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AERATION STUDIES ON PEAT SOIL. 2. THE EFFECTS OF TILLAGE AND CLIMATE

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SUMMARY

A 2-year field experiment was carried out on a peat soil with surface covers of grass ley, a barley crop and open fallow, to determine changes in soil aeration, soil temperature and depth to the water-table, and to relate these parameters to the rate of peat subsidence. The season was colder and wetter in 1987 than in 1988 and this allowed a comparison of the parameters under different weather conditions. Soil temperature was significantly higher under fallow than under grass (cereal intermediate), the differences being greater in the drier season. Depth to the water-table was least under fallow and greatest under barley once the crop had established. Oxygen content was related both to soil water content and to soil temperature. A combination of high water content and high respiration rate gave very low O_2 and high CO_2 values. Subsidence under the treatments was least (0.3 cm/year) under grass ley, 1.2 cm/year under barley and 1.6 cm/year under open fallow. These differences were due to better aeration and drying after tillage and to higher microbial respiration rates in the warmer bare peat.

INTRODUCTION

Field drainage is necessary to improve the bearing capacity of peat at the extremes of the growing season and to create a zone of aeration for crop roots. However, aeration of the peat also increases microbial degradation of the organic matter, especially at soil temperatures above 5^{o}C (Stephens & Stewart, 1977). This leads to surface subsidence and the gradual disappearance of the peat material. It has been observed in the field that subsidence rates are related to land use (McAfee, 1985), with higher rates occurring under cereal and open fallow than under grass ley.

This experiment is one of two carried out to determine if these differences in subsidence rate are due to tillage and mechanical breakdown of the peat or to aeration factors and differences in peat decomposition rate.

In a previous experiment (McAfee, 1989), aeration of a peat soil under three surface covers (grass, barley, fallow) was studied in undisturbed soil monoliths under controlled conditions. In general, drying, and thus aeration of the peat, was better under barley and fallow than under grass. Because the peat had not been ploughed, this difference was due to higher evaporation from the bare peat surface and higher water use by the cereal crop.

In the present experiment, field measurements of aeration were made on an undisturbed grass ley and on peat under barley and fallow, which had been tilled to a depth of 20cm in the spring. In addition to aeration measurements in the peat, factors such as rainfall, potential evapotranspiration and soil temperature were also measured intensively throughout the season. The peat subsidence rates under the different surface covers were also measured during the experimental period. The aim was to determine the effects of soil aeration, as influenced by land use and meteorological factors, on peat oxidation and surface subsidence.

MATERIALS AND METHODS

SITE AND TREATMENTS

The site and peat profile are as described by McAfee (1989). The field experiment was carried out over 2 years. In the autumn prior to the experiment (1986), 5 adjacent plots (all $100m^2$) were laid out parallel to, and 10m from, the main drainage canal. The surface elevation of these plots was measured at close intervals (20 points per plot). The 3 plots in the centre of the block were ploughed to 20cm depth in the following spring (1987) and the following treatments allocated: Plots 1 & 5 = undisturbed grass ley, 2 & 4 = barley, 3 = open fallow.

The fallow plot was weeded at intervals by hand or by shallow rotovating. In the second year of the experiment, treatments on plots were as in 1987 with the exception of plots 3 & 4, where the barley and fallow were crossed over so that only one year of fallow was allowed on any plot. The barley was sprayed with MCPA on two occasions per season to control fungal diseases. In 1987, which was a wet season, the barley crop failed in early August due to disease and storm damage. In 1988, the barley was harvested on 24 August. The grass ley was mowed once or twice per season and the grass removed. At the end of the experiment, the surface elevations were determined again at the same points on all plots and a mean value for subsidence calculated for each treatment.

EXPERIMENTAL METHODS

Oxygen content of soil air was measured weekly on all plots using a Beckman Monitor II membrane electrode. For each measurement, a hole was made to 50cm depth using a 2.5cm diameter corer. The electrode, which was calibrated to 20.9% for atmospheric air, was immediately lowered into the hole and O_2 content measured at 10cm intervals. The peat material extracted in replicate core holes (4 per plot) was pooled for each 10cm interval and retained for determination of gravimetric water content (drying under vacuum at 80^oC). Volumetric water content was measured weekly at 10cm intervals from 20cm depth using a neutron probe.

CO_2 content of soil air was measured weekly on gas samples extracted by syringe from fixed sampling probes in the plots. These were transported to the laboratory in Hamilton Gastight syringes and analysed by GC (HP 5880A). The depth to water-table was measured weekly at a fixed point on each plot. The tempertature of the soil was measured daily at 5, 10 and 30cm depth at fixed points on all plots by mercury bulb soil thermometers. Rainfall at the site was measured daily in a Pluvius raingauge set at 1.8m above the ground. Potential evapotranspiration was measured daily in a Andersson evaporimeter (Andersson, 1969). Dry bulk density of the tilled plots was measured at the end of the growing season on undisturbed soil cores extracted in 10cm layers using stainless steel cylinders (20 replicates per plot). In all cases, results for replicate plots were pooled, while results for years are reported separately.

RESULTS

The results of temperature measurements showed that there were distinct differences between those recorded at the soil surface (10cm) and at 30cm depth (Figs. 1 & 2). The temperature at the surface was always higher on bare soil than under grass. The soil under barley was initially similar in temperature to the fallow soil but after mid-season it was similar to the grassed plots. 1988 was a warmer, drier year than 1987 and the soil surface reached a higher peak temperature on all treatments, especially the fallow where a maximum of 28^oC was recorded (Fig.1). The temperature at 30cm depth (Fig. 2) fluctuated less than that at the surface but the 3 treatments followed the same trends. Again, the peak temperature was highest in 1988 and in the fallow soil.

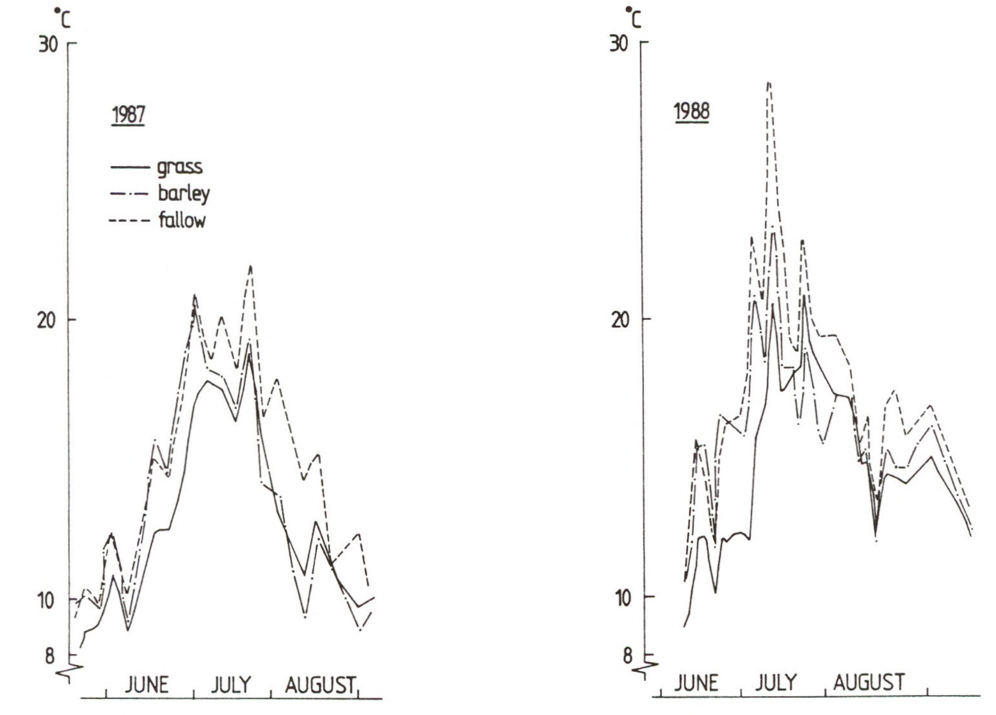

Figure 1. Soil temperature at 10cm depth in the three treatments in 1987 and 1988.

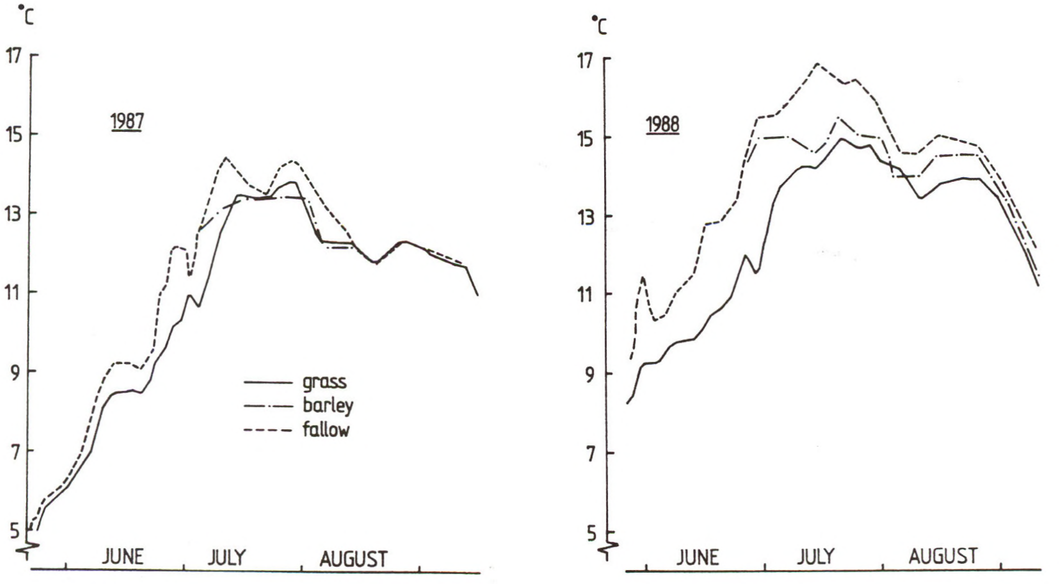

Figure 2. Soil temperature at 30cm depth in the three treatments in 1987 and 1988.

The depth to the water-table was generally determined by the balance between rainfall and evapotranspiration. The differences between seasons are indicated in Table 1 as the soil water deficit (20 May = 0) calculated from rainfall and potential evapotranspiration data at the site. 1987 was driest in mid-July with a soil water deficit of 110 mm and there was a rainfall surplus (> 1 mm/day) thereafter. In 1988, the soil water deficit was greatest (146mm) at the end of July and decreased only slightly after this.

Table 1. Rainfall, potential evapotranspiration and maximum soil water balance (Rain - PE, 20 May = 0) in 1987 and 1988. All in mm.

Time period	1987 Rain	1987 PE	1987 Balance	1988 Rain	1988 PE	1988 Balance
21-31 May	0	47	-47	9	47	-38
1-10 June	18	4	-33	35	27	-30
11-20 June	21	25	-37	10	41	-61
21-30 June	9	31	-59	0	39	-100
1-10 July	25	37	-71	15	43	-128
11-20 July	0	39	-110	31	37	-134
21-31 July	27	21	-104	23	35	-146
1-10 Aug	16	8	-96	42	31	-135
11-20 Aug	40	21	-77	27	25	-133
21-31 Aug	25	12	-64	24	24	-133

In the first half of the season, when there was a rainfall deficit, the water-table was highest (Fig. 3) where there was no crop or where the barley roots had not fully developed. As the barley developed (1988), the water-table in these plots fell continually throughout the growing season and was 10 - 20 cm lower than under the other treatments. The water-table in the fallow plot rose very quickly in response to rain in both years (Fig. 3), while under grass it responded somewhat to rainfall but this effect was modified by the requirements of the growing crop.

Water content of the soil varied with the season and with the land use. There was a difference between the upper 20 cm of the profile and the layers below. The surface layer tended to dry out more when the soil was bare (Table 2) although there were inconsistent fluctuations due to weather conditions immediately prior to sampling. There was a reversal of trends below 20cm depth (Table 3), with no drying occurring in the fallow

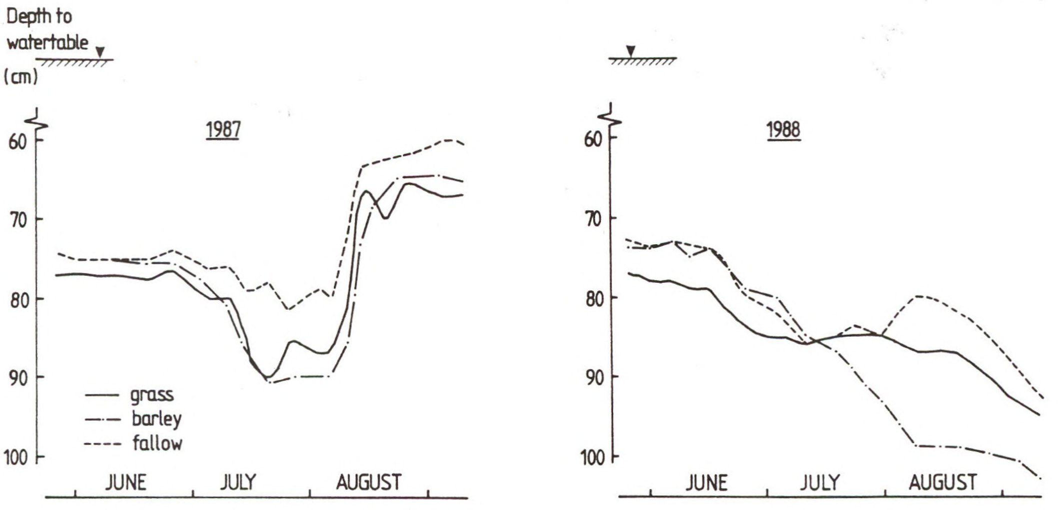

Figure 3. Depth to the water-table (cm) in the three treatments in 1987 and 1988.

soil regardless of the weather conditions. In both years, the surface layer dried to a minimum in early July and rewetted in the latter half of the season (Table 2). However, the surface layer of the fallow plot was slower to wet and, in the field, surface runoff and deep percolation via vertical cracks were observed. This was confirmed by water-table data (Fig. 3).

Table 2. Water content (% V/V) of the 0 - 10cm layer under grass, barley and fallow in 1987 and 1988.

Date	Grass		Barley		Fallow	
	1987	1988	1987	1988	1987	1988
16 June	50	61	47	54	49	54
30 June	52	30	51	29	52	37
13 July	44	35	37	33	28	34
28 July	59	50	48	48	48	43
14 August	72	53	68	49	63	50
26 August	65	50	69	51	67	47

In the fallow soil, there were no differences between years in the water content of the 20-30cm soil layer (Table 3) despite differences in depth to the water-table (Fig. 3). On the other treatments, the differences between years were due mainly to water use by the crop.

Table 3. Water content (% V/V) of the 20-30cm soil layer under grass, barley and fallow in 1987 and 1988.

Date	Grass		Barley		Fallow	
	1987	1988	1987	1988	1987	1988
16 June	62	50	60	64	63	65
30 June	63	44	61	52	64	64
13 July	63	41	59	45	64	63
28 July	51	44	48	47	63	66
14 August	63	47	62	54	66	65
26 August	66	49	63	58	66	66

Oxygen content of soil air (Figs. 4 & 5) decreased with depth within the soil profile on all occasions and under all treatments. Fluctuations in O_2 content were smaller and more frequent in the surface layer (Fig. 4) than in the 20-30cm layer (Fig. 5). Differences due to land use and weather were more distinct in the 20-30cm layer. In 1987, O_2 content was initially lowest under grass, where it increased to a peak at the end of July and decreased to very low values (<10%) in the subsequent period of rainfall surplus (Table 1). The tilled treatments were initially similar but when the fallow plot was weeded, its O_2 content increased (due to removal of

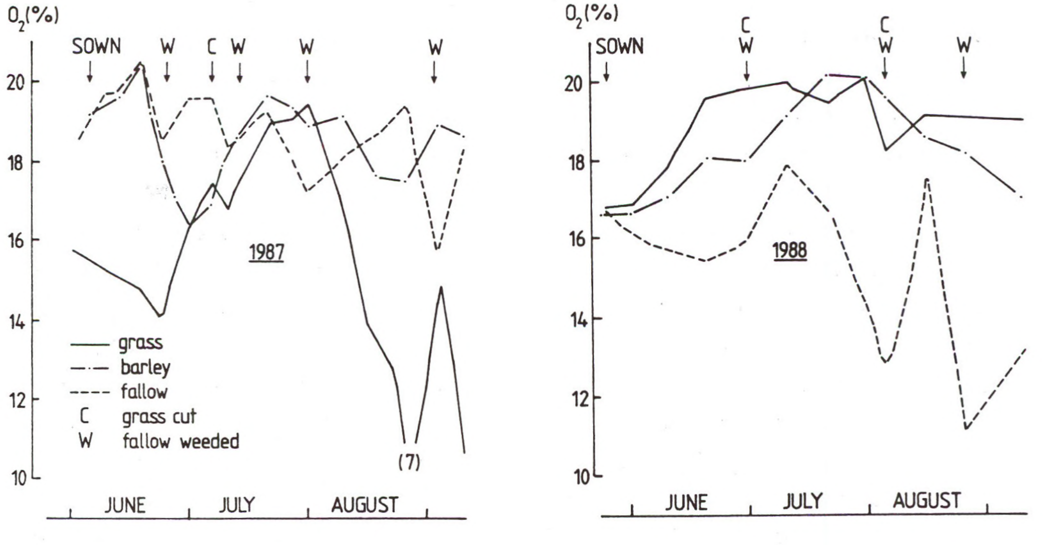

Figure 4. Oxygen content of soil air in the 0 - 10cm layer of the three treatments in 1987 and 1988.

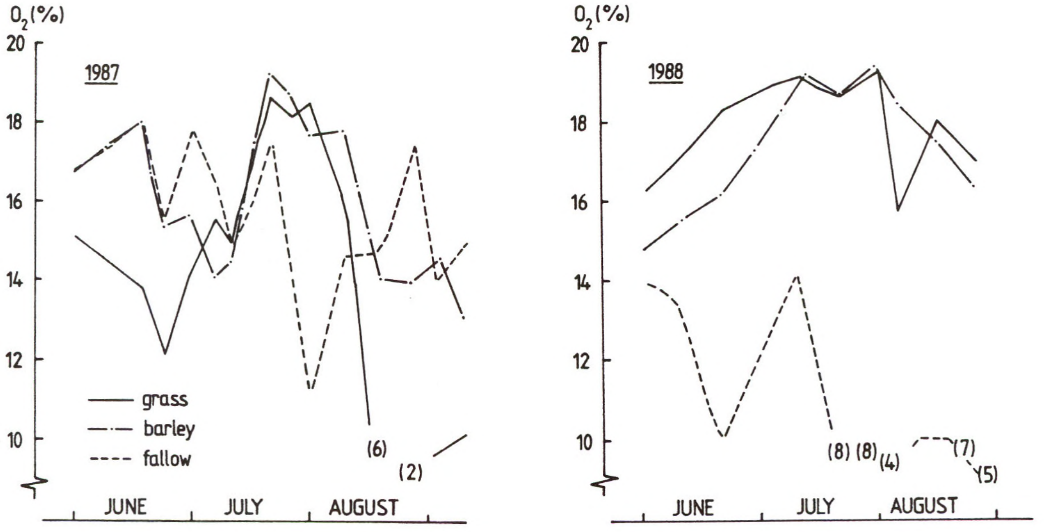

Figure 5. Oxygen content of soil air in the 20 - 30cm layer of the three treatments in 1987 and 1988.

respiring roots). When the barley crop died in late season, the oxygen content of the tilled plots lay around 17-18% at the surface and 14-15% at 20-30cm depth at the end of the season. In 1988, the cropped soil was drier (Table 2) and the actively growing grass and barley had similar O_2 contents which were relatively high in both the surface (Fig. 4) and the 20-30cm (Fig. 5) layers (17-19%), while values at both depths in the fallow soil decreased except for short periods after weeding.

