A slight inaccuracy may also occur in connection with the pressure cell treatment due to changes in the tare, i.e., the weight of the apparatus. The water content of the porous plate of the cell shows a decrease when moving from saturation to a matric suction value of pF 2. On the basis of a few weighings, however, it was established that the change in the water content of the plate is extremely small in comparison with the size of the sample (<0.5 volume per cent), and no attempts were made to eliminate its influence on the results.

During the course of treatment in the pressure cells as well as in the pressure plate and pressure membrane extractors, the volume of the samples slightly decreased due to drying. According to some studies, the shrinkage of the samples due to drying is directly proportional to the quantity of water removed (IRWIN 1968, p. 221). The shrinkage was studied in the present connection on the samples which had been treated in the pressure cells. It was not possible, however, to make a similar study on the samples which had been treated in the pressure plate and the pressure membrane extractors. Furthermore, as the amount and nature of the volume reduction of the samples do not describe the amount and nature of the compression of peat layers in the field, the volume of the peat samples at saturation was used for comparison in the case of the entire material of the study (cf. THORPE 1968; BROWN 1972, p. 72).

Particularly in the case of the pressure plate extractor, great changes in temperature may lead to variations in the pressure prevailing in the extractor. For this reason the apparatus should actually be used in a room kept at a constant temperature. This was not possible, however, in the Department of Peatland Forestry. To establish the influence of external conditions on the results, water retention determinations were performed at matric suctions between pF 2 and 4 on peat from the same sample plot (samples 48—51, Table 8) both in a thermostat room at the Peat Research Center of Satoturve Oy and in the laboratory of the Department of Peatland Forestry, University of Helsinki. In the former, the temperature was kept at 20° C. In the latter, temperature was recorded during

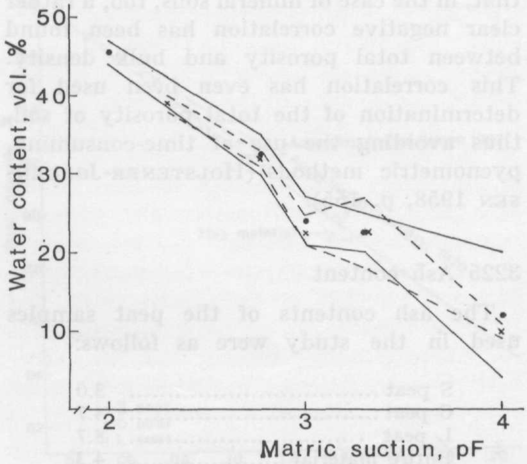

Fig. 13. Results from water retention determinations in a thermostat room (indicated by • ; confidence interval indicated by unbroken line) and under normal laboratory conditions (indicated by × and broken line respectively).

several weeks in the winter of 1967; thereby establishing that it usually varies between 21 and 24° C.

The results of the parallel determinations are shown in Fig. 13. In the case of both determinations, the water retention was of similar magnitude. It seems, on the basis of the results obtained, that small variations in the temperature do not significantly affect the results obtained by means of the pressure plate or the pressure membrane extractors.

In the case of the pressure cell determinations, special attention was given to ensure that equilibrium had really been reached between the suction used and the matric suction of the sample before the water content of the sample was determined. In the pressure cell method, the water table in the reservoir was lowered to a constant level once a day using a pipette. Fig. 14 demonstrates the time required to reach equilibrium (indicated with a small arrow). In the case of mineral soils, the time required to reach equilibrium (REGINATO and VAN BAVEL 1962, p. 2) is considerably shorter than for peat soils. The curves indicating the quantities of water that have been removed do not indicate the cumulative net quantity of water that has actually been drained when moving stepwise from saturation to

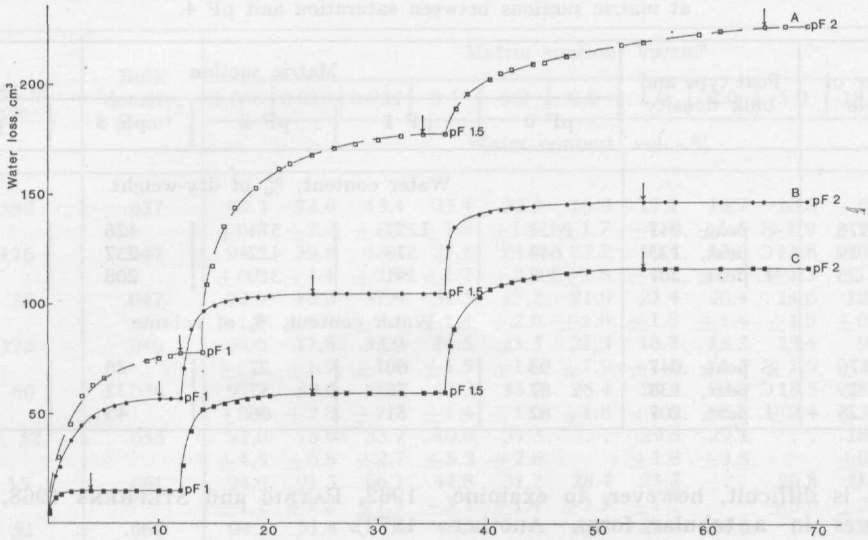

Fig. 14. Time required to reach equilibrium in pressure cell determinations. A = Sample 188, bulk density 0.056; B = Sample 153, bulk density 0.091; C = Sample 152, bulk density 0.155.

pF 2, but the values obtained are higher. After reaching pF values of 1.0 and 1.5, the samples were weighed, and the free water table was for some time raised above the level of the sample so as to add water to the sample. In this way it could be ensured that air had not entered between the porous plate and the suspended water column during the course of weighing.

Some research workers have found that the water contents corresponding to pF 3 depend to some extent on the method of determination used. The pressure plate extractor may give lower water retention values than the pressure membrane extractor (Sykes and Loomis 1967, p. 165). This may be the reason for the depression in the line of points in Fig. 13.

3312 Water desorption characteristics of peat

Retention of water in the soil is usually described in terms of the interrelationship between its water content and the corresponding matric suction, either in the form of a table or graphically. In the present connection, let us first examine the influence of the way in which the water content is expressed on the results which are obtained.

As with mineral soils, the water content of peat has often been expressed in terms of percentages of the dry weight of the peat concerned (Dyal 1960, Puustjärvi 1963). The figures presented in Table 13 reveal the misleading nature of this way of expression.

The low bulk density values obtained for Sphagnum peat lead to seemingly large water contents when determinations are expressed in terms of weight percentages. The use of weight percentages may even produce an opposite order of the peats according to their water retention as compared with the use of volume percentages. It has also been stressed, in several connections, that the water content of soils should be expressed in terms of volume percentages even when they have first been determined in terms of unit weight (Boelter and Blake 1964). In the following connection, the water contents have always been expressed in terms of volume precentages, although, as was established in the preceding section, the use of bulk density values which have been obtained from parallel samples in the calculations may be a source of dispersion of the results.

Tables 14—16 show the results of the water retention determinations performed by peat

Table 13. Examples on the use of dry-weight and volume percentages in water content determinations at matric suctions between saturation and pF 4.

Number of sample	Peat type and bulk density	Matric suction				
		pF 0	pF 1	pF 2	pF 3	pF 4
		Water content, % of dry-weight				
173–176	S peat, .047	2021	1277	574	426	213
16– 19	C peat, .135	644	578	422	237	126
22– 25	L peat, .207	396	391	319	208	126
		Water content, % of volume				
173–176	S peat, .047	95	60	27	20	10
16– 19	C peat, .135	87	78	57	32	17
22– 25	L peat, .207	82	81	66	43	26

type. It is difficult, however, to examine the figures in a tabular form. Another possibility is to examine the relationships between the water content of the peat and the matric suction graphically, either in the form of a fitted curve or fraction line. Fig. 15 shows the water desorption characteristics of slightly decomposed Sphagnum peat, moderately decomposed sedge peat and extremely well decomposed woody peat. The figure shows that of the peats studied, Sphagnum peat contains the greatest quantity of water at saturation, but it gives up its water more readily with increasing matric suction. In the case of peats which have reached a more advanced stage of decomposition, the water contents at saturation were lower, but the loss of water with increasing matric suction was also smaller. Results of a similar kind, and presented in the same way, have also been obtained previously for peat soils (Boelter 1962, Patric and Stephens 1968, Brown 1972).

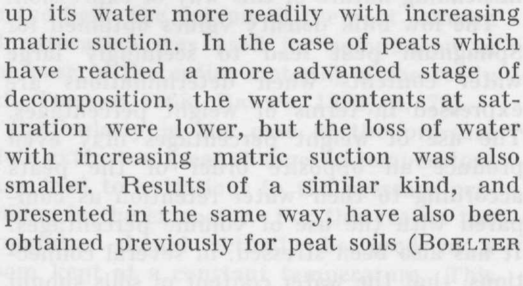

Fig. 15. Water desorption characteristics for different peat types (D_b = bulk density).

Carrying out far-reaching comparisons merely on the basis of the water desorption characteristics is difficult because a separate fraction line or curve should be drawn for each category of peat studied. This is due to the great influence of the structure of the peat on the level and form of the delineator used. For this reason, one of the aims of the present study was to find a structural characteristic of peat to which the water retention values obtained at different matric suctions could be referred.

If the curves indicating the water retention capacity of peats (Fig. 15) are compared with those obtained for mineral soils, it can be seen, that the water retention capacity of peat soils is always greater at low matric suction values (<pF 1.5). In the case of larger matric suction values, too, coarse mineral soils usually retain less water than slightly decomposed Sphagnum peat, the water retention capacity of clay being of similar magnitude to that of moderately decomposed peat (see, e.g., Andersson and Wiklert 1967, p. 19).

3313 Choice of an independent variable to describe the water retention of peat

In order to make it possible to examine the water retention capacity of peats with the aid of their water desorption characteristics more generally than in individual cases, the property, or the properties of the peat

Table 14. Results from water retention determinations on Sphagnum peats.

Number of sample	Bulk density, g/cm³	Matric suction, kp/cm²										
		0.000	0.010	0.032	0.1	0.2	0.6	1.0	2.0	5.0	10.0	15.0
		Water content, vol. - %										
181–182	.037	93.3	73.0	43.4	25.4	22.3	19.9	17.1	13.7	10.8	8.3	. .
		±0.7	±2.2	±1.7	±1.8	±1.9	±1.7	±1.8	±1.5	±1.9	±1.5	
173–176	.047	94.5	59.8	42.4	27.1	24.7	23.2	19.4	17.2	13.8	10.4	. .
		±0.7	±4.4	±2.9	±1.7	±2.0	±1.8	±1.7	±1.6	±1.5	±1.6	
53– 56	.047	92.9	70.0	47.9	31.5	27.2	21.9	21.4	20.4	14.6	12.9	. .
		±1.8	±5.0	±2.4	±1.4	±2.0	±1.6	±1.3	±1.4	±1.8	±0.4	
169–172	.049	94.6	77.8	53.9	34.5	25.3	21.3	18.3	15.3	13.4	9.4	. .
		±2.1	±1.9	±1.4	±1.5	±1.9	±1.9	±1.5	±1.7	±1.9	±1.4	
57– 60	.056	92.7	89.4	66.2	45.3	35.2	26.4	24.0	23.2	18.5	18.7	. .
		±0.8	±2.8	±2.2	±1.4	±1.0	±1.8	±1.0	±6.7	±2.4	±3.0	
8–10, 52	.058	92,0	75.0	53.7	40.8	37.3	. .	29.5	27.1	. .	18.0	. .
		±4.4	±6.8	±2.7	±5.3	±2.0		±1.8	±3.8		±0.5	
5–7, 15	.061	94.0	91.3	66.1	44.8	31.2	28.4	25.2	. .	20.8	18.0	. .
		±1.2	±1.2	±1.4	±3.1	±1.4	±1.3	±1.1		±3.0	±2.5	
48– 51	.068	94.3	91.4	80.0	48.5	. .	33.1	24.5	23.0	. .	12.8	9.5
		±1.7	±1.5	±0.7	±2.1		±2.7	±3.0	±2.8		±8.6	±3.4
177–180	.073	92.0	65.6	50.4	36.4	34.9	28.5	25.4	22.4	16.4	15.4	. .
		±2.0	±2.2	±2.0	±1.8	±1.5	±2.0	±1.7	±2.0	±1.8	±1.5	
93– 96	.075	93.9	87.2	74.5	53.4	. .	29.5	25.7	21.1	. .	15.4	11.9
		±1.5	±3.3	±2.9	±1.5		±2.2	±1.0	±1.6		±1.4	±2.9
157–160	.081	92.2	76.8	50.7	32.1	31.4	28.5	25.9	22.0	17.6	14.1	. .
		±1.4	±1.9	±2.4	±2.1	±2.0	±1.9	±1.5	±1.7	±1.5	±1.7	
77– 80	.081	90.9	80.4	62.0	44.1	38.2	28.1	26.5	23.7	22.9	15.5	. .
		±3.6	±2.9	±3.0	±3.5	±1.3	±1.2	±1.0	±0.6	±1.6	±3.6	
81– 84	.085	91.6	87.4	76.4	53.2	. .	32.9	29.9	26.1	. .	14.9	13.5
		±1.1	±1.7	±3.3	±2.0		±1.1	±2.0	±1.3		±0.4	±3.2
89– 92	.085	92.9	82.2	62.0	45.4		25.6	23.4	19.6		13.7	11.2
		±1.6	±2.6	±2.8	±2.6		±0.6	±1.1	±1.1		±1.4	±3.3
1– 4	.087	89.7	86.4	69.2	51.6	45.8	37.7	36.1		30.1	27.5	. .
		±0.7	±2.2	±6.9	±5.8	±2.9	±2.4	±1.4		±2.8	±3.2	
192–194	.089	91.6	89.4	78.5	54.6	38.3	30.7	28.0	24.7	20.6	17.5	. .
		±1.2	±1.8	±2.0	±1.4	±1.8	±2.0	±1.6	±1.7	±2.0	±1.7	
101–104	.090	90.1	80.1	61.3	41.6	. .	27.2	24.6	20.7	. .	13.1	11.3
		±1.5	±1.1	±2.3	±1.1		±0.6	±1.3	±0.9		±2.1	±2.4
105–108	.093	90.4	76.5	61.6	46.4	40.8	33.2	29.6	27.0	23.1	17.5	. .
		±1.5	±2.8	±2.4	±2.0	±1.9	±1.5	±1.9	±1.5	±3.8	±1.2	
30– 33	.104	90.0	88.6	75.0	63.3	. .	38.7	32.3	29.1	21.0	19.0	. .
		±2.1	±1.5	±1.2	±2.5		±1.5	±1.9	±1.6	±1.5	±2.8	
97–100	.108	90.7	84.8	73.7	60.5	. .	38.4	32.9	28.4	. .	20.4	17.2
		±1.7	±1.5	±2.4	±2.9		±1.6	±1.9	±1.1		±1.4	±4.4
85– 88	.108	91.1	88.2	77.8	61.6	. .	35.0	30.4	30.2	. .	20.5	17.9
		±2.2	±1.2	±1.5	±1.6		±0.9	±2.2	±3.8		±2.9	±3.4
73– 76	.108	89.3	84.0	71.0	55.4	49.2	38.7	31.4	27.7	25.7	24.1	. .
		±1.9	±2.8	±2.8	±2.8	±1.6	±1.0	±1.2	±2.0	±1.2	±0.5	
69– 72	.110	90.0	89.6	83.7	64.2	52.1	39.3	29.8	26.6	23.6	20.3	. .
		±1.9	±3.0	±4.0	±3.9	±1.5	±1.6	±1.4	±1.2	±1.4	±2.0	
189–191	.111	89.3	86.4	77.0	65.8	56.0	41.3	29.0	25.1	20.5	17.6	. .
		±0.7	±0.9	±1.5	±1.9	±2.0	±1.9	±1.5	±1.8	±1.3	±1.5	
20, 21, 42, 43	.113	89.2	87.5	81.0	70.8	. .	37.3	31.1	30.8	. .	16.2	14.8
		±1.2	±1.2	±2.0	±5.7		±1.8	±3.4	±4.2		±7.1	±3.6
44– 47	.179	85.5	84.9	79.8	68.4	. .	46.6	40.9	35.1	. .	25.4	20.2
		±1.5	±1.2	±1.6	±2.2		±1.7	±1.8	±0.5		±1.7	±2.9

Table 15. Results from water retention determinations on sedge peats.

