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PHYSICAL PROPERTIES OF PEAT SAMPLES IN RELATION TO SHRINKAGE UPON DRYING

JUHANI PÄIVÄNEN

Seloste

TURVENÄYTTEIDEN FYSIKAALISTEN OMINAISUUKSIEN SUHDE KUTISTUMISEEN KUIVATTAESSA

Saapunut toimitukselle 15. 4. 1982

The study discusses the amount of shrinkage of volumetric undisturbed peat samples when drying to an oven-dry (105 °C) condition. The amount of shrinkage is related to various physical properties of peat. In addition, some observations were performed on the shrinkage phenomenon during the drying process. The study results may be used when predicting the shrinkage of peat samples with various peat properties. Knowledge of this kind is particularly important in connection with peat harvesting.

1. INTRODUCTION

The importance of volumetric sampling in peat soil studies is well known. Bulk density is the ratio of the dry mass of peat sample to the volume of the undisturbed sample at a specific moisture condition. Accurate bulk density determinations are needed for e.g. water regime studies, to convert the water contents of peat measured in weight units into volume per centages (Päivänen 1969) or for fertility studies to convert basic concentration data into absolute amounts (Erviö 1970, Westman 1981). Because of the shrinkage – swelling properties of clay and organic soils the bulk density varies with the water content of the soil.

In mineral soils the volume changes due to the moisture content changes are traditionally regarded as linear functions of water contents at certain soil water potentials. This soil volume change has been called normal shrinkage. Residual shrinkage has been called the area where the relation between the changes in water content and soil volume is no longer linear (e.g. Haines 1923). In very wet soils the relation may also be non-linear; this has been called structural shrinkage (Stirk 1954). Soil swelling due to moistening is in principle a reverse phenomenon to shrinking and so the corresponding parts from the swelling and shrinking curves can be found (Kivisaari 1979).

Peat morphology studies have proved that the peat changes its former spongy-fibrous structure into an aggregate or granular one during the decomposition process. Small particles of peat mass, occurring in the form of flocks of coagulated humus and remnants of plant tissues, gradually approximate one another, thereby forming aggregates. The tendency of densification and shrinkage is particularly connected to humus particles. The second peat component – plant fiber – exhibits a different tendency. The changes occuring in the course of drying, manifested in the form of peat shrinkage, depend on the mutual relations and interacting forces of the two peat components (Okruszko 1960).

Segeberg (1962) approaches the peat shrinkage problem as follows. When peat dries the shrinkage can be expressed:

$$\Delta V_B = \Delta V_W - \Delta V_L , \qquad (1)$$

in which

ΔV_B = shrinkage of the peat sample,

ΔV_W = change in water volume (decrease),

ΔV_L = change in air volume (increase).

In this connection there may occur two borderline cases. At the first case $\Delta V_L = 0$ and the decrease in water volume (ΔV_W) = the shrinkage (ΔV_B). The shrinkage phenomenon then reaches its highest value. This has been called ideal shrinkage (ideale Schrumpfung) (Segeberg 1962) or normal shrinkage (e.g. Haines 1923). At the other borderline case the decrease in water volume (ΔV_W) = the increase in air volume (ΔV_L) and no shrinkage takes place.

The void ratio is the ratio of the volume of voids to the volume of soil solids. At the first borderline case (ideal shrinkage) we can say that the void ratio is reduced in proportion to the reduction in water content. However, when the voids are filled with both water and air, the volume cannot be reduced beyond a fixed point by drainage alone (MacFarlane 1959).

Segeberg (1962) has also introduced the term shrinkage coefficient (k) (Schrumpfungskoefficient) which refers to the ratio of the actual shrinkage to the calculated shrinkage (ideal shrinkage). The shrinkage coefficient may vary between $0 \leqq k \leqq 1$.

Feustel and Byers (1930) in their early work presented the calculation of the maximum percentage of shrinkage from the values for "maximum water-holding capacity" and the "apparent specific gravity" (bulk density) in the oven-dry condition. In actual fact this represents the usual way of calculating the shrinkage percentage when drying a water saturated peat sample at 105 °C to a constant weight (Peat testing . . . 1979).

Until now the published results concerning the shrinkage of peat upon drying have been scanty. Invariably, however, it has been considered that the shrinkage of peat samples is the greater the more decomposed (humified) the studied peat material is (Fleischer 1891, Tacke 1929, Løddesøl 1934, Lundblad 1945, Colley 1950, Okruszko 1960). In particular "sedimentary plastic peats" (Colley 1950) and "amorphous humus" (Okruszko 1960) show a great decrease in volume upon drying. The shrinkage of peat has also been found to increase with increasing sampling depth (McCool and Weidemann 1924). These findings are probably connected to the colloidal properties of the highly decomposed peat material (e.g. Lundblad 1945). Some "puddling" treatments where the natural structure of the peat is distroyed may also lead to an increase in the shrinkage properties of peat (Nilssen 1978, Njøs 1978). Disintergrated and mixed peat samples have also shown a considerable volume loss while drying to constant weight, and the greater the stage of decomposition the greater the loss in volume (Graham and Hicks 1980). Further more, the low sensitivity of undecomposed *Sphagnum* peat to shrinkage during the drying process has been frequently noticed. Such a phenomena has been considered one of the most important properties for undecomposed *Sphagnum* peat used as peat moss bedding for domestic animals (Fleischer 1891) and as a growth substrate in green-houses (Puustjärvi 1968).

However, very few scientists have presented accurate shrinkage percentages in connection with other physical properties of peat. These will be referred to in Chapter 5. Some have even stated that correlations between shrinkage and various properties of peat, such as the degree of decomposition, compressibility and dry density, are difficult to confirm (Hanrahan 1952).

The aims of this study are:

- to determine the amount of shrinkage of volumetric, undisturbed peat samples when drying to oven-dry (105 °C) condition
- to relate shrinkage to various properties of peat
- to make observations on the shrinkage phenomenon during the drying process.

The results of the study may be used as a means of predicting the shrinkage of peat samples with various properties of peat. The knowledge concerning the shrinkage during the drying processes are particulary important in connection with peat harvesting.

This investigation is part of a series of studies dealing with the physical and hydrological properties of peat accomplished in the Department of Peatland Forestry, University of Helsinki. The sample material and the laboratory measurements were taken several years ago in connection with the earlier studies, but my principal occupation in another field of forestry delayed the compilation of the report. It was not until I was granted the Scholarship for Senior Researcher by the Academy of Finland that I was again able to concentrate on the problem.

Mr. Jukka Laine, Lic. For. has greatly helped me in the planning of statistical analysis and computing. The stimulating discussions with him and Mr. Hannu Mannerkoski, Lic. For. on the concepts and phenomena connected with the shrinkage of peat have been very valuable. The English language of the manuscript has been checked by Mr. David Hotton, B.Sc. Professor Leo Heikurainen, professor Eino Mälkönen and Dr. C. J. Westman have read the manuscript. The constructive criticism has been highly appreciated. I wish to express my sincerest thanks to all the persons and institutions involved with this study.

2. METHODS OF THE STUDY

21. Determination of shrinkage caused by oven-drying

When determining the shrinkage of peat the dimensions of the samples are measured at field-moisture and after oven-drying (105 °C). The change in volume is expressed as a per centage of the volume of the fresh sample (Peat testing . . . 1979):

$$\Delta S = \frac{V_m - V_{od}}{V_m} \cdot 100 \qquad (2)$$

in which

ΔS = shrinkage per cent of volume,

V_m = volume of the fresh sample (cm^3),

V_{od} = volume of the oven-dried sample (cm^3).