Each oxygen content recorded (on all occasion, in all soil layers, all treatments and both years) was plotted against the air content of the soil at the time of measuring (Fig. 6). The air content was calculated from the water content (% V/V) and an average value of total porosity of 80% V/V for the undisturbed grass ley topsoil and 85% V/V for the subsoil and the tilled topsoil (McAfee, 1989). Except for the fallow plot in 1988, all points could be fitted to a single exponential function. The results for the fallow plot followed an analogous curve, but with lower O_2 values at a given air content (Fig. 6). A critical air content of 0.08-0.1 m^3/m^3 was indicated as the lower limit for soil aeration, while the soil can be considered to be suffering from water stress as respiration tails off at high air contents (>0.3 m^3/m^3).

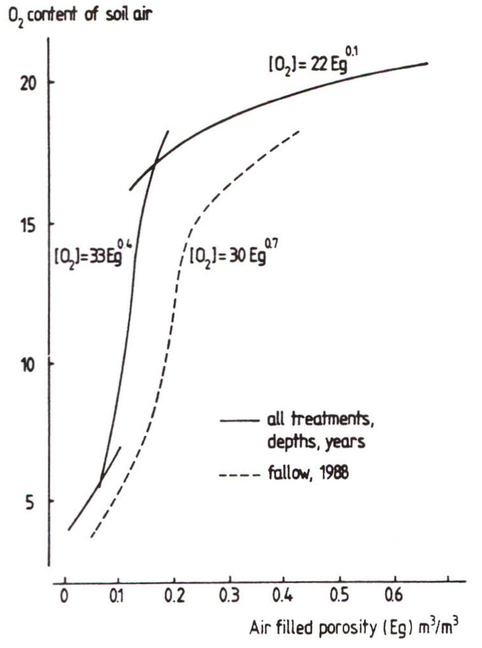

Figure 6. Oxygen content of soil air as a function of air-filled porosity (———) and the effect of increased soil temperature (------).

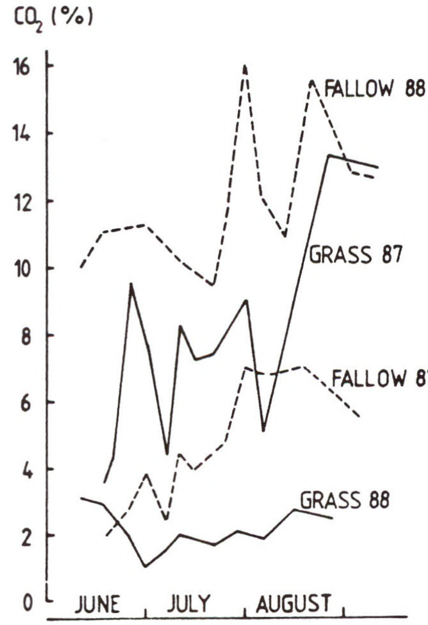

Figure 7. Carbon dioxide content of soil air at 30cm in grassed and fallow soil in 1987 and 1988.

The CO_2 concentration of soil air (Fig. 7) in soil where there are no respiring roots is a direct indication of microbial respiration and peat oxidation. The highest CO_2 values were recorded in the fallow soil in 1988 (10-16%) and under grass in 1987 (4-13%). The fallow soil had a lower range (2-7%) in 1987 and the lowest values were recorded in the driest soil at this depth (Table 3), namely that under grass in 1988.

The actual surface subsidence which occurred during the experimental period (Table 4) differed according to the surface cover. Subsidence was least under grass and greatest where one year of fallow had been included.

Table 4. Surface subsidence of soil under the different treatments.

Years of treatment	Subsidence cm/year	n	SE	Sig. of differences Grass	Barley
2 grass	0.32	40	0.3	-	**
2 barley	1.20	20	0.9	**	-
1 barley/1 fallow	1.66	35	0.5	***	*

significant difference * $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$

Tillage affected the porosity of the soil by decreasing the dry bulk density (Table 5). This was due to mechanical loosening and the effect remained throughout the season. Dry bulk density immediately after ploughing was much lower and more variable (results not shown) but it rapidly increased as the peat settled. This change means that total porosity of the ploughed soil also varied during the season and that there is an error in the volumetric water content of the ploughed topsoil early in the season.

Table 5. Dry bulk density (Mg/m^3) in the treatments at the end of the growing season.

Soil layer	n	Grass	Barley	Fallow
0-10	20	0.31^a	0.26^b	0.25^b
10-20	20	0.32^a	0.30^b	0.27^c
20-30	8	0.28^a	0.25^b	0.26^b
30-40	8	0.23^a	0.24^a	0.23^a

values within rows with a common superscript do not differ ($P < 0.05$)

DISCUSSION

Soil temperature was found to be significantly affected in the field by the surface cover, with the highest temperatures consistently occurring on the bare soil. No such differences were recorded in a lysimeter experiment on this peat (McAfee, 1989). The higher temperature in the field is probably due to a combination of the darker soil surface and the lower water content of the surface layers in the fallow soil (Table 2). A wet soil has a greater amount of water to be warmed and would be expected to be cooler than a drier soil under constant conditions. A dark soil surface absorbs more energy than a light coloured one and warms up more quickly at a particular water content. Under field conditions, soil water content more than any other factor determines the temperature of the soil (Brady, 1974).

The surface layer of the fallow plot was raised and aerated (lower dry bulk density) by tillage. This dry layer then acted as a shield, preventing evaporation from the lower layers. This effect has also been observed in the seedbed of mineral soils (Currie, 1984). Thus the fallow soil was drier than the cropped soil at the surface (Table 2) but wetter at 30cm depth (Table 3). It is also evident that evapotranspirative losses are the most important factor determining water content of the soil. The water contents of the lower topsoil and subsoil were surprisingly little affected by drying from above or by depth to the water-table.

The water-table on all plots was low (60cm) on all occasions and in all treatments in this experiment. However, the barley crop failed in the wet latter half of the 1987 season. This was not due to high water-tables but to poor infiltration and humid conditions within the crop stand. A characteristic of fen peats is that they lie in topographical depressions where wind drying is reduced. The variation in depth to the water-table between treatments means that there are differences in matric potential in the soil, and differences in aeration parameters between treatments are partly a result of these. This effect is also observed when grassed and afforested soils are compared (King *et al.*, 1986).

The 5-10^{o}C higher temperature on bare compared to cropped soil resulted in increased microbial respiration, while the higher water contents at depth reduced gas transport. The combined result was very low O_2 and high CO_2 contents, especially at 30cm depth in the fallow soil in 1988. The O_2 content of soil air was correlated to the air-filled porosity (or conversely to the water content) and to soil temperature (Fig. 6). The relationship between O_2 content and air-filled porosity was similar to that obtained for gaseous diffusion and air-filled porosity in this soil (McAfee, 1989). A critical air content of 8-10% V/V was indicated (Fig. 6) but air contents of ploughed topsoil are inaccurate when meassured in the early part of the season because of changes in dry bulk density.

The effects of increased temperature were to lower O_2 content at a particular air content. However, this effect was overridden by the effects of drying, which increased O_2 content, especially over a range of air-filled porosity from 0.07 to 0.15 m^3/m^3. It is likely that respiration rates were reduced at higher air contents due to lack of water necessary for microbial activity (Kowalenko *et al.*, 1978).

CO_2 production from the bare soil in the second year of this experiment exceeded that from cropped soil. Other work on peat soils (Belkovskiy & Reshetnik, 1981) has shown that higher CO_2 evolution occurs from cropped soil, due to combined root and microbial respiration. This was also shown in a lysimeter experiment on this peat (McAfee, 1989) where the bare soil was not previously tilled and drying was restricted to a shallow layer at the surface. The contradictory results obtained for 1988 may be due to water stress in the cropped soil. The range of O_2 and CO_2 values obtained are in agreement with findings by Belkovskiy & Reshetnik (1981) and King *et al.* (1986) on peat soils.

There was a tendency for mowing of the grass ley to lower O_2 contents by increasing respiration rates, as was observed by Hendrix *et al.* (1988). However, this effect was overridden by the opposite and stronger effect of drying in the surface layers (1988). Weeding increased O_2 contents of soil air by reducing respiration rates and by aiding surface drying.

The effect of tillage was to aerate the soil by decreasing dry bulk density and creating an uneven surface which dried more easily (Currie, 1984). Tillage also increased subsidence rates by increasing peat oxidation and perhaps by mechanical breakdown of the peat material.

In general, aeration status of the soil was determined by a combination of factors affecting soil water content and soil respiration rate. Soil water content was affected by evapotranspiration demands of the crop and by rainfall pattern, while respiration rate was affected by soil temperature. Thus a combination of fallow and barley gave significantly greater subsidence rates than barley alone, even in this short field experiment. Subsidence rates under grass are lower partly because less O_2 is available and partly because the grass tends to form a surface mat with accumulation of organic matter at the soil surface. Rate of decomposition of organic matter may vary with species of pasture grass comprising the sward or time of the season since fibrous or older grasses are likely to be more resistant to microbial decomposition (Hopkins *et al.*, 1988).

ACKNOWLEDGEMENTS

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HYDROPHYSICAL PROPERTIES OF PEAT RELICTS IN A FORMER BOG AND PERSPECTIVES FOR SPHAGNUM REGROWTH

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SUMMARY

In this study, the hydrophysical characteristics of peat layers in a partly cut-away peatland nature reserve are presented. The main objective is to discuss these properties in relation to growing conditions for *Sphagnum* moss species. Information about evapotranspiration and water-storage coefficients is provided by lysimeter experiments. Water-retention characteristics, hydraulic conductivity and capillarity are analysed.

In living bogs, water level fluctuations are very limited (less than 30-40 cm). In partly mined bogs, the mostly older, more humified upper peat layers differ strongly from those in undisturbed bogs. When after rewetting partly cut-away bogs (regeneration, rehabilitation), *Sphagnum* regrowth occurs, the young *Sphagnum* layer will be less than 30 cm after some decades. During this first phase of regeneration the young *Sphagnum* plants are vulnerable to drought because the moss layer is still not thick enough to establish sufficient 'self-regulating buffer' mechanisms to prevent a further lowering of the water-table. These mechanisms are closely related to hydrophysical properties of the upper peat layers.

INTRODUCTION

In the Netherlands, water management measures are taken to promote the regrowth of *Sphagnum* species in many of the remaining partly cut-away peatlands (Schouwenaars, 1988). For a better understanding of the hydrology of these peatlands, a field survey was carried out in the Engbertsdijksvenen. The study area is situated in the eastern part of the Netherlands, near the border with the F.R.G. ($52^{o}28'$N, $6^{o}40'$E).

This study deals with the hydrophysical characteristics of the upper peat layers. Romanov (1968) and Ivanov (1981) have described their importance for the hydrology of undisturbed bogs. Also Ingram and Bragg (1984) argue that the hydrophysical properties of the upper living layer of

Sphagnum mosses ('acrotelm') are responsible for its high water-storage capacity and high rate of horizontal water flow.

In this way, the upper layer plays an essential role in the regulation of water losses and water-level fluctuations. In living bogs, water-level fluctuations are very limited (less than 30-40cm). The deeper, more humified (i.e. decomposed) peat layers ('catotelm', see Ingram and Bragg, 1984) differ strongly from the upper layer.

Previous studies have shown extremely large differences in structure, bulk density and porosity between peat types. The high spatial variability (both horizontal and vertical) of peat properties in bog areas makes a correct assessment of representative values for properties like conductivity and bulk density extremely difficult. Boelter (1965, 1969) presented values for hydraulic conductivity and for water-storage characteristics of undecomposed *Sphagnum* moss peat, which clearly demonstrate the rapid change of these values over the upper 45cm of a living bog. Values for the more decomposed deeper peat layers are much lower than those for undecomposed peat and show great variability. Baden and Eggelsmann (1963), in an extensive overview with numerous data, clearly illustrate the problems related to methods of measurement. They show that, in peaty soils, the subfossil plant remains determine the hydraulic conductivity, which decreases with increasing degree of humification (i.e. decomposition). Saturated hydraulic conductivity of different types of peat is shown to be dependent on bulk density. Renger *et al.*(1976) found that unsaturated hydraulic conductivity and capillary rise also decrease with increasing bulk density. A very important and complicating factor in areas which have been drained is that the degree and duration of this drainage influence subsidence and soil consolidation resulting in different bulk densities for the same type of peat.

Kuntze (1966) shows that capillary rise in *Sphagnum* moss peat soils is related to their degree of humification. However, for both younger (H <5: von Post scale) and older (H >5) peat, indicator values for capillarity are widely spread and often within the same range of magnitude. For the older peat, capillary rise, on average, seems somewhat better.

The publications mentioned above, which are only a fraction of the studies on the hydrophysics of peat soils, illustrate that simplified approaches in the determination of hydrophysical characteristics in peat soils are hardly possible. The method presented by Bloemen (1983) underestimates the complexity of these soils. For model applications in a given peatland, field research is needed to obtain reliable parameter estimations.

In the Engbertsdijksvenen area, hardly any information was available on the hydrophysical properties of the peat soils. Peat mining activities over a number of decades have resulted in large differences in the properties of the upper peat layers.

In the Weichsel glacial, near the end of the Pleistocene era, eolian sands were deposited. In the Holocene, peat growth started on these sands, becoming general during the Atlanticum (8000-5000 B.P.). In this period, several metres of oligotrophic peat were formed, which are now strongly humified ('black' peat or Schwartztorf).

In the sub-Atlanticum (from ca. 3000 B.P.) 'young' *Sphagnum* moss peat accumulated under relatively cold and wet conditions. In some parts of the study area these layers, which are slightly to moderately humified (H3-4), are still present ('white' peat, Weisstorf). Their thickness varies from 0.5 to 1.5 metres. In most parts of the area, however, they have been removed completely by the peat mining industry. As a consequence, strongly humified peat lies at the surface.

The different peat mining concessions in the Engbertsdijksvenen expired between 1953 and 1983, and thereafter the State Forestry Service began to manage these areas, the aim being to re-establish the original ombrotrophic bog vegetation.

After excavation, vegetation development on the remaining bare peat soils has led to a dense cover of *Molinia caerulea*. Under drier conditions, *Betula pubescens* (birch) has invaded these sites. In most parts of the study area, water levels were raised by water management measures (i.e. construction of small dams in former drains). Here, birch is less able to colonise, and ericaceous plants like *Calluna vulgaris* and *Erica tetralix* are present. Some species, like *Andromeda polifolia* and many *Sphagnum* species seem to grow exclusively on the less humified peat layers. This has also been observed in many other areas (Podschlod, 1988).

In this study, the hydrophysical differences between representative peat layers are presented. The main objective is to discuss these properties and relate them to growing conditions for different plant species. Attention will be given to perspectives for *Sphagnum* regrowth.

METHODS

LYSIMETERS

Undisturbed soil columns were taken with a sampling device, having a diameter of 40cm and a length of 50cm (see Fig. 1). These columns were inserted in a lysimeter of the same size, closed at the bottom. Figure 2 illustrates schematically the sites at which the different samples were taken. Four columns were covered with *Molinia caerulea* (M1-4), four with *Calluna vulgaris* (C1-4) and eight with *Sphagnum papillosum* (S1-8). The

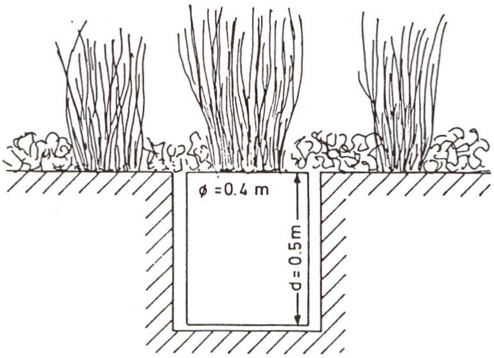

Figure 1. Dimensions of the lysimeters

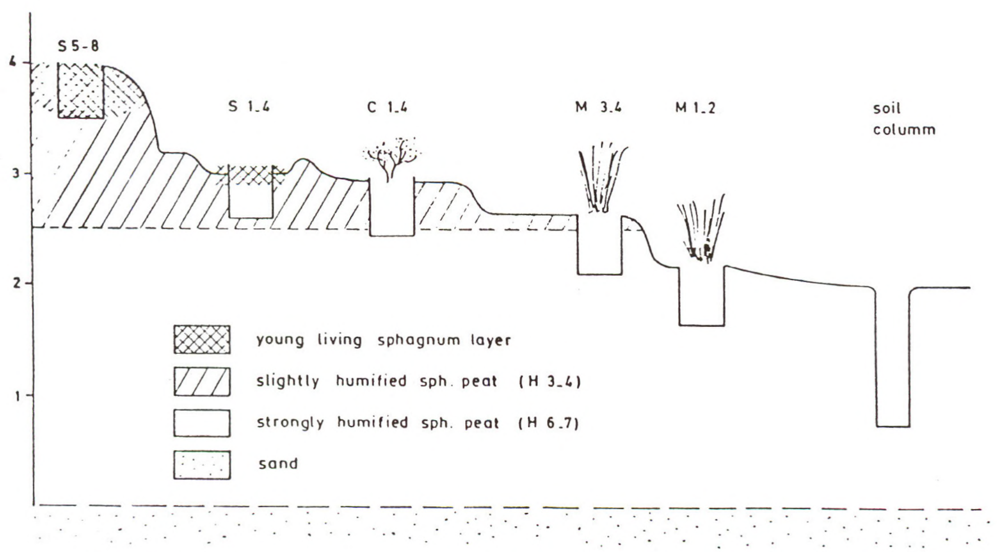

Figure 2. Schematic overview of sample locations in the study area.

selected sites represent the most important differences in peat properties within the study area. The lysimeters were installed in a 50cm-deep hole with a diameter of ca. 50cm to enable weighing. The space between the lysimeter and the wall of the hole was covered with litter to prevent evaporation. The lysimeters were taken out using a tripod and replaced after measurement. A spring-loaded scale was used for weighing. Its accuracy is about 0.05kg which corresponds to a water layer of 0.4mm depth.

In the period 11 May - 26 September 1988, the lysimeters were weighed at intervals varying from 3 to 9 days, depending on the weather conditions. In the period 5 May - 29 September 1989, this was repeated and lysimeters S5-S8 were added. These lysimeters contained columns from a superficially drained site where in the past no peat had been cut away. In addition, a soil column of 80cm length and 24cm in diameter was taken from a soil layer 40-120cm below the surface (Fig. 2).
Schouwenaars (1990) has reported on the evapotranspiration studies carried out with these weighable lysimeters.

WATER STORAGE COEFFICIENTS

Besides information about evapotranspiration, the lysimeter experiments provide accurate field data on water storage coefficients in the different layers. Total weight of the lysimeter and depth to water-table are measured simultaneously and this enables an analysis of the relation between soil water storage (in both the saturated and unsaturated zones) and water-table depth. Differences in weight result from changes in total water storage (ΔV). The latter can be expressed in mm water-layer, taking into account the surface area of the lysimeter ($0.125 m^2$).

In this study, the ratio between ΔV and the corresponding change in water-table depth (ΔW) was examined. This ratio is defined as the water storage coefficient.

SATURATED VERTICAL HYDRAULIC CONDUCTIVITY

From the same sites as those selected for the lysimeter experiments, $100 cm^3$ undisturbed samples were taken vertically at depths of 15 and 35cm and used for the determination of the saturated hydraulic conductivity.

WATER RETENTION CURVES

The same samples were used to determine soil water content as a function of pressure head. After complete saturation, water outflow through ceramic plates was measured under increasing air pressure at the top of the samples. This was done for pressures of 1, 3, 6.1, 10, 30 and 100kPa. Then the samples were dried at $105^{o}C$ for 48 hours.

