth (Table 1). The Db varied between 0.26 and 1.10 g cm^{-3} in the uppermost soil layers (5–10 cm and 15–20 cm). The Om of these layers varied between 8% and 79% indicating that some samples as such would have belonged to mull and mineral soil groups. In the 25–30-cm soil layer, the prevailing soil group was mull and in the 35–40-cm soil layer all samples were mineral soils.

The mean soil colour of the soil layers 5–10, 15–20 and 25–30 cm was 9.1YR 3.7/1.1. The Munsell hue of the soil layer 35–40 cm did differ significantly from the upper soil layers, but value and chroma were 1.0 and 0.8 units higher in the 35–40-cm soil layer, respectively.

Do, Dm, and colour values of the dry samples increased with increasing Db while Om decreased (Table 2). Om and Dm had a highly significant negative linear relationship, but the relationship between Om and Do was not statistically significant.

Water-retention characteristics

The WRC of soil layers 5–10 cm and 15–20 cm did not differ with statistical significance between the soil classes. The WRC of soil layers 25–30 and 35–40 cm were higher in thick peat soils than in shallow peat soils ($p < 0.001$).

Sampling depth had a statistically significant effect on WRC in the case of both soil classes ($p < 0.001$) (Fig. 2). In thick peat soils, the TP and water retention at matric potentials of – 1 kPa, – 5 kPa, – 10 kPa, and – 100 kPa in the uppermost sampling depth were significantly lower than those for the other soil layers (Tukey's test, $p < 0.05$). There were no statistically significant differences in water retention at the matric potential of – 1 500 kPa between the soil layers. The esti-

Table 1. Means and standard deviations for particle density (Dp, g cm^{-3}), density of organic matter (Do, g cm^{-3}), density of mineral soil (Dm, g cm^{-3}) and organic matter content (Om, %). Means with the same letter are not significantly different between soil layers ($p < 0.05$, Tukey's test).

Taulukko 1. Ainestiheyden (Dp, g cm^{-3}), orgaanisen aineksen tiheyden (Do, g cm^{-3}), kivennäisaineksen tiheyden (Dm, g cm^{-3}) ja orgaanisen aineksen osuuden (Om, %) keskiarvot ja keskihajonnat. Keskiarvot maakerroksittain, jotka on merkitty samalla kirjaimella, eivät eroa toisistaan (Tukeyn testi, $p < 0.05$).

Soil layer – *Maakerros*, cm	Dp	Do	Dm	Om
Thick peat soils – *Paksuturpeiset*				
5–10	2.00 ± 0.21b	0.18 ± 0.04b	0.19 ± 0.13b	53.7 ± 17.2b
15–20	1.89 ± 0.18ab	0.20 ± 0.04a	0.13 ± 0.11ab	63.1 ± 15.2ab
25–30	1.82 ± 0.16a	0.19 ± 0.03a	0.10 ± 0.09a	68.4 ± 13.0a
35–40	1.82 ± 0.12a	0.17 ± 0.03a	0.08 ± 0.05a	68.2 ± 10.4a
Shallow peat soils – *Ohutturpeiset*				
5–10	1.97 ± 0.15b	0.20 ± 0.02b	0.18 ± 0.08b	56.0 ± 12.3b
15–20	2.00 ± 0.26b	0.19 ± 0.04b	0.25 ± 0.29b	53.5 ± 21.7b
25–30	2.21 ± 0.30b	0.16 ± 0.05b	0.51 ± 0.42b	35.8 ± 24.9b
35–40	2.58 ± 0.08a	0.06 ± 0.06a	1.40 ± 0.41a	5.6 ± 6.6a

mated TP varied from 74% to 90% in the 5–10-cm soil layer and from 80% to 89% in the 35–40-cm soil layer.

In shallow peat soils, the water retention of the lowest sampling depth at the various matric potentials was significantly lower than in the other soil layers except at the matric potential of – 1 500 kPa, when the water retention in soil layers 5–10 cm and 15–20 cm differed with statistical significance from the lowest soil layer (Tukey's test, $p < 0.05$). The TP varied from 74% to 86% in the uppermost sampling depth, and from 32% to 67% in the lowest sampling depth.