Number of sample	Bulk density, g/cm³	Matric suction, kp/cm² 0.000	0.010	0.032	0.1	0.2	0.6	1.0	2.0	5.0	10.0	15.0
		Water content, vol. - %										
185−188	.054	94.3	68.0	47.9	35.5	22.0	18.4	16.7	12.6	7.9	6.3	. .
		±1.9	±2.1	±2.2	±2.9	±1.8	±1.2	±1.3	±0.9	±1.2	±1.1	
145−148	.079	91.7	82.9	61.8	35.9	31.7	25.2	23.4	19.2	17.3	14.4	. .
		±2.6	±1.0	±1.6	±2.2	±1.0	±1.0	±1.1	±1.6	±1.3	±3.3	
165−168	.084	90.6	86.2	56.4	36.4	33.4	29.8	26.8	23.5	20.2	16.4	. .
		±1.5	±2.2	±2.7	±1.9	±2.0	±1.8	±1.7	±2.5	±2.7	±2.4	
121−124	.084	89.7	85.0	74.5	53.4	36.0	29.0	24.7	22.1	17.6	14.7	. .
		±0.8	±2.0	±2.7	±3.8	±0.8	±1.2	±1.1	±2.7	±4.4	±4.5	
117−120	.093	87.3	85.4	77.8	64.0	41.4	28.8	23.4	22.7	21.9	17.0	. .
		±0.2	±0.5	±2.6	±2.1	±0.6	±1.2	±1.2	±1.8	±3.3	±2.8	
161−164	.112	89.3	86.5	80.7	52.5	45.6	35.4	32.0	25.1	20.6	18.4	. .
		±2.1	±0.8	±0.9	±1.5	±1.0	±1.2	±1.3	±1.9	±2.0	±1.8	
11− 14	.113	91.0	89.9	84.7	60.0	. .	33.8	27.2	29.3	. .	17.2	12.9
		±0.7	±1.2	±1.2	±0.7		±2.7	±0.5	±4.4		±5.0	±3.1
141−144	.131	89.3	87.2	79.2	59.8	53.8	46.3	41.5	36.1	32.0	28.6	. .
		±2.0	±1.5	±0.8	±2.3	±2.8	±2.9	±2.2	±1.5	±2.7	±4.4	
16− 19	.135	87.2	77.7	76.2	56.4	. .	33.3	31.6	28.8	. .	17.3	15.7
		±0.7	±1.1	±0.3	±1.8		±1.2	±3.1	±2.3		±2.9	±2.9
34− 37	.141	84.2	83.7	76.0	56.6	44.2	41.2	37.4	. .	36.3	32.6	. .
		±1.6	±1.3	±1.1	±1.8	±0.7	±1.2	±1.0	. .	±2.5	±1.2	
113−116	.156	83.9	80.7	78.8	67.1	54.7	41.0	37.4	35.2	29.3	27.0	. .
		±1.4	±0.7	±0.8	±1.6	±2.3	±0.7	±1.8	±3.1	±0.9	±2.4	
61− 64	.161	87.2	84.3	81.6	71.7	55.1	43.4	36.8	33.4	29.0	27.3	. .
		±0.7	±1.3	±1.0	±2.1	±1.6	±2.0	±1.1	±2.1	±3.6	±3.4	
38− 41	.165	82.4	81.8	70.5	57.5	50.1	48.2	44.2	42.5	41.9	32.4	. .
		±1.7	±1.0	±4.2	±3.0	±1.6	±2.6	±2.2	±5.9	±3.0	±1.3	
65− 68	.190	81.8	77.7	75.1	64.7	56.8	43.4	40.0	32.6	27.1	27.0	. .
		±1.2	±1.8	±2.6	±4.0	±1.1	±1.5	±1.7	±0.9	±1.5	±3.5	

Table 16. Results of water retention determinations on woody peats.

Number of sample	Bulk density, g/cm³	Matric suction, kp/cm² 0.000	0.010	0.032	0.1	0.2	0.6	1.0	2.0	5.0	10.0	15.0
		Water content, vol. - %										
153−156	.099	90.3	79.4	69.8	54.6	42.4	. .	29.8	27.1	. .	23.3	. .
		±1.8	±3.0	±2.7	±2.1	±1.7		±1.6	±2.1		±1.9	
133−136	.100	90.5	80.4	65.8	47.8	36.3	33.2	27.9	26.2	21.4	21.3	. .
		±0.9	±3.4	±2.3	±2.5	±1.1	±0.8	±1.1	±1.6	±3.7	±2.9	
129−132	.109	88.4	82.0	69.6	53.9	43.3	35.3	31.9	27.9	24.0	23.4	. .
		±1.4	±0.7	±1.0	±1.8	±1.4	±0.6	±1.1	±4.4	±0.6	±2.6	
26− 29	.145	86.7	83.1	69.6	57.9	49.3	45.2	43.6	. .	36.4	31.5	. .
		±2.6	±3.4	±6.9	±3.5	±3.5	±1.5	±1.5		±4.8	±5.5	
125−128	.150	84.6	82.1	76.0	58.3	49.4	39.9	36.2	30.7	26.0	26.3	. .
		±0.5	±1.5	±0.1	±0.8	±1.1	±1.2	±1.2	±2.5	±1.6	±2.8	
149−152	.172	83.3	80.0	70.8	59.9	50.9	. .	40.5	33.4	30.3	29.4	. .
		±1.5	±1.9	±1.1	±2.8	±1.2		±1.2	±2.1	±0.5	±1.8	
22− 25	.207	82.2	81.3	79.4	65.5	. .	44.6	42.6	38.7	. .	25.7	21.3
		±1.6	±1.5	±1.8	±2.3		±1.6	±1.0	±4.2		±6.0	±5.8

Table 17. Correlations between the quantity of water (% of volume) retained in peat at different matric suctions and certain characteristics describing peat structure.

Peat characteristic	Water content at different matric suctions				
	pF 0	pF 1	pF 2	pF 3	pF 4
Bulk density	−.928***	.233	.776***	.896***	.805***
Degree of humification	−.890***	.231	.778***	.879***	.755***
Specific gravity	.465***	−.197	−.484***	−.439***	−.412***
Total porosity	.920***	−.233	−.778***	−.886***	−.795***
Ash content	−.660***	−.090	.319*	.589***	.557***

which are best suited as independent variables must first be found. The variable must be simple in character, readily determinable and unambiguous. In the present study, the following characteristics of the peat samples studied were determined: the peat type, the degree of humification, the bulk density, the total porosity and the ash content. In the following connection, the possibilities of using these factors as independent variables in the water retention studies will be dealt with. Table 17 shows the correlations obtained between these characteristics of peat structure and the quantities of water retained in the peat at different matric suctions.

The table shows that the correlations between all the characteristics studied and the quantity of retained water are highly significant for peat at saturation, and again, at matric suctions above pF 2. The only exception to the general situation in the table is the correlation between the ash content and the water content at pF 2, which is significant. Moreover, it can be seen that the signs of the correlations between the various variables and the quantity of water retained change with increasing matric suction from pF 0 to pF 1 – pF 2.

The smallest correlation coefficients were obtained in the case of specific gravity and ash content. It should also be mentioned that Kunze (1965, p. 182) has obtained quite similar correlation coefficient values to those of the present study for the relationships between the ash content and the quantity of retained water at matric suctions of pF 2 and pF 4.2. As determination both of the specific gravity and ash content require work in the laboratory, and as they are inferior to the three other characteristics dealt with here with regard to their capacity to explain water retention, these characteristics will be disregarded in the continued examination of the study material.

On the basis of graphic examination and experiments with different function models, it was found that a quadratic function best explains the quantities of water retained by peat at different matric suctions with the aid of bulk density, degree of humification and total porosity, when each of these characteristics is used separately. Table 18 shows the coefficients of determination obtained by peat type and for the entire material of the study.

On the basis of the results presented in Table 18, the coefficient of determination is of similar magnitude in the case of each of the variables used, the degree of humification, however, being possibly the weakest characteristic with regard to its coefficient of determination. In the present study, the bulk density was decided on as the characteristic to which the water retention of peat was mainly referred. The usability of the total porosity is hampered by the laboriousness of its determination; in addition to the bulk density, the specific gravity is required. Determination of the degree of humification, in turn, involves some degree of subjectivity; moreover, it does not give the right picture of the density of the peat in the case, for example, of recently drained peat soils. As, nevertheless, the degree of humification is rather frequently used in European peat classification, changes in the water retention of peats are also expressed as a function of the degree of humification in the present study.

3314 Water content of peat at saturation

The water content of peats at saturation was determined from pressure cell samples

Table 18. Coefficients of determination (R^2) for the correlations between the water content of peat and its bulk density, degree of humification and total porosity, separately for each, at different matric suctions.

Peat characteristic	Water content at different matric suctions				
	pF 0	pF 1	pF 2	pF 3	pF 4
S peat					
Bulk density	.80	.30	.75	.74	.48
Degree of humification	.83	.17	.69	.67	.39
Total porosity	.79	.28	.74	.74	.48
C peat					
Bulk density	.79	.56	.65	.85	.78
Degree of humification	.82	.57	.64	.87	.80
Total porosity	.78	.59	.65	.85	.79
L peat					
Bulk density	.96	.29	.85	.84	.77
Degree of humification	.91	.53	.81	.82	.56
Total porosity	.97	.31	.83	.79	.67
Entire material					
Bulk density	.86	.27	.71	.81	.67
Degree of humification	.79	.17	.67	.78	.58
Total porosity	.85	.25	.70	.80	.66

before they were treated in the cells. The intention was to saturate the peats, or according to the definition of the concept, to fill all the voids between soil particles with water (ANON. 1970, p. 14).

A highly significant correlation was found to prevail between the water content of peat at saturation (y) and its bulk density (x), as follows (see Fig. 16):

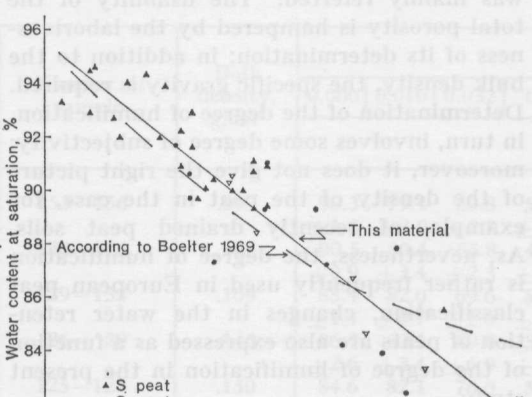

Fig. 16. Dependence of the water content of peat at saturation on its bulk density.

$$y = 97.95 - 79.72\,x;\ r^2 = .86;\ F = 280.12^{***}$$

The regression obtained on the basis of the present material was linear, and inclusion of the quadratic term showed to be of no importance. No significant differences were observed between the peat types either. For the sake of comparison, the dependence between the water content of peat at saturation and its bulk density as established by BOELTER (1969, p. 608) has been indicated in Fig. 16. The results obtained by BOELTER and those of the present study are very similar, although the curvilinear fitting of BOELTER's data has proved significant. The differences which can be observed between the delineators at high bulk density values are probably due to the different methods used in fitting the curves.

The water content at saturation and the total porosity, as determined in the present study, differ from each other to a considerable extent (see Figs. 11, 16 and 17). A highly significant dependence was found between the water content at saturation (y) and the total porosity (x) of the peats studied (Fig. 17):

$$y = -4.97 + 1.02\,x;\ r^2 = .85;\ F = 246.52^{***}$$

The line indicating this relationship, however, lies about 2.5 unit per cent below the broken line indicating the 1:1 relationship. On the basis of this, it appears that the method used has not made it possible to reach full saturation.

Another possibility is of course that there is a systematic error in the total porosity determinations. However, the total porosity values obtained in the present study were quite similar to those obtained in other studies. The relationship presented by VOMPERSKY (1968, p. 42) between the full water capacity and bulk density of peat is also in conformity with that obtained for the total porosity and bulk density in the present study. This fact, too, supports the assumption that, just as might have been the situation in BOELTER's study, the method used in the present study did not make it possible to reach full saturation. There is the possibility that some of the pores in the peat are blocked, that is to say, pores in which air has been trapped even if the soil is submerged. These pores are surrounded by pores which are so small that they can prevent air from escaping (cf. KOHNKE 1968, p. 168). This theory and the results obtained in the present study seem consequently to be at variation with the assumption presented by BOELTER (1969, p. 607) that »total porosity is considered to be equal to the water content at saturation.»

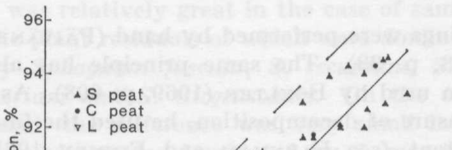

Fig. 17. Relationship between the water content of peat at saturation and its total porosity on the basis of the present material (unbroken line) and theoretically (broken line).

3315 Dependence of the water retention of peat on its bulk density

The changes in the water retention of peats with the advance of decomposition and with increasing density are examined, first with regard to the bulk density and later with regard to the degree of humification.

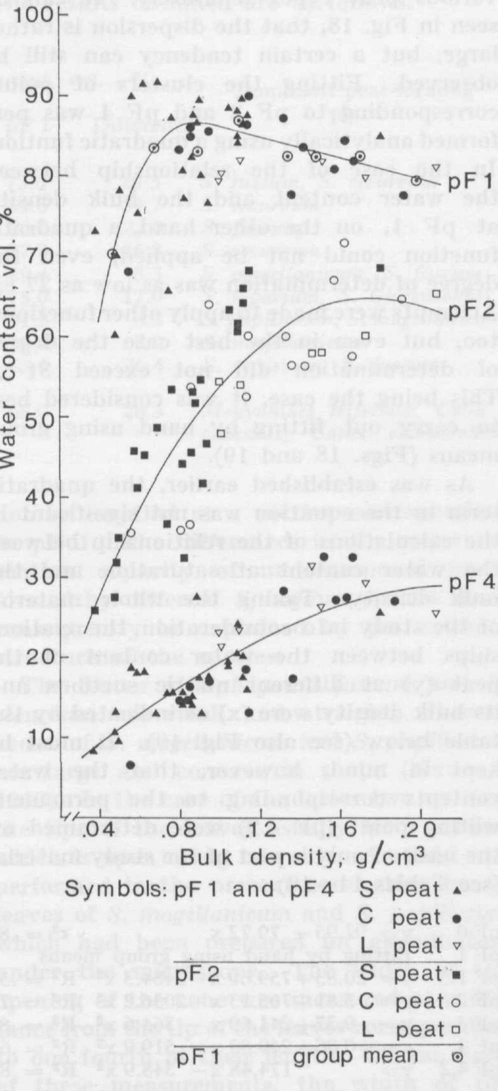

Fig. 18. Relationship between the quantity of water retained in peat at matric suctions of pF 1, 2 and 4 and its bulk density.

Fig. 18 illustrates the relationships between the quantity of water retained in the peat and its bulk density at matric suctions of pF 1, 2 and 4. The samples, which were representative of the different peat types studied, were divided rather unevenly with regard to the stage of decomposition. On average, the Sphagnum peats were less decomposed than the sedge and woody peats, the latter having reached a more advanced stage of decomposition (cf. also Tables 8—10). For this reason it would be unrealistic to treat the water retention properties of the various peat types separately. It can be seen in Fig. 18, that the dispersion is rather large, but a certain tendency can still be observed. Fitting the clusters of points corresponding to pF 2 and pF 4 was performed analytically using a quadratic funtion. In the case of the relationship between the water content and the bulk density at pF 1, on the other hand, a quadratic function could not be applied; even the degree of determination was as low as 27 %. Attempts were made to apply other functions, too, but even in the best case the degree of determination did not exceed 31 %. This being the case, it was considered best to carry out fitting by hand using group means (Figs. 18 and 19).