CAPILLARY FLUXES AND WATER SUCTION

To study capillary fluxes under dry conditions, 2 lysimeters (M4 with *Molinia* vegetation and S4 covered with *Sphagnum papillosum*) and the soil column were installed in a glasshouse. Two tensiometer cups were inserted in the lysimeters at 15 and 35cm depth, respectively. In the soil column, tensiometers were inserted at 20, 35 and 50cm depth and the water-table was maintained at a constant level of 70cm below the bare surface. Initially, lysimeter S4 was completely filled with water, and during the following measurement period no water was added. When lysimeter M4 was taken out of the field, it was completely unsaturated and in the glasshouse no water was added. Water losses from the lysimeters and the soil column were determined by weighing. For S4 this was done at intervals of 2 days during the first month and during the second and third months at intervals of 5-10 days. The measurement interval for the soil column experiment, which lasted about 2 months, also varied from 5-10 days. At the same time, water-levels were determined and water suctions in the different layers were measured using a tensiometer with an electronic pressure transducer.

With the information obtained from the water-retention curves, it was possible to determine changes in soil water content of the unsaturated zone. In combination with total water losses and changes in phreatic level, an analysis of capillary fluxes was made. In this way, unsaturated hydraulic conductivity at different water suction values could be determined and k-h-Θ relations could be deduced. Based on a pseudo-stationary approach presented by de Laat (1980) for 2 representative soil types [slightly humified H3-peat (lysimeter S4) and strongly humified H6-peat (soil column)], an analysis was made of capillary rise as a function of ground-water level and suction head at the bottom of a root zone.

RESULTS

WATER RETENTION CURVES

Under field conditions in these peat soils, the most relevant range of water suction values is from 0 to 100kPa (pF = 0 to pF = 3.0). Results for strongly humified *Sphagnum* peat (H6), representing lysimeters M1-4, are shown in Figure 3A and those for slightly humified *Sphagnum* peat (H3) in Figure 3B (lysimeters C1-4).

In lysimeters S1-4, the upper 5cm is formed by a green living *Sphagnum* layer, followed by ca. a 10cm-thick layer of dead *Sphagnum* remains (H1-2). The samples taken at 15cm depth represent the transition zone between this upper 'acrotelm' and the underlying slightly-humified *Sphagnum* peat layers (H3), which were at the surface before *Sphagnum* regrowth occurred (about 10

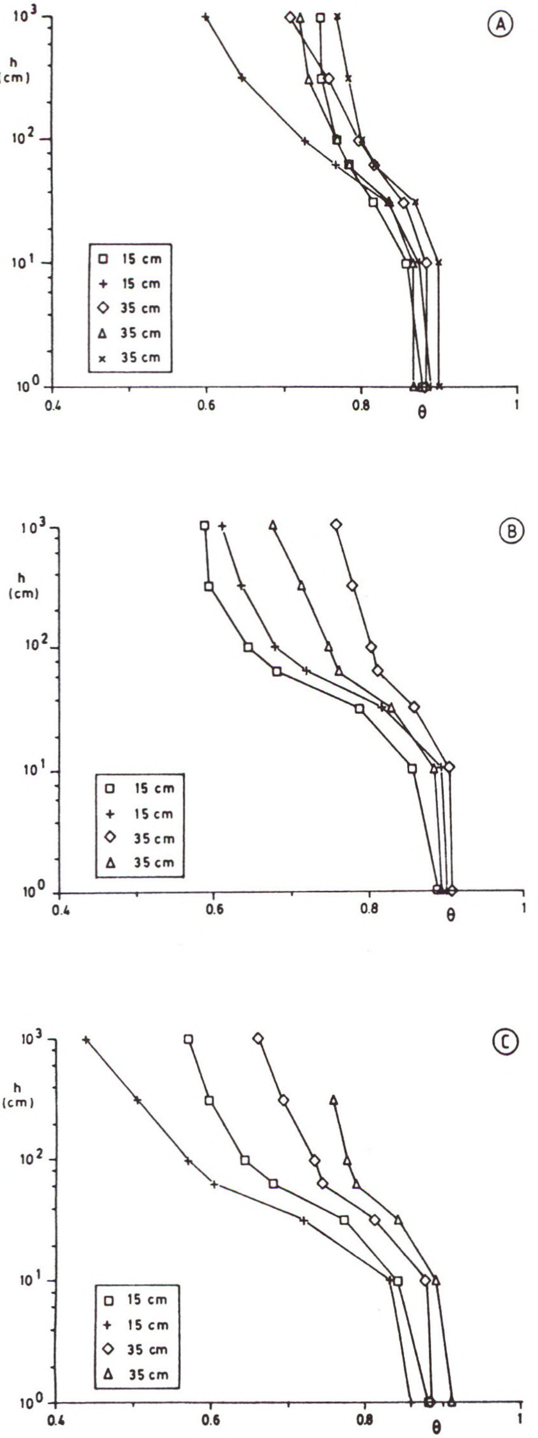

Figure 3. Water retention curves. (A : lysimeters M1-4; B : lysimeters C1-4; C : lysimeters S1-4).

to 15 years ago). The samples taken at 35cm depth represent *Sphagnum* peat layers with a humification degree of 3. Results for the S1-4 lysimeters are presented in Figure 3C.

Figures 3A, 3B and 3C show remarkable differences in available soil water in the range from 0 to 100kPa. Storage coefficients are highest in living *Sphagnum* layers and decrease with increasing degree of humification.

STORAGE COEFFICIENTS

The storage coefficients were determined by relating the decrease in water storage in the lysimeters with the lowering of the water-table. This was done by linear regression, for which good correlations were obtained. Results for lysimeter S2 are shown in Figure 4. Those for S4 under field conditions are shown in Fig. 5. Results for the S4 glass-house experiment are shown in Figure 6. Results for all lysimeters are listed in Table 1.

Table 1. Water storage coefficients determined from lysimeter experiments.

Lysimeter	Depth (cm) below surface	Storage coefficient 1)	Number of observations	Correlation coefficient(r^2)
M1	10-35	0.27	19	0.93
M2	0-30	0.18	16	0.96
M3	0-10	0.33	7	0.98
M4	5-13	0.14	6	0.92
C1	4-32	0.12	18	0.96
C2	0-35	0.11	19	0.96
C3	20-38	0.12	12	0.86
C4	0-23	0.13	10	0.95
S1	0-10	0.29	14	0.89
	10-25	0.17	5	0.99
S2	0-10	0.28	14	0.92
	10-25	0.17	7	0.94
S3	0-10	0.28	11	0.74
	10-30	0.17	11	0.96
S4	0-10	0.20	8	0.83
	10-30	0.11	8	0.96
S5	0-15	0.27	10	0.91
S6	5-20	0.23	8	0.92
S7	5-15	0.23	11	0.80
S8	0-15	0.34	12	0.94

1) regression coefficient obtained from linear regression between change in water storage [ΔV (cm^3 cm^{-2})] and change in water depth [ΔW (cm)] (for illustration also see Fig. 4)

For lysimeters S1-S4 and C1-4 results show good agreement with the water-retention characteristics, in contrast to those of M1-4. The causes of this difference will be discussed later.

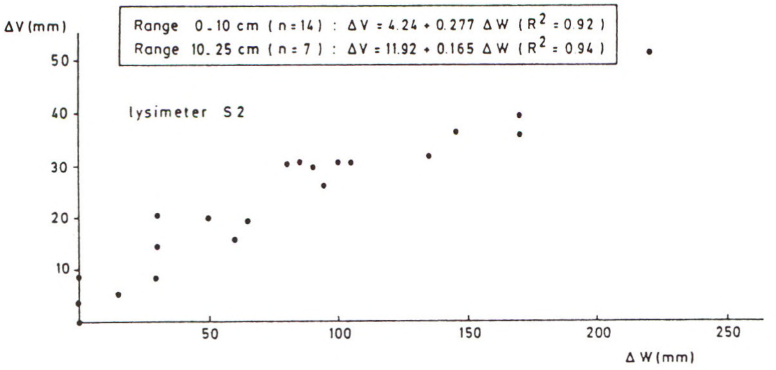

Fig. 4. Relation between decrease in water storage (ΔV) and water-table depth (ΔW) for lysimeter S2. The highest observed value for water storage is taken as a reference (ΔV & ΔW equal zero) and other observations related to it.

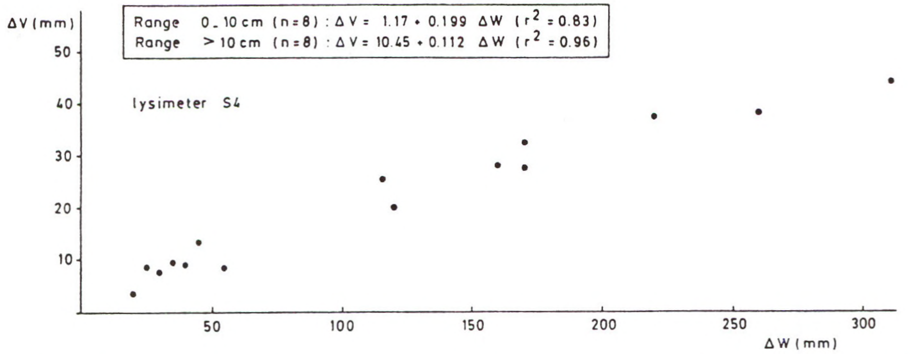

Fig. 5. Relation between decrease in water storage (ΔV) and water-table depth (ΔW) for lysimeter S4 under field conditions. The highest observed value for water storage is taken as reference (ΔV & ΔW equal zero) and other observations related to it.

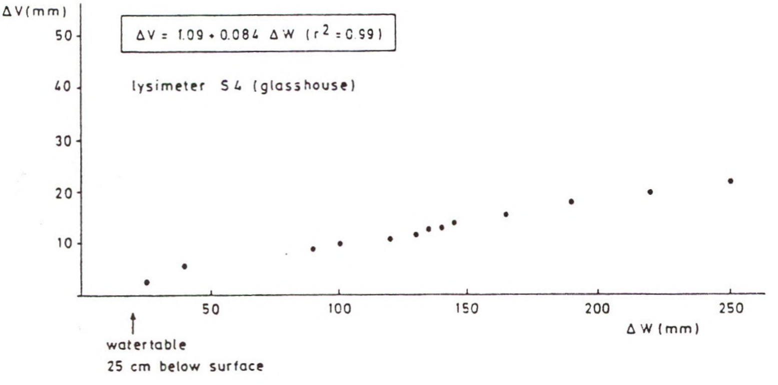

Fig. 6. Relation between decrease in water storage (ΔV) and water-table depth (ΔW) for lysimeter S4 under glasshouse conditions. Highest observed value for water storage is taken as reference (ΔV & ΔW equal zero) and other observations related to it.

SATURATED HYDRAULIC CONDUCTIVITY

Values for the vertical saturated hydraulic conductivity are presented in Table 2. High values are found for the *Sphagnum* lysimeters (S1-5), even at 35cm depth. In other columns, values are generally lower, due to more compact structure or higher degree of humification. The large contrast between topsoil(15cm) and subsoil(35cm), however, cannot be fully explained by these factors, as will be discussed later.

Table 2. Saturated hydraulic conductivity of soil column (Col) and lysimeter (C, M & S) samples.

Column/ lysimeter	Depth (cm)	k (cm day^{-1})	Column/ lysimeter	Depth (cm)	k (cm day^{-1})
Col 1	15	1.15	M1	15	3.70
Col 2	15	0.44	M2	15	0.75
Col 3	35	0.04	M3	35	0.37
Col 4	35	0.01	M4	35	9.34
Col 5	35	0.06	M5	35	0.01
C1	15	5.69	S1	15	2.59
C2	15	3.26	S2	15	7.19
C3	35	0.29	S3	35	11.52
C4	35	0.68	S4	35	6.71
			S5	35	2.14

UNSATURATED HYDRAULIC CONDUCTIVITY AND CAPILLARY FLUXES

During glasshouse experiments, capillary rise was determined and suction heads at different depths were measured. In Figure 7, the k-h relation obtained for lysimeter S4 is assumed to be representative for H3 peat, and that obtained for the soil column of the H6 peat. Table 3 shows

Table 3. Unsaturated hydraulic conductivity (k) for different suction heads (h) and corresponding soil water contents (Θ) for H6 peat (from soil column experiment) and H3 peat (from S4 lysimeter experiment).

	H6 peat			H3 peat	
h (cm)	k (cm day^{-1})	Θ (cm^3 cm^{-3})	h (cm)	k (cm day^{-1})	Θ (cm^3 cm^{-3})
0	1.00	0.88	0	7.00	0.87
10	0.70	0.86	10	1.00	0.84
20	0.50	0.84	20	0.30	0.78
31	0.40	0.83	31	0.20	0.74
50	0.20	0.78	50	0.10	0.64
100	0.04	0.74	100	0.02	0.60
250	0.003	0.70	250	0.0005	0.57
500	0.0008	0.68	500	0.00005	0.53
1000	0.00016	0.66	1000	0.000003	0.50

the relationships between hydraulic conductivity (k), suction head (h) and soil water content (Θ). The relationship between height above the water-table and suction head has been calculated for different flux densities of the capillary rise. The results are presented in Figure 8.

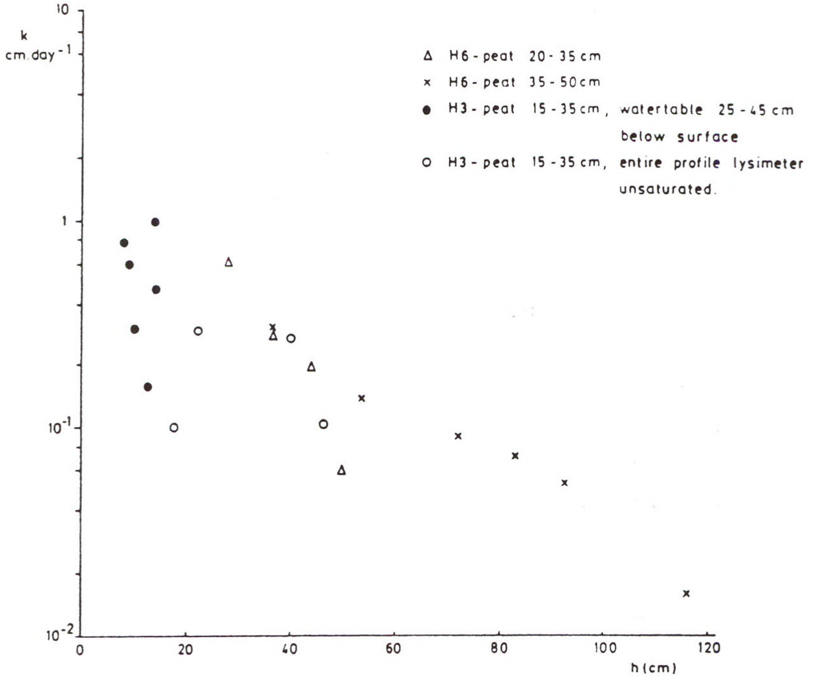

Fig. 7. Unsaturated hydraulic conductivity (k) for different suction heads (h) as determined with lysimeter experiments in the glasshouse. (H6 peat measured in soil column; H3 peat measured in lysimeter S4).

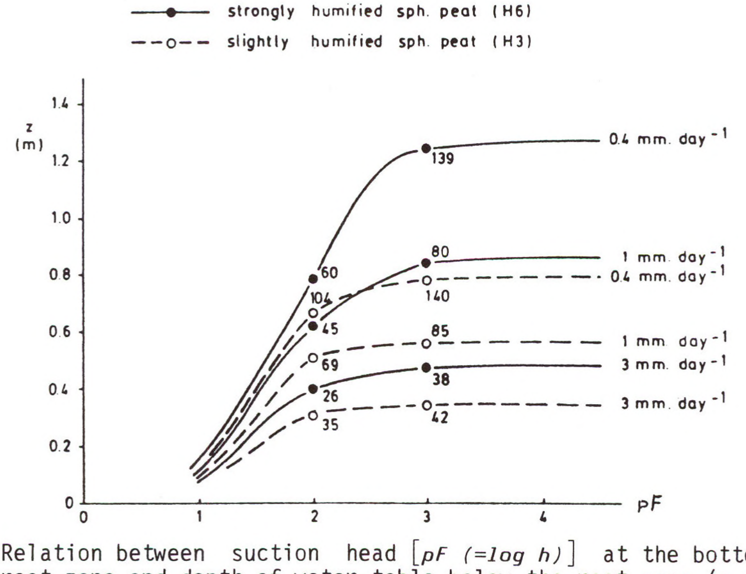

Fig. 8. Relation between suction head [*pF (=log h)*] at the bottom of the root zone and depth of water-table below the root zone (z in m) for different capillary fluxes (in mm day^{-1})

DISCUSSION AND CONCLUSIONS

Results from this investigation enable a comparison of hydrophysical properties of some representative peat layers in the study area. In partly-mined bogs, the mostly older, more humified upper peat layers differ strongly from those in undisturbed bogs.

For lysimeters S1-4 and C1-4, values for the storage coefficent obtained from the lysimeter experiments show good agreement with the water retention characteristics. This does not hold for lysimeters M1-4 with a *Molinia* vegetation, which are characterized by an intense root zone in the top 30cm and some cracks in the upper layers. The storage coefficients obtained from the lysimeter experiments are more reliable than those derived from water retention measurements in 100cm^3 samples. Here, during sampling, an attempt was made to exclude the cracks and larger roots which otherwise would influence (ie hamper) the determination of water retention and hydraulic conductivity.

It is shown that for sites M, C & Col, saturated hydraulic conductivity of the samples taken at 15cm depth is 10 to 100 times higher than those taken at 35cm depth. These differences cannot fully be explained by differences in peat type or degree of humification, but probably are caused by biological activity in the upper part of the soil. Saturated hydraulic conductivity is highest for the low to slightly humified peat (lysimeters S1-4 and C1-4). For C1-4 at 35cm depth, it has to be noted that here the peat is characterized by a very pronounced horizontal layered structure. In fact, the peat layers at 35cm depth in lysimeters S1-4 were formed in the same period of *Sphagnum* bog growth as those at a depth of 15cm in lysimeters C1-4 (see also Fig. 2).

From the glasshouse experiment with lysimeter S4, it is concluded that under dry conditions with relatively low water levels (25 - 45cm below the surface), capillary rise in these layers is sufficient to satisfy a low evaporative demand of the top layer. During the period of measurement in the glasshouse (more than 30 days with an average evapotranspiration of 0.8mm day^{-1}) water was deliverd from the saturated zone.

In the dry summer of 1989, water levels in the lysimeters S5-8 (young *Sphagnum* peat, Fig. 2) dropped to about 35cm depth. With the water-table in the range of from 10 to 35cm, evapotranspiration rates of 2mm day^{-1} were observed. The gradual and constant lowering of the water-table indicates that much of this water was delivered from the saturated zone.

Capillary rise is different in H6 than in H3 peat soils. In H3 peat soils, a higher water storage capacity and a resulting better water availability means that for equal water extraction rates (by evapotranspiration), the resulting lowering of the water-table and increase in suction head in the upper layer is much less than with H6 peat. When 60mm of water is extracted from an H6 peat soil, the water level will fall to ca. 70cm and capillary fluxes will not exceed 1mm day^{-1}. After the extraction of 60mm of water from an H3 peat soil (with a *Sphagnum* cover without root zone) the water level will fall to ca. 40cm below the surface and capillary fluxes of ca 2mm day^{-1} are still possible. This example shows that in these peat soils, capillary water supply and water availability should be clearly distinguished.

In living bogs, hydrophysical properties of the 'acrotelm' play an essential role in maintaining a high water level with very limited fluctuations. Schouwenaars (1990) shows that besides a high water storage coefficient in a living *Sphagnum* layer, reduction of evapotranspiration contributes to only a limited lowering of the water-table during a dry period. Evapotranspiration is reduced when the water-table drops below 10-15cm depth. Then, the upper living *Sphagnum* plants dry out and become yellowish. This phenomenon is in good agreement with results presented by Verry (1988).

When after the rewetting of partly cut-away bogs (regeneration, rehabilitation) *Sphagnum* regrowth occurs, the young *Sphagnum* layer will remain less than 30cm for some decades and then in drier periods the water-table may drop below 30-40cm from the surface. This is caused by the limited water storage coefficient of the underlying older and more humified *Sphagnum* peat layers. The resulting increased microbiological activity may hamper the development of the ombrotrophic *Sphagnum* plant communities. So, during the first phase of regeneration, young *Sphagnum* plants are vulnerable to drought because the layer thickness is still too limited to establish sufficient 'self-regulating buffer' mechanisms to prevent a further lowering of the water-table.