Most of the water was retained within the range – 100 kPa to – 1 500 kPa in both soil classes and in all sampling depths indicating that small pores (radius 0.2–3.0 μm) were the predominate pore size class (Table 3). The amount of water released at –1 kPa matric potential with respect to saturation (i.e. water retention within 0 kPa and – 1 kPa) was small indicating that large pores (radius > 300 μm) were relatively few in number. In thick peat soils, water retention between – 100 kPa and –1 500 kPa increased with increasing sampling depth while in other selected matric potential ranges the changes according to soil depth were statistically insignificant. The AFP at – 10 kPa matric potential (about field capacity) in thick peat soils was, on average, 16% in the 5–10 cm soil layer and decreased gradually to 12% with increasing sampling depth. The AFP of the 5–10 cm soil layer was > 10% in most of the sample plots, but < 20% in most of the sample plots in deeper soil layers (Fig. 3).

In shallow peat soils, water retention within the selected matric potential ranges decreased with sampling depth. Differences in water retention among the soil layers were statistically significant only within the range – 100 kPa to – 1 500 kPa (Table 3). The AFP at – 10 kPa matric potential was on average 17% in the upper sampling layer, and 8% in the lowest sampling layer. The AFP of the 5–10 and 15–20-cm soil layers was > 10% in most of the sample plots, but in deeper soil layers the AFP was usually < 10% (Fig. 3).

The correlations berween soil physical properties and water retention at selected matric potentials were increasingly smaller the lower the

Table 2. Simple correlations between physical properties of the studied peat soil samples. Soil color of dry samples according to Munsell notations is indicated with an index d and moist samples with an index m (mineral and mull soil samples excluded, n = 78).

Taulukko 2. Turvemaanäytteiden fysikaalisten ominaisuuksien väliset yksinkertaiset korrelaatiot. Maan väri ilmaistuna Munsell-järjestelmän mukaan mitattuna on ilmaistu kuivista näytteistä kirjaimella d ja kosteista näytteistä kirjaimella m (kivennäis- ja multamaanäytteet poistettu, n = 78).

	Db	Do	Dm	Om	Hue_d
Db	1.000				
Do	0.581***	1.000			
Dm	0.913***	0.201	1.000		
Om	– 0.683***	0.170	– 0.909***	1.000	
Hue_d	0.573***	0.310**	0.534***	– 0.414***	1.000
$Value_d$	0.462***	0.270*	0.424***	– 0.308**	0.689***
$Chroma_d$	0.409**	0.291**	0.350**	– 0.201	0.432***
Hue_m	– 0.040	– 0.052	– 0.024	– 0.006	– 0.003
$Value_m$	0.013	– 0.083	0.063	– 0.113	0.263*
$Chroma_m$	0.407**	0.342**	0.328**	– 0.161	0.408***

	$Value_d$	$Chroma_d$	Hue_m	$Value_m$	$Chroma_m$
$Value_d$	1.000				
$Chroma_d$	0.851***	1.000			
Hue_m	– 0.032	– 0.052	1.000		
$Value_m$	0.424***	– 0.083	0.063	1.000	
$Chroma_m$	0.663***	0.342**	0.328**	0.342**	1.000