As was established earlier, the quadratic term in the equation was not significant in the calculations of the relationship between the water content at saturation and the bulk density. Taking the whole material of the study into consideration, the relationships between the water content of the peat (y) at different matric suctions and its bulk density were (x) as indicated by the table below (see also Fig. 19). It must be kept in mind, however, that the water contents corresponding to the permanent wilting point (pF 4.2) were determined on the basis of only a part of the study material (see Tables 14—16).

pF 0	$y = 97.95 - 79.72\,x$	$r^2 = .86$
pF 1	Fitting by hand using group means	
pF 1.5	$y = 20.83 + 759.69\,x - 2484.3\,x^2$	$R^2 = .59$
pF 2	$y = 3.81 + 705.13\,x - 2036.2\,x^2$	$R^2 = .71$
pF 3	$y = 9.37 + 241.69\,x - 364.6\,x^2$	$R^2 = .81$
pF 4	$y = 0.06 + 249.80\,x - 519.9\,x^2$	$R^2 = .67$
pF 4.2	$y = 174.48\,x - 348.9\,x^2$	$R^2 = .81$

A similar examination method was used in the preliminary study, but in that case all fittings were performed by hand (PÄIVÄNEN 1968, p. 33). The same principle has also been used by BOELTER (1969, p. 608). As a measure of decomposition, he used the fiber content (see FARNHAM and FINNEY 1965) and the bulk density of the peats studied.

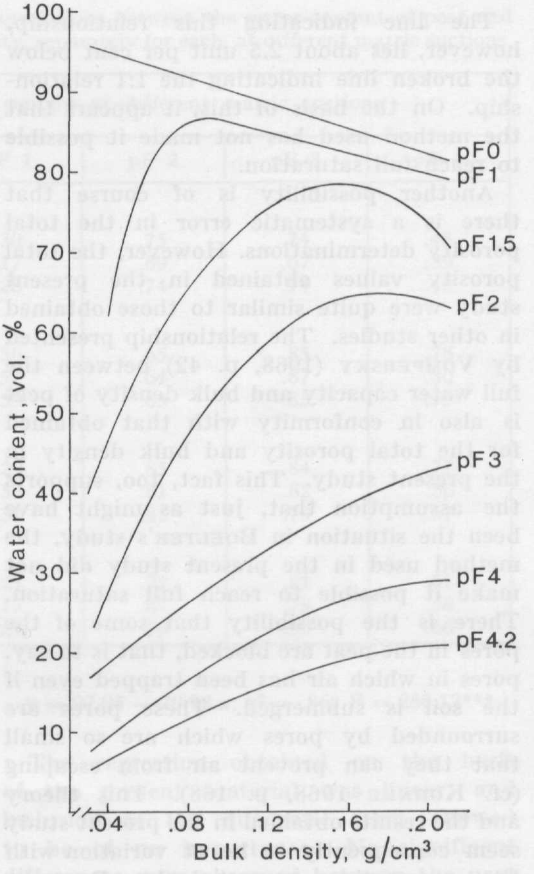

Fig. 19. Relationships between the quantity of water retained in peat at various matric suctions and its bulk density.

It can be seen in Fig. 19 that when the bulk density increases above 0.09 g/cm³ there is a negative correlation between the water content corresponding to pF 1 and the bulk density of a similar kind to that observed between the water content at saturation and the bulk density. At lower bulk densities, however, some of the peat samples have retained large quantities of water, and other samples, relatively small quantities (Fig. 18). In particular, the peats which have a low bulk density have lost considerable amounts of water at a suction corresponding to a 10 cm column of water. Fig. 18 gives reason for the conclusion that bulk density cannot alone explain the differences in water retention over this range. Attention was paid to this phenomenon already in the preliminary study, and it was therefore assumed that the very plant residuals (the *Sphagnum* species) dominating undecomposed Sphagnum peat would, in addition to the bulk density, be of importance for the water retention capacity of the peat at low matric suctions (PÄIVÄNEN 1968, p. 35). The same phenomenon can be observed in the results presented by BOELTER (1969, p. 608), although he has paid no attention to the species composition of the plant residuals of the peat studied.

In the present study, all peat samples which had a bulk density less than 0.075 g/cm³ were examined with regard to the species composition of the plant residuals. Some notes were made on the plant residuals when sampling in the field. These were completed both by examination of the samples when they had dried and by re-examination of the species composition of the peat in the sampling spot in the field. The results obtained are as follows:

Sample number	Bulk density, g/cm³	Degree of humification	Water content, vol. - % pF 0	pF 1	Difference	Dominant peat-forming plant
S peat						
181–182	.037	1	93.3	73.0	20.3	*S. fuscum, S. recurvum*
173–176	.047	1	94.5	59.8	34.7	*S. recurvum*
53– 56	.047	1	92.9	70.0	22.9	*S. fuscum*
169–172	.049	1	94.6	77.8	16.8	*S. recurvum*
57– 60	.056	1	92.7	89.4	3.3	*S. magellanicum, S. fuscum*
8– 10, 52	.058	1	92.0	75.0	17.0	*S. riparium, S. Girgensohnii*
5– 7, 15	.061	2	94.0	91.3	3.3	*S. papillosum, S. magellanicum*
48– 51	.068	1–2	94.3	91.4	2.9	*S. magellanicum*
177–180	.073	3	92.0	65.6	26.4	*S. recurvum, S. fuscum*
C peat						
185–188	.054	1	94.3	68.0	26.3	*Menyanthes trifoliata, Calla palustris, Carex chordorrhiza*

It can be seen from the table that the difference in the water content of the samples between saturation and a suction of pF 1 was relatively great in the case of samples the plant residuals of which were dominated by *Sphagnum fuscum, S. recurvum, S. riparium* and *S. Girgensohnii*. On the other hand, the difference was very small in the case of samples dominated by *S. magellanicum* and *S. papillosum.*

The leaves of sphagnous plants are made up of large hyaline cells and narrow, green cells situated between the former. It is the hyaline cells that retain water (NEWBOULD 1958, p. 102). As there are no great differences in size between the hyaline cells of different *Sphagnum* species, the high water retention capacity at low matric suctions of the species belonging to the group *palustria* cannot be explained with the aid of differences in their cell tissues. Moreover, the hyaline cells are so small (HEIKURAINEN and HUIKARI 1952, p. 31) that they cannot be emptied at a suction corresponding to pF 1. The differences in the water retention capacity of undecomposed peats formed by different *Sphagnum* species must consequently be explained by the external structure of the species.

The leaves of *Sphagnum fuscum* and *S. recurvum* are small and straight, whereas those of *S. magellanicum* and *S. papillosum* are large and concave in shape (NYHOLM 1969). In the case of the latter two species, the tips of the leaves usually form a cone which is open along one side. A study was performed in the present connection on 40 leaves of *S. magellanicum* and *S. papillosum* which had been prepared for examination under the microscope. The width of the opening of the cone was measured at a distance from the tip of the leaves corresponding to one fourth of their length. On the basis of these measurements, the width of the opening was on average 95 ± 13 μm. As will be indicated later in this work (p. 55), the diameter of the largest water-filled pores at a matric suction of pF 1 is 300 μm. Thus, the size and form of the leaves of *Sphagnum* mosses belonging to the group *palustria* explain their greater water retention capacity at low matric suctions in undecomposed peat in comparison with *S. fuscum* and *S. recurvum*. The result obtained is supported by the observation made by OVERBECK and HAPPACH (1957, p. 369), that the capacity of a layer of living *S. magellanicum* to retain water against gravity is superior to that of a layer of *S. fuscum*.

In any case, it can be established that the difference in water content at saturation and at pF 1 is not without significance, at least in the case of slightly decomposed peats, as sometimes has been assumed (PUUSTJÄRVI 1963, p. 61).

In the curves illustrating the relationships between water content and bulk density, there is also a culmination point at the matric suction values of pF 1.5 and pF 2. In the former case, it corresponds to a bulk density of 0.15, and in the latter case, of 0.18 g/cm^3. The occurrence of such a culmination point may be due to heterogeneity in the study material and to the fitting of the curve using a quadratic equation. On the other hand, it may also be due to the real pore size distribution and its influence on the quantities of water retained. The suction corresponding to pF 2 is so small that it cannot empty pores of medium size, not to mention small ones (RICHARD and BEDA 1953, p. 296). The latter possibility is supported for example by the observation made by HOLSTENER-JØRGENSEN (1958, p. 155), according to which the water content corresponding to pF 2 decreases in the case of mineral soils with increasing bulk density. If the bulk density could be further increased from the maximum value recorded in the present study (0.2 g/cm^3) to the minimum presented by HOLSTENER-JØRGENSEN (0.8 g/cm^3), it would probably be found that the water content corresponding to pF 2 decreases at this range of variation in bulk density, too.

At the pF values 3, 4 and 4.2 peat contains more water as its bulk density increases. Nevertheless, the regression between water content and bulk density becomes less steep when moving from pF 3 to pF 4.2.

There are only limited possibilities for comparing the results from the water retention determinations carried out with those obtained from other studies. Firstly, only few water retention determinations have been performed previously on natural, undisturbed peats. Secondly, in several connections the water contents obtained have been expressed in terms of percentages of the dry weight of the samples studied, and as no bulk densities have been indicated, comparisons are impossible. The results on the water retention capacity of peats presented by BOELTER (1969, p. 608) support those obtained in the present study. The figures presented by STEWART *et al.* (1963, p. 53) concerning the quantities of water retained in a couple of moderately decomposed peats at pF 2 and pF 4.2 and those presented by STURGES (1968, p. 263) on three well-decomposed peats at pF 2 and pF 3, are within the limits of variation of the figures obtained in this study. Likewise, the water contents of different peats at the permanent wilting point (pF 4.2) presented by FEUSTEL and BYERS (1936, p. 21) are in good conformity with the results of the present study. On the other hand, the result obtained by PAAVILAINEN (1967, p. 11), according to which there is no correlation between the air space and bulk density of peat at pF 2, is probably due to the smallness of his study material and a relatively small range of variation in bulk density.

3316 Dependence of the water retention of peat on its degree of humification

Fig. 20 shows the relationships between the quantity of water retained in the peat and the degree of humification at pF 1, 2 and 4. Comparison with Fig. 18 shows that, particularly in the case of undecomposed peat, bulk density is superior to the degree of humification in explaining water retention capacity. Peat samples which belong to the same group according to their degree of humification (H 1), differ from each other with regard to their bulk density. In the case of undecomposed peats, the bulk density is in turn capable of describing to some extent the pore size distribution, although it was established in the preceding section

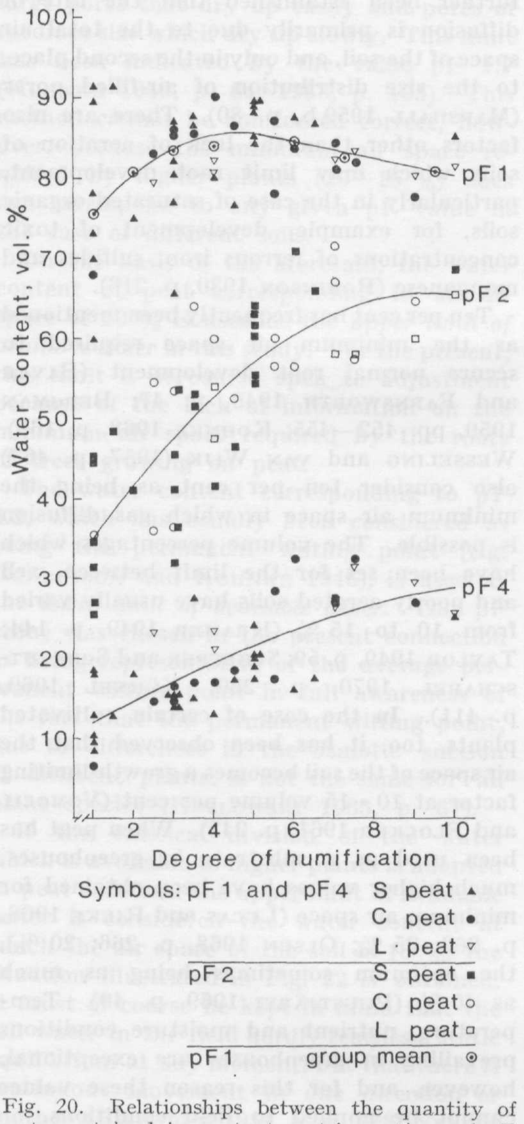

Fig. 20. Relationships between the quantity of water retained in peat at matric suctions of pF 1, 2 and 4 and its degree of humification.

that the species composition of the plant remnants forming the peat probably influences water retention capacity in the case of undecomposed peats. Furthermore, it ought to be kept in mind that bulk density is better able to describe, for example the compression of peat immediately after draining. The increase in the rate of decomposition due to draining becomes visible as an increase in the degree of humification only at a later stage.

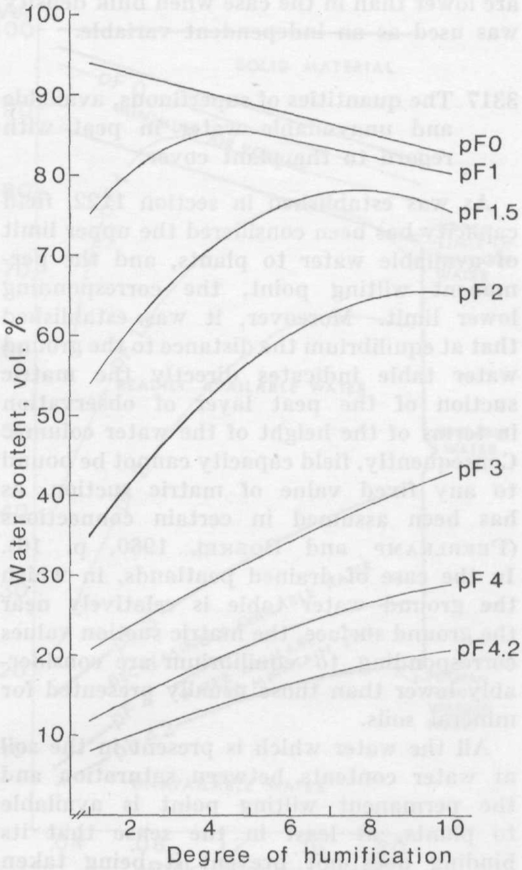

Fig. 21. Relationships between the quantity of water retained in peat at various matric suctions and its degree of humification.

As the degree of humification has been used traditionally to describe the properties of peat, the relationships between the water content of the peat (y) at different matric suctions and the degree of humification (x) was calculated for the entire material of the study (see also Fig. 21):

pF 0	$y = 95.17 - 1.26\,x$	$r^2 = .79$
pF 1	Fitting by hand using group means	
pF 1.5	$y = 46.20 + 8.32\,x - 0.54\,x^2$	$R^2 = .50$
pF 2	$y = 27.03 + 8.14\,x - 0.43\,x^2$	$R^2 = .67$
pF 3	$y = 17.59 + 3.22\,x - 0.07\,x^2$	$R^2 = .78$
pF 4	$y = 8.81 + 3.03\,x - 0.10\,x^2$	$R^2 = .58$
pF 4.2	$y = 5.80 + 2.27\,x - 0.08\,x^2$	$R^2 = .86$

For the aforementioned reasons the curves describing the relationships slope considerably less than those presented in Fig. 19. Likewise, the coefficients of determination are lower than in the case when bulk density was used as an independent variable.

3317 The quantities of superfluous, available and unavailable water in peat with regard to the plant cover

As was established in section 1122, field capacity has been considered the upper limit of available water to plants, and the permanent wilting point, the corresponding lower limit. Moreover, it was established that at equilibrium the distance to the ground water table indicates directly the matric suction of the peat layer of observation in terms of the height of the water column. Consequently, field capacity cannot be bound to any fixed value of matric suction, as has been assumed in certain connections (Peerlkamp and Boekel 1960, p. 10). In the case of drained peatlands, in which the ground water table is relatively near the ground surface, the matric suction values corresponding to equilibrium are considerably lower than those usually presented for mineral soils.