When after peat excavation a strongly humified peat soil (eg H6 peat) is covered with *Molinia*, it will be almost impossible to establish a *Sphagnum* vegetation. This is largely supported by field observations (eg Podschlod, 1988). Not only will the hydrophysical properties of these peat soils result in lower water-tables but the evapotranspiration rates of the *Molinia* vegetation will remain high even in dry periods (Schouwenaars, 1990). This implies that when excess rainfall occurs after such a period it will take a longer time before high water levels are restored. As a consequence, these sites are characterized by high water-level fluctuations, which favour plant species like *Molinia*. Here the only possibility for *Sphagnum* regrowth is in floating mats after permanent innundation of the area (see Joosten, 1989 and Schouwenaars, 1988).

ACKNOWLEDGEMENTS

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EXPERIMENTAL DRYING OF THIN LAYERS OF PEAT

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SUMMARY

Three different size classes of fuel peat were dried in thin layers under varying levels of relative humidity in order to (1), assess the effects of peat size and relative humidity on drying rate, and (2), derive equations to describe moisture loss rates for a range of peat sizes and relative humidities.
Results showed that increases in peat size and relative humidity led to decreases in drying rate. Moisture loss curves were converted to dimensionless moisture ratio curves that were described by the equation $MR = \exp(-kt^n)$. The factor k was dependent on peat size and relative humidity. The factor n was dependent only on peat size. Data for the largest size class (sod peat) showed that an increase in initial moisture content led to a decrease in drying rate. These results could be incorporated in a model in order to predict drying rates of fuel peat under varying ambient drying conditions.

INTRODUCTION

This work was carried out as part of a three-year project funded jointly by the UK Department of Energy and the Commission of the European Communities (CEC). The overall aim of this project is to assess the potential for developing and expanding the use of fuel peat in the UK, particularly in Scotland.

The drying of fuel peat to a moisture content where it is suitable for combustion is an important process. Moisture content determines not only the calorific value of the fuel, but how it behaves during the feeding process, and how efficient the combustion process is. Therefore, it is not surprising to find that there have been numerous studies on the drying of peat. Both in Ireland (Ward, 1988) and in Finland (Jarvinen, 1988), work has been done on modelling milled peat drying in the field. In Canada (Theriault *et al*, 1982), the potential of using solar energy to dry stacks of milled peat has been investigated. Methods of artificially de-watering excavated peat have also been studied (Leger *et al*, 1987; Pirkonen, 1988).

Most of the work mentioned above appears to have concentrated on milled or excavated peat, but more recently attention has been given to the drying of sod peat which has been macerated and extruded. In Scotland, virtually all of the peat produced for fuel purposes is sod peat. Sod peat dries more slowly on the bog than milled peat, and so it is sometimes necessary for further post-harvest drying to be carried out. There are a number of ways of doing this. The sod peat can be stacked in different ways; air can be forced through it or allowed to convect naturally; and the circulated air can be heated or unheated. Work on the practical aspects of the post-harvest drying of sod peat was initiated in Finland and has also been studied in Sweden (Malmberg, 1988). However, there is a need for additional basic information on the drying characteristics of sod fuel peat and so experimental thin-layer drying work was carried out at SCAE with the following aims:

1) to assess the effect of peat lump size on drying rate,
2) to fit drying equations to the moisture loss curves obtained so that drying rate under varying conditions of relative humidity could be predicted.

This study was confined to drying processes in the absence of solar radiation and is therefore of most relevance to post-harvest drying in stacks, under cover or in containers.

EQUIPMENT AND EXPERIMENTAL METHODS

A diagram of the equipment used is shown in Figure 1. The equipment, normally used by the Engineering Systems Department at SCAE for the drying of swaths and thin layers of grass, was kindly made available for work with peat. In this equipment, air of known relative humidity and temperature was passed through thin layers of peat at a high flow rate and moisture loss was measured at frequent intervals. Under such conditions, air flow is not a limiting factor in the drying process. The only factors which affect drying rates are the size of the peat lumps and the condition of the drying air. The principles of thin-layer drying technology for a range of commodities have been described by Hall (1980). Mass transfer is believed to be the mechanism for drying in this situation but the smallest sizes may also dry by convective thermal flow.

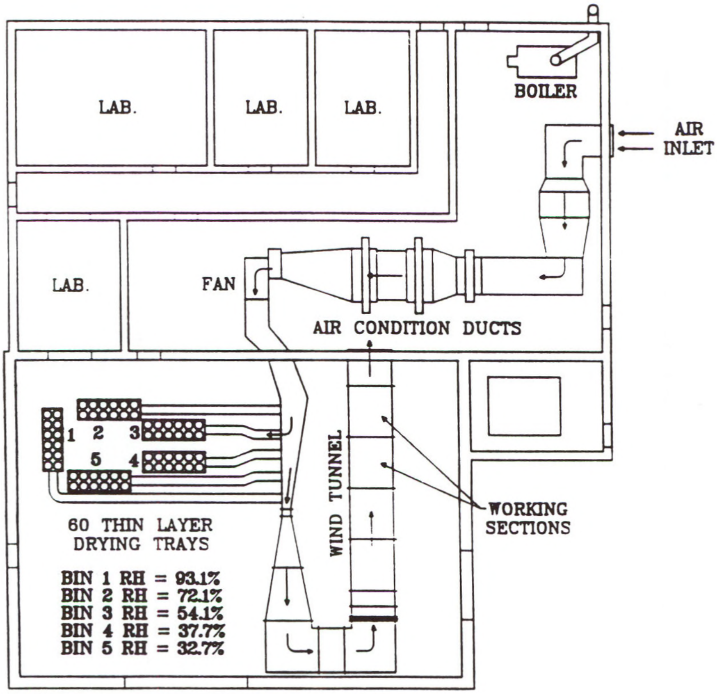


Figure 1. Diagram of drying apparatus at SCAE.

A bulk sample of sod peat was obtained from a local peat producer. The peat, extracted from a raised bog, was moderately humified, having a degree of decomposition of H4-6 on the von Post scale. It was obtained soon after harvest and had an average moisture content in excess of 50% wet basis.

This bulk sample of peat was separated into three different size classes using a nest of square meshed sieves. The sieve mesh sizes were 64 x 64 mm, 16 x 16 mm, 1 x 1 mm and a base tray. The three different size classes obtained by sieving were as follows:

Size 1. Lumps of peat with minimum dimensions greater than 64 mm. In practice, the mean length of the lumps of peat in this size class was approximately 133 mm, and this size class was chosen to represent sod peat.

Size 2. This size class consisted of lumps with maximum dimensions less than 64 mm and minimum dimensions greater than 16 mm, and these sizes were chosen to represent crushed sod peat.

Size 3. This size class consisted of lumps with maximum dimensions less than 16 mm and minimum dimensions greater than 1 mm. It was chosen to represent peat "fines" or dross.

Thin layers of peat were arranged in the drying trays (see Fig. 1). Of the twelve trays in each bin, four contained thin layers of size 1 peat, four contained thin layers of size 2 peat, and four contained thin layers of size 3 peat. The positions of the trays in each bin were selected at random.

The drying air was supplied from the conditioning ducts (see Fig. 1) at a dewpoint of 13°C. As air entered the duct leading to each of the five drying bins it was warmed to a set temperature to give a set relative humidity. Thus a range of drying air conditions could be simulated. The air velocity in the different bins was balanced at the start of the tests. The condition of the air in each of the five bins is shown in Table 1.

Table 1. Air condition in each of the five drying bins.

Bin No.	Mean dry bulb temperature (°C)	Mean dewpoint temperature (°C)	Mean relative humidity (%)
1	14.30	13.2	93.1
2	18.30	13.2	72.1
3	22.98	13.2	54.1
4	29.08	13.2	37.7
5	31.56	13.2	32.7

All the trays were weighed at least three times daily. Initially, it was intended that this would continue until the trays reached constant weight. This proved to be no problem for the trays containing size 3 peat which reached constant weight in two or three days. However, some of the trays containing size 1 peat were still showing some weight loss even after ten days. It was assumed that all the trays in any particular bin would eventually reach the same equilibrium moisture content, and so once the trays containing size 3 peat (the fastest drying size) reached constant weight, all the trays in the bin in question were removed and placed in an oven at 105°C for 48 hours to obtain oven-dry weights. From these weights, initial moisture contents and all subsequent moisture contents throughout the drying period could be calculated for each tray. The equilibrium moisture content for all trays in a particular bin was taken to be the final moisture content that trays of size 3 had reached, as in all cases trays containing this size class reached constant weight before the end of the drying period.

RESULTS

As stated above, the mean equilibrium moisture content for each drying air condition was derived from the moisture loss curves for trays containing size 3 peat. A plot of equilibrium moisture content against relative humidity is shown in Figure 2. Other drying studies have shown this relationship to be sigmoid (Hall, 1980; Henderson, 1952). This may be the case with peat, but it cannot be proved at present due to the lack of data points below a relative humidity of 30%. It seems logical that a fitted curve would pass through the origin, as air of 0% relative humidity should remove virtually all of the free-moving moisture within the lumps of peat.

In this case, a regression analysis was performed over the range of relative humidity covered by the data (a useful range in itself). This resulted in a good cubic fit, details of which can be seen in Figure 2.

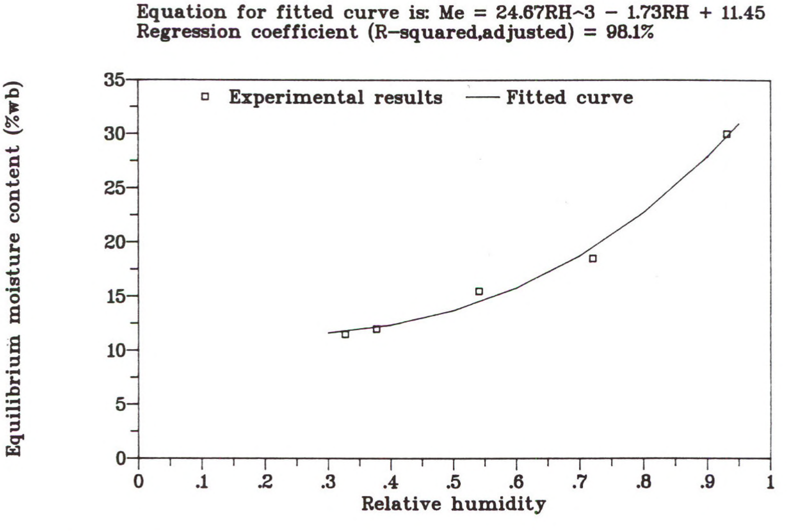


Figure 2. Effect of relative humidity on equilibrium moisture content.

Moisture loss curves were constructed for all the trays. The moisture content values making up these curves were converted to a dimensionless moisture ratio which has been widely used in drying different commodities (Hall, 1979). This has the form:

$$MR = \frac{Mt-Me}{Mo-Me}$$

Mt = moisture content at time t (hours)
Mo = initial moisture content
Me = equilibrium moisture content

It follows that initially MR = 1, and at equilibrium MR = 0. Moisture ratio curves were constructed for all the trays. An example of these can be seen in Figure 3 for size 2 peat dried in air at a relative humidity of 54%. Although the four curves shown are for the same size classes of peat dried under the same air conditions, the difference in moisture loss rates is probably due to different size distributions in each tray within the overall size class limits. For this reason, one mean curve was produced from the four curves of the same size class for each drying condition. Examples of these mean curves are shown in Figures 4, 5 & 6 for three air conditions (14.3, 23.0 and 31.6^{o}C and corresponding relative humidities of 91.3, 54.1 and 32.7%). The three size classes are shown on the same graph for each of the drying conditions. Again, it is assumed that, given sufficient time, all moisture ratio curves would have reached zero as all size classes dried under the same air conditions would have eventually reached the same equilibrium moisture content. This may not seem to be the case for the higher relative humidities, but it can be seen from Figures 4-6 that as relative humidity decreases, the curves do begin to show convergence towards zero moisture ratio. Provided that the composition of the material did not vary with size, it would indeed be very unusual for size to have an effect on the value of the equilibrium moisture content although for large sizes, the real equilibrium moisture may never be achieved in practice because of very low mass transfer and capillary condensation effects. The dominant effect of size, however, is on the **rate** of moisture loss.

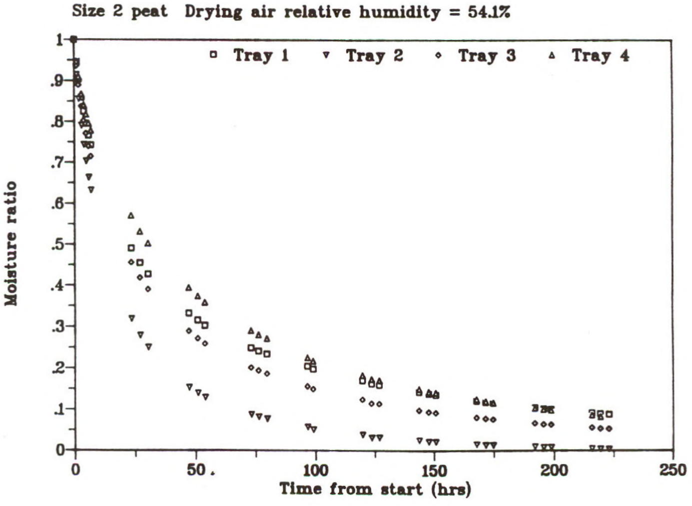


Figure 3. Examples of moisture ratio curves.

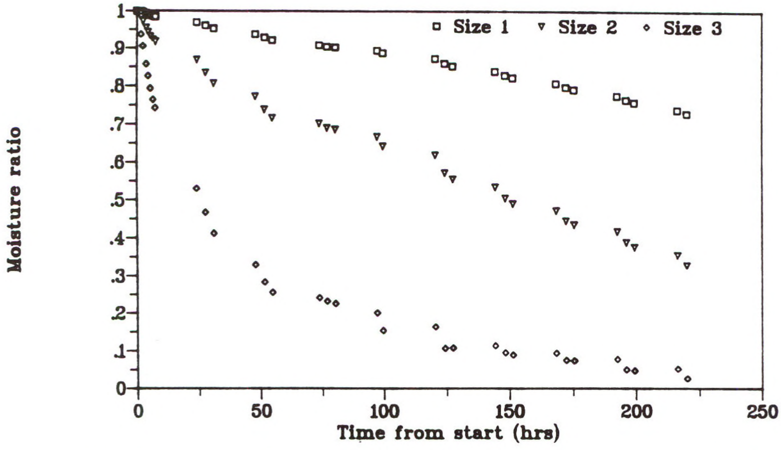


Figure 4. Mean moisture ratio curves for a drying air of 93.1% relative humidity and a temperature of 14.3°C.

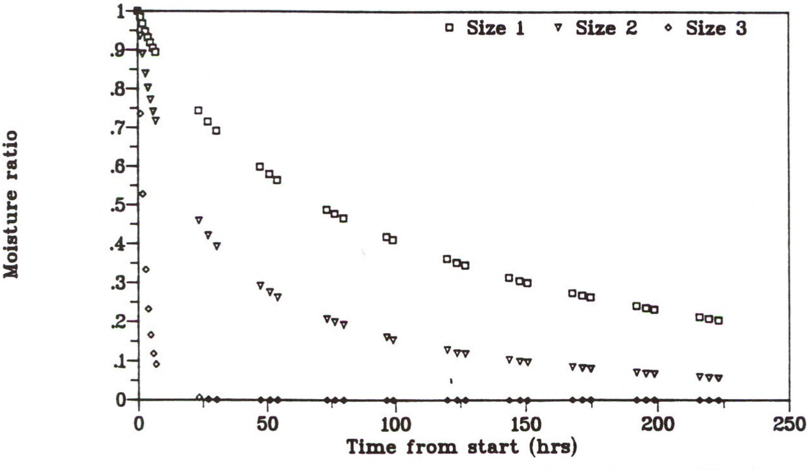


Figure 5. Mean moisture ratio curves for a drying air of 54.1% relative humidity and a temperature of 23.0°C.

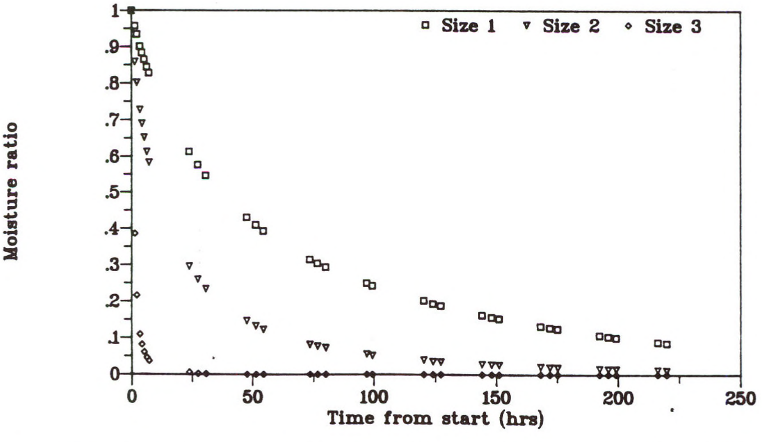


Figure 6. Mean moisture ratio curves for a drying air of 32.7% relative humidity and a temperature of 31.6°C.

SELECTION OF EQUATIONS TO DESCRIBE MOISTURE RATIO CURVES

When selecting a suitable form of equation to fit the moisture ratio curves, reference was made to a review of thin-layer drying techniques compiled by Sokhansanj and Cenkowski (1988). Many of the equations in this review were of the form:

$$MR = \exp(-kt^{n}) \qquad (1)$$

It was considered likely that a negative exponential form of equation would fit the experimental data well so this form of equation was selected. Equation (1) can undergo a double log transformation to yield the following equation:

$$\log(-\ln MR) = \log k + n \log(t) \qquad (2)$$

Equation (2) is of the form $y = c + mx$, which is the form of equation for a straight line. In this case c is the intercept which is equivalent to log k, and m is the gradient which is equivalent to n.

Data for all the moisture ratio curves were transformed to log(-lnMR) and log(t). Linear regression was performed on the transformed data to assess the goodness of fit and to obtain values for k and n for equations to describe each curve. Regression results are shown in Table 2 and values of k and n are shown in Table 3.

Table 2. Results of linear regression.

Rel. humid. (%)	Size class	t ratio for logk	t ratio for n	Prob. of logk not different to zero	Prob. of n not different to zero	St. Devn.	R^2 (Adj.) (%)
93.1	1	-58.04	+36.21	0.000	0.000	0.09514	97.7
	2	-57.50	+43.65	0.000	0.000	0.06242	98.4
	3	-54.11	+59.36	0.000	0.000	0.04495	99.1
72.1	1	-146.44	+113.62	0.000	0.000	0.02759	99.8
	2	-95.57	+92.13	0.000	0.000	0.02901	99.6
	3	-8.38	+20.66	0.000	0.000	0.08675	94.5
54.1	1	-100.53	+88.82	0.000	0.000	0.03518	99.6
	2	-63.36	+72.15	0.000	0.000	0.03565	99.4
	3	-10.17	+20.34	0.000	0.000	0.06536	97.9
37.7	1	-165.77	+161.70	0.000	0.000	0.01935	99.9
	2	-99.11	+121.78	0.000	0.000	0.02149	99.8
	3	-2.27	+10.51	0.053	0.000	0.09302	92.4
32.7	1	-126.55	+126.65	0.000	0.000	0.02256	99.8
	2	-63.31	+88.57	0.000	0.000	0.02704	99.6
	*3	+0.02	+14.40	0.986	0.000	0.05414	95.8

* The t ratio for log k is very low, indicating that the value of log k is not significantly different to zero; hence a probability approaching one. This is because the actual k value is very close to one, which means that log k would be close to zero, ie the regression fit would pass through the origin.

Table 3. Regression values for k and n.