The method described was also followed in this part of the study.

Different kinds of methods have been used to measure the shrinkage of soil samples after drying.

1. The most accurate method of measuring volume loss unless samples of regular shape can be obtained is by displacement of mercury in a special pycnometer bottle (Haines 1923).
2. Another application is based on the principle of displacement of small spherical particles (Vidal and Schuch 1966), glass beads, 850–1000 µm diameter (van Dijk and Boekel 1968) or sand (Boelter 1962) of a known bulk density instead of liquid.
3. A vernier caliper has been used to obtain the average core height and diameter (e.g. Segeberg 1962, Miller 1966, Peat testing . . . 1979). Also a flexible steel tape has been used to measure the circumference of the core (Yule and Ritchie 1980).

In this study the shrinkage was measured from the oven-dry core by filling the space previously occupied by peat with sand of a known bulk density (Boelter 1962). The absolute volume reduction (shrinkage) was calculated by dividing the weight of sand with its pre-calibrated bulk density. Fine textured "Blokzilj" sand (see van der Harst and Stakman 1965) with a bulk density of 1.32 g/cm^3 was used in the study. The shrinkage was calculated as a per centage of the original volume of the sample (348 cm^3).

22. Determination of shrinkage during the drying process

The magnitude of the shrinkage during the drying process was examined with a submaterial in the laboratory. The peat samples in cores (348 cm^3) were saturated with water. Following saturation, the sample may swell to such an extent that some peat has to be cut away from the upper surface of the sample using a sharp knife. The water content of the sample at saturation was determined by weighing the sample. During drying in an oven at 105 °C the sample was reweighed and remeasured at intervals 3, 5, 7, 9, 11, 13, 24 and 31 hours after the drying began.

In this section of the study the method based on the displacement of sand was impossible to apply, largely because it presupposes the use of temporary samples. The only method which enables a remeasurement of one and the same sample when drying progresses is one which measures the linear dimensions of the sample. With regard to the core diameter, two measurements from both ends of the soil core were taken; for the core height four measurements to an accuracy of 1 mm were used. With these measurements the average volume of the sample at each stage of wetness was calculated. The water loss and prevailing water content of the sample were also checked. The shrinkage of the sample was calculated both in absolute figures, and in per centages of the original (saturated) peat volume.

3. MATERIAL, PREHANDLING, AND CALCULATIONS

The sample material is primarily from forest drainage areas located near to each other in Central Finland (61° 50′N; 24° 20′E). The samples were collected in the field by sampling cylinders with a volume of 348 cm^3. The method was indentical to that used in water retention studies (see Päivänen 1973). Peat type, humification degree (von Post 1922) and sampling depth were recorded in the field. Aiming to preserve the natural undisturbed structure the samples were taken to the laboratory, where they were weighed in fresh condition. The samples were dried to constant weight at 105 °C and reweighed. The water content of the sample was computed both as a per centage of volume and of fresh weight at sampling, and bulk density on wet volume basis by dividing the dry weight by the constant volume (348 cm^3).

The material was divided into groups according to the dominant peat constituent, thereby representing *Sphagnum* peats (S peats), *Carex* peats (C peats) and woody peats (L peats). In total the original material consists of 466 peat samples.

In studies concerning the water retention properties of peat the volume of the peat samples at saturation have been used as a comparison (e.g. Boelter 1962, Päivänen 1973). Already at the low water tensions peat shows some shrinkage (Pessi 1961, p. 253, Boelter 1962, p. 61). For the range of water contents as found in the field, however, the method based on fresh volume has appeared to be satisfactory for bulk density determinations (Irwin 1968). This has also been agreed in fertility studies (Westman 1981).

The latter two studies refer to peat samples collected from virgin peatlands. Since this material originated from forest drainage areas the water content at the time of sampling varied considerably. Therefore, it was decided to restrict the material used in the final calculations to samples which differed by less than 2.0 per cent unit of fresh weight from the water content at saturation at the corresponding level of bulk density (Figure 1). The theoretical water content of peat on a fresh weight basis at saturation depends on density of solids, total porosity and bulk density (solid line in Figure 1):

$$P_t = \frac{(D_s - D_b)}{D_s} \cdot 100 \qquad (3)$$

$$W_w = \frac{P_t}{P_t + 100\,D_b} \cdot 100 \qquad (4)$$

in which P_t = total porosity, per cent of volume
D_s = density of solids, g/cm^3
D_b = bulk density, g/cm^3
W_w = water content at saturation, per cent of fresh weight

In this connection it was assumed that the average density of solids of peat is 1.5 g/cm^3. The effect of density of solids on the total porosity – and likewise on this theoretical water content at saturation – has previously been discussed (Päivänen 1973, p. 38).

The above restriction means that the volumetric water content of peat samples included in the final material may, at the very most, differ from the theoretical water content at saturation by 28.8 per cent unit for peats of bulk density 0.05 g/cm^3, and by 10.0 per cent unit for peats of bulk density 0.20 g/cm^3. According to this procedure 26 samples were disregarded.

The general physical properties of the sample material appears from Table 1. It can be seen that the bulk density of the S peat samples has the widest range, but on average they are less compact than the other two peat types. On average the water content at sampling is 5–7 per cent volume units smaller compared to the water content at experimental saturation (see Päivänen 1973, Figure 16).

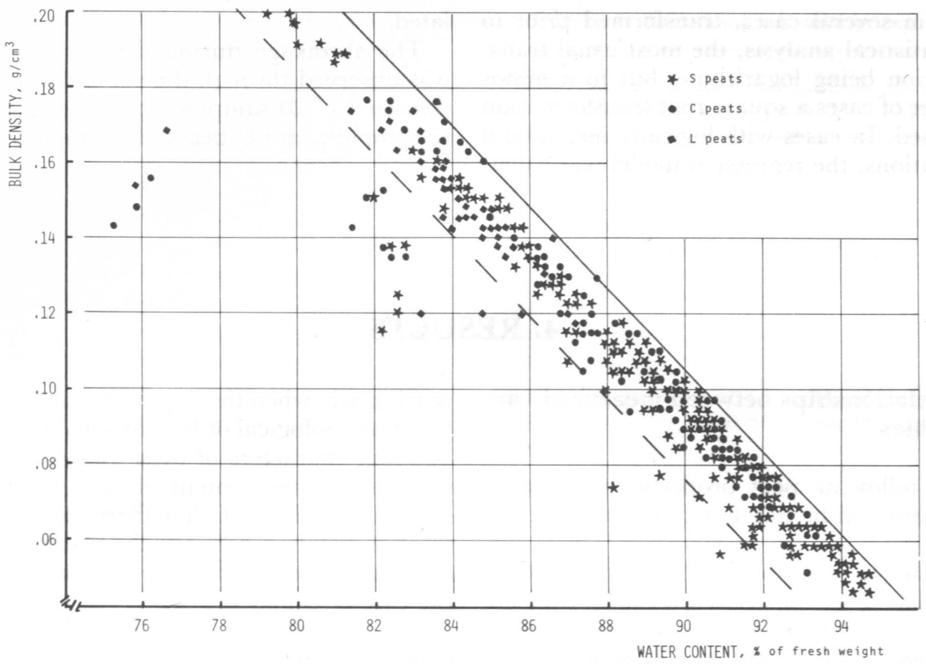

Figure 1. The relationship between water content, per cent of fresh weight at sampling and bulk density. The solid line represents the theoretical water content at saturation in peat with corresponding bulk density. Disregarded samples on the left side of the broken line (see text).