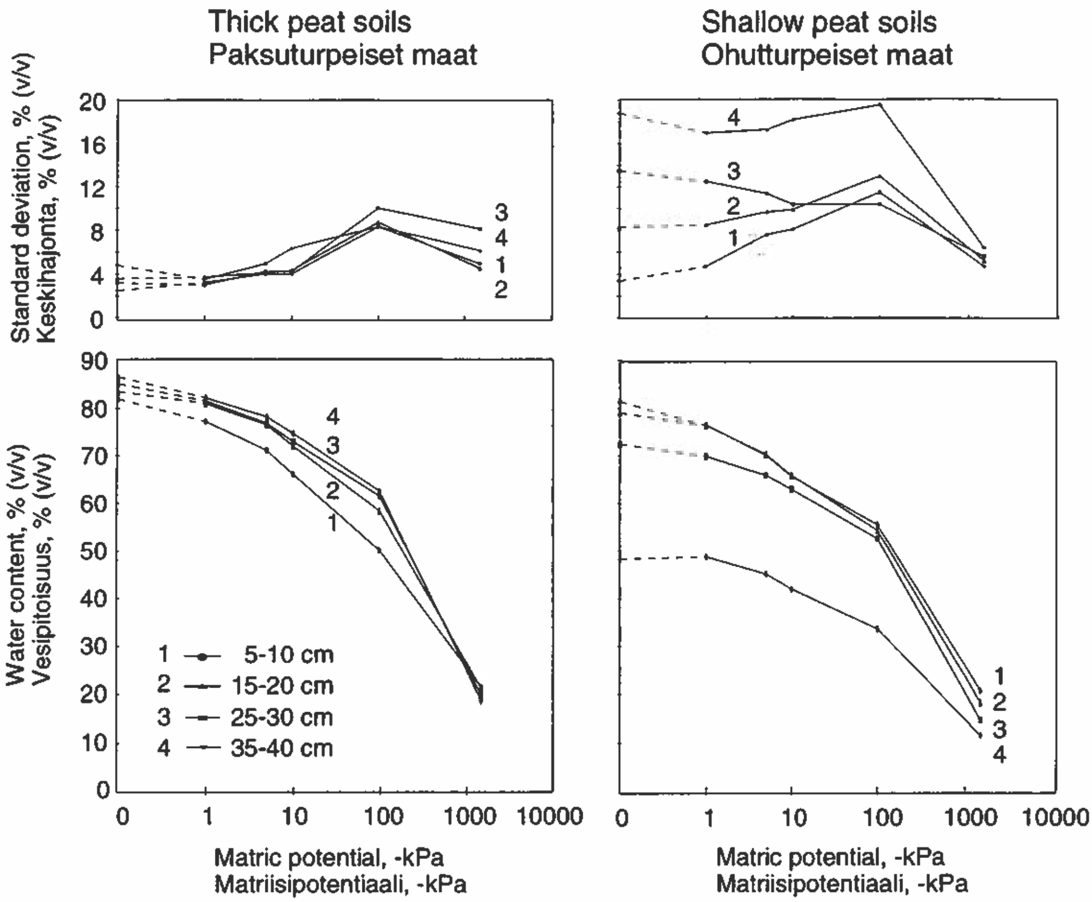

Fig. 2. Mean water retentions and their standard deviations of peat soils at different matric potentials by soil layers.

Kuva 2. Turvemaiden keskimääräinen vedenpidätyskyky eri matriisipotentiaalin arvoilla maakerroksittain.

matric potential (Table 4). In general, however, water retention at the selected matric potentials decreased with increasing Db and decreasing Om. The highly significant correlation between Db and TP was described by the regression equation:

$$TP = 96.5 - 41.5\ Db\ (R^2 = 0.956,\ RMSE = 1.0) \quad (7)$$

DISCUSSION

The stands studied in this paper have also been used in a previous study concerning the nutritional status of soil and trees in afforested fields (Hytönen & Ekola 1993), where the within-stand variation in soil physical properties was found to be great. Therefore, the present results obtained from these sample plots cannot be generalized for the entire stand, but each sample plot should be considered as a separate observational unit. In many cases, the two sample plots in a particular stand belonged to different soil classes. This fact emphasizes the necessity of sampling soils within a stand by establishing several plots. The studied peat soils have most likely been in agricultural use for several decades prior to afforestation. Furthermore, the effect of afforestation on the studied soil physical properties has probably been relatively small. Although most of the studied stands had been ploughed for planting, it should be noted that the soil samples used were taken from those spots that were not disturbed during afforestation.

The soil physical properties presented here differ considerably from those of undrained peat-