Relative humidity (%)	k value			n value		
	Size 1	Size 2	Size 3	Size 1	Size 2	Size 3
93.1	0.00164	0.0155	0.0594	0.9567	0.7565	0.7409
72.1	0.01020	0.0430	0.4242	0.8433	0.7188	0.5433
54.1	0.02170	0.0866	0.3928	0.8046	0.6622	0.8788
37.7	0.03200	0.1008	0.7483	0.8097	0.6772	0.6326
32.7	0.03920	0.1433	1.0016	0.9769	0.6509	0.5600

The regression values of k and n were fitted into the equation $MR = \exp(-kt^n)$ for all the size classes and drying conditions, and points were calculated over the same time period covered by the experimental data. The calculated points were plotted alongside the moisture ratio experimental data in order to assess the suitability of this form of equation for describing moisture loss in peat samples. An example of these plots can be seen in Figures 7-9 for all the size classes (dried in air at a relative humidity of 54%).

Next, the relationships between relative humidity and the k and n values were examined. There was a definite relationship between k values and relative humidity for all three size classes, namely, that increasing relative humidity led to decreasing k values. However, there was no clear relationship between relative humidity and n values, the latter changing relatively little over the full range of relative humidities. Therefore, it was decided to calculate mean n values for each size class and to recalculate the k values accordingly. The mean values are shown in Table 4.

Table 4. Mean n values.

Size class	Mean n	Standard deviation
1	0.8382	0.0703
2	0.6931	0.0438
3	0.6711	0.1398

The linear regression line for data always passes through a "centroid" (x mean, y mean). Therefore, if x(mean) and y(mean) were calculated for each mean moisture ratio curve and then substituted along with the relevant

Fig. 7

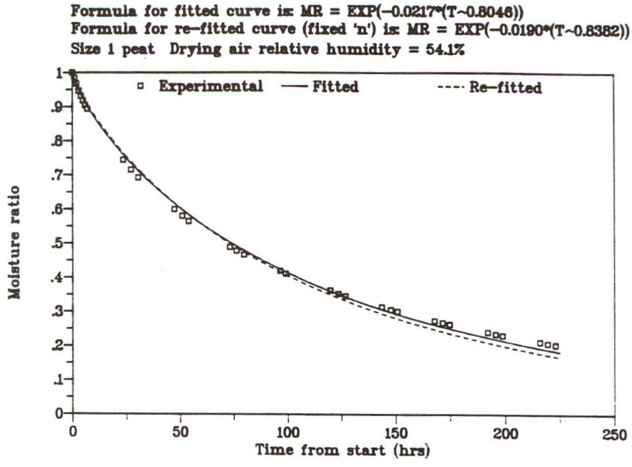


Fig. 8

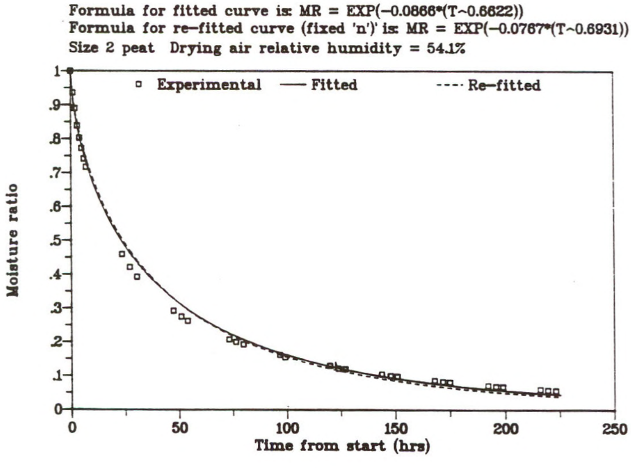
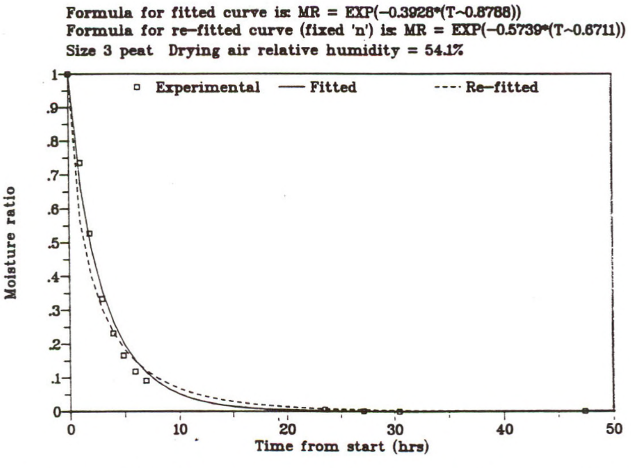


Fig. 9



Figures 7, 8 & 9. Curves fitting to mean moisture ratio data for Size 1, Size 2 & Size 3 peat; RH of drying air = 54.1%.

mean value of n (as shown in Table 4) in the equation:

$$\log(-\ln MR) = \log k + n\log(t), \quad (\log(-\ln MR) \equiv y(\text{mean}))$$
$$(\log(t) \equiv x(\text{mean}))$$

a new value of log k, and hence k, could be calculated. This was done for all the mean moisture ratio data and the re-calculated values of k are shown in Table 5.

Table 5. Recalculated k values based on fixed values of n.

Rel. humidity %	Revised k values Size 1	Size 2	Size 3
93.1	0.0026	0.0199	0.0780
72.1	0.0101	0.0475	0.2680
54.1	0.0190	0.0767	0.5739
37.7	0.0283	0.0948	0.6975
32.7	0.0308	0.1215	0.8083

These new k values and the fixed values of n were used to calculate points over the same time period covered by the experimental data for all the mean moisture ratio curves. These points were plotted on the same graphs as the original calculated curves for comparison with both the original calculated curves and the experimental data (see again Figs. 7-9).

The relationship between the new k values and relative humidity was then examined. Plots of k against relative humidity showed near straight line relationships for all three size classes. Linear regression analysis yielded the results shown in Table 6.

Table 6. Results of regression analyses for recalculated values of k.

Size class	t ratio for intercept	t ratio for gradient	Prob. of intercept=0	Prob. of gradient=0	St. Devn.	R^2 Adj(%)
1	+30.91	-19.94	0.000	0.000	0.001190	99.0
2	+16.26	-9.71	0.001	0.002	0.008051	95.9
3	+22.09	-13.98	0.000	0.001	0.043190	98.0

Equations: Size 1: $k = 0.0457 - 0.0475RH$
Size 2: $k = 0.1627 - 0.1564RH$
Size 3: $k = 1.1852 - 1.2083RH$

Note: RH is decimalized in these equations. Therefore, if RH = 1 (ie 100% relative humidity, saturated air) is substituted in the equations in Table

6, in all cases k approximates to zero. This means that the equation

$$MR = \exp(-kt^n) \text{ approximates to } MR \simeq \exp(0) \simeq 1.$$

This makes sense, as with saturated air no drying can take place and so the moisture ratio remains equal to one.

Chi-square tests were performed to examine the difference between the calculated points and the experimental points. In no cases were these differences significant (at the 95% level). This indicated that the form of equation chosen described the experimental moisture loss curves well.

The relationships between the values of k and n and the three different size classes were now examined. Plots of k against the three size classes, at each of the relative humidity levels in the experiment, are shown in Figure 10. It should be noted that the curves drawn on this graph are not regression fits (they were automatically selected as best fits by computer), as it was considered that there were too few points to carry out a regression analysis. However, the graph does give a useful indication of how k values change with material size.

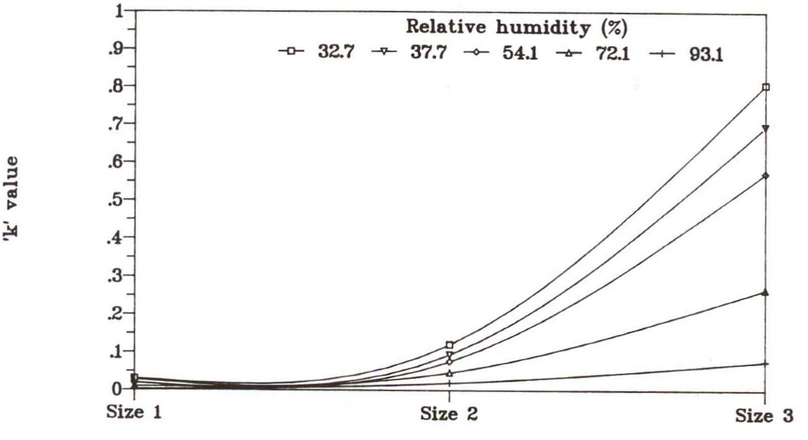


Figure 10. Effect of peat size and relative humidity on 'k' values.

A plot of mean n values against size class is shown in Figure 11. Again, the curve is not a regression fit, but was selected automatically as a best fit by computer.

Finally, the effect of initial moisture on the drying rates of size 1 peat was examined. Because "thin layers" of size 1 peat only consisted of two or three large lumps, it meant that the initial moisture contents of these thin layers varied quite widely between approximately 35% and 60% wet

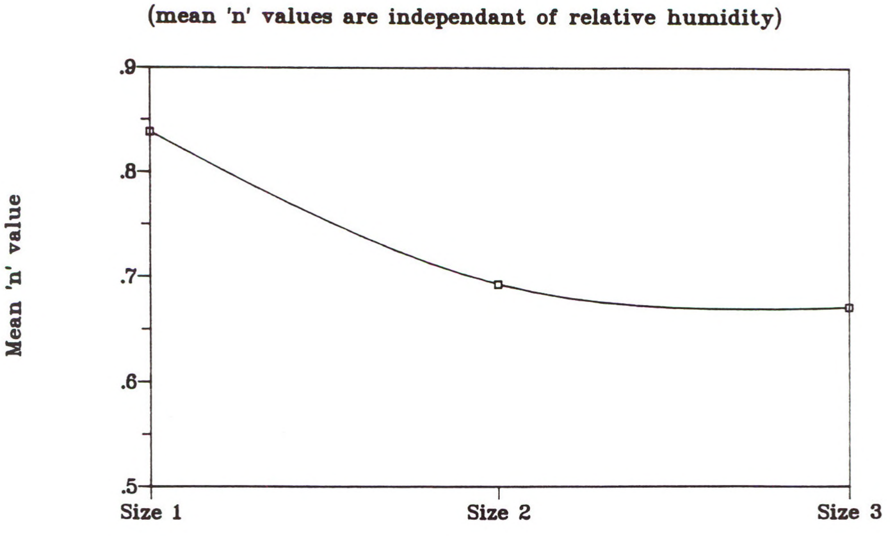


Figure 11. Effect of peat size on mean 'n' values.

basis. The initial moisture contents of thin layers of size 2 and 3 peat were much more uniform, since these thin layers consisted of numerous lumps or particles. Therefore, only the thin layers of size 1 peat showed sufficient variation in initial moisture content to enable the effect on drying rate to be examined.

The moisture ratio curves for every thin layer of size 1 peat (four for every drying condition, making twenty in all) were taken, and equations to describe these curves were derived separately as described previously. This gave twenty values of k and twenty values of n for the equation, $MR = \exp(-kt^n)$, covering a range of initial moisture contents. The value of k proved to be the main indicator of drying rate. As before, k was clearly dependent on the relative humidity of the drying air. Therefore, the values of k were plotted against the initial moisture content for each drying condition. These plots can be seen in Figure 12. The lines drawn on the plots are linear regression fits, but the accuracy of these is doubtful due to the small number of points for each line. The true relationship may well be exponential or even curvi-linear. However, it would seem that increasing the moisture content results in a decreasing value of k, which indicates a lower drying rate, always assuming that n remains constant.

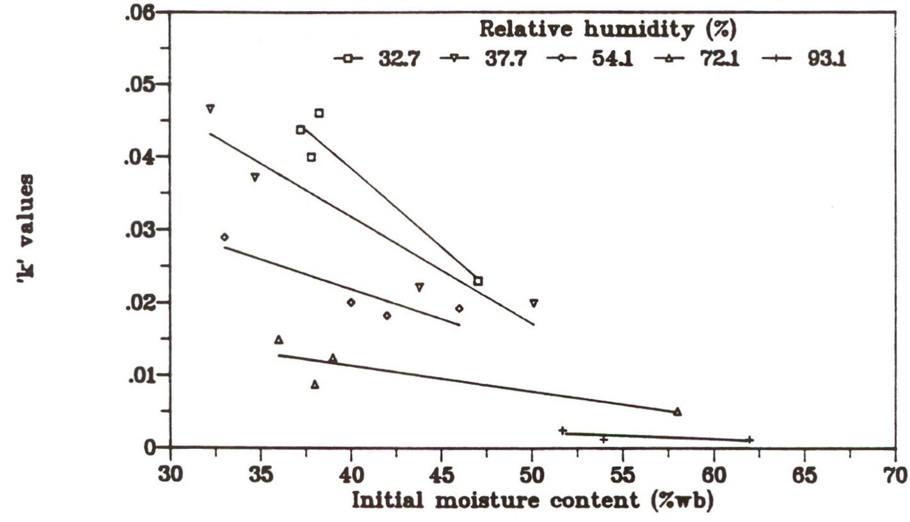


Figure 12. Effect of initial moisture content on 'k' values for size 1 peat.

The values of n did not appear to be related to drying air condition. Therefore, all the values were plotted together against initial moisture content (see Figure 13). It can be seen that increasing initial moisture content results in an increasing value of n, but the increase is not great. The line shown is the result of linear regression analysis as described in Table 7 below.

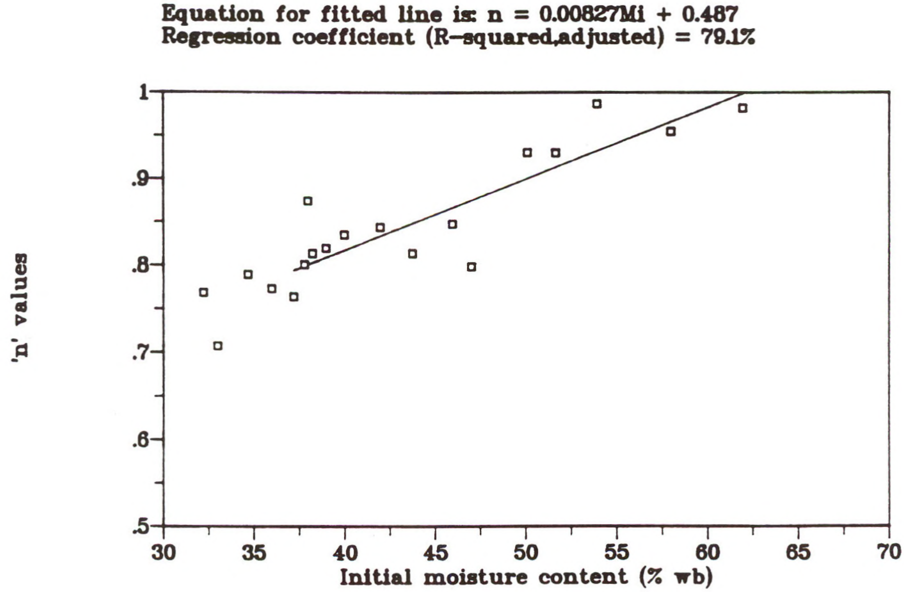


Figure 13. Effect of initial moisture content on 'n' values for size 1 peat.

Table 7. Results of regression analysis on the relationship between values of 'n' and initial moisture content for size 1 peat.

Size class	t ratio for intercept	t ratio for gradient	Prob. of intercept =0	Prob. of gradient =0	Standard deviation	R^2 Adj(%)
1	11.12	8.31	0.000	0.000	0.03619	79.1

Equation is $n = 0.4866 + 0.0083Mi$ (Mi expressed as % wb).

It was not clear whether, given increasing initial moisture content, a decreasing value of k is compensated for by an increasing value of n, to give the same moisture loss rate. Therefore, the values of k and n were used to calculate points for moisture ratio curves over a 250 hour period for all the size 1 peat samples. Overall, the curves did seem to indicate that a higher initial moisture content resulted in a lower rate of moisture loss, and that the effect was more noticeable at lower relative humidities. Figures 14a & 14b show two examples. This relationship is related to the expression of moisture loss in terms of moisture ratio and by the nature of the drying process involved. More experimentation would be required to confirm these results. If the results are accurate, the findings would be of importance when considering the drying of sod peat (particularly in stacks after harvest), because the moisture content at harvest could have an effect on the subsequent **rate** of drying of peat when stacked.

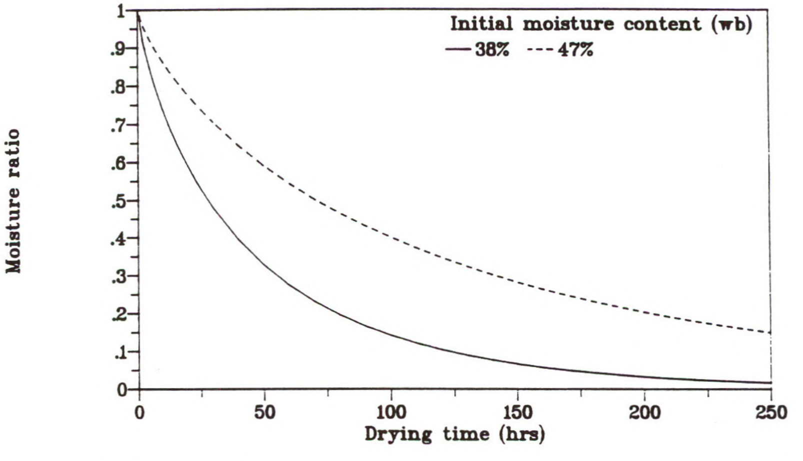


Figure 14a. Example of fitted drying curves for different initial moisture contents (Size 1 peat). Relative humidity of drying air = 32.7%.

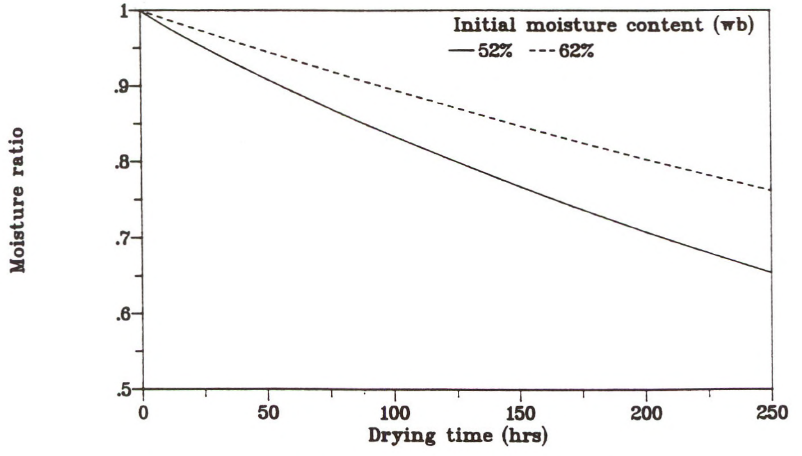


Figure 14b. Example of fitted drying curves for different initial moisture contents (Size 1 peat). Relative humidity of drying air = 93.1%.

DISCUSSION

It has been shown that equations can be constructed to predict the loss of moisture from different size classes of peat arranged in thin layers. The factors in the equations can be linked to both drying air relative humidity and the size of the peat. In the case of peat size, there is no doubt that when arranged in thin layers, smaller sizes dry more quickly than the larger ones. However, more data would be required to describe the exact nature of this relationship.

The effect of relative humidity on what equilibrium moisture content can be achieved has been described for a useful range of humidity values. More experimentation with air of lower relative humidities would be required in order to identify the exact nature of the curve as shown in Figure 2. There is no reason to believe that different sizes of peat reach different equilibrium moisture contents for a given air condition. All that is affected is the drying **rate**. Indeed, projection of the calculated curves used to describe the experimental data has shown that, even at a relative humidity of 93%, all the peat samples would eventually reach the same equilibrium value. For the wettest of the size 1 peat, the time estimated for this to happen was over 200 days.

It would seem that for size 1 peat at least, a higher initial moisture content results in a slower drying rate. If further work was to confirm this, it would have important implications for the drying of sod peat, because the moisture content at harvest could have an effect on the subsequent drying rate of peat when stacked.