All the water which is present in the soil at water contents between saturation and the permanent wilting point is available to plants, at least in the sense that its binding does not prevent it being taken up by plants (Andersson and Wiklert 1970, p. 18). Superfluous water in the soil may, however, impair aeration of the soil to such an extent that the low oxygen supply and lack of carbon dioxide removal inhibit growth. In the case of undrained peatlands, the ground water table is frequently located at the very level of the ground surface or near it, and in such cases the pore space of the soil is completely filled with water. If the water moves very slowly, anaerobic conditions prevail in the soil (Lähde 1969). Under such conditions it might be appropriate to define the upper limit of available water as the air void volume below which aeration of the soil becomes a growth-limiting factor. Oxygen and carbon dioxide move in the soil either dissolved in the water or by diffusion in the air space of the soil, the latter being the more common way. Thus, soil aeration depends first and foremost on the volume of the air space of the soil (Hillel 1971, p. 125). It has further been established that the rate of diffusion is primarily due to the total air space of the soil, and only in the second place, to the size distribution of air-filled pores (Marshall 1959 b, p. 80). There are also factors other than the lack of aeration of soils which may limit root development, particularly in the case of saturated organic soils, for example, development of toxic concentrations of ferrous iron, sulfides and manganese (Robinson 1930, p. 216).

Ten per cent has frequently been mentioned as the minimum air space required to secure normal root development (Baver and Farnsworth 1940, p. 47; Bergman 1959, pp. 452–455; Kohnke 1968, p. 169). Wesseling and van Wijk (1957, p. 467) also consider ten per cent as being the minimum air space in which gas diffusion is possible. The volume percentages which have been set for the limit between well and poorly aerated soils have usually varied from 10 to 15 % (Kramer 1949, p. 144; Taylor 1949, p. 59; Scheffer and Schachtschabel 1970, p. 239; Kühnel 1969, p. 411). In the case of certain cultivated plants, too, it has been observed that the air space of the soil becomes a growth-limiting factor at 10–15 volume per cent (Vomocil and Flocker 1961, p. 243). When peat has been used as a substrate in greenhouses, much higher values have been obtained for minimum air space (Lucas and Rieke 1968, p. 262: 25 %; Olsen 1968, p. 266: 20 %), the optimum sometimes being as much as 40 % (Puustjärvi 1969, p. 49). Temperature, nutrient and moisture conditions prevailing in greenhouses are exceptional, however, and for this reason these values cannot be applied to field conditions.

There is only little information available on the minimum air space required by the roots of trees growing on peat. According to a study performed by Paavilainen (1967, p. 15), it seems that the roots of pine trees growing on pine swamp do not penetrate the soil down to a depth at which the air space of the peat drops below 10 %. Despite this result, Paavilainen (1967, p. 17), probably basing his conclusion on traditional practice, places the limit between available and unavailable water at pF 2. Quite recently, the concept aeration porosity limit was introduced as the limit between large pores that dry up easily and pores of medium size which dry up slowly. This limit has been indicated by the value pF 1.7 (KOHNKE 1946, p. 64; 1968, p. 163). This method cannot be considered correct, however, because the minimum air space required by higher plants (10–15 %) does not correspond to any given pF value in the case of different soils.

On the basis of the aforesaid, the water content of peat corresponding to an air space of 10 % is used as the *upper limit of available water* in this study. For the present, this limit is of course open to adjustment because of the lack of information on the minimum air space required by the roots of trees growing on peat.

The water content corresponding to pF 4.2, which has usually been considered as being the permanent wilting point (e.g. ROBERTSON and KOHNKE 1946), is used as the *lower limit of available water*. This pF value was chosen in the present connection as being representative of the average permanent wilting point in full awareness of the fact that the permanent wilting point, due to differences in the osmotic suction of different plants, is not the same for all plant species (KOZLOWSKI 1965, p. 67).

If the classical division of the water which is available to higher plants is adapted to peat soils and the upper limit of available water is considered the water content at which the air space of the soil is 10 %, the situation illustrated in Fig. 22 is obtained. It must of course be kept in mind that the soil water in the field hardly reaches a static equilibrium at any moment, but that there is continuous movement in one direction or another (RICHARDS 1951 b, p. 778; NERPIN and CHUDNOVSKII 1970, p. 148; HILLEL 1971, p. 206). Nevertheless, Fig. 22 is capable of illustrating the quantity of water which is available to plants in the case of peats with different bulk density at any hypothetical equilibrium of the soil water. As was mentioned earlier, the total volume of water held by peat at saturation did not equal that of the total porosity according to the present study. The upper limit of available water was obtained by deducting the minimum air space, 10 unit per cent, plus the solid matter volume from the total volume of the soil. Thereby, it was

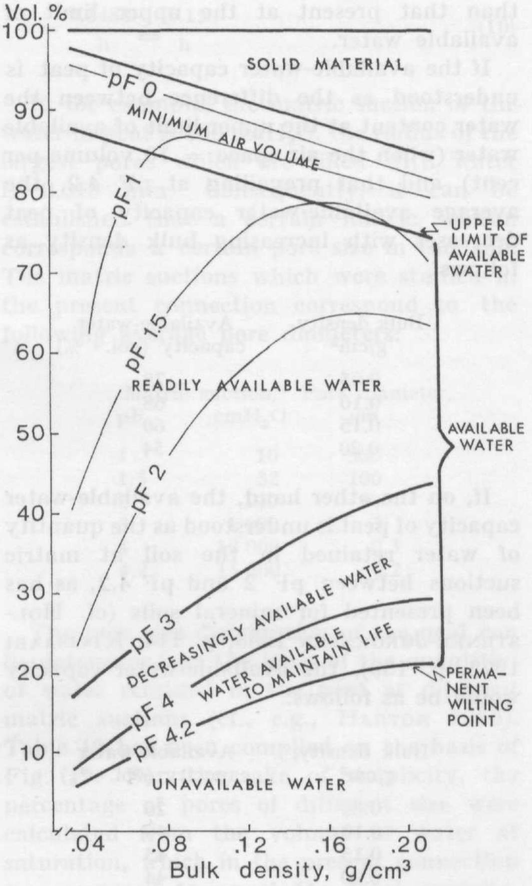

Fig. 22. Volumes of solid material and minimum air space as well as of water available (readily available + decreasingly available + available to maintain life) and unavailable to plants in peats with different bulk density. The thin lines show the quantities of water retained in the peat at pF 0, 1, 1.5 and 2.

established that different matric suction values can be obtained for different peats. In the case of undecomposed peat, the minimum air space is obtained at a matric suction below pF 1, the corresponding value being pF 1.5 for peats at an advanced stage of decomposition. At equilibrium, the ground water table should be located about 32 cm below the layer of observation in the case of peats of the latter kind. All the water which enters this minimum air space is superfluous water. The optimum water content of peat with regard to the growth of trees is probably considerably smaller than that present at the upper limit of available water.

If the available-water capacity of peat is understood as the difference between the water content at the upper limit of available water (when the air space = 10 volume per cent) and that prevailing at pF 4.2, the average available-water capacity of peat decreases with increasing bulk density as follows:

Bulk density, g/cm^3	Available-water capacity (vol. - %)
0.05	78
0.10	68
0.15	60
0.20	54

If, on the other hand, the available-water capacity of peat is understood as the quantity of water retained in the soil at matric suctions between pF 2 and pF 4.2, as has been presented for mineral soils (cf. Holstener-Jørgensen 1958, p. 114; Kivisaari 1972, p. 139), the available-water capacity would be as follows:

Bulk density, g/cm^3	Available-water capacity (vol. - %)
0.05	26
0.10	40
0.15	45
0.20	44

As can be seen from the table, the available-water capacity, when defined in the traditional way, increases with increasing bulk density. It is worth mentioning in this connection that the available-water capacity, when it has been defined in this way for mineral soils, increases with increasing bulk density in the case of coarse soils, whereas, in the case of clay and mull soils, it decreases with increasing bulk density (Heinonen 1954, p. 56).

At present, we do not yet know the optimum water content or the optimum matric suction with regard to the growth of forest trees. The range of the water contents corresponding to favorable growth is probably limited, on one hand, by the water content at pF 3 (cf. Heinonen 1954, p. 16), and on the other hand, by the minimum air space required. This range has been indicated in Fig. 22 using the term readily available water.

3318 The quantity of water that can be removed from peat by draining

On the basis of the results obtained from the water retention determinations, estimations can be carried out concerning the quantity of water that can be removed from peat soils by draining them. There is reason, however, first to define a few concepts, in order to avoid misunderstandings.

The concept *specific yield* is frequently used to describe the relationship between the quantity of water that has been added to or removed from soil and the subsequent change in the level of the ground water table (Tolman 1937, p. 482; Todd 1959, p. 23). The concept covers the change in the water quantity both in the saturated soil layer and in the unsaturated layer above the ground water table. In Finland, the same phenomenon has been described by means of the term *ground water coefficient* (Heikurainen 1963; Päivänen 1964). In determinations of the specific yield and the ground water coefficient, the changes taking place in the water content of the whole soil profile must be taken into consideration (cf. Heikurainen 1971, p. 21). As hysteresis affects the relationship between the changes in the quantity of water and in the ground water table, this relationship must be determined separately for desorption and for sorption.

The concept specific yield has also been used in another sense, namely, to indicate the relationship between the quantity of water draining from a saturated peat sample during 24 hours due to gravity, and the total volume of the sample (Satterlund 1960, p. 16).

For use in the case of water retention determinations to be carried out only in the laboratory, Boelter (1969, p. 607) introduced the term *water yield coefficient*, which is a modification of the concept specific yield, and refers to the ratio of the difference between the water quantities retained at saturation and at pF 2 and the total volume of the sample. Thus, the coefficient expresses the maximum quantity of water which drains from peat when the water table is lowered from zero by 100 cm as measured from the observed peat layer assuming that no evaporation takes place and that the change in the water content in the unsaturated layer above the layer of observation is zero. Thus, the water yield coefficient describes also the theoretical maximum quantity of water which can be removed from the topmost layers of a peat soil by means of efficient draining alone.

On the basis of Fig. 19, the following average water yield coefficients were obtained from the present study material:

Bulk density, g/cm^3	Water yield coefficient, cm^3/cm^3
0.05	0.60
0.10	0.36
0.15	0.22
0.20	0.18

It can be seen from the table, that the quantity of water that can be removed by draining rapidly decreases with increasing bulk density of the peat.

332 Pore size distribution in peat

In a simplified form, the pore space of a soil can be considered to be a network of capillary canals. At equilibrium, the surface tension existing in a capillary pore equals the weight of a water column as determined at the free water table:

$$2\,\pi\, r\, \gamma = \pi\, r^2\, \varrho\, gh\, \cos\alpha. \qquad (9)$$

in which

- r = radius of the capillary pore
- γ = surface tension coefficient for water (72.75 dyn/cm; temperature = 20 °C)
- ϱ = density of water
- h = capillary rise
- g = acceleration of gravity (981 cm/sec²)
- α = contact angle of water

Usually it is assumed that the contact angle between the water and the capillary pore equals zero, and this means that

$$r = \frac{0.1484}{h} \cong \frac{0.15}{h} \qquad (10)$$

If, for example, the matric suction of the water in peat is 100 cmH_2O, the radius of the largest pores which are filled with water is 0.015 mm. Consequently, it can be established that a certain matric suction corresponds a certain pore size in the soil. The matric suctions which were studied in the present connection correspond to the following average pore diameters:

Matric suction, pF	cmH_2O	Pore diameter, μm
1	10	300
1.5	32	100
2	100	30
3	1 000	3
4	10 000	0.3
4.2	15 000	0.2

The pore size distribution of the peat can be determined on the basis of the quantities of water retained in the peat at different matric suctions (cf., e.g., Hartge 1965). Table 19 has been compiled on the basis of Fig. 19. For the sake of simplicity, the percentage of pores of different size were calculated from the volume of water at saturation, which in the present connection was assumed to equal the total porosity. As was established, this was not exactly true, but the difference was of minor importance for the results. On the other hand, we do not know to which size category of pores the blocked pores, or those filled by air at saturation, belong (see p. 47).

It can be seen from the table that the quantity of large (>30 μm) pores rapidly decreases and that of medium-sized (30-0.2 μm) and small (<0.2 μm) pores increases

Table 19. Average pore size distribution of peats with different bulk density (% of the volume of water at saturation).

Bulk density, g/cm^3	Pore size, μm						
	>300	300—100	100—30	30—3	3—0.3	0.3—0.2	<0.2
0.05	21.3	22.3	20.2	13.7	10.5	3.6	8.4
0.10	3.9	16.7	18.9	27.2	11.1	6.6	15.6
0.15	3.3	5.2	16.7	31.3	13.3	8.7	21.5
0.20	3.0	7.2	11.6	26.2	16.5	9.9	25.6

with increasing bulk density. Correspondingly, it has been established that the proportion of large fibers in the peat rapidly decreases and that of small fibers increases with increasing bulk density (STANEK 1961, p. 26).

On the basis of the pore size distribution, certain conclusions can also be made concerning the capillary rise of water in peat. In undecomposed peat, most pores (64 %) are large, non-capillary pores. It is clear that the capillary fringe is very narrow in such situations, according to ROMANOV (1968, p. 69), ranging between 15 and 30 cm. With increasing bulk density, the proportion of the effective capillary pore system in the total pore volume increases, and so the capillary rise of water is capable of compensating for the loss of water due to evaporation in the topmost peat layer by transferring water from the ground water table to the surface. The decrease in the capillary rise due to lowering of the ground water table is reflected in the form of a decrease in evapotranspiration as shown in lysimeter experiments (PÄIVÄNEN 1964, p. 90), and as a delay in the daily drop in the level of the ground water table due to evapotranspiration in the field (HEIKURAINEN 1971, pp. 10 and 21).

333 An example of the variation in the water content in the rhizosphere of a drained peat soil

In the following connection an example is given for the purpose of illustrating how the combined use of laboratory and field determinations can serve the estimation of the quantities of superfluous, available and unavailable water in the rhizosphere at varying levels of the ground water table.

The points in Fig. 23 indicate matric suction values obtained by tensiometers in the 5—10 cm peat layer at different levels of the ground water table. The site was a dwarf-shrub-dominated pine swamp in an advanced stage of drainage, the peat in the layer concerned was ErC peat H4 with a bulk density of 0.113 g/cm³. The unbroken line shows the theoretical matric suction corresponding to the distance of

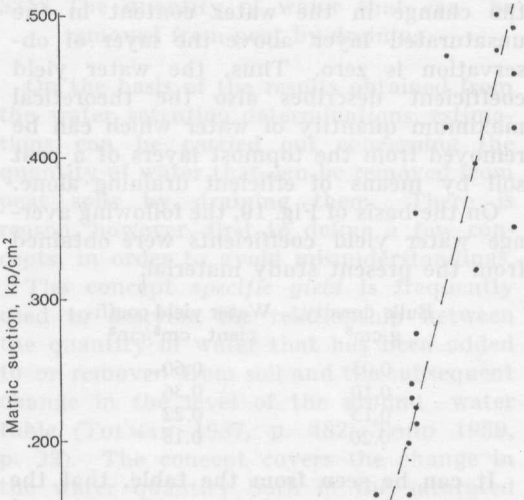

Fig. 23. Tensiometer recordings on the matric suction of sedge peat 5—10 cm below the ground surface at different depths of the ground water table. The unbroken line indicates the theoretical matric suction, the broken line having been obtained by fitting the actual recordings by hand.

the ground water table from the layer of observation (cf. RICHARDS 1941 b). The matric suction values obtained with the tensiometers differ from the theoretical values only when the distance between the layer under study and the ground water table reaches 62 cm. From this point on, the matric suction increases at an extremely rapid rate. In many other studies, too, it has been found that evapotranspiration and capillary rise decrease with increasing depth of the ground water table (e.g. VIRTA 1966, p. 30; PAAVILAINEN and VIRRANKOSKI 1967, p. 18; ROMANOV 1968, p. 71).

Table 20 presents the matric suction values at different levels of the ground water table as indicated by the fitted curve in Fig. 23. In addition, the table shows the water con-

Table 20. Tensiometer recordings on the matric suction 5—10 cm below the ground surface at different depths of the ground water table, water content at different matric suctions and corresponding volumes of superfluous and readily available water.

Dist. between ground water table and layer of observation, cm	Matric suction, kp/cm²	Water content, vol. - %	Superfluous water, vol. - %	Readily available water, vol. - %
30	0.030	85	4	
35	0.035	83	2	
40	0.040	81	0	
45	0.045	79		47
50	0.050	76		44
55	0.055	74		42
60	0.060	73		41
65	0.095	60		28
70	0.160	50		18
75	0.250	46		14
80	0.350	39		7
85	0.460	36		4

tent corresponding to each matric suction value as obtained from water retention determinations carried out in the laboratory. If 10 % by volume is considered to be the minimum air space of peat, then all the water present at values exceeding this, in the case of peats with a bulk density of 0.113 g/cm³, 81 % by volume, would be superfluous. At pF 3 (32 %), difficulties with the water supply would already check growth (cf. HEINONEN 1954, p. 16). Against this background, the quantities of superfluous and of readily available water corresponding to different levels of the ground water table were also calculated and inserted in the table. The limit values remain still more or less open, it is true, but this is due to the fact that the optimum relationship between soil water and different tree species has not been established so far (HEIKURAINEN 1967).