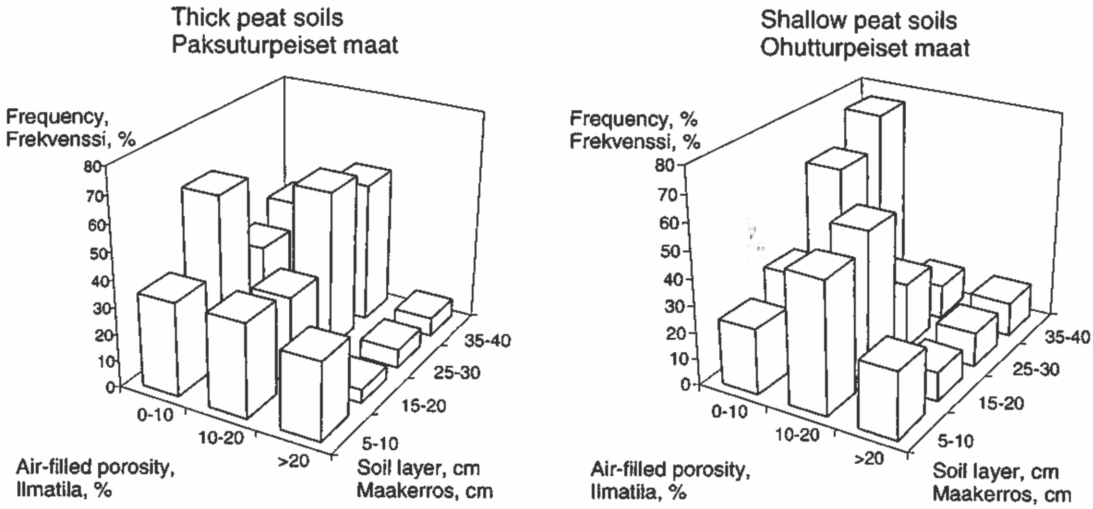

Fig. 3. The frequency of different air-filled porosity classes at –10 kPa matric potential in studied peat soils by soil layers.

Kuva 3. Turvemaiden maan ilmatilaluokkien (– 10 kPa matriisipotentiaalilla) frekvenssit eri maakerroksissa.

lands and peatlands drained for forestry (Päivänen 1973, Westman 1981). The differences are more marked in the uppermost soil layers as is also the case with the chemical properties of the soil (Urvas 1985, Wall & Hytönen 1996, Hytönen & Wall 1997). In Päivänen's (1973) material, the ash content was usually < 10% and Db < 0.2 g cm^{-3}; these values are close to the lowest values in the present material. Pessi (1961a, c) stated that continued cultivation may cause peat to loose its inherent character and become transformed to resemble humic soil. The results of this study support this hypothesis. The high Db and low Om of the peat resulted mainly from the use of mineral soil as a soil ameliorant or from mixing mineral soil from the lowermost soil layers during ploughing. Soil compaction and humification of peat probably have also had an effect on the bulk density and ash content. In western Finland, the amount of added mineral soil has been, on average, 230 m^3 ha^{-1} (Wall & Hytönen 1996), most of which is located in the uppermost soil layers while minor amounts will have been transported to deeper soil layers (Kaunisto 1991, Wall & Hytönen 1996). The mineral

Table 3. Means and standard deviations of water retention (%) at selected matric potential ranges by soil classes and soil layers. Means with the same letter are not significantly different between soil layers ($p < 0.05$, Tukey's test).

Taulukko 3. Maan vesipitoisuus eri matriisipotentiaaliväleillä maaluokittain ja maakerroksittain. Keskiarvot maakerroksittain, jotka on merkitty samalla kirjaimella eivät eroa toisistaan (Tukeyn testi, p < 0.05).

Soil layer, cm *Maakerros*	Matric potential range, – kPa - *Matriisipotentiaaliväli* 0–1	1–10	10–100	100–1500
Thick peat soils – *Paksuturpeiset*				
5–10	4.8 ± 4.1a	10.9 ± 5.5a	14.9 ± 6.9a	30.1 ± 9.5a
15–20	2.3 ± 3.3a	9.0 ± 2.9a	13.1 ± 7.0a	37.3 ± 8.9ab
25–30	3.2 ± 3.2a	8.7 ± 3.9a	11.6 ± 8.0a	41.0 ± 9.4b
35–40	4.0 ± 3.4a	8.0 ± 3.3a	12.0 ± 7.7a	44.0 ± 9.3b
Shallow peat soils – *Ohutturpeiset*				
5–10	5.1 ± 3.3a	11.6 ± 4.8a	11.5 ± 5.0a	31.9 ± 7.8b
15–20	3.0 ± 3.6a	10.3 ± 4.1a	11.3 ± 6.0a	35.7 ± 10.9b
25–30	2.5 ± 4.0a	6.4 ± 4.1a	9.3 ± 6.1a	38.1 ± 8.9b
35–40	1.2 ± 1.1a	6.4 ± 7.1a	8.7 ± 5.9a	18.4 ± 10.2a

soil mixed into the peat is often unevenly distributed and occurs in lumps, which means that the structure of the soil is rather heterogenous. The particle-size distribution of the mineral soil in peat was not determined here, but the predominant fraction in the mineral soil admixture in thick peat soils is commonly silt (Wall & Hytönen 1996).