The above information is of primary relevance to post-harvest drying but might find application in attempts to predict the drying rates of extruded peat on the bog surface providing that additional factors such as capillary water rise (the "wick" effect) and radiant solar heat could be taken into account. The problem of drying cut peat in stacks is complicated by the resistance of the stack to air flow. Such resistance is size dependent. Initial measurements made at SCAE on beds of peat of the same size classes as used in the thin-layer experiments have shown that resistance to airflow is inversely proportional to peat size. However, in a practical situation the problem is not so straightforward, because a peat stack may contain widely varying lump sizes in different proportions throughout the stack. The problem could probably be overcome by repeating measurements several times with different samples of peat as received from a number of producers. It may be possible to measure the resistance to airflow and rate of moisture loss of different shaped stacks of peat in a wind tunnel. To conclude, construction of a model to predict the drying rates of peat stacks in ambient conditions is certainly possible, but more experimental data would be required to confirm the reliability of such a model.

ACKNOWLEDGEMENTS

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THE SHAPE OF BOGS FROM A HYDROLOGICAL POINT OF VIEW

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SUMMARY

Two hydrological, mathematical models are presented that simulate the groundwater tables of raised bogs, one with a homogeneous body of peat and one with acrotelm and catotelm, in which the former carries the bulk of the discharge of the water. As the surface of bogs and the level of the groundwater are closely related, these models are used to describe the shape of bogs. Special attention is paid to the relation between the height of the bog (hm) and its diameter (B). The role of open water, ponds, "meerstallen", "Mooraugen", sloughs and other features is also discussed. A main conclusion is that the open waters of bogs serve to increase the discharge and not to store water for dry periods.

INTRODUCTION

Raised bogs are special landscapes with some peculiar features. For example they consist of more than 90% water, yet they are solid enough to walk on. Another striking feature is their ability to grow in both vertical and horizontal directions. In the course of a few millenia, a raised bog can reach several metres in thickness and several kilometres in cross-section.

From a hydrological point of view, the gradual rise of the water table in an expanding raised bog is an interesting phenomenon. The water table rises together with the bog surface and one may use hydrological principles and formulae to describe the shape of bogs. Ingram (1982, 1983) was the first to do so by presenting a purely hydrological model to explain the relationship between the height and width of raised bogs. In this paper, a slightly different model is presented and an explanation given of the function of open water ("meerstallen", "Mooraugen") in the hydrology of raised bogs.

CAPILLARY RISE

The fact that raised bogs grow in time is generally not seen as a surprising feature. On the other hand, from a hydrological point of view, there is the surprising phenomenon that the water table rises at the same rate as the bog surface. The general opinion is that the rise is due to capillary rise i.e. a raised bog behaves like a sponge. This, however, is very unlikely. Boelter(1965) showed that the capillary rise is only of the order of a few decimetres, whereas the elevation of the bog surface - and thus the water table - above the surroundings may be more than 5 metres.

Figure 1 shows the capillary rise in *Sphagnum* peat under the influence of an upward movement of water caused by evaporation at the bog surface. As the rate of evapotranspiration of a raised bog in summer is 3 to 5mm/day and the maximum suction of Sphagna is not more than pF2, the maximum capillary rise is only some 300mm. From this it is obvious that capillary rise cannot explain the elevation of the water table in a raised bog.

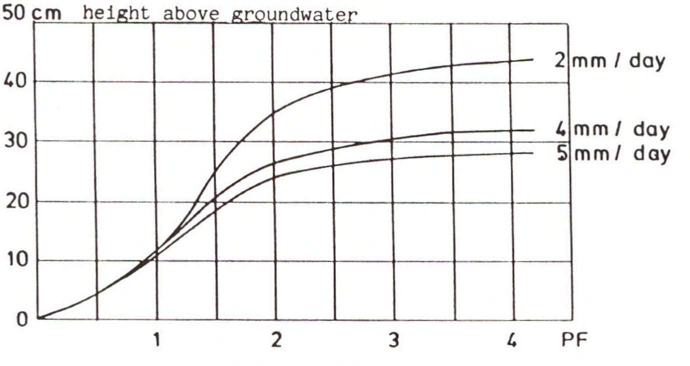

Figure 1. Capillary rise (in cm above groundwater level), as a function of the suction (pF) and the rate of evapotranspiration (2, 4 & 5 mm/day). (after Rijtema, 1969).

THE FLOW OF GROUNDWATER

In a raised bog, precipitation is the only source for the groundwater. The outflow of water from a raised bog comprises evapotranspiration, surface runoff and groundwater flow, either downward to the mineral subsoil or laterally to the surroundings of the bog. For the moment we will neglect the surface runoff, although, as will be seen later, this is far from correct.

The equilibrium between the supply, discharge and storage of the water can be described by two basic hydrological principles:

- Darcy's law, which states that the rate of groundwater flow (q) is linearly related to the slope of the groundwater table (i) and the hydrological conductivity of the medium through which the flow takes place (k):

$$q = -k \cdot i$$

- The principle of continuity, which implies that the amount of water supplied to an area is equal to the discharge plus the change in water storage.

An equation for the height of the water table in a raised bog can be derived from these two hydrological principles. Ingram (1982, 1983) was the first to use this approach, which is presented here as Case I. In order to improve this approach, a more realistic model has been developed and is presented here as Case II.

CASE I.

Figure 2 shows the model of a raised bog used in Ingram's approach. It is assumed that the hydrological conductivity (k) is the same throughout the whole body of peat. Another assumption is that the groundwater in the bog is independent of the groundwater in the mineral subsoil under the bog. In the Netherlands, this is a realistic assumption as the deepest layers of the peat consist of the so-called "gliede" which has a very high resistance to groundwater flow. This layer causes a "perched water table" in the peat

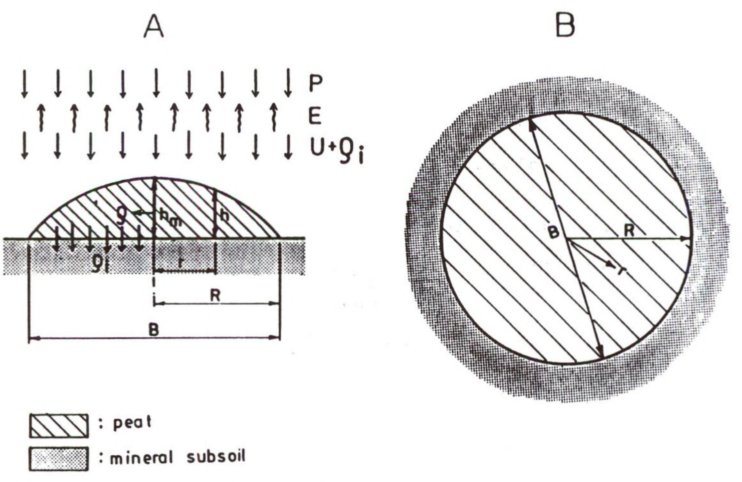

Figure 2. Model of a raised bog used in Case I.
A: cross-section B: top view

body, with a hydraulic head that is often several metres above the piezometric level of the groundwater in the underlying sandy substrate. Under these conditions, the flow of the groundwater can be described by:

$$Q = -2\pi rh \,.\, k \,.\, dh/dr \qquad \text{(Darcy's law)}$$

$$dQ = 2\pi r \,.\, U \,.\, dr \qquad \text{(Continuity)}$$

Where: Q : Rate of horizontal flow of groundwater through the peat (m^3/day)

U : Precipitation minus evapotranspiration minus loss of groundwater to mineral subsoil (m/day)

r : distance from the centre of the bog (m)

h : height of the water table in the bog (m) (As the height of the bog is more or less the same as the height of the groundwater table, h also describes the shape of the bog)

k : hydrological conductivity of the peat (m/day)

also R : radius of the bog (m)

B : width of the bog (m) (B = 2R)

Solving the above two equations using the following boundary conditions:

$$r = 0 \text{ than } Q = 0 \text{ and } r = R \text{ than } h = 0$$

yields:

$$h^2 = U/(2k) \,.\, (R^2 - r^2) \qquad (1)$$

The relationship between the height of the groundwater and the height of the bog in the centre (hm) and the width of the bog (B)is:

$$hm = B\sqrt{(U/8k)} \qquad (2)$$

This means that there is a linear relation between the height of the water table in the centre (hm) and the width of the bog.

CASE II

Figure 3 shows the more realistic model used for this case. In this model it is assumed that the horizontal groundwater occurs in the upper layer of the peat (D). This upper layer is synonymous with the acrotelm concept (see Ingram, 1982; Ivanov, 1981). It is assumed that in the remainder of the peat, the catotelm, only a very small vertical flow of groundwater to the mineral subsoil takes place.

The groundwater flow in the Case II model can be described by:

$$Q = -2\pi r \,.\, D \,.\, k \,.\, dh/dr \qquad \text{(Darcy's law)}$$

$$dQ = 2\pi r \,.\, U \,.\, dr \qquad \text{(Continuity)}$$

where D is the thickness of the acrotelm; other symbols are as previously described.

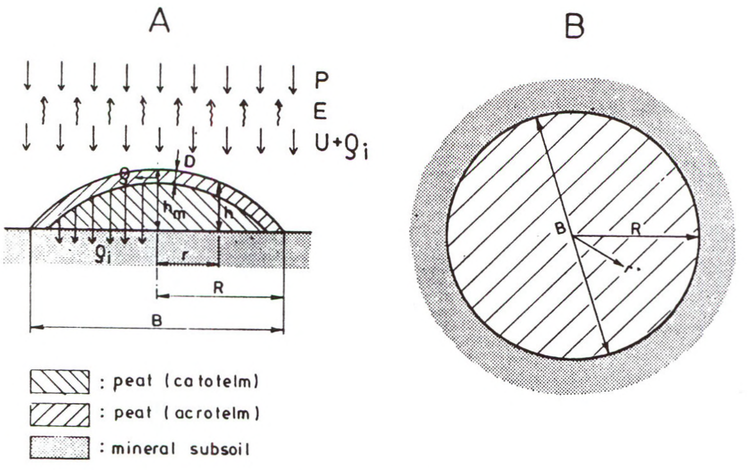

Figure 3. Model of a raised bog used in Case II.
A: cross section B: top view

Solving the two equations using the following boundary conditions:

$$r = 0 \text{ than } Q = 0 \text{ and } r = R \text{ than } h = 0$$

yields:

$$h = U/(4k \cdot D) \cdot (R^2 - r^2) \qquad (3)$$

$$hm = U/(16k \cdot D) \cdot B^2 \qquad (4)$$

According to this model, the relationship between hm and b is not linear but quadratic.

RESULTS

In order to evaluate the two approaches presented here, it is necessary to estimate the values of U and k. U is defined as:

$$U = P - E - Qi$$

where P : precipitation (m/day)
E : evapotranspiration (m/day)
Qi : seepage of groundwater from the bog to the mineral subsoil (m/day)

For conditions which prevail in the Netherlands, the values of P, E and Qi are 750, 550 and several tens of mm/year, respectively, which for U yields:

$$U = 750 - 550 - 30 = 170 \text{ mm/year}$$

This 170mm/year is the amount of the precipitation which has to be transported horizontally through or over the peat.

Values for k are known from the literature (Table 1).

Table 1. k-values of some types of peat according to data from the literature (see Joosten & Bakker, 1987).

Living *Sphagnum* peat	k = some tenths of m/day
Sphagnum peat (young)	k = 0.5 - 2.0 m/day
Sphagnum peat (old)	k = 0.1 - 0.01 m/day
Reed peat	k = 0.2 m/day
Wood peat	k = 0.5 m/day
Gliede	k = 0.001 - 0.0001 m/day

With the above data the relationship between hm and R can be evaluated. For young bogs consisting mainly of living and young *Sphagnum* peat, k is taken as 3m/day and the acrotelm is assumed to have a thickness of 0.5m. Using these values, equations (2) and (4) yield:

Formula (2)	Formula (4)
$hm = \sqrt{(0.000465/(8 \times 3))} \cdot B$	$hm = 0.000465/(16 \times 3 \times 0.5) \cdot B^2$
$hm = 0.0044 \cdot B$	$hm = 0.0000194 \cdot B^2$

These relationships are shown in Figure 4 together with values from undisturbed bogs in areas with different amounts of precipitation in Sweden (Granlund, 1932). For areas with precipitations of 700 and 800 mm/year, growth in height diminishes with increasing width of the bog i.e. the vertical growth of the middle of the bog decreases with time.

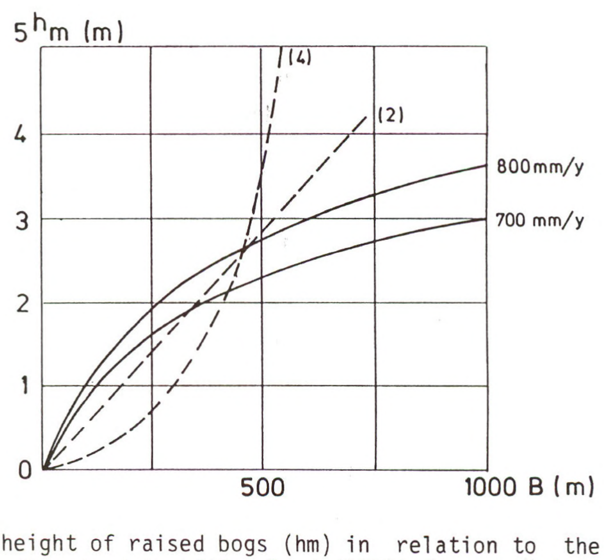

Figure 4. The height of raised bogs (hm) in relation to the width (B) according to data of Granlund (1932) for a precipitation of 700 and 800 mm/year and to the mathematical relations in this paper.

According to the relations between hm and B presented in this paper, this can only be due to a decrease of U or to an increase in k. The first cannot be the case because precipitation, evapotranspiration and seepage to the mineral subsoil are more or less constant in time. From this it follows that U will also remain relatively constant. This implies that the hydrological conductivity of a raised bog has to increase in time.

Figure 5 shows the relationship between hm and B for undisturbed bogs in real situations according to Granlund (1932) and Eggelsmann (1967). Using the data from Figure 5 and equations (2) and (4), values of k can be calculated. These are shown in Table 2.

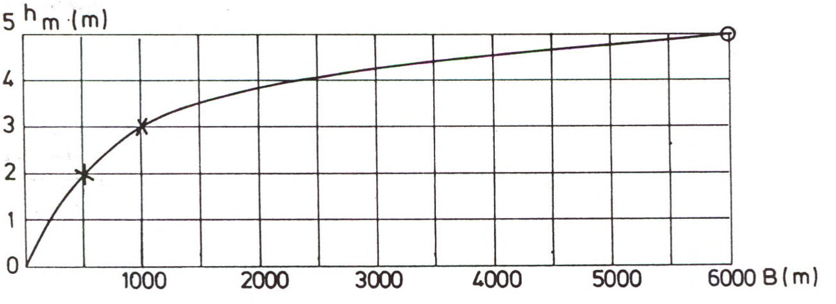

Figure 5. The relationship between hm and B according to Granlund (1932) and Eggelsman (1967) for areas with a precipitation of approximately 750 mm/year. (X - Granlund ; 0 - Eggelsman).

Table 2. Width (B) and height (hm) from Figure 5 and calculated values of k derived fron equations (2) and (4).

B (m)	hm (m)	k (2) (m/day)	k (4) (m/day)
100	0.5	2.3	1.2
500	1.9	4.0	8.0
1000	3.0	6.5	19
2000	3.8	16	61
3000	4.2	30	125
4000	4.5	46	207
5000	4.7	66	309
6000	5.0	84	419

From Table 2 it can be seen that the magnitude of k, k(2) as the average value for the complete thickness of the bog and k(4) as the average value for the upper 0.5 metre of the bog, is increasing with time. An explanation of this phenomenon is that the amount of open water in the upper layer of a bog increases with time. this means that the ponds ("Mooraugen, "Meerstallen") serve mainly to allow a large discharge of water from the bog.

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PROBLEMATIC STRUCTURE STANDARDS OF HORTICULTURAL PEAT

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SUMMARY

It is well known that structure standards for horticultural peat are of limited value due to the high variability of the results of analyses. The reasons for this are usually attributed to the analytical methods employed. In this account, however, the primary reasons are ascribed to changes in the peat colloids caused by the drying of the peat during production and storage. The more the peat dries, the more its colloidal properties change and the wider the dispersion of the results of structure analyses, independent of the analytical methods used. A clear distinction must be made between the reversible colloids of undecomposed *Sphagnum* remains and the irreversible humic acids, which are mostly decomposition products of woody plants.

INTRODUCTION

Standards for the structural characteristics of horticultural peats are still required. Over the years, many different criteria and methods have been suggested and developed, including those proposed by the International Peat Society (Puustjärvi & Robertson, 1975), but few are used in practice. The reason for this is clearly illustrated in Table 1, which shows the great variability in results obtained when industrially-produced substrates were analysed at 23 laboratories in 12 countries (Schmilewski & Günther, 1988). How is it possible that, for example, an important characteristic like air capacity of one and the same sample of *Sphagnum* moss peat substrate can range from 9% to 53%?

The results in Table 1 indicate quite clearly, *inter alia*, that the current structure standards for peat are of little value. What is the reason for this? Usually, it has been ascribed to the analytical methods employed. This is, of course, one reason but it is very unlikely to account for the whole problem. There must be some primary factors that affect the relevant structural properties of peat. These should be considered when interpreting analytical results.

Table 1. Variation in the results of physical analyses of 5 horticultural substrates carried out according to the customary methods used in 23 laboratories in 12 countries (Schmilewski & Günther, 1988).

Sample No.	Loose density g/l	Pore volume %	Water capacity %	Air capacity %
1	81-121	91.7-94.8	40.6-85.0	9.0-52.5
2	110-166	88.5-94.8	48.3-87.0	4.0-46.5
3	120-194	86.6-94.9	48.0-82.0	0.4-40.9
4	190-276	84.2-95.3	51.1-83.0	2.4-49.4
5	160-253	84.1-96.6	38.3-85.5	0.7-58.5

Sample 1: Light *Sphagnum* moss peat
" 2: 70% black peat and 30% light *Sphagnum* moss peat
" 3: 70% frozen black peat and 30% rockwool
" 4: "Einheitserde T"
" 5: A ready-mixed substrate composed of composted bark and raised bog peat

SUBSTRATE STRUCTURE FROM THE PLANT'S STANDPOINT

The growth of the plant is related to the water and air economies of the substrate, i.e. to its structure. The overall structure of the substrate is a resultant of the arrangement and bonding of individual substrate particles into structural units, and of the arrangement and bonding of these units. Therefore, a complete quantitative characterization of the peat structure would involve an evaluation of the size and shape of the structural units and the size distribution and continuity of pore spaces within and between the units. Hence, peat structure is a complex phenomenon that cannot be characterized precisely by a single measurement. The quantitative methods presently in use evaluate only a portion of the overall phenomenon. A question arises as to which single measurements are of greatest significance to the growth of the plant.

As far as the plant is concerned, soil structure equates largely with porosity. Root hairs require pores larger than about 10µm for growth and development. Water moves freely only through pores larger than about 300µm and young roots also need pores of about this size for easy entry. Water only drains out of the soil through pores larger than 30µm. Consequently, the pore size distribution of the peat substrate is the most important property to be standardized.

PORE SIZE DISTRIBUTION

As already mentioned, the pore size distribution is the most important characteristic of peat structure. Unfortunately, it can be measured only by using indirect methods. The most widely used are sieve analysis and the determination of the curve of peat moisture characteristics.

SIEVE ANALYSIS

In this procedure, a sample of air-dry peat is placed in a nest of sieves, which is shaken over a certain time and in a certain way to separate different size fractions from each other. After this, the pore size distribution can be estimated using arithmetical calculations. This method concerns only the pores between peat aggregates - not those within them. It may give, however, useful information on differences in the structure of peats of similar type (for example, weakly decomposed *Sphagnum* moss peats).