Tensiometer determinations of a similar kind were carried out in the case of seven sample plots. The distance between the ground water table and the peat layer under study (5—10 cm below the ground surface) at which the capillary rise of water appeared to be hampered varied between 40 and 70 cm. On average, the capillary rise of water reached the layer under study from deeper levels of the ground water table, the greater the bulk density of the peat:

Bulk density of the observed layer, g/cm³	Distance between the observed layer and the ground water table at which capillary rise to the former becomes difficult, cm
0.084	40
0.084	50
0.093	55
0.110	50
0.113	62
0.145	70
0.156	70

These field measurements, consequently, also support the ideas presented in the end of the preceding section concerning the influence of pore size distribution on the capillary rise of water in peat. In the examination of the figures presented in the above table, it should be kept in mind, that the data concerning bulk density is valid only for the peat layer in which tensiometer measurements were performed and that no detailed information is available on the possible changes in bulk density with increasing soil depth.

On the basis of the total data obtained from tensiometer determinations, it appears that, even in cases where the ground water table is located far below the ground surface, the distance of the ground water table from the part of the rhizosphere studied and evapotranspiration do not decrease the water content of this layer down to the limit of decreasing growth, not to mention the permanent wilting point.

34 Discussion

So far our knowledge of the water retention capacity of Finnish peat soils has been extremely poor. Information has been needed in particular about the water retention capacity of undisturbed, natural peats which have kept their original structure. Such data is required for the regulation of soil water relationships in peat soils by means of draining so as to reach optimum conditions with regard to tree growth. The present study is an attempt to make up for this lack of knowledge.

The peat sample material which was collected is not very evenly divided, for example, by peat type and degree of humification. The Sphagnum peats collected are representative primarily of slightly decomposed peats, whereas the woody peats had reached a more advanced stage of decomposition. The Sphagnum peats also dominated the material collected, and the woody peats were represented by the smallest sample number. Nevertheless, the material collected can probably be considered representative of the most common degrees of humification of peats composed of different groups of plant species (cf. ANON. 1973). The peat sample material was collected from a geographically rather small area in Central Finland. Despite this fact, the possibilities of making generalizations on the results will probably not be hampered because, in the situations where comparisons could be carried out, the water retention characteristics of the peats studied in the present connection showed to be very similar to those recorded, for example, for peats of the Lake States area in the U.S.A. (BOELTER 1962, 1964 a, 1969). Furthermore, it ought to be kept in mind that the ash contents of the peats studied were low, usually under ten per cent, and this is a feature which the peat soils of the northern coniferous zone have in common.

The results from the water retention determinations performed were referred to peat structure characteristics as far as possible. For this reason the peat type, degree of humification, bulk density, total porosity and ash content of the peats were examined. During examination of the results, it was established that it would have been unrealistic to handle the water retention capacity of different peat types separately because of the differences in the distribution of the peat samples of different peat types with regard to their degree of humification.

As can be seen from Table 11 (p. 36), there was a correlation between almost all the characteristics chosen for the description of the structure of the peats under study. Thus, the use of multivariable analysis for the description of water retention capacity would have made the interpretation of the results difficult. From a practical viewpoint, it would of course have been favorable if the degree of humification had proved well suited as an independent variable. However, the bulk density of peat proved to be the characteristic best suited for this purpose. Bulk density is more objective and gives probably a better picture of the pore size distribution of peat than the degree of humification. This is particularly true in the case of slightly decomposed peats. In the use of bulk density, for example, the compression of the peat substrate following draining is automatically taken into consideration. On the other hand, it must be remembered that bulk density determinations are laborious operations inasmuch as they require volumetric sampling in the field and weighing of the samples after drying at 105°C.

The possible sources of error involved in the methods used for determining the water retention capacity of peat were discussed in detail in section 3311, and for this reason, they can be disregarded in the present connection. The water contents of the peats were expressed in this study in terms of percentages of volume of samples at saturation. This is a better method than the use of dry-weight percentages, although, in the case of water contents corresponding to a matric suction of > pF 2, the former were obtained only indirectly, using separate bulk density samples in the determinations.

The determinations of total porosity and of the volume of water at saturation carried out in the study resulted in volume percentages which differed from each other. The differences were due, however, to incomplete saturation of the samples.

Particularly in the case of undecomposed peat, the bulk density (and still less the degree of humification) was not able alone to explain fully the water retention capacity of the peat at low matric suctions. On the basis of the results obtained in the present study, the species composition of the plant residuals (*Sphagnum* species) forming the peat is of the greatest importance for water retention in undecomposed peats. Brown (1972, p. 77), too, has established that »peat desorption may be more a function of structure and macrospore distribution than of density».

The bulk density of peat expressed as a quadratic equation explained 67–81 % of the variation in the water content of the peats at matric suctions from pF 2 to pF 4.2. The coefficient of determination of the degree of humification was usually lower than that obtained for bulk density.

In the calculations of the superfluous, available and unavailable water from the viewpoint of higher plants, the field capacity, which has been traditionally used in corresponding studies in mineral soils, was not used in the present study. This was because the air space below which soil aeration becomes a factor checking plant growth was considered to form a better basis. On the basis of the literature, the air space to be used in this sense was defined at 10 %. If the permanent wilting point (pF 4.2) is considered as being the lower limit of available water, the average available-water capacity decreases with increasing bulk density. The quantity of water which can be removed by draining, too, decreases with increasing bulk density.

On the basis of the quantities of water retained in peat at different matric suctions, the pore size distribution of the peat can be determined. The reliability of the results obtained is decreased, however, as a result of swelling and shrinking of the peat caused by variations in the water contents (cf. Reincke 1931).

The present study was based primarily on laboratory determinations of the water retention capacity of peat. Tensiometer determinations were performed, however, in seven sample plots. The use of laboratory and field determinations in combination was illustrated by means of an example concerning the determination of the quantities of superfluous, available and unavailable water in the rhizosphere of peat soil. The determinations carried out indicated that there is evidently no risk of overdrainage in the case of forest drainage, at least not without fertilizer application (cf. Huikari and Paarlahti 1967, p. 105).

4 SUMMARY

The present paper is a part of a larger study of the basic hydrologic properties of peat. This part of the study deals with the hydraulic conductivity and water retention capacity of peat and with their dependence on certain structural properties of peat. The data of the study was collected in central Finland (61°50'N; 24°20'E) from peatlands which have been drained for forestry purposes.

The piezometer principle was applied to the field measurements carried out on the hydraulic conductivity of peat. The data on the rate of rising of the water table consists of 1280 recordings. Moreover, the study includes a comparison between the hydraulic conductivity values obtained using this field method and those obtained in the laboratory in conjunction with the preliminary study.

The data concerning the water retention capacity of peat was obtained from determinations in the laboratory. The material studied consisted of a total of 1843 peat samples, 188 of which were studied in pressure cells, 1250 using pressure plate extractors and 405 using pressure membrane extractors. In the case of seven sample plots, field measurements of matric suction were performed during one growing season. The purpose of these measurements was to find out what level the matric suction can reach in the rhizosphere of drained peat soils.

Each of these two partial studies indicated that neither the hydraulic conductivity nor the water retention capacity of peat can be studied without regard to the quality and structure of the peat concerned, so that the results obtained must be related to some of the characteristics used to describe the stage of decomposition and the density of the peat.

On the basis of the results obtained from the study, the following conclusions may be drawn:

— The limits of the quantitative range of variation in the hydraulic conductivity of peat can be put at 2.0×10^{-6} and 1.1×10^{-2} cm/sec.

— The variation occurring in the hydraulic conductivity of peat is extremely large even within the same peat layer, at times being as much as ± 40 % from the mean. The reliability of the method is good, however, because of the very large differences occurring between peats of different degree of humification and between different sampling depths.

— As the hydraulic conductivity is different for various peat types, it must be studied separately for each type.

— Superficial peat layers do not show similar regularity with regard to their hydraulic conductivity as do deeper peat layers. This is probably due to the frequent occurrence of macropores in the topmost peat layer (tree root movement, decaying roots, irreversible colloids) and, to the great density and the advanced stage of decomposition of the peat. For this reason, the calculations were performed separately for values from the whole profile and for the hydraulic conductivity values obtained for the 25 cm and deeper peat layers.

— In the case of Sphagnum peat, 45 % of the variation in hydraulic conductivity was explained by the bulk density of the peat, 63 % by the degree of humification and 47 % by the sampling depth. For the other peat types studied, the coefficient of determination, when only one variable was used, was lower. An exception to this was the sampling depth in the case of woody peat, which explained 55 % of the variation in hydraulic conductivity recorded for this peat type.

— The use of a function including two independent variables (the sampling depth and the bulk density or the degree of humification) explained over 70 % of the variation in hydraulic conductivity in the case of Sphagnum peat and about 60 % of that of sedge and woody peats.

— The coefficients of determination of the readily determinable independent variables used in the present study were limited. They were capable of describing the porosity of peat only by quantity (bulk density and

degree of humification), and moreover, their power of explaining the pressure conditions, colloids, etc., which influence the hydraulic conductivity (sampling depth) was extremely limited. The movement of water in peat, however, is first and foremost influenced by such factors as the size, arrangement and continuity of the pores occurring in the soil. Determination of these factors and their insertion in a function is so complicated, however, that it would probably be easier and more accurate to measure hydraulic conductivity directly.

— Hydraulic conductivity determinations in the laboratory evidently lead to overestimation.

The principal results from the part of the study concerning the water retention of peat and the conclusions which could be drawn are as follows:

— At saturation peat contains 82—95 volume per cent of water, the corresponding percentages being 25—72 at pF 2, 17—44 at pF 3 and 10—21 at pF 4.2.

— The bulk density of peat seemed to be the factor best able to explain its water retention capacity. At saturation, the water content of the peat was higher, the smaller its bulk density. In the case of slightly decomposed peats, particularly at low matric suctions, the species composition of the plant residuals forming the peat was also shown to influence the water retention capacity. With increasing bulk density at pF 2, the water content of peat increased very strongly up to a bulk density value of 0.18 g/cm³. At the pF values of 3, 4 and 4.2, the peat contains more water, the higher its bulk density. This relationship becomes less steep, however, when moving from pF 3 to pF 4.2.

— Particularly in the case of peat soils in which the ground water table is located relatively near the soil surface, there is no reason to use field capacity as the upper limit of water available to the plants. Under such conditions this limit should be placed at the air content (10 %) of the peat below which the aeration of the soil becomes a growth-limiting factor. In the case of undecomposed peats, the minimum air space required by the plants is reached at pF values below 1, the corresponding value being approximately pF 1.5 in the case of decomposed peats. Furthermore, if the lower limit of available water is considered to be at the permanent wilting point (pF 4.2), the available-water capacity of the peat thus obtained decreases with increasing bulk density.

The quantity of water which can be removed from a site by draining decreases with increasing bulk density in such a way that it, in the case of well decomposed peat (bulk density 0.20 g/cm³) is slightly less than one third of that for slightly decomposed peat (bulk density 0.05 g/cm³).

— The tensiometer determinations performed in the field seemed to indicate that, even if the ground water table is located at great depths (about 80 cm), the distance between the ground water table and the soil layer (5—10 cm below the ground surface) under study and the evaporation do not lead to a decrease in the water content in the layer concerned down to the limit of decreasing growth, and at least not to the permanent wilting point.

— On the basis of the pore size distribution of the peats and the tensiometer determinations carried out, the level of the ground water table at which the capillary rise of water to the rhizosphere becomes difficult could be determined.

REFERENCES

AHTI, E. 1971. Maaveden jännityksen mittaamisesta tensiometrillä. Summary: Use of a tensiometer in measuring soil water tension. Folia for. Inst. For. Fenn. 112. (10 p.).

— » — 1972. Kenttäkapasiteetti ojitettujen turvemaiden vesisuhteiden ilmentäjänä. Summary: Field capacity as an indicator of water relations in drained peatlands. Suo 23, 105–109.

ANDERSEN, A. 1968. Undersøgelser over fysiske og kemiske forhold i tørv. Summary in English. Horticultura 22, 87–95.

ANDERSSON, S. and WIKLERT, P. 1967. Markfysikaliska undersökningar i odlad jord. XVII. Om de vattenhållande egenskaperna hos rena system och blandsystem av sand, lera och torv. Summary: On the water-retaining properties in pure systems and mixed systems of sand, clay and peat. Grundförbättring 20, 3–27.

— » — 1970. Markfysikaliska undersökningar i odlad jord. XX. Studier av några markprofiler i Norrland. Summary: Soil physical studies in cultivated soils. XX. Studies of some soil profiles in Norrland. Ibid. 23, 3–76.

ANON. 1962. Soil physics terminology. Bull. of the Int. Soc. of Soil Sci. 20, 2–5.

— » — 1967. West-European methods for soil structure determination. The State Faculty of Agr. Sci., Ghent. Belgium.

— » — 1970. Glossary of Soil Science Terms. Soil Sci. Soc. of America. Madison, Wisconsin. (27 p.).

— » — 1973. Classification of peat. Proc. 4th Int. Peat Congr., Vol. V, 97–103.

ASLYNG, H. C. 1952. Characterization of soils. Årsskr. Kong. Vet. o. Landbohøjsk., 20–56.

AUBERTIN, G. M. 1971. Nature and extent of macropores in forest soils and their influence on subsurface water movement. U.S. For. Serv. Res. Pap. NE-192. (33 p.).

BADEN, W. and EGGELSMANN, R. 1963. Zur Durchlässigkeit der Moorböden. Z. Kulturtecknik u. Flurberein. 4, 226–254.

BAVEL, C. H. M. van and KIRKHAM, D. 1948. Field measurement of soil permeability using auger holes. Soil Sci. Soc. Amer. Proc. 13, 90–96.

BAVER, L. D. and FARNSWORTH, R. B. 1940. Soil structure effects in the growth of sugar beets. Soil Sci. Soc. Amer. Proc. 5, 45–48.

BAY, R. R. 1966. Evaluation of an evapotranspirometer for peat bogs. Water Resour. Res. 2, 437–442.

— » — 1967. Techniques of hydrologic research in forested peatlands, U.S.A. Proc. XIV Congr. Int. Union For. Res. Organ., Section 11, 400–415.

BAY, R. R. and KLAWITTER, R. A. 1963. What's new in wetland hydrology. Rep. Proc. Soc. Amer. Foresters, 175–177.

BAZIN, T. 1966. Water permeability of peat-bog soils. Soviet Soil Sci. No. 8, 957–960.

BECKER-DILLINGEN, J. 1939. Die Ernährung des Waldes. Handbuch der Forstdüngung. Berlin. (589 p.).

BEERS, W. F. J. van 1958. The auger-hole method. A field measurement of the hydraulic conductivity of soil below the water table. Int. Inst. for Land Reclamation and Improvement. Bull. 1. (32 p.).

— » — 1965. Some nomographs for the calculation of drain spacings. Ibid. 8. (48 p.).

BENECKE, P. and RENGER, M. 1969. Ergebnisse von Felddurchlässigkeitsmessungen mittels der Bohrlochmethode nach Hooghoudt-Ernst. Summary: Results of the permeability measurements in situ with the auger hole method according to Hooghoudt-Ernst. Z. Kulturtechnik u. Flurberein. 10, 68–80.

BERGMAN, H. F. 1959. Oxygen deficiency as a cause of disease in plants. Bot. Review 25, 417–485.

BERKMANN, M. 1913. Untersuchungen über den Einfluss der Pflanzenwurzeln auf die Struktur des Bodens. Int. Mitt. Bodenk. 3, 1–49.

BOELTER, D. H. 1962. A study of some physical properties of several peat materials and their relation to field water conditions in the peat bog. University of Minnesota. Univ. Microfilms, Inc., Ann Arbor, Michigan. (102 p.).