It can also be concluded that, at the time of sampling, the matric suction in S peats has been far less than in C and L peats, around 0.01 kp/cm^2 (1 kPa). This situation is probably very common for the peat layers 15–55 cm in peatland forest drainage areas on peatlands.

The general relationship between the variables studied was shown with the help of a simple correlation analysis. The variables

Table 1. Mean values and ranges of the measured variables by peat types.

	S peats		C peats		L peats	
Variable	Mean	(Range)	Mean	(Range)	Mean	(Range)
Bulk density (fresh vol.), g/cm^3	.094	(.045–.200)	.098	(.051–.177)	.144	(.105–.175)
Bulk density (dry vol.) g/cm^3	.243	(.060–.797)	.190	(.071–.662)	.267	(.165–.362)
Degree of humification, (von Post 1922)	4.4	(1–9)	4.1	(1–9)	6.8	(4–8)
Sampling depth, cm	32	(5–55)	37	(15–55)	37	(15–55)
Water content at sampling, % of volume	83	(70–95)	84	(69–95)	81	(73–91)
Water content at sampling, % of fresh weight	90	(80–95)	90	(82–93)	85	(83–89)
n	210		157		67	

were, in several cases, transformed prior to the statistical analysis, the most usual transformation being logarithmic but in a minor number of cases a square root transformation was used. In cases with logically meaningful correlations, the regression model was calculated.

The shrinkage during the drying process was observed through the submaterial which consisted of 20 samples representing S peats (8 samples) and C peats (12 samples).

4. RESULTS

41. Relationships between measured variables

The following peat properties were measured and will be discussed in the study:

Shrinkage, per cent of volume (2); bulk density fresh volume basis, g/cm^3 (3); sampling depth, cm (4); water content at sampling, per cent of volume (5); degree of humification (von Post 1922) (6), bulk density dry volume basis, g/cm^3 (7) and water content at sampling, per cent of fresh weight (8).

Simple correlations between the various peat soil properties measured and some of their transformations are presented by peat type in Table 2.

All physical properties were expected to be possible independent variables when explaining the shrinkage of peat upon drying. As anticipated, some of these peat properties carry strong intercorrelations.

As in other studies a highly significant correlation was found in this investigation between bulk density fresh volume basis and degree of humification (e.g. Päivänen 1969, Puustjärvi 1970, Karesniemi 1972, Päivänen 1973, Raitio and Huttunen 1976, Silc and Stanek 1977, Tolonen and Saarenmaa 1979). However, since the determination of the degree of humification is a subjective one, it has been omitted from future calculations.

The strongest correlation was found between bulk density and water content per centage of fresh weight at sampling (e.g. Tolonen and Saarenmaa 1979, Korpijaakko et al. 1981). The possibility of using this as a means for predicting the bulk density of peat will be discussed at a later date (Laine and Päivänen 1982). In soil science the volumetric water content has often been prefered, particularly when the approach has been on a plant physiological or hydrological basis. The different characters of these two ways to express the water content of peat are further reflected in the fact that there exists only a weak correlation between the water contents of S peats, and, invariably no correlation in the case of C and L peats.

The correlation between the sampling depth and bulk density is significant only for S peat. Quite low positive correlations and even some negative correlations have been found in an earlier study between sampling depth and bulk density in corresponding drained peatlands for the layers from 15 to 55 cm (Päivänen 1973).

42. Shrinkage in relation to other physical properties of peat

The average shrinkage for the peat types studied was:

	Mean	(Range)
S peats	52.5 %	(15.5 – 79.3)
C peats	45.8	(18.1 – 83.9)
L peats	45.1	(34.8 – 54.3)
Total material	48.9	(15.5 – 83.9)

According to the analysis of variance there is a highly significant difference between the average shrinkage in S and C peats (F 22.22*** d.f. 1,365) and S and L peats (F 14.67***, d.f. 1,275), but not between C and L peats (F 0.23, d.f. 1,222). This observation alone is, however, not very useful for two reasons: firstly, shrinkage is influenced by the bulk density of peat, and secondly the diffe-

Table 2. Simple correlations between the peat soil variables (and their transformations) measured by peat types.

Variable[1]	Variable[1]								
	2	3	4	5	6	7	8	9	10
S peats									
3	.657***[2]								
4	.477***	.275**							
5	.113	–.107	.424***						
6	.791***	.829***	.536***	.114					
7	.802***	.919***	.418***	–.092	.866***				
8	–.635***	–.990***	–.211**	.228**	–.796***	–.906***			
9	.684***	.979***	.261**	–.059	.828***	.874***	–.971***		
10	.902***	.907***	.405***	.007	.892***	.939***	–.892***	.925***	
11	–.633***	–.990***	–.212**	.229**	–.795***	–.908***	1.000***	–.968***	–.890***
C peats									
3	.415***								
4	.412***	.032							
5	.150	.118	.303**						
6	.472***	.909***	.234**	.131					
7	.766***	.844***	.178*	.139	.796***				
8	–.380***	–.981***	.027	.061	–.887***	–.812***			
9	.400***	.988***	.019	.153	.884***	.818***	–.969***		
10	.773***	.873***	.210**	.171*	.831***	.954***	–.848***	.879***	
11	–.380***	–.980***	.025	.062	–.887***	–.813***	1.000***	–.968***	–.847***
L peats									
3	.373**								
4	.007	.051							
5	.004	.085	.206						
6	.277*	.696***	.192	.159					
7	.800***	.840***	.060	.018	.591***				
8	–.373**	–.948***	.009	.229	–.634***	–.819***			
9	.400***	.997***	.037	.102	.713***	.851***	–.943***		
10	.794***	.849***	.037	.054	.627***	.995***	–.819***	.866***	
11	–.371***	–.947***	.007	.229	–.632***	–.817***	1.000***	–.942***	–.817***
Total material									
3	.411***								
4	.347***	.196**							
5	.116*	–.123*	.341***						
6	.548***	.873***	.377***	–.008					
7	.770***	.799***	.288**	–.071	.787***				
8	–.386***	–.988***	–.143**	.257**	–.850***	–.783***			
9	.426***	.984***	.195**	–.085	.859***	.769***	–.973***		
10	.805***	.855***	.305**	–.013	.851***	.936***	–.838***	.870***	
11	–.385***	–.988***	–.144**	.258**	–.849***	–.784***	1.000***	–.971***	–.836***

[1] Variables:

2 = shrinkage, per cent of volume
3 = bulk density fresh volume basis, g/cm^3
4 = sampling depth, cm
5 = water content at sampling, per cent of volume
6 = degree of humification (von Post, 1922)
7 = bulk density dry volume basis, g/cm^3
8 = water content at sampling, per cent of fresh weight
9 = ln (variable 3)
10 = ln (variable 7)
11 = $\sqrt{}$ (variable 8)

[2] Levels of significance:

*** = significant at the 0.1 % level
** = significant at the 1 % level
* = significant at the 5 % level

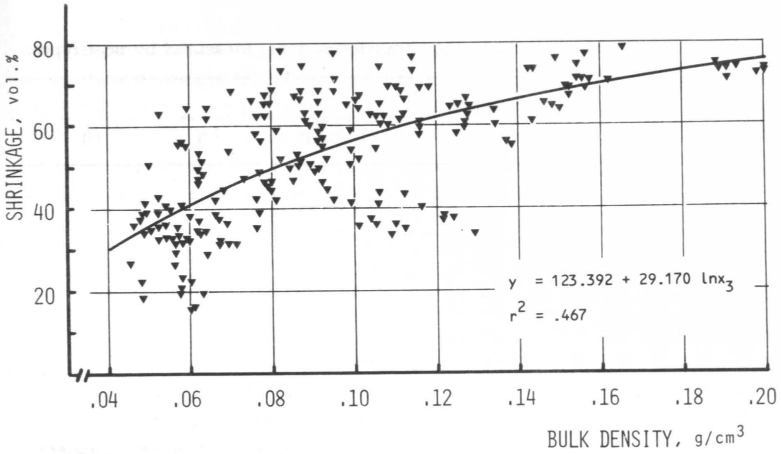

Figure 2. The dependence of shrinkage (y) on bulk density (x_3) in *Sphagnum* peats.

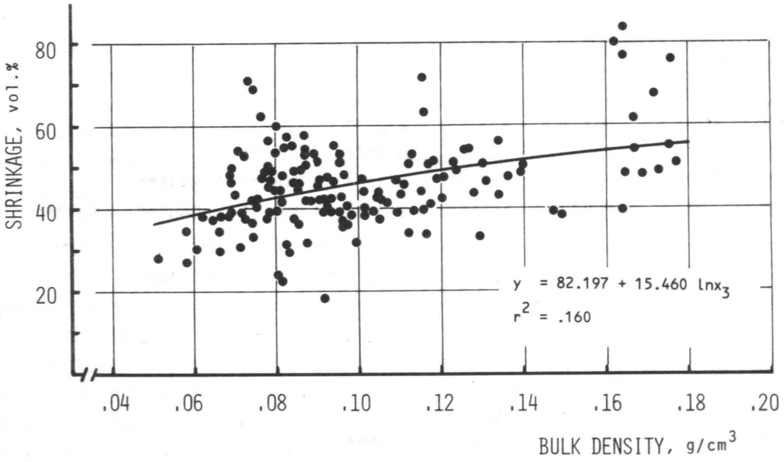

Figure 3. The dependence of shrinkage (y) on bulk density (x_3) in *Carex* peats.

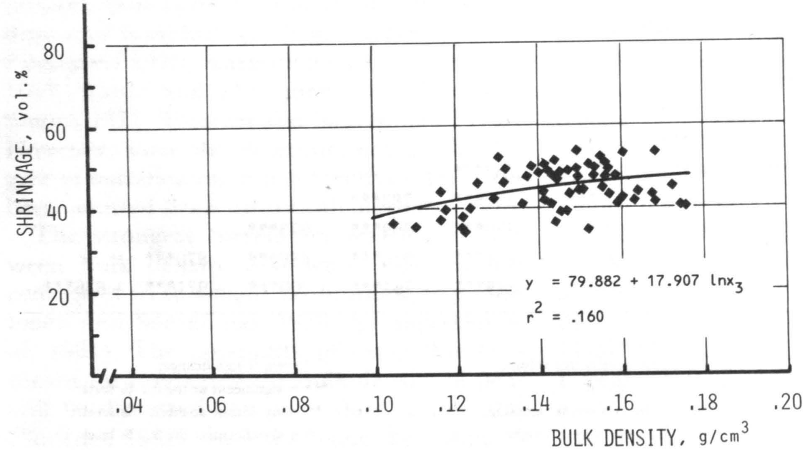

Figure 4. The dependence of shrinkage (y) on bulk density (x_3) in woody peats.

rent peat types are not evenly distributed in different bulk density classes (Figures 2–4).

To verify the possible statistical differences in the level of shrinkage between the peat types, an analysis of covariance was applied to eliminate the effects of variations depending on bulk density within the peat type. The results attained a highly significant difference between the level of shrinkage in S and C peats (F 21.00***, d.f. 1.365), between S and L peats the difference is almost to reach the level of significance (F 3.83, d.f. 1,275; tabulated $F_{5\ \%}$ 3.88), but no difference is to be found between C and L peats (F 0.01, d.f. 1,222).

In S and C peats the simple correlations between shrinkage and individual independent variables are all highly significant with the exception of water content per cent of volume at sampling. In L peats only bulk density on a dry volume basis reaches a highly significant level (Table 2).

It appears logical that with increasing bulk density the volumetric shrinkage ought to approach asymptotic at a certain level. Therefore the logarithmic transformation of bulk density values was applied when explaining the shrinkage with bulk density alone (Figures 2–4). The degree of determination is, however, relatively low: 47, 16 and 16 per cent in S, C and L peats, respectively.

In addition to bulk density one would expect that the sampling depth and/or water content at sampling have an effect on the quantity of shrinkage. Multiple regression models with both bulk density and sampling depth as independent variables increased the degree of determination to 56 and 32 per cent in S and C peats respectively (Table 3). To visualize the effect of the latter variable on shrinkage the sampling depth has been standardized to the levels of 15, 35 and 55 cm in Figures 5 and 6. However, in L peats the sampling depth did not increase the information.

Using water content, per cent of volume, instead of sampling depth as a second independent variable in the model, a lower degree of determination was achieved. Including water content, per cent of volume, as the third independent variable no significant improvement in the degree of determination was noticeable.

Table 3. The regression models for the relationships between the shrinkage (dependent variable) and some other physical properties of peat. Independent variables as in Table 2.

Independent variables	Regression			
	Constant	Regr.coeff.	T-value	R^2
		S peats		
9	123.392	29.170	13.51***	.467
9	104.103	25.603	12.60***	.563
4		.330	6.72***	
11	556.121	−53.110	11.82***	.402
11	483.655	−46.721	11.36***	.524
4		.369	7.29***	
		C peats		
9	82.197	15.460	5.43***	.160
9	69.459	15.162	5.92***	.324
4		.318	6.10***	
11	311.738	−28.098	5.14***	.145
11	306.676	−28.890	5.91***	.323
4		.332	6.37***	
		L peats		
9	79.88	17.910	3.52***	.160
11	265.868	−23.964	3.23**	.139

The volumetric information on the dry matter and water content of peat together with the information concerning sampling depth explained the shrinkage of peat relatively poorly.

The possibility of avoiding laborous volumetric sampling when predicting the shrinkage of peat upon drying could be considered to be an advantage. In the previous chapter it was pointed out that there is a strong negative correlation between bulk density and water content, per cent of fresh weight. Therefore it appeared feasible to examine the regression models where the shrinkage of peat is a dependent variable and water content, per cent of fresh weight, an independent variable.

With regard to S peats the degree of determination with this type of model was 40 per cent, but the other two peat type groups were

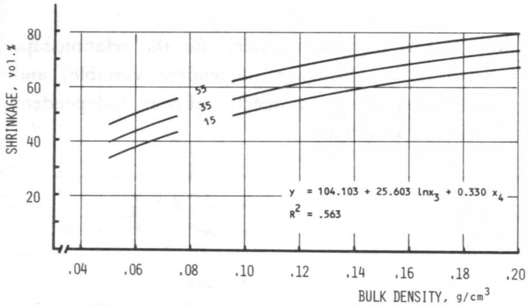

Figure 5. The dependence of shrinkage (y) on bulk density (x_3) and sampling depth (x_4) in *Sphagnum* peats.