In most cases, however, the results of sieve analyses are given directly as particle size distribution (textural grades) and have been included as such in peat standards (Puustjärvi & Robertson, 1975).

Sieve analysis is rather sensitive to the moisture content of the peat as illustrated in Table 2, which shows that the particle size decreases as the peat dries. For example, when the proportion of <0.5mm particles was only 0.13% in the moistest peat, it was as high as 19.5% in the driest sample. This is obviously due to the fact that small peat particles with

Table 2. The results of a sieve analysis of light *Sphagnum* moss peat at three different moisture contents (Puustjärvi, 1982).

Particle size mm	Moisture content, % by weight 69	57	26
<0.5	0.13	3.8	19.5
0.5 - 1.0	1.8	17.6	17.1
1.0 - 2.0	21.1	30.4	15.4
2.0 - 4.0	36.0	17.2	13.4
4.0 - 8.0	28.1	16.1	15.5
8.0 -16.0	9.6	10.6	12.5
>16	3.4	4.3	5.9

a large surface area compared to their weight adhere to each other as a consequence of the higher moisture content to form large peat aggregates. On the other hand, it should be borne in mind that sieving makes peat finer than it really is, as is shown in Table 3 (Puustjärvi, 1977).

Table 3. The effect of sieving on the break-down of peat. The same peat samples in 10 replicates were sieved three times without mixing the different grades between each riddling.

Diameter mm	1st sieving % by weight	2nd sieving % by weight	3rd sieving % by weight
>10	7.0	6.1	5.5
10 - 20	12.9	12.5	11.6
4 - 10	21.9	21.8	21.8
2 - 4	12.9	12.9	12.9
1 - 2	12.3	12.3	12.5
<1	33.3	34.6	35.6

A comparison of Tables 2 & 3 shows that the effect of moisture content on particle size analysis is much more striking than that of the sieving. Hence, it seems advisable to sieve peat samples when relatively dry.

CURVE OF THE PEAT MOISTURE CHARACTERISTIC

The curve of the peat moisture characteristic is obtained when the moisture content of the peat is plotted against its matrix potential. The equivalent pore size distribution can be calculated from it. The pores between and within the particles are included. Since the matrix potential is inversely proportional to the effective radius of the pores containing the air-water menisci, the slope of the curve plotted against the matrix potential gives a picture of the pore size distribution in the peat.

Figure 1 provides the basic information on the water and air economies of four peat substrates within the matrix potential range of 0-100 mbar (pF 0-2) (Puustjarvi & Robertson, 1975). The figure shows that the air capacity (total pore space - water space) of coarse *Sphagnum* moss peat at -5mbar is about 26% by volume whereas the black peat at the same water potential is entirely saturated with water - it does not contain any air at all. It is, therefore, obvious that the coarser the peat under the higher matrix potential, the more important it is to measure the water and air capacities, and vice versa.

In many analytical methods the water and air capacities are measured at different matrix potentials, for example at -5, -50 and -100mbar. The two last mentioned potentials are advisable, as during culture the matrix potential is kept just at these levels. However, the water content of peat after ample irrigation is most problematic - especially at the beginning of the culture. After this kind of irrigation, the fine-structured peats may almost be saturated with water. Here it might be advisable to give the water and air capacities of peat products as measured at container capacity (-5 mbar). The air capacity of light *Sphagnum* peat ranges from about 8% to 30% by volume.

In light *Sphagnum* moss peat, the water and air space gradients are almost constant (according to our measurement about 0.56 volume-%-units per one cm of depth) as shown in Figure 2. Therefore, the water and air capacities given at container capacity might be sufficient without the need for measurements at lower potentials.

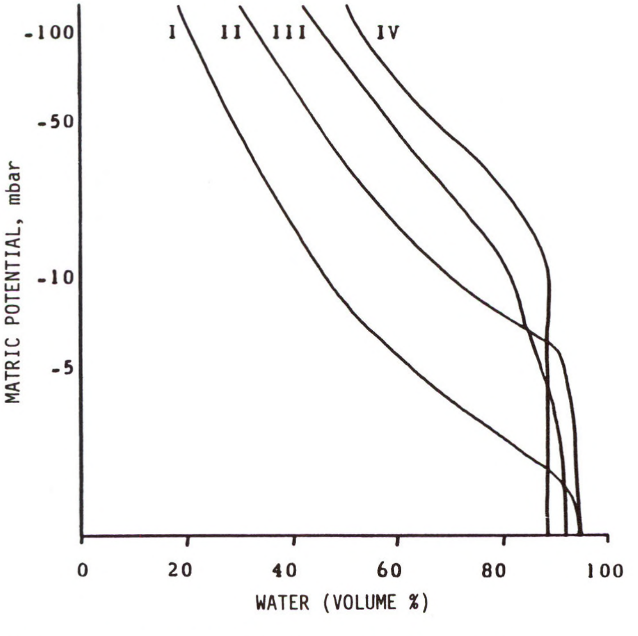

Figure 1. Moisture characteristic curves for different types of peat.
I : Coarse *Sphagnum* peat (light)
II : Medium coarse *Sphagnum* peat (light).
III : Fine *Sphagnum* peat (dark).
IV : Black peat.

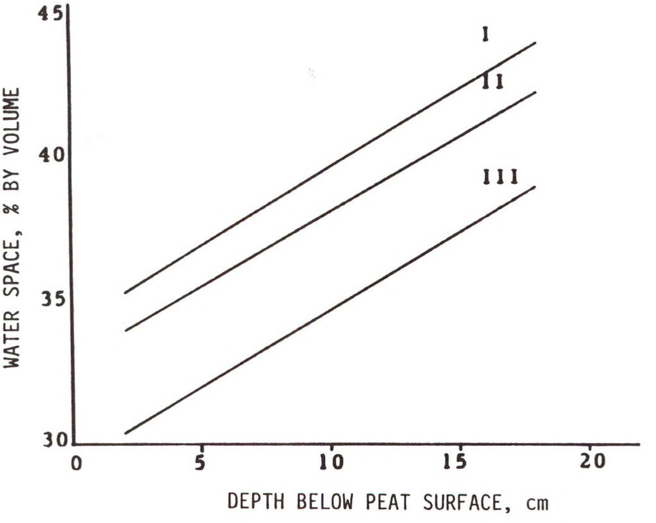

Figure 2. The water spaces of fine (I), medium (II) and coarse (III) *Sphagnum* moss peats as a function of the depth below the peat surface.

THE EFFECT OF DRYING ON PEAT STRUCTURE

THE COLLOIDAL STATE OF PEAT

Peats - including undecomposed *Sphagnum* plants - contain a considerable amount of organic colloids. Due to their large specific surface, such colloids constitute the most important ingredients of the peats. This increased surface area gives rise to pronounced surface phenomena, in particular, to the process of adsorption, which is the concentration of gas, liquid, solid, or the solute, or a solvent of a solution at the interface.

The colloidal state of peat depends on its water content. For example, the ability of peat to bind water decreases during drying and simultaneously the peat shrinks. Both of these phenomena are seen in the structure of peat. Hence, the loose density as well as the water and air capacities are functions of the moisture content of peat at the moment of measurement.

Peat in its natural state has a very high moisture content. During plant culture it is also kept wet, its matric potential ranging from about -30 to -100 mbar. Prior to excavation, the bog must be drained and the peat is dried further during production. During storage, its water content is about 50% by weight, corresponding to a matrix suction of about 1 to 10 bars. Since this suction is exerted by the air-water menisci on the peat particles, it pulls the particles together and results in the shrinkage of the peat during drying. Therefore, the loose density of peat is a function of the water content. This should be taken into account when interpreting analytical results for peat structure.

THE EFFECT OF DIFFERENT TYPES OF COLLOIDS ON THE STRUCTURE OF PEAT DURING DRYING

Most of the colloids of virgin peat have an affinity for water and it is due to them that the water-holding capacity of peat is so high. Drying has a different effect on different colloids. When, for example, the humic acids dry out, the peat hardens into coal-like clods, which are very difficult to remoisten. On the other hand, the colloids of pure *Sphagnum* moss peat are easy to rewet after drying, provided the peat is not over-dried. If it is, it cannot be rewetted. In such a case, it can be used for combating oil pollution.

It is easy to understand that even small amounts of different types of colloid may have a significant effect on the water-holding capacity of peats. This is shown in Figure 3. Light *Sphagnum* moss peat samples (200) were divided into two groups:

Group I: Residues of *Sphagnum* mosses at least 40% by weight and of woody plants less than 3%.

Group II: Residues of *Sphagnum* mosses from 75 to 91% and of woody plants more than 3%.

The material of both groups was further divided on the basis of the percentage of particles <1mm: 0-10%, 10-20%, etc. Then the water and air capacities were measured at -5mbar. Figure 3 shows that the air capacity of pure *Sphagnum* peat is a rectilinear function of the particle size distribution. Light *Sphagnum* peat with a significant content of wood remains, on the contrary, does not show any correlation between the air capacity and the particle size distribution. The reason for this lies obviously in the significant amount of humic acids in the *Sphagnum* moss peat containing woody remains. The humic acids have a reduced particle size and air capacity, and an increased water capacity and loose density.

The woody remains in light *Sphagnum* moss peat may have a striking effect on the air capacity of peat if they have decomposed in stockpiles. As very active and almost entirely irreversible colloids, they make peat

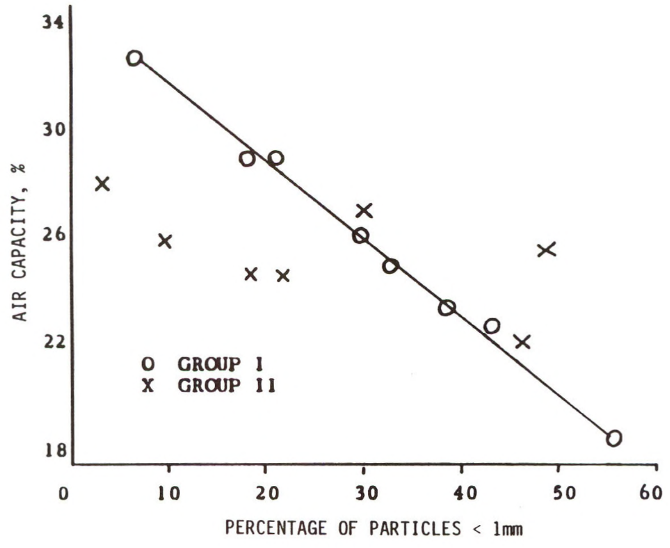

Figure 3. The effect of the percentage of <1mm particles on the air capacity of light *Sphagnum* moss peat. Group I : Pure *Sphagnum* moss peat. Group II : *Sphagnum* moss peat with woody residues.

water-repellent. For this reason, the conventional determination of air capacity results in abnormally large and inaccurate values of up to 50-70% (Puustjärvi, 1982).

CONCLUSIONS

1. Peat structure is a very complex phenomenon that cannot be characterized precisely by single physical measurements. The quantitative methods presently in use evaluate only a portion of the overall phenomenon.

2. The most difficult problem is caused by the drying of peat during production and storage. Even small changes in the colloid content of peat and in its moisture content may have a striking effect on its structure parameters.

3. The more coarse-structured the peat at the higher matrix potential, the more important it is to measure the water and air capacities. The advisable matrix potential for light *Sphagnum* peat moss might be -5 mbar (container capacity). This indicates the large pores, through which water moves freely. Simultaneously, these pores represent the absolute air capacity.

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HYDRAULIC RESISTANCE OF PEAT LAYERS AND DOWNWARD SEEPAGE IN BOG RELICTS

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SUMMARY

In many bog relicts in northwestern Europe, attempts have been made to restore the former bog vegetation. To create suitable ecological and hydrological conditions for the ombrotrophic vegetation, it is necessary to reduce water losses. In order to evaluate the impact of different water management measures, it is important to quantify downward seepage from the bog relicts to the underlying aquifer.

In the Engbertsdijksvenen (Netherlands), the water balances of three small catchments (15 - 25ha) were studied. In the winter period, downward seepage varied from ca. 0.2mm day^{-1} (in strongly humified peat relicts more than 2.5m thick) to ca. 1.4mm day^{-1} (from pools with on average only a 20cm- thick peat layer at the bottom). It was found that the vertical hydraulic resistance of the lower strongly humified Sphagnum peat layers is an almost linear function of their total thickness. Values are in the range of 3500-4000 days m^{-1}, which corresponds to an average saturated hydraulic conductivity of ca.0.25-0.30mm day^{-1}.

INTRODUCTION

In the Netherlands, bog relicts cover about 9000ha, which is only 5% of the area occupied by bogs in the 17th century. In most of these relicts, the upper peat layers have been cut away and the thickness of the remaining peat layers varies considerably. In the Netherlands as well as in Lower Saxony (F.R.G.) most of these areas are managed as nature reserves or will be managed as such after the peat mining activities have ended. Because of the scarcity of oligotrophic wetlands in this part of northwestern Europe, the main objective for their management is the restoration of the original bog vegetation. Eggelsmann (1988) describes experiences in Germany and presents hydrological guidelines for rewetting and restoration. Joosten (1989) discusses several options for the regeneration of bogs.

In many relicts it is observed that, in summer, the groundwater level drops below 40cm depth, which is commonly accepted as the critical level for the growth of bog plant communities (Verry, 1988). In recent studies (Schouwenaars, 1988a & 1988b; Schouwenaars & Vink, 1990) it is shown that the hydrophysical properties of the upper peat layers play a dominant role in the pattern of groundwater fluctuation. During peat mining, the bogs were drained and in many bog relicts deep open drains cut into the underlying sandy aquifer. As a consequence, downward seepage from these areas has increased when compared with undisturbed bogs. From the water balance of a relatively undisturbed bog in Konigsmoor (F.R.G.), Eggelsmann (1960) found a downward seepage of 35-40 mm year^{-1}. Blankenburg and Kuntze (1987) argue that the thickness of the remaining peat layers, originally the lowest, oldest and most compacted ones with a very low permeability, should be at least 0.5m to guarantee that downward water losses remain less than 60mm year^{-1}.

In many bog relicts attempts have been made to reduce downward seepage by refilling the open drains which cut into the underlying aquifer and by diverting agricultural drainage channels that cross the areas. For several bog relicts, it is considered that only the creation of hydrological buffer zones will reduce the losses to an acceptable level. One of the problems in the design of such zones is that the vertical permeability of the peat relicts varies considerably. As a consequence, the hydraulic resistance of the peat layers can only be estimated roughly.

The experiences mentioned above have led to this study in which the water balance of 3 small catchments in a bog relict are analysed and downward seepage is determined. This enables the study of seepage in relation to the thickness of the peat layers and the piezometric heads in the aquifer beneath the peat. An attempt is made to draw some general conclusions on the relation between the thickness of the peat remnants and downward seepage in bog relicts.

DESCRIPTION OF THE STUDY AREA

The study area of 850ha (Fig. 1) is situated in the eastern part of the Netherlands near the border with the F.R.G. ($52^{o}28'$N, $6^{o}40'$E). In the Weichsel glacial, near the end of the Pleistocene era, aeolian sands were deposited. In the Holocene, peat growth started on these sands, becoming general during the Atlanticum (8000-5000 B.P.). In this period, several metres of oligotrophic *Sphagnum* peat were formed, which are now strongly humified ('black' peat, Schwartztorf).

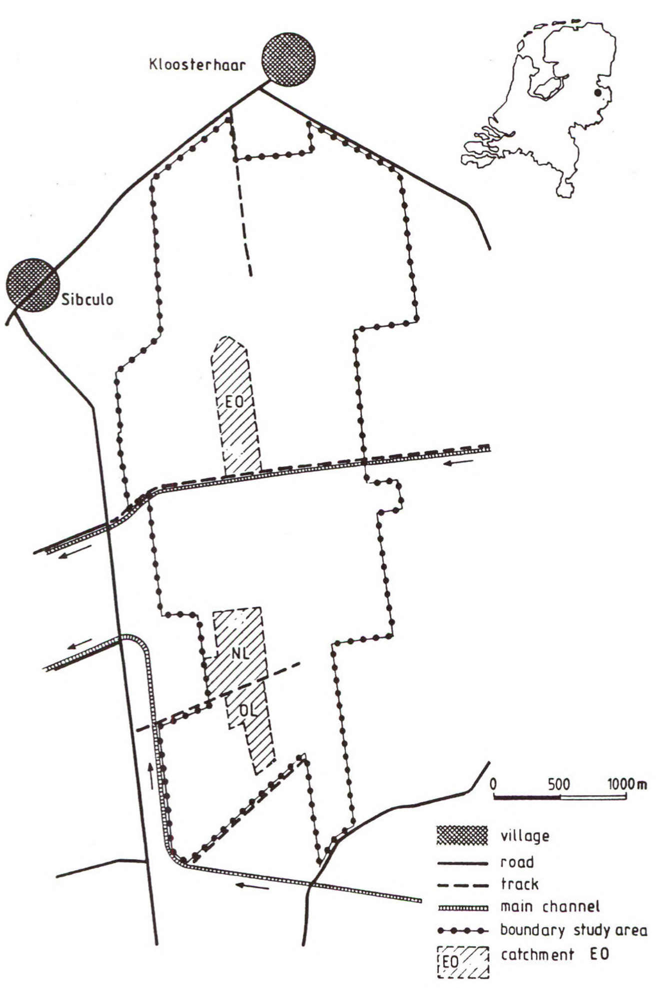

Figure 1. The Engbertsdijksvenen area and the location of the catchments.

In the sub-Atlanticum (from ca. 3000 B.P.) 'young' *Sphagnum* moss peat was formed under relatively cold and wet conditions. In some parts of the study area these layers, which are slightly to moderately humified, are still present ('white' peat, 'Weisstorf'). Their thickness varies from 0.5 to 1.5 metres. In most parts of the area they were completely removed by the peat mining industry. As a consequence, the older strongly humified peat now lies at the surface. The different peat mining concessions in the Engbertsdijksvenen expired between 1953 and 1983 and thereafter the State Forestry Service began to manage these areas, the aim being to reestablish the original ombrotrophic bog vegetation. After excavation, vegetation development on the remaining bare peat soils has led to a dense cover of *Molinia caerulea*, often with *Betula pubescens*. In most parts of the study area, water levels were raised by the construction of small dams in former drains. Under these wet conditions, birches have less chance and heather species like *Calluna vulgaris* and *Erica tetralix* may become dominant. The peat mining activities resulted in large spatial differences in topography and consequently in different properties of the upper peat layers. Some species like *Andromeda polifolia* and many *Sphagnum* species seem to grow exclusively on sites where the less humified peat layers are still present.

The mean annual precipitation in the area is 754mm. Mean annual evaporation from open water is about 600mm and evapotranspiration from vegetated sites is estimated at about 480mm.

WATER BALANCE STUDIES

WATER BALANCE TERMS

Bogs and bog relicts are ombrogenous, which means that they are fed only by precipitation. They are situated on relatively high parts of the landscape. Therefore their water balance is simple:

$$P = E + R + L + S + dB$$

where P is precipitation, E is evapotranspiration, R is superficial runoff, L is lateral water loss through the peat relicts, S is downward seepage, and dB is the change in water storage within the catchment. All terms can be expressed in mm per period.

CATCHMENTS

Three catchments were selected for measurement. They show differences in topography, area of open water and thickness of the peat layers (Fig.1). The Engbertsdijk-Oost (EO) catchment is 25.5ha in area and shows a very regular pattern of peat ridges (3 to 5m wide), alternating with parallel water-holding gullies (1 to 5m wide). About 30% of the area consists of open water. In the northern part, the total thickness of the peat layers is 4m, the upper metre being only slightly humified. In the southern part, this upper peat layer has been removed and here the moderately to strongly humified peat relict is about 2.5m thick. Because the gullies are about 0.5m deep, the minimum thickness of the peat layers within the catchment is 2m. Superficial runoff occurs in the winter period and this water flows southwards, perpendicular to the orientation of the ridges and gullies, overflowing the former at low places. Two larger drains have the same north-south orientation but in recent years they were blocked to rewet the area. The vegetation is dominated by *Molinia caerulea*. Locally, *Erica* *tetralix* is abundant.