— » — 1964 a. Water storage characteristics of several peats *in situ*. Soil Sci. Soc. Amer. Proc. 28, 433–435.

— » — 1964 b. Laboratory techniques for measuring water storage properties of organic soils. Ibid. 28, 823–824.

— » — 1965. Hydraulic conductivity of peats. Soil Sci. 100, 227–231.

— » — 1969. Physical properties of peats as related to degree of decomposition. Soil Sci. Soc. Amer. Proc. 33, 606–609.

— » — 1972. Methods for analyzing hydrologic characteristics of organic soils in marsh-ridden areas. Int. Symp. on the Hydrology of Marsh-Ridden Areas, Minsk, Byelorussian SSR. (11 p.).

— » — and BLAKE, G. R. 1964. Importance of volumetric expression of water contents of organic soils. Soil Sci. Soc. Amer. Proc. 28, 176–178.

BOERSMA, L. 1965. Field measurement of hydraulic conductivity below a water table. In: BLACK, C. A. Methods of soil analysis. Agronomy 9. Part I, 222–233.

BROWN, J. L. 1972. Some physical properties of organic soil materials. Unpublished M. Sc. thesis, Soils Department, University of Minnesota. (147 p.).

BRÜLHART, A. 1969. Jahreszeitliche Veränderungen der Wasserbindung und der Wasserbewegung in Waldböden des schweizerischen Mittellandes. Mitt. Schweiz. Anst. Forstl. Versuchsw. 45, 125—232.

BUCKMAN, H. O. and BRADY, N. C. 1965. The nature and the properties of soils. New York. (567 p.).

COLLEY, B. E. 1950. Construction of highways over peat and muck areas. American Highways 29, 3—6.

COLLINS, H.-J. and SCHAFFER, G. 1967. Eine quantitative Abschätzung des Fugeneinflusses bei hydraulischen Messungen an Stechzylinderproben. Z. Kulturtechnik u. Flurberein. 8, 374—382.

COLMAN, E. A. 1947. A laboratory procedure for determining the field capacity of soils. Soil Sci. 63, 277—284.

CZERATZKI, W. 1958. Eine keramische Platte zur serienmässigen Untersuchung von Porengrössen im Boden im Spannungsbereich bis ca — 1 Atm. Z. PflErnähr. Düng. Bodenk. 81, 50—56.

DARCY, H. 1856. Les Fontaines publiques de la Ville de Dijon. Paris. (647 p.).

DISERENS, E. 1934. Beitrag zur Bestimmung der Durchlässigkeit des Bodens in natürlicher Bodenlagerung. Schweiz. Landw. Monatstr. 12.

DYAL, R. S. 1960. Physical and chemical properties of some peats used as soil amendments. Soil Sci. Soc. Amer. Proc. 24, 268—271.

EGGELSMANN, R. and MÄKELÄ, T. 1964. Einfluss von Entwässerung und landwirtschaftlicher Nutzung auf die Durchlässigkeit des Moorbodens. J. Sci. Agric. Soc. Finland 36, 77—84.

ELONEN, P. 1971. Particle-size analysis of soil. Acta Agr. Fenn. 122. (122 p.).

ELOWSON, S. and PERTTU, K. 1970. Mätningar av vatteninnehållet i låghumifierad sphagnumtorv med gravimetriska metoder och mikrovågteknik. Summary: Measurements of water content in low humified peat by gravimetric methods and microwave technics. Rapp. Uppsats. Instn. Skogsföryngr. Skogshögsk. 22. (22 p.).

FARNHAM, R. S. and FINNEY, H. R. 1965. Classification and properties of organic soils. Adv. Agronomy 17, 115—162.

FERDA, J. 1968. Kotazce stanoveni rozchodu prikopu pri odvodnovani raselinistnich pud. Summary: On the problem of ditch spacing determination in peat soil draining. Lesnicky casopis, 14, XLI.

FEUSTEL, I. C. and BYERS, H. G. 1930. The physical and chemical characteristics of certain American peat profiles. U.S. Dept. Agr. Tech. Bull. 214. (26 p.).

— » — and BYERS, H. G. 1936. The comparative moisture-absorbing and moisture-retaining capacities of peat and soil mixtures. Ibid. 532. (25p.).

FLANNERY, R. D. and KIRKHAM, D. 1964. A soil core water permeameter for field use. Soil Sci. 97, 233—241.

FREVERT, R. K. and KIRKHAM, D. 1948. A field method for measuring the permeability of soil below water table. Highway Res. Board Proc. 28, 433—442.

GALVIN, J. 1965. Influence of soil moisture regimes and peat mulch on tomato growth in a glasshouse. Irish J. Agr. Res. 4, 19—24.

GARDNER, W. R. 1968. Availability and measurement of soil water. In: KOZLOVSKI T. T. Water deficits and plant growth I, 107—135.

GETOV, L. V. 1963. The changes in the water permeability of peatbog soils resulting from drainage. (Translated from Russian.) IPST Cat. No. 661. Jerusalem. (13 p.).

GOODE, W. E. and CHRISTIANSEN, J. E. 1945. Obtaining soil cores for permeability tests. Agr. Engin. 26, 153—155.

GÖTTLICH, K. and BIRNBACHER, H. 1956. Zur Verwendung naturfrischer oder lufttrockener Proben bei der Bestimmung des Spezifischen Gewichtes von Torfen in Wasser-Pyknometer. Z. PflErnähr. Düng. Bodenk. 73, 102—106.

GUSTAFSSON, Y. 1940. The influence of temperature on the permeability of soils to water. LantbrHögsk. Ann. 8, 425—456.

HANRAHAN, E. T. 1954. An investigation of some physical properties of peat. Geotechnique 4, 108—123.

HARRISON, D. S. and WEAVER, H. A. 1958. Some drainage characteristics of a cultivated organic soil in the Everglades. Soil & Crop Sci. Soc. Florida 18, 184—192.

HARST, G. G. van der and STAKMAN, W. P. 1965. Soil moisture retention curves II. Directions for the use of the sand-box apparatus Range pF 0 to 2.7. Note of the Institute for Land and Water Management Research. Wageningen. (17 p.).

HARTGE, K. H. 1961. Die Messung der Wasserpermeabilität an Stechzylinderproben. Z. Kulturtechnik u. Flurberein. 2, 103—114.

— » — 1965. Die Bestimmung von Porenvolumen und Porengrössenverteilung. Summary: Determination of pore volume and pore size distribution. Ibid. 6, 193—206.

HASUND, S. 1910. Myrdyrkning. Kristiania. (72 p.).

HEIKURAINEN, L. 1955. Rämemännikön juuriston rakenne ja kuivatuksen vaikutus siihen. Referat: Der Wurzelaufbau der Kiefernbestände auf Reisermoorböden und seine Beeinflussung durch die Entwässerung. Acta For. Fenn. 65.3. (85 p.).

— » — 1963. On using ground water table fluctuations for measuring evapotranspiration. Ibid. 76.5. (16 p.).

— » — 1964. Improvement of forest growth on poorly drained peat soils. Int. Rev. For. Res. 1, 39—113.

— » — 1967. On the possibilities of optimum drainage in peat lands. Proc. XIV Congr.

Int. Union For. Res. Organ., Section 23, 264—277.

Heikurainen, L. 1971. Pohjavesipinta ja sen mittaaminen ojitetuilla soilla. Summary: Ground water table in drained peat soils and its measurement. Acta For. Fenn. 113. (23 p.).

— » — and Huikari, O. 1952. Turvelajin mikroskooppinen määrittäminen. Summary: The microscopic determination of peat types. Commun. Inst. For. Fenn. 40.5 (29 p.).

— » —, Päivänen, J., and Sarasto, J. 1964. Ground water table and water content in peat soil. Acta For. Fenn. 77.1. (18 p.).

Heinonen, R. 1954. Multakerroksen kosteussuhteista Suomen maalajeissa. Summary: Moisture conditions in Finnish topsoils. Agrogeol. Julk. 62. (82 p.).

Hermsmeier, L. F. 1966. Hydraulic conductivity and other physical characteristics of some »wet» soils in southwestern Minnesota. U.S. Agric. Res. Serv. 41—127. (17 p.).

Hillel, D. 1971. Soil and water. Physical principles and processes. Academic Press. New York and London. (288 p.).

Hintikka, V. 1972. Wind-induced root movements in forest trees. Commun. Inst. For. Fenn. 76.2. (56 p.).

Holmen, H. 1964. Forest ecological studies on drained peat land in the province of Uppland, Sweden. Parts I—III. Studia For. Suec. 16. (236 p.).

Holstener-Jørgensen, H. 1958. Jordbundsfysiske undersøgelser i danske bøgebevoksningar. Summary: Physical soil-investigations in Danish beech-stands. Forstl. Forsøgsv. Danm. 25, 93—223.

Hove, P. 1969. Grøfteproblemer i myr. Summary: Drainage problems in peat soils. Meld. Norg. Landbrukshøgsk. 48, No. 8. (9 p.).

Huikari, O. 1959. Kenttämittaustuloksia turpeiden vedenläpäisevyydestä. Referat: Feldmessungsergebnisse über die Wasserdurchlässigkeit von Torfen. Commun. Inst. For. Fenn. 51.1. (26 p.).

— » — and Paarlahti, K. 1967. Results of field experiments on the ecology of pine, spruce, and birch. Ibid. 64.1. (135 p.).

Illner, K. 1962. Untersuchungen über die Wasserdurchlässigkeit von Niedermoorböden mit der Bohrlochmethode. Z. Landeskultur 3, 19—28.

Ilyin, N. I. and Dzerktser, E. R. 1971. Ob opredelelny koeffitsienta filtratsy torfyanoy pochvy. Summary: On the determination of peat soil filtration coefficient. Pochvovedeniye No. 4, pp. 127—131.

Irwin, R. W. 1968. Soil water characteristics of some Ontario peats. Proc. 3rd Int. Peat Congr., pp. 219—223.

Jackson, R. D., Bavel, C. H. M. van, and Reginato, R. J. 1963. Examination of the pressure-plate method for measuring capillary conductivity. Soil Sci. 96, 249—256.

Järnefelt, H. 1958. Vesiemme luonnontalous. Porvoo—Helsinki. (325 p.).

Järvinen, J. 1962. Pohjavesipinnasta kosteussadannesten ja pohjavesikaivojen valossa. Suo 13, 25—27.

Joffe, J. S. 1932. Lysimeter studies: I Moisture percolation through the soil profile. Soil Sci. 34, 123—143.

Johnson, H. P., Frevert, R. K., and Evans, D. D. 1952. Simplified procedure for the measurement and computation of soil permeability below the water table. Agr. Engin. 33, 283—286.

Karesniemi, K. 1972. Dependence of humification degree on certain properties of peat. Proc. 4th Int. Peat Congr., Vol. II, 273—282.

Khafagi, A. 1944. Die Durchlässigkeit des Bodens in seiner natürlichen Lagerung. Schweiz. Z. Vermessungsw. Kulturtechnik 42, 10—17, 35—44, 63—69, and 78—83.

Kirkham, D. 1945. Proposed methods for field measurements of permeability of soil below the water table. Soil Sci. Soc. Amer. Proc. 10, 58—68.

— » — 1965. Saturated conductivity as a characterizer of soil for drainage design. In: Drainage for Efficient Crop Production Conference. Conference Proc. Am. Soc. Agr. Eng., St. Joseph, Michigan, pp. 24—31.

— » — and Bavel, C. H. M. van 1948. Theory of seepage into auger holes. Soil Sci. Soc. Amer. Proc. 13, 75—82.

Kivinen, E. 1948. Suotiede. Helsinki—Porvoo. (219 p.).

Kivisaari, S. 1972. Kivennäismaan huokoisuuden ja vedenpidätyskyvyn riippuvuus tekstuurista. Unpublished Lic. Agr. thesis, Dep. Agr. Chemistry and Physics of Helsinki University. (196 p.).

Klyavin'sh, Y. Y. 1963. Degree of forest drainage in Latvian SSR. In: The increase of productivity of swamped forests. (Translated from Russian.) IPST Cat. No. 660. Jerusalem, pp. 70—76.

Kohnke, H. 1946. The practical use of the energy concept of soil moisture. Soil Sci. Soc. Amer. Proc. 11, 64—66.

— » — 1968. Soil physics. McGraw-Hill, Inc. (224 p.).

Kopecky, J. 1914. Die physikalischen Eigenschaften des Bodens. Int. Mitt. Bodenkunde 4, 138—180.

Korpijaakko, M. and Radforth, N. W. 1972. Studies on the hydraulic conductivity of peat. Proc. 4th Int. Peat Congr., Vol. III, 323—334.

Kozlowski, T. T. 1965. Water metabolism in plants. Tokyo. (227 p.).

Kramer, P. J. 1949. Plant and soil water relationships. New York — Toronto — London. (347 p.).

Kühnel, H. 1969. Untersuchung des Dränungserfolges an 50 Jahre alten Anlagen. Mitt. Schweiz. Anst. Forstl. Versuchsw. 45, 331—436.

Kuntze, H. 1965. Physikalische Untersuchungsmethoden für Moor- und Anmoorböden. Landwirtsch. Forsch. 18, 178—191.

Låg, J. and Einevoll, O. 1954. Preliminary studies on the water permeability of raw humus in podzol profiles in the western part of Norway. Meld. Norg. Landbrukshøgsk. 34, 525–532.

Lähde, E. 1966. Vertical distribution of biological activity in peat of some virgin and drained swamp types. Acta For. Fenn. 81.6. (15 p.).

— » — 1969. Biological activity in some natural and drained peat soils with special reference to oxidation-reduction conditions. Ibid. 94. (69 p.).

Lucas, R. E. and Rieke, P. E. 1968. Peats for soil mixes. Some air-water relationships and suggested plant nutrient standard. Proc. 3rd Int. Peat Congr., pp. 261–263.

Lukkala, O. J. 1929. Tutkimuksia soiden metsätaloudellisesta ojituskelpoisuudesta erityisesti kuivatuksen tehokkuutta silmälläpitäen. Referat: Untersuchungen über die waldwirtschaftliche Entwässerungsfähigkeit der Moore mit besonderer Rücksicht auf den Trocknungseffekt. Commun. Inst. For. Fenn. 15. (301 p.).

Luthin, J. N. and Kirkham, D. 1949. A piezometer method for measuring permeability of soil *in situ* below a water table. Soil Sci. 68, 349–358.

L'vovich, M. J. 1966. Water balance and soil. Soviet Soil Sci. No. 9, 1019–1029.

MacFarlane, I. C. 1969. Engineering characteristics of peat. In: MacFarlane, I. C. Muskeg engineering handbook. University of Toronto Press, pp. 78–126.

Malmström, C. 1923. Degerö Stormyr. En botanisk, hydrologisk och utvecklingshistorisk undersökning över ett nordsvenskt myrkomplex. Referat: Degerö Stormyr. Eine botanische, hydrologische und entwicklungsgeschichtliche Untersuchung eines nordschwedischen Moorkomplexes. Medd. Stat. Skogsförsöksanst. 20, 1–206.

— » — 1928. Våra torvmarker ur skogsdikningssynpunkt. Summary: Our peat areas from the point of forest-draining. Ibid. 24, 251–372.

— » — 1939. Methoden zur Untersuchung der Wasserverhältnisse von Torfböden. Handbuch der biologischen Arbeitsmethoden 11: 4 I, 373–390.

Marshall, T. J. 1959 a. Relations between water and soil. Commonwealth Bureau of Soils. Tech. Commun. 50. (89 p.).

— » — 1959 b. The diffusion of gases through porous media. J. Soil Sci. 10, 79–82.

McNeal, B. L. and Reeve, R. C. 1964. Elimination of boundary-flow errors in laboratory hydraulic conductivity measurements. Soil Sci. Soc. Amer. Proc. 28, 713–714.

Meshechok, B. 1969. Tørrlegging av myr ved ulik grøfteavstand og grøftedybde. Summary: Drainage of swamps at different ditch distances and ditch depths. Medd. Norske Skogforsøksv. Nr. 98, Bind XXVII, 227–294.

Mitscherlich, E. A. 1920. Bodenkunde für Land- und Forstwirte. Berlin. (317 p.).

Nerpin, S. V. and Chudnovskii, A. F. 1970. Physics of the soil. (Translated from Russian.) IPST Cat. No. 2203. Jerusalem. (466 p.).