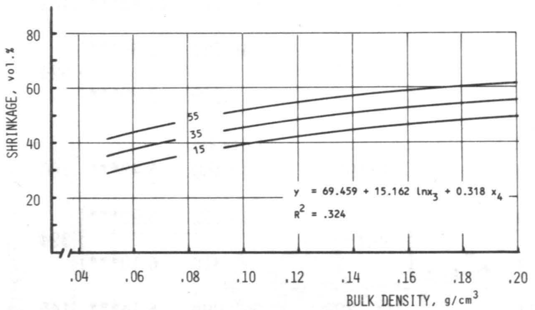

Figure 6. The dependence of shrinkage (y) on bulk density (x_3) and sampling depth (x_4) in *Carex* peats.

much smaller. Adding the sampling depth to the model increased the degree of determination to 52 and 32 per cent in S and C peats, respectively (Table 3). Thus this model proved to be almost as good at explaining the shrinkage of peat as the model where bulk density and sampling depth were used as independent variables.

43. Bulk density dry volume basis in relation to other physical properties of peat

Sometimes the volume reduction of peat upon drying has been demonstrated by calculating the regression between bulk density on a fresh and dry volume basis (e.g. Boelter and Blake 1964). It is natural that a strong interdependence exists within the regression since the data is based on samples where the constant mass is divided by the volume prior to and post drying. If the shrinkage were independent on decomposition of peat (expressed as bulk density values), this relationship would be linear and the volume reduction equal to the reciprocal of the slope. However, as the shrinkage usually increases with increasing decomposition, the dependence of bulk density dry volume basis on bulk density fresh volume basis will also be curvilinear.

In this material the logarithmic transformation of bulk density values increased the correlation. Depending partly on the aforementioned interdependence, the degree of determination is high when explaining bulk density dry volume basis with bulk density fresh volume basis: 86, 77 and 75 per cent in S, C and L peats, respectively (Figures 7–9). Adding sampling depth to the model increased the degree of determination to 88 and 81 per cent in S and C peats, respectively (Table 4), but did not have an effect on L peats.

In addition, bulk density dry volume basis can be predicted with the help of water content, per cent of fresh weight at sampling (Table 5). Depending on the differences in shrinkage the correlation is not, however, as self-evident as between water content, per cent of fresh weight at sampling and bulk density wet volume basis (cf. Table 2). Adding sampling depth to be a secondary independent variable the degree of explanation increased from that reached with water content, per cent of fresh weight alone from 82 to 88 and from 66 to 70 per cent in S and C peats, respectively (Table 5).

44. Shrinkage during the drying process

The material, which consists of 20 samples, was divided into four groups according to the dominant peat constituent and degree of decomposition (described with bulk density, fresh volume basis):

Group number	Peat type	Number of samples	Bulk density, g/cm^3 Mean	(Range)
1	S peat	4	.099	(.095 – .104)
2	–"–	4	.132	(.117 – .147)
3	C peat	4	.133	(.126 – .138)
4	–"–	8	.166	(.146 – .185)

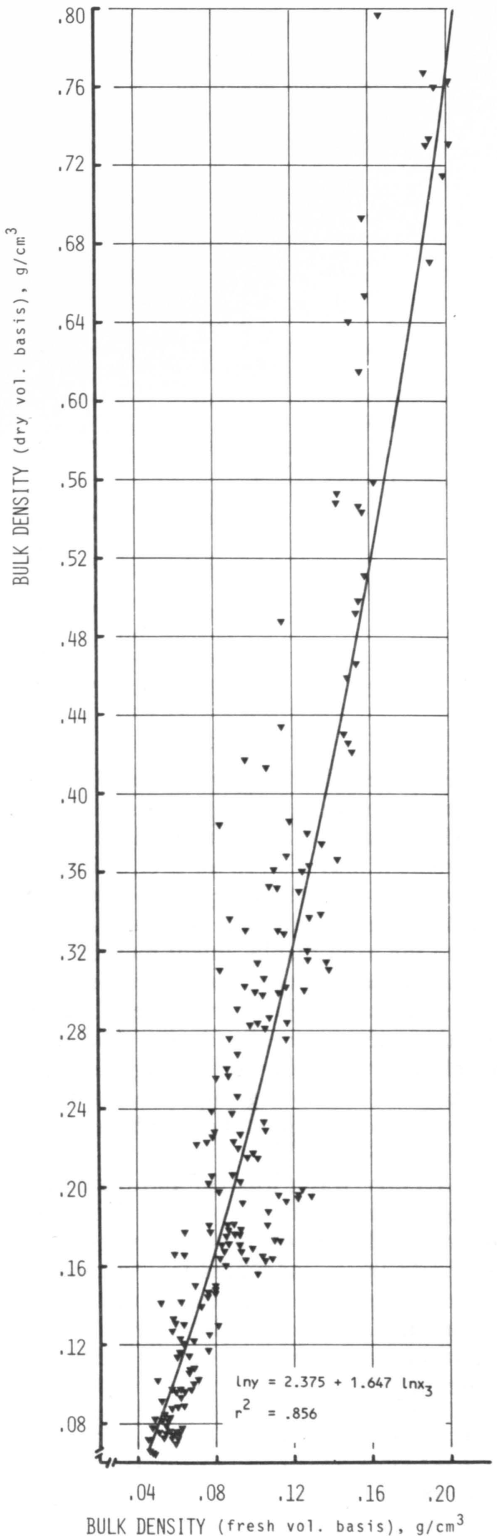

Figure 7. The dependence of bulk density dry volume basis (y) on bulk density fresh volume basis (x_3) in *Sphagnum* peats.

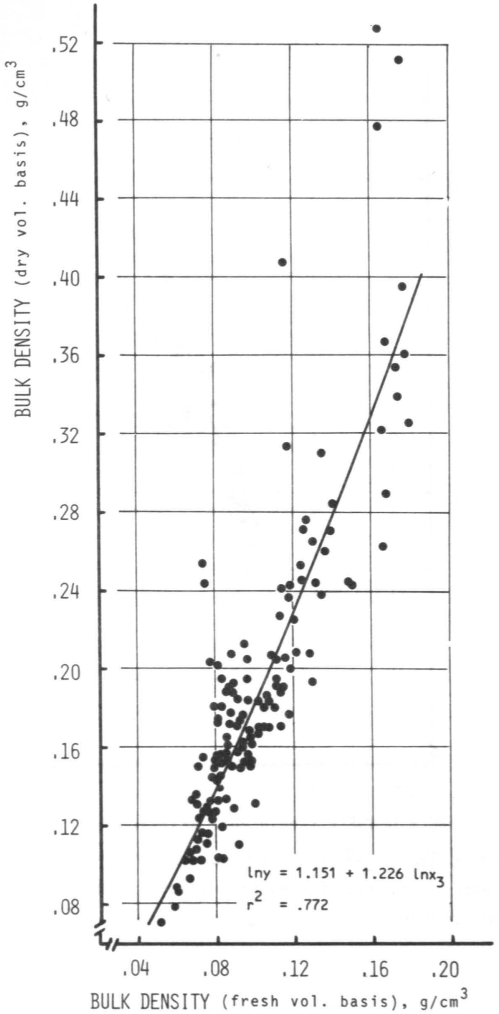

Figure 8. The dependence of bulk density dry volume basis (y) on bulk density fresh volume basis (x_3) in *Carex* peats.