The degree of decomposition of peat has been shown to be an important physical characteristic related to Db, TP and WRC (Boelter 1969, Päivänen 1969, 1973). The determination of the degree of decomposition according to von Post's (1922) method for agricultural peat soils was hampered here by the high amount of mineral soil in the peat. However, the Munsell value of the studied soils was low, indicating a high decomposition rate. The variation in Munsell value, as well as other colour attributes, was small. This was reflected in weak correlations between bulk density and colour attributes. Therefore, soil colour was not a good indicator of the degree of decomposition.

The total porosity of the studied peat soils was lower than that of natural *Sphagnum* bog peat (Päivänen 1973) and peat growth media (Heiskanen 1993), but their water retention at low matric potential values was considerably higher. This indicates that agricultural peat fields possess a finer structure than pure, low-humified peat media. The TP was higher than on mull soils (Heinonen 1954). The WRC of low-humified peat can be predicted fairly well from Db (Päivänen 1973, Heiskanen 1993b). In the study material, Db and the other soil physical characteristics used had, in general, a weak relationship with WRC. Apparently agricultural peat soils have lost their original structure due to compaction and decomposition of peat and the addition of mineral soil. The shrinkage at desorption of the studied soils was low which is an indication of the absence of large pores (e.g. Heiskanen 1994). In these soils, water retention is very likely predominantly characterized by micro-pore formation caused by biochemical transformations of plant phenolic constituents in decomposition (Flaig 1986).

The air-filled porosity of the growth medium is commonly used to estimate the level of aeration and the availability of oxygen to plant roots (Glinski & Stepniewski 1985). An AFP value of 20% of the soil volume has been suggested as be-

Table 4. Simple correlations between water retention at selected matric potentials (WC) and other soil physical properties. Soil color of dry samples according to Munsell notations is indicated with an index d (mineral and mull soil samples excluded, n = 78).

Taulukko 4. Maan eri matriisipotentiaalirvojen vesipitoisuuksien (WC) ja muiden fysikaalisten ominaisuuksien väliset yksinkertaiset korrelaatiot. Maan väri ilmaistuna Munsell-järjestelmän mukaan on ilmaistu kuivista näytteistä kirjaimella d (kivennäis- ja multamaanäytteet poistettu, n = 78).

	TP	WC1	WC5	WC10	WC100	WC1500
Db	– 0.964***	– 0.693***	– 0.411***	– 0.322**	– 0.076	0.183
Dm	– 0.771***	– 0.695***	– 0.499***	– 0.421***	– 0.183	0.252*
Do	– 0.775***	– 0.277*	0.009	0.066	0.189	– 0.064
Om	0.468***	0.578***	0.494***	0.440***	0.261*	– 0.269*
Hue_d	– 0.544***	– 0.453***	– 0.372***	– 0.309**	– 0.037	0.156
$Value_d$	– 0.449***	– 0.312**	– 0.274*	– 0.271*	– 0.084	– 0.040
$Chroma_d$	– 0.416***	– 0.237*	– 0.124	– 0.111	0.038	– 0.116

	Q1500	WC0–1	WC1–10	WC10–100	WC100–1500
Db	0.183	– 0.123	– 0.235*	– 0.199	– 0.176
Dm	0.252*	0.076	– 0.085	– 0.138	– 0.319
Do	– 0.064	– 0.449***	– 0.393***	– 0.213	0.220
Om	– 0.269*	– 0.241*	– 0.068	0.042	0.404***
Hue_d	0.156	0.007	– 0.003	– 0.242	– 0.123
$Value_d$	– 0.040	– 0.071	0.088	– 0.137	– 0.060
$Chroma_d$	– 0.116	– 0.132	– 0.078	– 0.162	0.101

ing adequate for tree seedlings (Warkentin 1984), but in peat media an AFP value of 40–50% has been considered to be favourable (Puustjärvi 1973, Heiskanen 1997). The term 'field capacity' refers to the state of the soil when the downward movement of water due to gravity has essentially ceased following saturation (Veihmeyer & Hendrickson 1931). The field capacity of soils is not an exact property but is dependent on the level of the ground-water table (Ahti 1972). Thus, field capacity as the upper limit for plant available water is not appropriate in peat soils with high ground-water levels (Ahti 1972, Päivänen 1973). For example, Päivänen (1973) suggests as the upper limit for available water the AFP value below which aeration becomes a limiting growth factor. In the present material, AFP measured at – 10 kPa matric potential was between 8% and 17%, being thus around the minimum requirement. Therefore, – 10 kPa matric potential appears to be an appropriate upper limit for plant available water for the soils now studied.