Newbould, P. J. 1958. Peat bogs. New Biology 26, 88–105.

Olsen, O. B 1967. Determination of volume weight and other properties of peat. Unpublished report from the Hydrotechnical Laboratory of the Royal Veterinary and Agricultural College of Copenhagen. (12+3 p.).

— » — 1968. Peat and other substrates. Proc. 3rd Int. Peat Congr., pp. 264–267.

— » — 1969. Bestemmelse af dyrkningssubstraters fysiske egenskaber. Horticultura 23, 63–67.

O'Neal, A. M. 1949. Soil characteristics significant in evaluating permeability. Soil Sci. 67, 403–409.

Overbeck, F. and Happach, H. 1957. Über das Wachstum und den Wasserhaushalt einiger Hochmoorsphagnen. Flora 114, 335–402.

Paavilainen, E. 1963. Turpeen vesipitoisuudesta ja pohjavesipinnasta. Summary: On water content of peat and ground water level. Suo 14, 8–9.

— » — 1966. Maan vesitalouden järjestelyn vaikutuksesta rämemännikön juurisuhteisiin. Summary: On the effect of drainage on root systems of Scots pine on peat soils. Commun. Inst. For. Fenn. 61.1. (110 p.).

— » — 1967. Männyn juuriston suhteesta turpeen ilmatilaan. Summary: Relationships between the root system of Scots pine and the air content of peat. Ibid. 63.6. (21 p.).

— » — and Virrankoski, K. 1967. Tutkimuksia veden kapillaarisesta noususta turpeessa. Summary: Studies on the capillary rise of water in peat. Folia for. Inst. For. Fenn. 36. (16 p.).

Päivänen, J. 1964. Menetelmä pohjavesikertoimen ja pintakasvillisuuden haihdunnan määrittämiseksi. Summary: A method to determine the ground water coefficient and the ground vegetation transpiration. Suo 15, 88–91.

— » — 1968. Tutkimuksia turpeen fysikaalisista ominaisuuksista, erityisesti tilavuuspainosta, vedenläpäisevyydestä ja vedenpidätyskyvystä. Unpublished Lic. For. thesis. Dep. Peatland Forestry of Helsinki University.

— » — 1969. The bulk density of peat and its determination. Silva Fenn. 3, 1–19.

Patric, J. H. and Stephens, F. R. 1968. Soil-moisture levels in some representative soils near Juneau, Alaska. Soil Sci. 106, 172–176.

Peerlkamp, P. K. and Boekel, P. 1960. Moisture retention by soils. Reprint Versl. Mede. Comm. Hydrol. Onderz. T.N.O. 5, 122–138.

Pjavtsenko, N. I. 1958. Metod opredelenija stepeni razlozhenija torfa po objemnomy vesy. [Determining the humification degree on the basis of volume weight.] Moskva. (11 p.).

POST, L. von 1922. Sveriges geologiska undersöknings torvinventering och några av dess hittills vunna resultat. Sv. Mosskulturför. Tidskr. 1, 1–27.

POULOVASSILIS, A. and CHILDS, E. C. 1971. The hysteresis of pore water: The non-independence of domains. Soil Sci. 112, 301–312.

PUUSTJÄRVI, V. 1955. On the colloidal nature of peat-forming mosses. Arch. Soc. »Vanamo» 9: suppl., 257–272.

— » — 1956. On the cation exchange capacity of peats and on the factors of influence upon its formation. Acta Agr. Scand. 6, 410–449.

— » — 1963. Turpeen vesitaloudesta. Summary: On the water economy of garden peat. Suo 14, 56–62.

— » — 1968. Standards for peat used in peat culture. Peat & Plant News 1, 19–26.

— » — 1969. Water-air relationships of peat in peat culture. Ibid. 2, 43–55.

— » — 1970. Degree of decomposition. Ibid. 3, 48–52.

RAWLINS, S. L. 1971. Some new methods for measuring the components of water potential. Soil Sci. 112, 8–16.

REEVE, R. C. and JENSEN, M. C. 1949. Piezometers for ground water flow studies and measurement of subsoil permeability. Agr. Engin. 30, 435–438.

— » — and KIRKHAM, D. 1951. Soil anisotropy and some field methods for measuring permeability. Trans. Amer. Geophys. Un. 32, 582–590. Discussion 33, 461–462.

REGINATO, J. and BAVEL, C. H. M. van 1962. Pressure cell for soil cores. Soil Sci. Soc. Amer. Proc. 26, 1–3.

REINCKE, R. 1931. Über den Luftgehalt des Niederungsmoorbodens. Z. PflErnähr. Düng. Bodenk. 20, 217–232.

RICHARD, F. 1953. Über die Verwertbarkeit des Bodenwassers durch die Pflanze. Mitt. Schweiz. Anst. Forstl. Versuchsw. 29, 17–37.

— » — 1963. Wasserhaushalt und Entwässerung von Weideböden. Ibid. 39, 245–269.

— » — and BEDA, J. 1953. Methoden zur Bestimmung der Wasserbindung und der Porengrössen in natürlich gelagerten Waldböden. Ibid. 29, 293–314.

RICHARDS, B. G. 1965. Determination of the unsaturated permeability and diffusivity functions from pressure plate outflow data with non-negligible membrane impedance. In 'Moisture equilibria and moisture changes in soils beneath covered areas'. Butterworths-Sydney, 47–54.

RICHARDS, L. A. 1941 a. A pressure-membrane extraction apparatus for soil solution. Soil Sci. 51, 377–386.

— » — 1941 b. Uptake and retention of water by soil as determined by distance to a water table. J. Amer. Soc. Agron. 33, 778–786.

— » — 1947. Pressure-membrane apparatus — Construction and use. Agr. Engin. 28, 451–454.

RICHARDS, L. A. 1948. Porous plate apparatus for measuring moisture retention and transmission by soil. Soil Sci. 66, 105–110.

— » — 1949. Methods of measuring soil moisture tension. Ibid. 68, 95–112.

— » — 1952. Report of the subcommittee on permeability and infiltration, committee on terminology, Soil Science Society of America. Soil Sci. Soc. Amer. Proc. 16, 85–88.

— » — and FIREMAN, M. 1943. Pressure-plate apparatus for measuring moisture sorption and transmission by soils. Soil Sci. 56, 395–404.

— » — and GARDNER, W. 1936. Tensiometers for measuring the capillary tension of soil water. J. Amer. Soc. Agron. 28, 352–363.

— » — and WEAVER, L. R. 1944. Moisture retention by some irrigated soils as related to soil moisture tension. J. Agric. Res. 69, 215–235.

ROBERTSON, L. S. and KOHNKE, H. 1946. The pF at the wilting point of several Indiana soils. Soil Sci. Soc. Amer. Proc. 11, 50–52.

ROBINSON, W. O. 1930. Some chemical phases of submerged soil conditions. Soil Sci. 30, 197–217.

RODE, A. A. 1959. Das Wasser im Boden. Berlin. (464 p.).

ROMANOV, V. V. 1968. Evaporation from bogs in the European territory of the USSR. (Translated from Russian.) IPST Cat. No. 1968. Jerusalem. (183 p.).

ROMELL, L.-G. 1922. Luftväxlingen i marken. Resümee: Die Bodenventilation als ökologischer Factor. Medd. Stat. Skogsförsöksanst. 19, 125–359.

ROSE, C. W. 1966. Agricultural physics. Pergamon Press. Oxford. (230 p.).

SABO, E. D. 1963. Some results of projects to increase productivity of swamped forests by means of drainage. In: The increase of productivity of swamped forests. (Translated from Russian.) IPST Cat. No. 660. Jerusalem, pp. 57–69.

SARASTO, J. 1960. Turpeen maatumisasteen määrittämisestä. v. Postin maatumisasteen ja Pjavtshenkon maatumisprosentin vertailu. Referat: Zur Bestimmung der Zersetzung des Torfes. Acta For. Fenn. 71.2. (16 p.).

— » — 1961. Kokeita turpeen vedenläpäisevyydestä. Suo 12, 24–25.

— » — 1963. Tutkimuksia rahka- ja saraturpeiden vedenläpäisevyydestä. Summary: A study on the permeability to water of different kind of peat. Ibid. 14, 32–36.

SATTERLUND, D. 1960. Some interrelationships between ground water and swamp forests in the western upper peninsula of Michigan. Ph.D. thesis. University of Michigan, University Microfilms. Inc., Ann Arbor, Mich. (170 p.).

SCHEFFER, F. and SCHACHTSCHABEL, P. 1970. Lehrbuch der Bodenkunde. Ferdinand Erke Verlag, Stuttgart. (448 p.).

SCHENDEL, U. 1962. Beziehung zwischen der Infiltrationsrate und dem Wasservorrat eines roterdigen, lehmigen Sandbodens bis zu einer Tiefe von 25 bis 30 cm. Z. Kulturtechnik u. Flurberein. 3, 99–102.

SCHILFGAARDE, J. van 1957. Approximate solutions to drainage flow problems. In: LUTHIN, J. N. Drainage of agricultural lands. Agronomy 7, 73—112.

SCHLICHTING, E. and BLUME, H.-P. 1966. Bodenkundliches Praktikum. Hamburg-Berlin. (209 p.).

SCHMEIDL, H., SCHUCH, M., and WANKE, R. 1970. Wasserhaushalt und Klima einer kultivierten und unberührten Hochmoorfläche am Alpenrand. SchrReihe Kuratoriums Kulturbauw. H. 19. (174 p.).

SCHOFIELD, R. K. 1935. The pF of the water in soil. Trans. 3rd Int. Congr. Soil Sci. (Oxford) II, 37–48.

SEGEBERG, H. 1952. Zur Methodik der Wasserdurchlässigkeitsbestimmung von Moorböden untersucht an einem interglazialen Torfvorkommen. Wasser und Boden 4, 345–348.

— » — 1955. Zur Methodik der Bestimmung der spezifischen Gewichte von Torfen. Z. PflErnähr. Düng. Bodenk. 68, 233–237.

— » — 1957. Untersuchungen über die Verwendung grubenfrischer und lufttrockener Torfe bei den Bestimmung ihrer spezifischen Gewichte. Ibid. 76, 47–54.

— » — 1958. Über die Bestimmung der Struktur organogener Böden im Felde. Int. Symp. on Soil Structure. Ghent, 244–250.

SILLANPÄÄ, M. 1956. Studies on the hydraulic conductivity of soils and its measurement. Acta Agr. Fenn. 87, 1–109.

— » — 1959. Comparisons of some field methods for measuring the hydraulic conductivity of soils. Acta Agr. Scand. 9, 59–68.

SMITH, W. O. 1949. Pedological relations of infiltration phenomena. Trans. Am. Geophys. Union 30, 555–562.

SMITH, R. M. and BROWNING, D. R. 1947. Soil moisture tension and pore space relations for several soils in the range of the »field capacity». Soil Sci. Soc. Amer. Proc. 12, 17–21.

STANEK, W. 1961. The properties of certain peats in northern Ontario. Unpublished M.Sc. thesis, University of Toronto. (54 p.).

STEINBRENNER, E. C. 1951. An improved method for determining the water permeability of forest soils. Soil Sci. Soc. Amer. Proc. 15, 379–381.

STEWART, E. H., POWELL, D. P., and HAMMOND, L. C. 1963. Moisture characteristics of some representative soils of Florida. U.S. Agric. Res. Serv. 41–63 (53 p.).

STURGES, D. L. 1968. Hydrologic properties of peat from a Wyoming mountain bog. Soil Sci. 106, 262–264.

SYKES, D. J. and LOOMIS, W. E. 1967. Plant and soil factors in permanent wilting percentages and field capacity storage. Ibid. 104, 163–173.

TANSKANEN, H. 1972. Hivenalkuaineiden vertikaalisesta esiintymisestä turvekerrostumassa. Summary: On the vertical distribution of microelements in peat soils. Suo 23, 63–69.

TAYLOR, S. A. 1949. Oxygen diffusion in porous media as a measure of soil aeration. Soil Sci. Soc. Amer. Proc. 14, 55–61.

— » — 1952. Use of mean soil moisture tension to evaluate the effect of soil moisture on crop yields. Soil Sci. 74, 217–226.

THORPE, V. A. 1968. Determination of the volume weights, waterholding capacity, and air capacity of water-saturated peat materials. J. of the A.O.A.C. 51, 1296–1299.

TODD, D. K. 1959. Ground water hydrology. New York. (336 p.).

TOLMAN, C. F. 1937. Ground water. New York — London. (593 p.).

TROEDSSON, T. 1955. Vattnet i skogsmarken. Zusammenfassung: Das Wasser des Waldbodens. Kungl. Skogshögsk. Skr. 20, 1–215.

TVEITEN, A. 1956. Anvendelse av torv i dammer. Summary: Applicability of peat as an impervious material for earth dams. Norwegian Geotech. Inst., Publ. 14. (11 p.).

WADLEIGH, C. H. and AYERS, A. D. 1945. Growth and biochemical composition of bean plants as conditioned by soil moisture tension and salt concentration. Plant Physiol. 20, 106–132.

VAHTERA, E. 1955. Metsänkasvatusta varten ojitettujen soitten ravinnepitoisuuksista. Referat: Über die Nährstoffgehalte der für Walderziehung entwässerten Moore. Commun. Inst. For. Fenn. 45.4. (108 p.).

WALKER, P. 1952. Depth and spacing for drain laterals as computed from core-sample permeability measurements. Agr. Engin. 33, 71–73.

WEAVER, H. A. and SPEIR, W. H. 1960. Applying basic soil water data to water control problems in Everglades peaty muck. U.S. Agric. Res. Serv. 41–40. (15 p.).

WECHMANN, A. 1943. Die Durchlässigkeit von Moorböden. Dt. Wasserwirtschaft 38, 136–138.

VEIHMEYER, F. J. and HENDRICKSON, A. H. 1949. Methods of measuring field capacity and permanent wilting percentage of soils. Soil Sci. 68, 75–94.

WENZEL, L. K. 1942. Methods for determining permeability of water-bearing materials with special reference to discharging-well methods. Geological Survey Water-Supply Paper 887. (192 p.).

WESSELING, J. and WIJK, W. R. van 1957. Soil physical conditions in relation to drain depth. In: LUTHIN, J. N. Drainage of agricultural lands. Agronomy 7, 461–504.

VIRTA, J. 1966. Measurement of evapotranspiration and computation of water budget in treeless peatlands in the natural state. Comm. Phys.-Math. Soc. Sci. Fenn. 32.11. (70 p.).

Woodruff, C. M. 1940. Soil moisture and plant growth in relation to pF. Soil Sci. Soc. Amer. Proc. 5, 36–41.

Wolkewitz, H. 1959. Die Weiterentwicklung des Verfahrens der pF-Untersuchung zur Feststellung der Bindungsintensität des Wassers im Boden. Kulturtechniker 47, 37–50.

Vomocil, J. A. and Flocker, W. J. 1961. Effect of soil compaction on storage and measurement of soil air and water. Trans. A.S.A.E. 4, 242–246.

Vompersky, S. E. 1968. Biologicheskic osnovy effektivnosti lesoosusheniya. (Biological foundations of forest drainage effiency.) Izg. »Nauka». Moskva. (312 p.).

Yefimov, V. N. and Vasil'kova, M. G. 1971. Content and composition of humic substances in peat soils. Soviet Soil Sci. 3, 314–321.

Young, K. K. and Dixon, J. D. 1966. Overestimation of water content at field capacity from sieved sample data. Soil Sci. 101, 104–107.

Youngs, E. G. 1964. An infiltration method of measuring the hydraulic conductivity of unsaturated porous materials. Ibid. 97, 307–311.

Seloste

TURPEEN VEDENLÄPÄISEVYYS JA VEDENPIDÄTYSKYKY

Tutkimus kuuluu osana turpeen vesitaloudellisten perusominaisuuksien selvitykseen ja siinä tarkastellaan turpeen vedenläpäisevyyttä ja vedenpidätyskykyä sekä näiden riippuvuutta eräistä turpeen rakennetta kuvaavista ominaisuuksista. Molempien tutkimusosien aineistot on kerätty Keski-Suomesta (61° 50'N, 24° 20'E) metsäojitetuilta soilta.