The dependence of the mean relative shrinkage on time for the four peat groups following drying in an oven at 105 °C is shown in Figure 10. When examined by peat type, the magnitude of shrinkage differed significantly from each other in well and moderately well decomposed peats during the whole drying process. On the other hand, differences between peat types are not always this apparent largely because of a dissimilarity in the stages of decomposition. However, we can consider that all the four groups differ from each other with regard to the magnitude of shrinkage during subsequent phases ($\geq$ 13 h) of drying.

The total shrinkage reached in this submaterial was considerably smaller compared to samples with equal bulk density values in

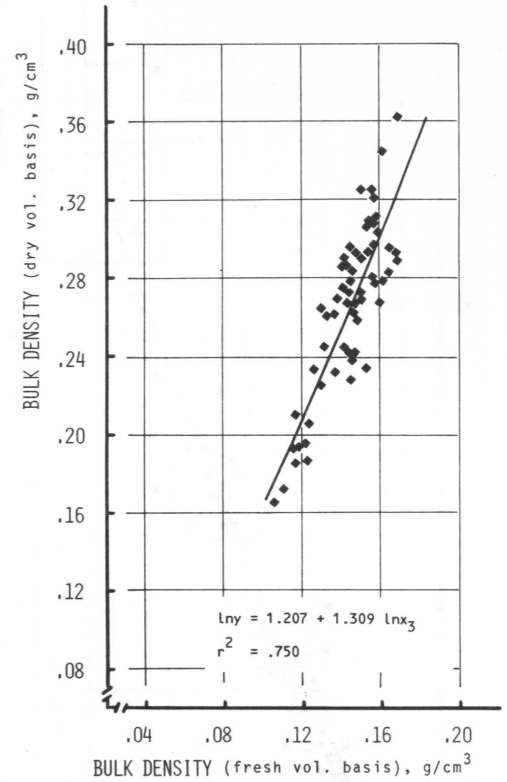

Figure 9. The dependence of bulk density dry volume basis (y) on bulk density fresh volume basis (x_3) in woody peats.

Table 4. The regression models for the relationships between logarithmic bulk density dry volume basis (dependent variable) and some other physical properties of peat. Independent variables as in Table 2.

Independent variables	Regression			
	Constant	Regr.coeff.	T-value	R^2
		S peats		
9	2.375	1.647	35.12***	.856
9	1.932	1.566	35.93***	.885
4		.008	7.19***	
		C peats		
9	1.151	1.226	22.89***	.772
9	.931	1.221	24.84***	.809
4		.005	5.49***	
		L peats		
9	1.207	1.309	13.96***	.750

Table 5. The regression models for the relationships between bulk density dry volume basis (dependent variable) and some other physical properties of peat. Independent variables as in Table 2.

Independent variables	Regression			
	Constant	Regr.coeff.	T-value	R^2
		S peats		
8	4.203	−.044	31.16***	.824
8	3.900	−.042	34.36***	.877
4		.003	9.46***	
		C peats		
8	2.561	−.026	17.41***	.662
8	2.527	−.027	18.61***	.702
4		.001	4.56***	
		L peats		
8	2.296	−.024	11.55***	.672

the main material (cf. Figures 2 and 3). Some comparison with the sand displacement method indicated that the three dimensional measurement may lead to an over estimation of the volume of the sample which resulted in a smaller volume reduction of about 1/5 compared to the sand displacement method. The material is too scanty to examine the errors between the methods in more detail. However, the measurements during shrinkage give reliable results for comparing the differences between the four groups. Furthermore, it is possible to identify different phases in the shrinkage process.

The average water loss (x) and the corresponding average volume loss (y) in the four peat groups during the drying process were plotted and the linear regressions calculated. The calculations were based on means and therefore no attention will be given to the correlation coefficients, only the constants (Figure 11):

1 $y = -3.785 + 0.327\ x$
2 $y = -4.470 + 0.563\ x$
3 $y = -4.470 + 0.267\ x$
4 $y = -2.220 + 0.470\ x$

As seen from the regression equations above, the y-intercepts all have negative values. This indicates that initially, although some water has been lost, no shrinkage occurs and the drained pores have a "stable-volume". This has been called structural shrinkage (Stirk 1954) or structural water loss phase (cf. Yule and Ritchie 1980). This is followed by shrinkage water loss phase, where a linear relationship prevails between the water and volume loss; water originates mainly from "variable-volume" pores. The residual water loss phase, where water continues to be lost but the volume remains unchanged, did not materialize in this data. Possibly both "variable-volume" and "stable-volume" pores were losing water at the same soil water suction. Should the drying process be slower (lower temperature) a residual water loss phase could possibly occur in peat soils.

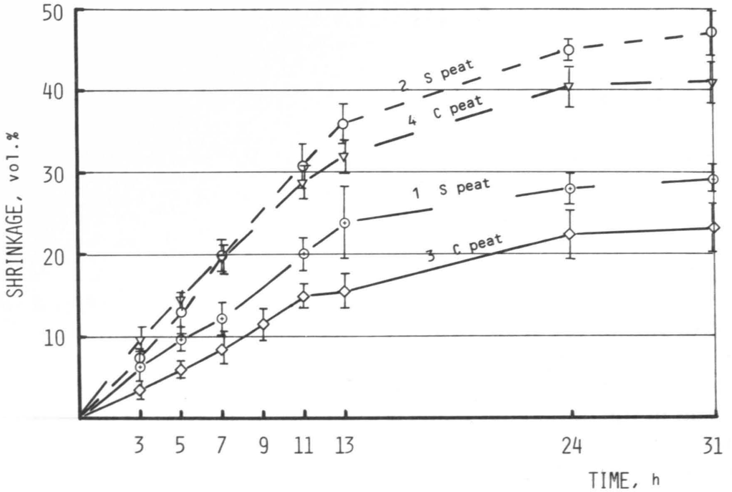

Figure 10. The relationship between drying time and shrinkage. Peat groups as indicated on page 256.

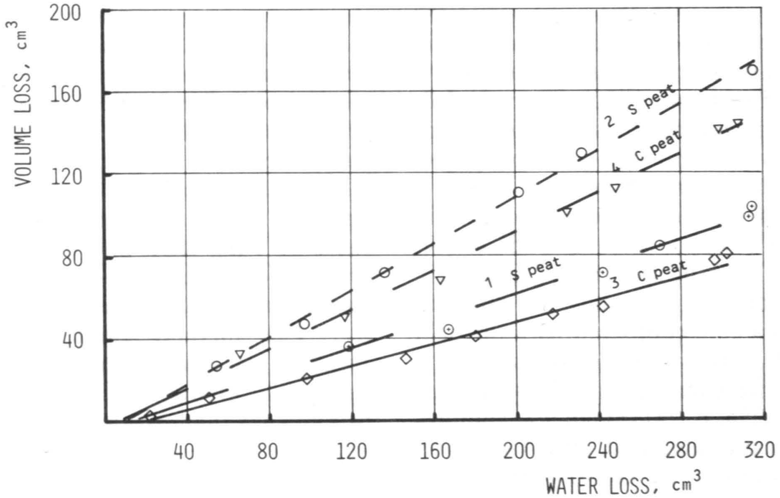

Figure 11. The dependence of the average volume loss (y) on the average water loss (x). Peat groups as indicated on page 256.