The studied water-retention curves indicated that these former agricultural peat soils are dominated by fine pores (pore diameter < 3 µm) and the amount of larger pores (pore diameter > 300 µm) is small. Consequently, when an AFP value of 20% is attained, the soil matric potential is lower than – 100 kPa and water availability is below optimum. On the other hand, when the soil matric potential is > – 100 kPa and water availability is within the favourable range, the AFP value is below optimum. Therefore, the results suggest that the favourable range for water and aeration conditions is rather narrow and thus difficult to achieve in the studied peat soils.

In a pilot study on thick peat soils conducted in 1996, we monitored the soil-water content using TDR (time domain reflectometry) in one sample plot per stand in three stands. The mean soil-water content of these Scots pine stands in the 0–20-cm soil layer varied between 70 and 86% in June and between 66 and 82% in July. Because the mean total porosity was between 87 and 88%, AFP was, on average, within 1–22% in these plots. Therefore, because the AFP was usually < 20%, the average aeration conditions appear to have been clearly below the optimum in these peat soils.

The problem with the studied soils in terms of adequate drainage and AFP is shown by estimating the required ground water level using a simplified form of the equation of capillarity: $r = 0.15/h$, where r = the radius (cm) of the largest pores filled with water and h = capillary rise (cm) (Hillel 1982). If, for example, the matric potential of the top of the thick peat soil is desired to be – 10 kPa, the AFP, on average, is 16% according to present results. According to the equation, the radius of the largest pores filled with water is 15 µm at –10 kPa matric potential with the corresponding capillary rise of 100 cm from the ground-water level. Thus, effective drainage with an AFP value of at least 20% on the studied soils requires a denser and deeper ditch network than is usually recommended for peatland forestry. A mean drainage depth of 40 cm and a ditch spacing of between 20 and 60 m has been recommended as optimal for peat soils drained for forestry (Päivänen 1990).

The present results show that the soil physical properties of afforested former agricultural peat soils are generally rather unfavourable considering the adequacy of aeration and water availability for forest growth. The AFP at – 10 kPa matric potential is highest in the uppermost soil layer and decreases with increasing soil depth; this indicates deteriorating physical conditions with increasing soil depth. High soil-water retention can lead to high water content and low AFP which can cause waterlogging and hypoxia (Lotocki 1977, Heiskanen 1995). The actual AFP values below 10-cm soil depths are commonly so low that root penetration may be inhibited and the formation of superficial root systems promoted (Paavilainen 1967). The amounts of macronutrients in afforested peat fields are high in comparison to those of ordinary forest soils indicating a high potential yield for tree growth (Wall & Hytönen 1996). The main problem (together with nutritional imbalances in the soil) seems thus to be high water-table levels together with predomination of fine pores in the soil. Therefore, soil preparation such as mounding with denser ditching increasing the amount of large pores in the soil and the distance from the ground-water level could be practicable when afforesting peat fields. Further studies are, however, needed to test *in situ* the hypothesis that aeration and water availability are limiting factors for the survival and growth of trees planted on former agricultural fields.

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TIIVISTELMÄ:

Metsitettyjen turvepeltojen maan fysikaaliset ominaisuudet

Peltojen metsityksistä huomattava osa, noin 40% on kohdistunut turvemaille. Turvemailla metsitystulos ja puuston kasvu on ollut heikompi kuin kivennäismailla. Metsitettyjen peltojen kuivatuksen parannus on todettu usein tarpeelliseksi. Tämän tutkimuksen tarkoituksen oli selvittää metsitettyjen turvepeltojen fysikaalisia ominaisuuksia, erityisesti vedenpidätyskyvyn osalta, ja arvioida näitä ominaisuuksia metsänkasvatuksen kannalta.