Vedenläpäisevyyden mittaukset suoritettiin piezometri-periaatteella maastossa. Yksittäisiä vedennousunopeuden havaintoja sisältyy aineistoon 1280 kpl. Lisäksi tutkimuksessa suoritetaan tällä kenttämenetelmällä ja esitutkimuksessa (PÄIVÄNEN 1968) laboratoriomenetelmällä saatujen vedenläpäisevyyksien vertailuja.

Turpeen vedenpidätyskykyä koskevat tiedot perustuvat laboratoriomittauksiin ja aineiston muodostaa 188 imukammiolaitteessa, 1250 painelevylaitteessa ja 405 painekalvolaitteessa käsiteltyä turvenäytettä. Seitsemällä koealalla suoritettiin lisäksi maaveden jännityksen mittauksia tensiometriperiaatteella yhden kasvukauden aikana Näiden mittausten tarkoituksena oli selvittää, kuinka suureksi maaveden jännitys voi kasvaa, metsäojitetun suon ritsosfäärikerroksessa.

Turpeen vedenläpäisevyydestä voidaan tutkimuksen perusteella tehdä seuraavat päätelmät:

— Turpeen vedenläpäisevyyden kvantitatiivinen vaihtelualue voidaan rajata seuraavilla arvoilla: $2.0 \times 10^{-6} - 1.1 \times 10^{-2}$ cm/s. Turpeen laadulla ja rakenteella on ratkaiseva vaikutus vedenläpäisevyyden suuruusluokkaan, kuten myöhemmin esitetään.

— Turpeen vedenläpäisevyyden vaihtelu samassakin turvekerroksessa on suuri, jopa ±40 % keskiarvosta. Käytetyn menetelmän luotettavuus on kuitenkin riittävä, koska eri maatumisastetta olevat turpeet sekä eri havaintosyvyydet poikkeavat vedenläpäisevyyksiensä puolesta erittäin paljon toisistaan.

— Koska eri pääturvelajia olevien turpeiden vedenläpäisevyydet poikkeavat toisistaan, on niiden vedenläpäisevyyksiä tarkasteltava erikseen.

— Pintaturvekerroksien vedenläpäisevyyksissä ei ole samaa säännönmukaisuutta kuin syvemmissä turvekerroksissa. Tämä johtunee pintaturvekerroksen toisaalta suuresta makrohuokosten ja -tiehyiden määrästä (juuriston aiheuttama liike, lahoavat juuret, irreversiibelit kolloidit), toisaalta usein pitkälle maatuneesta ja tiiviistä turpeesta. Tämän vuoksi laskelmat on suoritettu erikseen sekä koko aineiston että 25 cm ja sitä syvemmistä turvekerroksista mitattujen vedenläpäisevyyksien osalta.

— Rahkaturpeiden kohdalla tilavuuspaino selittää vedenläpäisevyyden vaihteluista 45 %, maatumisaste 63 % ja havaintosyvyys 47 %. Muiden turvelajien kohdalla yhden riippumattoman muuttujan selityskyky on yleensä aina näitä alhaisempi. Poikkeuksen muodostaa puuturpeiden kohdalla havaintosyvyys, joka selittää 55 % vedenläpäisevyyden vaihteluista.

— Kahden riippumattoman muuttujan (havaintosyvyys ja tilavuuspaino tai maatumisaste) funktiomalli pystyy selittämään turpeen vedenläpäisevyyden vaihteluista rahkaturpeissa yli 70 % sekä sara- ja puuturpeissa noin 60 %.

— Tähän tutkimukseen valittujen, helposti määritettävien riippumattomien muuttujien selityskyky on siis rajoitettu; ne eivät voi kuvata turpeessa olevia huokosia kuin korkeintaan määrällisesti (tilavuuspaino ja maatumisaste) ja turpeen vedenläpäisevyyteen vaikuttavia paineoloja, kolloideja jne. (havaintosyvyys) myös vain rajoitetusti. Veden liikkumiseen vaikuttaa kuitenkin ennen kaikkea huokosten koko, suuntautuminen ja jatkuvuus. Näiden seikkojen mittaaminen ja sijoittaminen ennustusmalliin on jo niin komplisoitua, että helpompaa ja varmempaa on suurta tarkkuutta vaativissa tapauksissa pyrkiä vedenläpäisevyyden suoraan mittaamiseen.

— Laboratoriossa suoritetut vedenläpäisevyyden mittaukset johtavat liian suuriin arvoihin.

Turpeen vedenpidätyskykyä koskevan tutkimusosan päätulokset ja niistä tehtävät johtopäätökset ovat lyhyesti lueteltuina seuraavat:

— Kyllästyskosteudessa turve sisältää 82—95, pF 2:ssa 25—72, pF 3:ssa 17—44 ja pF 4.2:ssa 10—21 tilavuusprosenttia vettä.

— Turpeen tilavuuspaino näyttää parhaalta turpeen vedenpidätyskyvyn selittäjältä. Kyllästyskosteudessa turpeen vesipitoisuus on sitä suurempi, mitä pienempi on sen tilavuuspaino. Heikosti maatuneessa turpeessa erityisesti alhaisilla maaveden jännityksen arvoilla tilavuuspainon lisäksi myös kasvinjäännöskoostumus vaikuttaa turpeen vedenpidätyskykyyn. Tilavuuspainon kasvaessa vesipitoisuus pF 2:ssa kasvaa erittäin voimakkaasti aina tilavuuspainon arvoon 0.18 g/cm³ saakka. pF-arvoilla 3, 4 ja 4.2 turve sisältää aina sitä enemmän vettä, mitä suurempi on sen tilavuuspaino. Vuorosuhde loivenee kuitenkin siirryttäessä pF 3:sta pF 4.2:een.

— Erityisesti turvemailla, joilla pohjavesipinta on suhteellisen lähellä maanpintaa, ei ole järkevää käyttää kenttäkapasiteettia kasveille käyttökelpoisen veden ylärajana. Tällaisissa olosuhteissa lienee parasta asettaa rajaksi se ilmatila (esim. 10 %), jonka alapuolella maan tuulettuminen tulee kasvua rajoittavaksi tekijäksi. Maatumattomassa turpeessa jo alle pF 1:ssä ja maatuneessa turpeessa noin pF 1.5:ssä saavutetaan kasvien tarvitsema minimi-ilmatila. Jos edelleen alarajaksi asetetaan pysyvä lakastumispiste (pF 4.2), pienenee näin rajattu turpeen hyötykapasiteetti tilavuuspainon suuretessa.

— Ojituksella poistuva vesimäärä pienenee turpeen tilavuuspainon kasvaessa siten, että hyvin maatuneessa turpeessa (til. paino 0.20 g/cm³) se on vajaa 1/3 siitä, mitä se on heikosti maatuneessa (til. paino 0.05 g/cm³) turpeessa.

— Kentällä suoritettujen tensiometrimittausten perusteella näyttää siltä, ettei haihdunta ja syvälläkään oleva pohjavesipinta aiheuta juuristokerroksen vesipitoisuuden alenemista edes vähenevän kasvun rajalle saatikka sitten lakastumispisteeseen.

— Huokoskokojakautuman ja tensiometrimittausten perusteella voidaan päätellä se pohjavesipinnan etäisyys, jota syvemmältä veden kapillaarinen nousu pintaturvekerrokseen vaikeutuu.

PÄIVÄNEN, JUHANI O.D.C. 114.444: 181.31

1973. Hydraulic conductivity and water retention in peat soils. ACTA FORESTALIA FENNICA 129. 00 p. Helsinki.

The paper is a part of a larger study of the basic hydrologic properties of peat. This part of the study deals with the hydraulic conductivity and water retention capacity of peat and with their dependence on some of its structural properties. Also, the possibilities to estimate the quantities of water superfluous, available and unavailable to the plant cover as well as the quantities of water that can be removed from various peat soils through drainage are discussed.

Author's address: Department of Peatland Forestry, University of Helsinki, Unioninkatu 40 B, SF-00170 Helsinki 17.

PÄIVÄNEN, JUHANI O.D.C. 114.444: 181.31

1973. Hydraulic conductivity and water retention in peat soils. ACTA FORESTALIA FENNICA 129. 00 p. Helsinki.

The paper is a part of a larger study of the basic hydrologic properties of peat. This part of the study deals with the hydraulic conductivity and water retention capacity of peat and with their dependence on some of its structural properties. Also, the possibilities to estimate the quantities of water superfluous, available and unavailable to the plant cover as well as the quantities of water that can be removed from various peat soils through drainage are discussed.

Author's address: Department of Peatland Forestry, University of Helsinki, Unioninkatu 40 B, SF-00170 Helsinki 17.

PÄIVÄNEN, JUHANI O.D.C. 114.444: 181.31

1973. Hydraulic conductivity and water retention in peat soils. ACTA FORESTALIA FENNICA 129. 00 p. Helsinki.

The paper is a part of a larger study of the basic hydrologic properties of peat. This part of the study deals with the hydraulic conductivity and water retention capacity of peat and with their dependence on some of its structural properties. Also, the possibilities to estimate the quantities of water superfluous, available and unavailable to the plant cover as well as the quantities of water that can be removed from various peat soils through drainage are discussed.

Author's address: Department of Peatland Forestry, University of Helsinki, Unioninkatu 40 B, SF-00170 Helsinki 17.

PÄIVÄNEN, JUHANI O.D.C. 114.444: 181.31

1973. Hydraulic conductivity and water retention in peat soils. ACTA FORESTALIA FENNICA 129. 00 p. Helsinki.

The paper is a part of a larger study of the basic hydrologic properties of peat. This part of the study deals with the hydraulic conductivity and water retention capacity of peat and with their dependence on some of its structural properties. Also, the possibilities to estimate the quantities of water superfluous, available and unavailable to the plant cover as well as the quantities of water that can be removed from various peat soils through drainage are discussed.

Author's address: Department of Peatland Forestry, University of Helsinki, Unioninkatu 40 B, SF-00170 Helsinki 17.

maaveden jännityksen arvoilla tilavuuspainon lisäksi myös kasvijäännöskoostumus vaikuttaa turpeen vedenpidätyskykyyn. Tilavuuspainon kasvaessa vesipitoisuus pF 2:ssa kasvaa erittäin voimakkaasti aina tilavuuspainon arvoon 0.18 g/cm³ saakka. pF-arvoilla 3, 4 ja 4.2 turve sisältää sitä enemmän vettä, mitä suurempi on sen tilavuuspaino. Vuorosuhde loivenee kuitenkin siirryttäessä pF 3:sta pF 4.2:een.

— Erityisesti turvemailla, joilla pohjavesipinta on suhteellisen lähellä maanpintaa, ei ole järkevää käyttää kenttäkapasiteettia kasveille käyttökelpoisen veden ylärajana. Tällaisissa olosuhteissa lienee parasta asettaa rajaksi sa ilmatila (esim. 10 %), jonka alapuolella maan tuulettomuus tulee kasvua rajoittavaksi tekijäksi. Maatumattomassa turpeessa jo alle pF 1:ssä ja maatuneessa turpeessa noin pF 1.5:ssä saavutetaan kasvien tarvitsema minimi-ilmatila. Jos edelleen alarajaksi asetetaan pysyvä lakastumispiste (pF 4.2), pienenee näin rajattu turpeen hyötykapasiteetti tilavuuspainon suuretessa.

— Ojituksella poistuva vesimäärä pienenee turpeen tilavuuspainon kasvaessa siten, että hyvin maatuneessa turpeessa (til. paino 0.20 g/cm³) se on vajaa 1/3 siitä, mitä se on heikosti maatuneessa (til. paino 0.05 g/cm³) turpeessa.

— Kentällä suoritettujen tensiometrimittausten perusteella näyttää siltä, ettei kuivuus ja syvälläkään oleva pohjavesipinta aiheuta juuristokerroksen vesipitoisuuden alenemista edes vähenevän kasvun rajalle saatikka sitten lakastumispisteeseen.

— Huokoskokojakautuman ja tensiometrimittausten perusteella voidaan päätellä se pohjavesipinnan etäisyys, josta syvemmältä veden kapillaarinen nousu pintaturvekerrokseen vaikeutuu.

PÄIVÄNEN, JUHANI O.D.C. 114.444: 181.31

1973. Hydraulic conductivity and water retention in peat soils. ACTA FORESTALIA FENNICA 129. 00 p. Helsinki.

The paper is a part of a larger study of the basic hydrologic properties of peat. This part of the study deals with the hydraulic conductivity and water retention capacity of peat and with their dependence on some of its structural properties. Also, the possibilities to estimate the quantities of water superfluous, available and unavailable to the plant cover as well as the quantities of water that can be removed from various peat soils through drainage are discussed.

Author's address: Department of Peatland Forestry, University of Helsinki, Unioninkatu 40 B, SF-00170 Helsinki 17.

PÄIVÄNEN, JUHANI O.D.C. 114.444: 181.31

1973. Hydraulic conductivity and water retention in peat soils. ACTA FORESTALIA FENNICA 129. 00 p. Helsinki.

The paper is a part of a larger study of the basic hydrologic properties of peat. This part of the study deals with the hydraulic conductivity and water retention capacity of peat and with their dependence on some of its structural properties. Also, the possibilities to estimate the quantities of water superfluous, available and unavailable to the plant cover as well as the quantities of water that can be removed from various peat soils through drainage are discussed.

Author's address: Department of Peatland Forestry, University of Helsinki, Unioninkatu 40 B, SF-00170 Helsinki 17.

PÄIVÄNEN, JUHANI O.D.C. 114.444: 181.31

1973. Hydraulic conductivity and water retention in peat soils. ACTA FORESTALIA FENNICA 129. 00 p. Helsinki.

The paper is a part of a larger study of the basic hydrologic properties of peat. This part of the study deals with the hydraulic conductivity and water retention capacity of peat and with their dependence on some of its structural properties. Also, the possibilities to estimate the quantities of water superfluous, available and unavailable to the plant cover as well as the quantities of water that can be removed from various peat soils through drainage are discussed.

Author's address: Department of Peatland Forestry, University of Helsinki, Unioninkatu 40 B, SF-00170 Helsinki 17.

PÄIVÄNEN, JUHANI O.D.C. 114.444: 181.31

1973. Hydraulic conductivity and water retention in peat soils. ACTA FORESTALIA FENNICA 129. 00 p. Helsinki.

The paper is a part of a larger study of the basic hydrologic properties of peat. This part of the study deals with the hydraulic conductivity and water retention capacity of peat and with their dependence on some of its structural properties. Also, the possibilities to estimate the quantities of water superfluous, available and unavailable to the plant cover as well as the quantities of water that can be removed from various peat soils through drainage are discussed.

Author's address: Department of Peatland Forestry, University of Helsinki, Unioninkatu 40 B, SF-00170 Helsinki 17.

ACTA FORESTALIA FENNICA

EDELLISIÄ NITEITÄ — PREVIOUS VOLUMES

KANNATTAJAJÄSENET — UNDERSTÖDANDE MEDLEMMAR

CENTRALSKOGSNÄMNDEN SKOGSKULTUR
SUOMEN METSÄTEOLLISUUDEN KESKUSLIITTO
OSUUSKUNTA METSÄLIITTO
KESKUSOSUUSLIIKE HANKKIJA
SUNILA OSAKEYHTIÖ
OY WILH. SCHAUMAN AB
OY KAUKAS AB
KEMIRA OY
G. A. SERLACHIUS OY
KYMIN OSAKEYHTIÖ
SUOMALAISEN KIRJALLISUUDEN KIRJAPAINO
KESKUSMETSÄLAUTAKUNTA TAPIO
KOIVUKESKUS
A. AHLSTRÖM OSAKEYHTIÖ
TEOLLISUUDEN PAPERIPUUYHDISTYS R.Y.
OY TAMPELLA AB
JOUTSENO-PULP OSAKEYHTIÖ
TUKKIKESKUS
KEMI OY
MAATALOUSTUOTTAJAIN KESKUSLIITTO
VAKUUTUSOSAKEYHTIÖ POHJOLA
VEITSILUOTO OSAKEYHTIÖ
OSUUSPANKKIEN KESKUSPANKKI OY
SUOMEN SAHANOMISTAJAYHDISTYS
OY HACKMAN AB
YHTYNEET PAPERITEHTAAT OSAKEYHTIÖ
RAUMA-REPOLA OY
OY NOKIA AB, PUUNJALOSTUS

ISBN 951-651-004-3