5. DISCUSSION

It is stressed that this paper deals only with peat samples.

In field conditions the removal of water leads both to subsidence and to development of shrinkage cracks (MacFarlane 1959, Pyatt 1973). The formation of cracks increases the difficulty of applying laboratory results to field conditions. Thus when calculating the air-water regime of soil in the field only the linear shrinkage in the vertical plane has been recommended for measurement, since the shrinkage of the soil in the horizontal plane is accompanied by the formation of cracks (Dardzhimanov and Papisov 1973). It has been reported, particularly in Scotland, that following drainage and afforestation, blanket peats become progressively dry and develop wide shrinkage cracks in the humified peat layers after canopy closure (Pyatt and Graven 1979). In the Netherlands it has also been found that in peat soils under grassland the water-table may fall to such an extent that in dry periods the upper layers may desiccate irreversibly (Hooghoudt 1950). The principle cause of this phenomenon seems to be the formation of very hard compact soil aggregates during the drying process.

Although volume reduction also occurs in the field upon drying, the magnitude of volume reduction and the spacial and geometric arrangement of the peat may be different when dried in a core compared with the field (Boelter 1962). The volume of the sample is also known to have an effect on the shrinkage value (Tikka 1955, p. 24). Small-size samples may show greater apparent shrinkage than larger ones owing to the fact that the larger the sample the more is cracking likely to occur. Preferably, a comparison to other studies should be made to samples of the same size. A sample with an infinite size approaches those conditions prevailing in the field.

Thus the results achieved in this study cannot be applied directly to field conditions. However, the results are able to demonstrate the effect of other peat properties on shrinkage of peat core samples when drying at 105 °C. The results are also a more reliable reference in connection with peat harvesting. Shrinkage of undisturbed peat samples of this study may, however, be smaller than in the case of disturbed (pretreatment with freezing, mixing etc.) samples (cf. van Dijk and Boekel 1968, Nilssen 1978, Njøs 1978).

Shrinkage depends on the water content at sampling. The shrinkage of samples originally at field water content is smaller than if the samples were saturated before drying (Boelter 1962). Therefore throughout prehandling, the material was reduced by disregarding samples with very low water content (see Figure 1, p. 251). This can be considered all the more important as the samples were collected from peatlands drained for forestry. In the remaining data the water content at the time of sampling, per cent of volume, did not show any significant correlation to the amount of shrinkage (cf. Table 2). On the other hand there was a significant negative correlation between water content at sampling, per cent of fresh weight, and shrinkage (Table 2 and 3). This is explained by intercorrelations in the first place between shrinkage and bulk density, and secondly, between bulk density and water content at sampling, per cent of fresh weight.

The large variation in shrinkage values reported in earlier studies can be seen in Table 6. Very often information concerning other physical properties of peat is rather sparse, particularly that concerning sample size. The method employed to measure shrinkage may also cause differences in the results. The greatest deficiency concerning all the figures is that they are usually means and very little information, if any, is available about their variation.

Text books dealing with peat soils often refer to the early figures presented by Fleischer (1891). In explaining these figures no corresponding bulk density values were given, but in this connection they have been calculated according to the known mass and volume of dry peat, and shrinkage.

From the average figures obtained in different studies it can be seen that generally the shrinkage is the larger the more advanced the decomposition. If the variation is presented, it is sizeable (see van Dijk and Boekel 1968, p. 1056). In some cases the large variation can be calculated from the original measurements (Boelter 1962, p. 99–100).

Table 6. The shrinkage of peat according to earlier studies.

Reference	Peat type	Stage of decomposition	Bulk density, fresh vol.basis	Shrinkage, vol. %	Remarks
Fleischer 1891, p. 20	*Sphagnum*	Undecomposed	.062	52	Germany
	Eriophorum	Slightly decomposed	.098	77	
	Eriophorum – Calluna	Decomposed	.104	83	
McCool & Weidemann 1924, p. 125–126				23–84	USA
Lundblad 1945, p. 7	*Carex*	Undecomposed	.136	39.6	Sweden
	"	Slightly decomposed	.137	66.6	
	"	Decomposed	.137	80.1	
	Eriophorum – Sphagnum	Slightly decomposed	.130	64.2	
	"	Decomposed	.136	75.8	
Colley 1950, p. 5	Moss/fibrous sedge peats			10 –	Florida, USA
	Sedimentary plastic peats			– 50	
MacFarlane 1959, p. 27				23–90	Different parts of the USA
Okruszko 1960, p. 56	*Sphagnum*	Deg. of decomposition	5 %	0	Poland
	Carex	"	15 %	21	
	Carex – Phragmites	"	25 %	49	
	Phragmites	"	35 %	67	
Boelter 1962, p. 61	*Sphagnum*	Undecomposed	.020	49.6	Minnesota, USA
	"	"	.056	45.6	
	"	Partially decomposed	.153	51.2	
	Aggregated peat	Moderately well dec.	.237	58.5	
	Carex	Slightly dec.	.156	53.9	
	"	"	.125	55.4	
van Dijk & Boekel 1968, p. 1056	*Eriophorum – Sphagnum*	$H_{3-4\ 1/2}$		53	the Netherlands
	"	$H_{5-6\ 1/2}$		55	
	"	H_{7-9}		62	

Here, as in some other studies, the shrinkage increased with increasing sampling depth (e.g. McCool and Weidemann 1924). This has been found also in clay soils (Petruzzelli et al. 1980). It is likely that such a phenomenon is connected with the amount of colloids which, for the soil types in question, increases along with depth.

In general, it can be considered that the amount of shrinkage obtained in this study is of the same magnitude as that experienced in the other studies. However, the large variation and the possible reasons for it have not been thoroughly discussed in the past. The best multiple regression models in this study explained only 56 to 32 per cent of the variation in the shrinkage of S and C peats, respectively. It has to be admitted that in addition to the main peat type, stage of decomposition (described with bulk density) and sampling depth or water content at sampling, per cent of volume, other peat properties can have an effect on the magnitude of shrinkage.

It seems to be possible to predict shrinkage without volumetric sampling. The water content at sampling, per cent of fresh weight, and sampling depth explained the shrinkage of peat almost as well as bulk density and sampling depth.

The regression concerning the dependence of bulk density, dry volume basis, on bulk density, fresh volume basis, (Chapter 43) is partly self-evident. The results were none the less presented because in certain cases it may be an advantage to be able to predict bulk density on a dry volume basis from bulk density fresh volume basis. Earlier research has shown the latter to be quite promising in describing other physical properties of peat

(Päivänen 1976). Thus the relationship (see Figures 7–9) is expected to be used in practice contrary to that supposed by Boelter (1962, p. 58–59).