Keski-Pohjanmaan alueelta arvottuun otokseen sisältyi 21 turvepeltoa (orgaanisen aineksen pitoisuus > 40 %), jotka oli metsitetty männylle vuosina 1973–1974 tai 1981–1982. Metsiköihin perustettiin kaikkiaan 31 koealaa, joista 21 oli paksuturpeisia (turvekerroksen paksuus > 30 cm) ja 10 ohutturpeisia (turvekerroksen paksuus < 30 cm). Koealoilta otettiin tilavuustarkat maanäytteet (162 cm^3) kerroksista 5–10, 15–20, 25–30 ja 35–40 cm. Maanäytteistä analysoitiin tiheys, orgaanisen aineksen osuus, väri ja vedenpidätyskyky.

Maan tiheys oli syvyydellä 5–10 cm keskimäärin 0.37 g cm^{-3}. Paksuturpeisilla mailla tiheys pieneni ja orgaanisen aineksen osuus kasvoi maakerroksen syvyyden lisääntyessä (Kuva 1, Taulukko 1). Ohutturpeisilla mailla maan tiheys kasvoi ja orgaanisen aineksen osuus pieneni syvyyden lisääntyessä. Maan tiheyden ja orgaanisen aineksen pitoisuuden vaihteluväli oli laaja johtuen kivennäismaan käyttämisestä maanparannusaineena tai kivennäisaineen sekoittumisesta pohja-

maasta turpeeseen maanmuokkauksen yhteydessä (Taulukko 1). Maan väri ilmoitettuna Munsell-värijärjestelmällä oli keskimäärin 9.1YR 3.7/1.0 syvyydellä 5–10 cm. Maan väriarvojen vaihtelu oli vähäistä ja maan värin sekä maan tiheyden välinen korrelaatio oli heikko. Tämän vuoksi maan värin käyttöarvo maan tiheyden tai maatuneisuuden tunnuksena oli heikko.

Maakerroksen syvyydellä oli tilastollisesti merkitsevä vaikutus vedenpidätyskykyyn (Kuva 2, Taulukko 3). Paksuturpeisten maiden kokonaishuokostila ja vedenpidätyskyky oli suurin syvyydellä 35–40 cm ja pienin syvyydellä 5–10 cm. Kokonaishuokostila oli keskimäärin 81% syvyydellä 5–10 cm ja 86% syvyydellä 35–40 cm. Ohutturpeisilla mailla vedenpidätyskyky oli suurin syvyydellä 5–10 cm ja pieneni maakerroksen syvyyden kasvaessa. Suurin osa vedestä pidättäytyi matriisipotentiaalivälillä – 100...– 1 500 kPa molemmilla maatyypeillä osoittaen, että maan huokoskokojakaumassa hienot huokoset (d 0.2–3.0 m) olivat vallitsevia. Vedenpidättyminen matriisipotentiaalivälillä 0...– 1 kPa oli vähäinen osoittaen suurten huokosten vähäistä määrää.

Maan ilmatila oli matriisipotentiaalilla – 10 kPa (kenttäkapasiteetin likiarvo) 5–10 cm:n syvyydellä keskimäärin 16% ja ilmatila pieneni maakerroksen syvyyden kasvaessa (Kuva 3). Kyseinen ilmatila on alhainen verrattuna kirjallisuudessa esitettyihin arvioihin maan riittävästä ilmatilasta (n. 20%). Maan ilmatilan ollessa riittävä maan vesipotentiaali oli kuitenkin alle – 100 kPa eli käyttökelpoisen veden määrä oli tällöin alle optimin. Tulosten perusteella voidaan siten olettaa metsitettyjen turvepeltojen fysikaalisten olosuhteiden olevan usein epäsuotuisat puuston kasvulle ja maan fysikaalisten ominaisuuksien parantamisen olevan tarpeen. Peltomaiden kuivatusolojen parannus vaatinee tiheämpää ojaverkostoa kuin turvemailla on totuttu käyttämään, koska vesi on sitoutunut pääosin hienohuokosiin ja on siten vaikeasti poistettavissa. Maanmuokkaus esimerkiksi mätästämällä, jossa maan huokoskokojakaumaa muutetaan lisäämällä suurhuokosten määrää ja kohotetaan maan pinnan etäisyyttä pohjavesipinnasta, on suositeltavaa.

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