Dealing with the shrinkage during the drying process the submaterial proved that a structural water loss phase took place, where water is removed but no shrinkage occurs, (e.g. Stirk 1954, Yule and Ritchie 1980). In the shrinkage water loss phase a linear relationship prevailed between the water and volume loss. In certain studies the volume loss has been discovered to be almost equal to the water loss (Irwin 1968) supporting the theoretical consideration about "variable-volume" pores (Yule and Ritchie 1980) or "Lyo-Gele drying out" (Segeberg 1962) However, in this study the volume loss was considerably smaller than the corresponding water loss indicating that both "variable-volume" and "stable-volume" pores were losing water at the same time. Consequently no residual water loss phase was observed; this may have been caused by the high temperature (105 °C) used in this study. However, there is still some disagreement between this material and the results presented by Irwin (1968), but unfortunately the whole series of measurements up to constant weight are not given and therefore a comparison with other phases is not possible.

6. SUMMARY

In the study at hand the shrinkage values of peat core samples (348 cm^3) collected from peatlands drained for forestry are discussed. The main material consisted of 434 samples. The following peat properties were observed to explain shrinkage: peat type, bulk density fresh and dry volume basis, degree of humification (von Post 1922), sampling depth, and water content at sampling, volume and fresh weight basis. The shrinkage after drying to constant weight at 105 °C was measured by applying the sand displacement method.

Some observations were also made with a submaterial of 20 samples on the nature of the shrinkage phenomenon by measuring the linear dimensions of a sample frequently during the drying process.

Great variation was found in the shrinkage of peat. It was considered advisable to handle the material in the three peat type groups – *Sphagnum* (S peats), *Carex* (C peats) and woody (L peats) peats – although the shrinkage of C and L peats did not differ significantly from each other. Due to the intercorrelations and subjectivity in determining a variable etc., only in those cases with logically meaningful correlations were the regression models calculated.

Bulk density and sampling depth explained 56 and 32 per cent of the variation in shrinkage in S and C peats, respectively. In L peats the sampling depth did not provide any further information and the degree of determination with bulk density alone was as low as 16 per cent. In S and C peats the water content at sampling, per cent of fresh weight, and sampling depth were almost as good independent variables as bulk density and sampling depth when predicting the shrinkage of peat. This indicates that without volumetric sampling the estimates of the relative shrinkage have nearly the same realibility as with information including bulk density.

Bulk density dry volume basis largely depended on bulk density fresh volume basis – the degree of determination 86, 77 and 75 per cent in S, C and L peats, respectively – as expected.

The submaterial showed that at least two phases occur in the drying process: structural water loss phase (no shrinkage) and shrinkage water loss phase (linear relationship between the water and volume loss). On the contrary, the residual water loss phase sometimes reported did not materialize.

The results obtained help to understand the considerable variation in the amount of shrinkage reported in previous literature. Information concerning the shrinkage of peat upon drying and the factors influencing this process are regarded as being particularly valuable in connection with harvesting and technical usage of peat.

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SELOSTE

TURVENÄYTTEIDEN FYSIKAALISTEN OMINAISUUKSIEN SUHDE KUTISTUMISEEN KUIVATTAESSA

Tutkimuksessa tarkastellaan metsäojitetuilta turvemailta kerättyjen tilavuustarkkojen (348 cm^3) näytteiden perusteella turpeen kutistumista kuivattaessa. Pääaineiston muodostaa 434 näytettä, joista mitattiin tai arvioitiin seuraavat kutistumista mahdollisesti selittävät tunnukset:

- pääturvelaji: rahka (S)-, sara (C)- tai puu (L)-turve
- turpeen tiheys tuoreen ja kuivatun tilavuuden perusteella, g/cm^3
- maatuneisuus von Postin (1922) maatumisasteina
- näytteenottosyvyys, cm
- vesipitoisuus näytteenottohetkellä, prosentteina tilavuudesta ja tuorepainosta

Turpeen kutistuminen kuivatuskaapissa (105 °C) suoritetun kuivatuksen jälkeen määritettiin punnitsemalla, kuinka paljon hienoa, tiheydeltään tunnettua hiekkaa mahtuu kutistuneen näytteen vapauttamaan tilaan näytesylinterissä.

Suppeahkon näytemäärän (20 kpl) perusteella tehtiin lisäksi havaintoja turpeen kutistumisesta itse kuivatusvaiheen aikana.

Turpeen kutistumisessa voitiin todeta suurta vaihtelua. Osoittautui tarkoituksenmukaiseksi tarkastella kutistumista pääturvelajeittain. Johdonmukaisen riippuvuussuhteen vallitessa kutistumisen ja selittävän tekijän välillä ko. selittäjää käytettiin muuttujana muodostetuissa malleissa. Mahdollisiksi selittäviksi tekijöiksi hyväksyttävien muuttujien määrää pienensivät tekijöiden väliset korrelaatiot ja eräiden tekijöiden määrityksen subjektiivisuus.

Turpeen tiheys ja näytteenottosyvyys selittivät turpeen kutistumisen vaihteluista rahkaturpeissa 56 % ja saraturpeissa 32 %. Puuturpeissa näytteenottosyvyys ei lisännyt merkitsevästi selitysastetta ja pelkän tilavuuspainon selityskyky jäi 16 %:iin. Rahka- ja saraturpeissa näytteenottohetken vesipitoisuus prosentteina tuorepainosta ja näytteenottosyvyys olivat lähes yhtä hyviä kutistumisen selittäjiä kuin tilavuuspaino ja näytteenottosyvyys. Turpeen suhteellista kutistumista voidaan siten tietyllä tarkkuudella ennustaa myös ilman työlästä tilavuustarkkaa näytteenottoa.

Koska kahdella eri tavalla lasketuissa tiheyksissä turpeen massa pysyy muuttumattomana ja vain jakaja muuttuu, on selvää, että selitettäessä kuivatun turpeen tilavuuden perusteella laskettua tiheyttä tuoreen näytteen tilavuuden perusteella lasketulla tiheydellä ovat selitysasteet korkeita; rahkaturpeissa 86 %, saraturpeissa 77 % ja puuturpeissa 75 %. Jos turpeen kutistuminen olisi riippumaton turpeen maatuneisuudesta (tiheytenä mitattuna), olisi näin laskettujen tiheyksien välinen riippuvuus suoraviivainen. Koska kutistuminen kuitenkin yleensä lisääntyy maatumisen myötä, myös laskettu riippuvuus on käyräviivainen (kuvat 7–9).

Suppean lisäaineiston perusteella voitiin todeta, että kuivumiskutistumisessa on havaittavissa ainakin kaksi vaihetta: Aluksi näytteestä poistuu vettä, mutta näyte ei vielä kutistu. Tätä on kutsuttu rakenteelliseksi veden luovutusvaiheeksi. Tämän jälkeen poistuvan veden määrän ja kutistumisen välillä vallitsee suoraviivainen riippuvuus, jota on myös kutsuttu varsinaiseksi kuivumiskutistumisvaiheeksi (kuva 10). Aineiston perusteella ei voitu sitä vastoin erottaa jäännösveden luovutusvaihetta, joka joskus mainitaan kirjallisuudessa. Tälle olisi ominaista se, että vettä vielä poistuu, mutta näytteen tilavuus säilyy muuttumattomana.

Tutkimuksessa saadut tulokset auttavat ymmärtämään kirjallisuudessa esitettyjen kutistumista koskevien hajanaisten tietojen suurta vaihtelua. Turpeen kutistumisen ja siihen vaikuttavien tekijöiden tunteminen on erityisen tärkeää turpeen korjuun ja teknisen hyväksikäytön yhteydessä.