The Nieuwe Leidijk (NL) catchment covers 22.7ha of which only 10% is permanently open water. The greater part consists of a 2m-thick, strongly humified peat relict in which small, water-holding, blocked drains occur at intervals of 15 to 20m. Over a smaller part of the area, a 0.5m-thick slightly humified peat layer still remains on top of the former 2m layer. Excess water flows to a long shallow pool with an outlet to the south. The thickness of the peat layer below the bottom of the pool varies from 0.4 to 1m. Most of the area is covered with dense *Molinia* vegetation.

The Oude Leidijk (OL) catchment covers 15.0 ha of which 70% comprises open water. The large pools were created when the lowest parts of the area were inundated after peat cutting. At the bottom of these pools, the thickness of the peat relict varies from 0.2 to 0.8m and some former drains reach into the underlying sand. In the eastern part, the peat relicts are 1.5 to 2m deep. Outwith the pools, the vegetation is dominated by *Molinia* and *Betula pubescens*. The OL catchment receives the discharge from the NL catchment.

RAINFALL

Rainfall was recorded at two sites. One recorder with permanent registration was installed near Kloosterhaar in the northern part of the study area. In the NL catchment, a raingauge was used to record weekly totals. The measurement error is estimated at 2%.

EVAPOTRANSPIRATION

Potential evapotranspiration was calculated by multiplying the reference values of Makkink (Feddes, 1987), obtained from a nearby meteorological station, by a correction factor.

Feddes (1987) shows that, in summer, the factor to be used for the calculation of open water evaporation varies from 1.30 in April to 1.17 in September. In the winter, many sites in the study area are inundated and almost no green plants are present. However, the dead leaves of *Molinia* cause considerable evaporation of intercepted water. Therefore in this study, the correction factor for winter periods is taken at 1.1. The error is estimated at 5%.

For summer periods, the factor has been determined from lysimeter experiments (Schouwenaars, 1990).

DISCHARGE MEASUREMENTS

In the EO catchment, weekly cumulative values of the discharge were measured with a watermeter installed in a tube with a diameter of 10cm. Its accuracy is very high and measurement errors are estimated at 5%. In the other catchments, a V-shaped long, crested weir was installed and water levels were permanently recorded. With a discharge lower than ca. 5 litres sec^{-1}, as often occurred in the winter period 1988-89, its accuracy is low. From tests in these periods, it was concluded that discharge might have been systematically underestimated by 15%.

WATER STORAGE

At different sites, open water and groundwater levels were permanently recorded. In addition, weekly observed piezometers were used. The average observation density was 1 per 3ha. For the peat soils in question, the water storage coefficient is taken at 25% (Schouwenaars & Vink, 1990). For each catchment, the different sites are supposed to be representative for a given part of the catchment. Hence, the changes in total water storage can be derived from the observed water level fluctuations. Because of the great spatial diversity of both the pattern of peat relicts and their hydrophysical properties, the errors in the determination of stored water quantities are significant and taken at 30%. To reduce the impact of these uncertainties, the periods for which water balances are determined are selected in such a way that on both the first and the last day of the balance period the observed water levels are almost equal.

LATERAL AND DOWNWARD SEEPAGE

These terms are determined from the water balance equations, using the measured values discussed above.

THE RELATION BETWEEN HYDRAULIC RESISTANCE AND THICKNESS OF THE PEAT LAYERS

In the case of downward seepage, Darcy's equation for the relation between flux density q (m day^{-1}), the difference in hydraulic head between two points ΔH(m) and the hydraulic resistance c (days) is:

$$q = \Delta H / c \qquad (1)$$

The hydraulic resistance can also be described as:

$$c = d_1/k_1 + d_2/k_2 \ldots\ldots\ldots\ldots\ldots d_n/k_n$$

where d is thickness (m) and k the hydraulic permeability (m day^{-1}) of the respective layers (i = 1, n) between the two points.

Measurements of the phreatic levels in the peat and the piezometric heads in the underlying sand layer, combined with measured downward fluxes, allow the determination of the total hydraulic resistance of the peat layers.

Many authors have shown that the hydraulic permeability of peat layers decreases with increasing degree of decomposition of the peat (e.g. Baden & Eggelsmann, 1963; Boelter, 1969). Hence, in a bog profile, hydraulic resistance is greatest in the lowest, stongly humified peat layers. We can describe the vertical hydraulic resistance (c) as a function of total thickness of the peat layers (D) as follows:

$$c = a \,.\, D^b \qquad (a > 0,\ b > 0) \qquad (2)$$

For a peat profile with slightly humified peat on top of strongly humified peat, one may expect the value for parameter b to be less than 1. Equations 1 and 2 give:

$$q = \Delta H \,/\, a \,.\, D^b \qquad (3)$$

Every catchment was divided into sub-areas (i = 1, n). For every sub-area i, with a given average thickness of the peat D_i, Equation 3 was applied, using data of both phreatic tubes and deep piezometers. With an area A_i of the sub-area i, the total seepage Qc ($m^3\ day^{-1}$) of the catchment is:

$$Qc = \sum_{i=1}^{n} q_i \,.\, A_i$$

combined with Equation 3:

$$Qc = \sum_{i=1}^{n} H_i \,.\, A_i \,/\, a \,.\, D_i^{\,b} \qquad (4)$$

For every catchment the difference between the measured seepage Qm (from the water balance) and calculated Qc can be determined. A sensitivity analysis was made for different sets of values for a and b in Equation 4.

RESULTS

Values of water balance terms for different periods in the winter 1988-89 are shown in Table 1. Totals for downward and lateral seepage are given as the calculated average over the balance period and expressed in mm day^{-1}.

From Table 1 it can be concluded that downward and lateral losses are highest in periods with high rainfall. In these periods with high water levels some unmeasured superficial runoff (leakage) may occur and lateral flow through the upper slightly humified peat layers (if present) may be substantial. In the northern part of the EO-catchment, some lateral seepage may occur in the 0.5-1.0m-thick less humified upper peat layer (slightly humified with relatively high horizontal permeability). For this catchment the average downward seepage is estimated at 0.15-0.20 mm day^{-1}. In the northwestern part of the NL catchment, some lateral outflow was observed through the 0.5m-thick upper peat layer. Given these observations, average downward seepage in the NL catchment is estimated at 0.25-0.50mm day^{-1}. For the OL catchment, average downward seepage is estimated at 1.0-1.4mm day^{-1}.

Table 1. Water balance parameter values (mm day^{-1}) for 3 catchments in the Engbertsdijksvenen in the winter period 1988-1989.

Location & period (day/month)	Precipitation	Evapotranspiration	Storage loss	Discharge 1)	Downward + lateral seepage	Estimated error 2)
ENGB. DIJK-OOST						
8 Dec- 9 Jan	2.17	0.17	0.58	2.38	0.20	±0.21
14 Dec- 3 Mar	1.85	0.40	0.16	1.44	0.17	±0.10
8 Dec-14 Mar	1.89	0.37	0.06	1.35	0.23	±0.08
NIEUWE LEIDIJK						
16 Nov- 3 Jan	2.48	0.21	0.01	1.36	0.92	+0.05/-0.25
16 Nov-18 Jan	2.22	0.21	-0.05	1.05	0.91	+0.05/-0.21
16 Nov-24 Jan	2.05	0.21	0.02	1.15	0.71	+0.04/-0.21
16 Nov-16 Feb	1.83	0.29	-0.08	0.94	0.52	+0.05/-0.19
23 Dec-24 Feb	1.26	0.36	0.08	0.82	0.16	+0.04/-0.16
3 Jan-16 Feb	1.07	0.38	-0.18	0.44	0.07	+0.06/-0.12
OUDE LEIDIJK						
25 Oct-30 Nov	1.47	0.45	0.71	-0.12	1.85	+0.24/-0.20
16 Nov- 9 Feb	1.76	0.16	0.05	0.67	0.98	-0.06/-0.14
14 Dec-24 Feb	1.75	0.34	0.12	0.36	1.17	-0.03/-0.13
14 Dec-14 Mar	1.89	0.41	-0.05	0.08	1.45	+0.03/-0.05
25 Oct-14 Mar	1.89	0.40	-0.29	0.13	1.06	+0.07/-0.13

1) For the OL catchment this is the difference between its discharge and the recharge from the NL catchment.

2) Based upon the following errors for the different terms: Precipitation 2%; evapotranspiration 5%; storage loss 30%; discharge for watermeter (EO) 5%. For the weirs in NL and OL, discharge might be systematically underestimated by 15%.

An example of the calculations based upon Equation 4 is presented in Table 2 (where c = 3500 $D^{1.0}$).

Table 2. Calculated downward seepage in the 3 catchments using a unique relation between the thickness of the peat layers and the hydraulic resistance and its comparison with the seepage determined from the water balance studies.

Catchment	Sub-area	Area	Head loss 1)	Peat layer thickness	Hydraulic resistance	Downward seepage	Total downward loss
		A (ha)	ΔH (m)	D (m)	c=3500 $D^{1.0}$ (days)	qc (mm day^{-1})	Qc (m^3 day^{-1})
EO	1	2.5	3.0	4.0	14000	0.21	5.36
	2	8.5	2.5	3.5	12250	0.20	17.35
	3	3.0	2.5	3.0	10500	0.24	7.14
	4	8.0	2.5	2.5	8750	0.29	22.86
	5	3.5	2.0	2.0	7000	0.29	10.00
							62.71
NL	1	2.7	2.5	2.5	8750	0.29	7.71
	2	14.1	2.0	2.0	7000	0.29	40.29
	3	3.8	1.5	1.5	5250	0.29	10.86
	4	2.1	1.8	0.5	1750	1.03	21.60
							80.46
OL	1	3.8	1.0	0.2	700	1.43	54.29
	2	7.2	1.2	0.3	1050	1.14	82.29
	3	4.0	1.5	1.5	5250	0.29	11.43
							148.01

1) When the piezometric head in the sand is below the peat base only the head loss over the peat layers is regarded.

A further examination of the hydraulic resistance was made by varying the values for the parameters a and b in Equation 4. In Table 3, both the measured and the calculated downward seepage are presented for the most relevant values of **a** (3500 < a < 4500) and **b** (0.7 < b < 1.0).

Table 3. Measured downward seepage from the 3 catchments and calculated values using different parameter sets for the relation between thickness of the peat and its hydraulic resistance.

Catch-ment	Measured average seepage	Measured total seepage	Calculated seepage with $c = a \cdot D^b$ (days) a = 3500, b = 0.7	a = 3500, b = 0.8	a = 3500, b = 0.9	a = 3500, b = 1.0	a = 3000, b = 1.0	a = 4000, b = 1.0
	($mm\ day^{-1}$)	($m^3\ day^{-1}$)	($m^3\ day^{-1}$)					
EO	0.15-0.20	38- 51	86	77	70	63	73	55
NL	0.25-0.50	57-114	90	86	83	80	94	70
OL	1.00-1.40	150-210	104	116	131	148	173	130

CONCLUSIONS AND DISCUSSION

From Table 3 it is concluded that the hydraulic resistance (c) of the peat layers in the study area can be described as a function of their total thickness (D) by using Equation 2 where:

$$3500 < a < 4000 \text{ and } b \sim 1.0$$

In Table 3 it is shown that with these c-values the downward seepage in the OL catchment is somewhat underestimated. Some former drains reaching into the sand probably caused the measured seepage to be higher than the one calculated (Table 3).

For $D > 1$m a lower b-value (eg 0.7) would result in a reduced resistance and higher losses. For $D < 1$m results will be the opposite (see Table 3: EO and OL catchments, repsectively). For the moderately to strongly humified peat layers in the study area there is no indication that values for b should be taken less than 1.0.

In most parts of the study area, the piezometric head in the sand is below the base of the peat. For the calculation of downward fluxes through the peat layers as a function of their total hydraulic resistance, only the head loss over the peat layers is of importance. During the winter period the phreatic water level mostly equals surface level. In that case, which does not hold for pools (eg OL-catchment), downward seepage is independent of the thickness of the peat layers and always yields about 0.25-0.30mm day^{-1}. This value corresponds well with the average vertical saturated hydraulic conductivity of the strongly humified peat layers in the study area for which Schouwenaars and Vink (1990) found values from 0.1 to 0.6 mm day^{-1}. This implies that yearly downward seepage amounts to 80-100mm. Before peatland exploitation, piezometric heads in the underlying sand were higher and downward seepage from the undisturbed bog in the study area was probably 60-80mm year^{-1}, which is about twice as much as found for Konigsmmor (Eggelsmann, 1960).

When water conservation measures lead to the creation of permanent pools, the seepage at these sites will depend on the ratio between water depth and thickness of the peat layers at the bottom. With a water depth of 1m above a peat layer of 2m, seepage will be about 0.40mm day^{-1} (1.5 times 0.27mm day^{-1}). In the pools of the OL catchment with a water depth of 0.8m above a peat layer with an average thickness of 0.2m, seepage is about 1.4mm day^{-1}. This is only possible during the winter period when runoff from neighbouring areas flows into the OL catchment. During spring this inflow will end and from then onwards the lowering of the water levels in the pools will reduce seepage.

The conclusions mentioned above may be valid for bogs and bog relicts in general. However, it is evident that caution is required because accurate estimations of seepage as a closing term of the water balance are hardly possible. Given the high spatial variability in thickness of the peat relicts within the catchments, estimates on area and thickness of peat for sub-areas can only be approximate. As a consequence, a detailed analysis of the hydraulic resistance is difficult. Nevertheless this study shows that by studying different catchments with significant differences in hydrological properties satisfactory results can be obtained, because reasonable agreement exists between water balance measurements and calculations based on the hydrophysical properties of the peat layers.

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RADISH GROWTH ON EXTRACTED PEATS

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SUMMARY

Radish growth (above ground biomass) was tested in soil mixes containing whole or extracted peats and peat extract solutions. Peats that were extracted with water, weak acid, weak base or organic solvents produced 20 - 30% less biomass than whole (unextracted) peats, while those extracted with strong acid or base produced the least radish growth (65-70% less than whole peats). The addition of weak extracts back to the extracted peats resulted in biomass production equal to that in the whole peats. Addition of the weak acid extract to whole peats caused biomass production to increase 18%. In general, radish biomass was highest in peats with added weak extracts, and production increased linearly as the pH of the extract decreased.
These results indicate that severely hydrolysed peats are not suitable media to support radish growth, while peats extracted with weak acid or base, water or organic solvents retain some advantages of whole peat. Solutions of weak acid extracts (300ppm) apparently stimulate radish growth when added to whole peat-soil mixes and may be useful as discrete products or as value-additions for horticultural peats.

INTRODUCTION

Peat is used extensively in horticulture, agriculture, silviculture etc because of the physical and chemical advantages provided to plants. Physical advantages include water retention, ion-exchange capacity, aeration and other properties that improve soils as culture media. Various humic substances and possibly other chemical constituents of peat also may be stimulatory to plant growth. Numerous reports have shown that humic and fulvic acids extracted from soils and peats can stimulate plant growth (eg Kononova, 1966; Linehan, 1977; Vaughan *et al*., 1985; Rengo *et al*., 1989). Peat-induced stimulation of plant growth has been studied in detail but the mechanisms of stimulation are still unknown, and the chemicals in peat that are responsible for this effect are not well characterized. Although most demonstrations of growth stimulation by humic substances have been in controlled artificial conditions (eg Pihlaja *et al*., 1983; Rengo *et al*., 1989) there are some indications that humic substance applications can benefit crop growth in agricultural or horticultural situations (Garvilchik *et al.*,1980; Rauthan & Schnitzer, 1981; Vaughan & Malcolm, 1985; Zhao, 1989).

The Center for Environmental Studies, Bemidji State University, has investigated various uses for Minnesota peats and recently developed schemes for producing multiple products from a single peat feedstock (Spigarelli *et al.*, 1990). Our goal is to develop compatible processes that will: 1) remove a peat fraction without sacrificing yield or quality of subsequent products; 2) produce multiple high value products; 3) completely utilize the feedstock; and 4) minimize the rate of depletion of peat resources while maximizing the economic benefits. Minnesota's peat industry presently emphasizes production of whole peats for bulk sale as horticultural media and soil conditioning products. Although traditional peat-based horticultural products are effective and profitable, our research is attempting to provide better alternatives for using peat, by developing value added products.

Our objectives in this study were to: 1) evaluate various chemical fractions of peat as growth stimulants; and 2) test the effects of these fractions when removed from or added to horticultural peats. Greenhouse studies using radish plants (*Raphinus sativus* L. vc. Early Scarlet Globe) were conducted to assess the suitability of chemically extracted peats for use as components of plant growth media and to investigate the possibility of producing humic enhancers of plant growth.

MATERIALS AND METHODS

Peat was collected from a stockpile of harvested peat sods at the Fens peatland in northeastern Minnesota (SE 1/4 of section 36, T55N, R18W). Peat at the site is of reed-sedge origin with an average humification of H-5.6 and an average ash content of 7.4% (Peat Consultants Sweden, 1983). The peat was air dried and milled to pass through a 1mm sieve prior to extraction or incorporation in plant growth media.

Peat extract solutions were prepared by extracting 100g of peat with 600ml of either distilled water, 0.01 N HCl or 0.05% NaOH for 18 hours at 20-25^{o}C with occasional stirring by hand. The extraction slurries were filtered through Whatman No.1 filter paper and the filtrate (extract) was stored at 4^{o}C in the dark. The remaining peat was washed with distilled water, filtered, dried and saved for use in greenhouse experiments; the second filtrate was discarded. Concentrations of dissolved and suspended matter in the extracts were determined by evaporation of subsamples at 105°C; the proportion of material in the acid soluble (fulvic acid) fraction and the acid insoluble (humic acid) fraction, and the ash contents of these fractions were determined by acidifying subsamples to pH 1 with HCl, centrifuging to separate the fractions, oven drying and ashing at 550°C.

Other peat samples were successively extracted three times with 1% NaOH at a ratio of 250g of peat to 3500ml of NaOH solution at 70-80°C with constant stirring for 24 hours to remove humic substances (conventional dehumification).

Strong acid hydrolyses were conducted in the same way as weak acid extractions, except that 1N HCl was used at 100°C for 18 hours. The dehumified and strong acid hydrolyzed peats were washed with distilled water 8 times and then slurries of peat and water were neutralized with NaOH or HCl to pH 4.5, filtered and air dried before use in the soil mixes.

GREENHOUSE EXPERIMENTS

Plant growth media were prepared by mixing air dried peat (about 10% moisture content) with silica sand to produce a mix containing 11% peat by oven dry weight. The composition of sand particle sizes was 88% medium sand (2.0mm-300µm) and 12% fine sand (<300µm). Commercial soil lime (100% $CaCO_3$ equivalent, 20% MgO) was added to the soil mixes at a rate of 0.59g lime/100g soil mix. Components were measured and mixed individually, placed in standard 4 inch square plant pots and prewatered with distilled water to ensure full wetting of the soil components. Six radish seeds (2.36-3.00mm diameter) were planted in each pot and immediately watered with the appropriate solution. Control solutions contained 0.87g of a soluble commercial fertilizer per litre of distilled water (Table 1); treatment solutions contained this level of fertilizer in addition to peat extracts.

All pots received equal volumes of irrigation solution and the amount added was sufficient to cause free drainage from all pots. Watering continued throughout the experiments as needed. One week after planting, the number of plants per pot was reduced to four by removing the smallest plants in each pot. Plants were harvested after three to four weeks and above ground biomass was determined gravimetrically after drying at 60-70°C.

Table 1. Elemental composition of fertilizer solution (870 mg/l) used in greenhouse experiments.

Element	Concentration (mg/l)
N	200
P	70
K	122
Fe	0.87
B	0.17
Mn	0.43
Zn	0.43
Cu	0.43

ANALYSES

Routine pH determinations were performed with a pH meter and a combination electrode with a calomel reference. Plant tissue analyses were performed by the University of Minnesota Research Analytical Laboratory. Peat soil testing was conducted by Minnesota Valley Testing (New Ulm, Minnesota). The HCl-barium acetate method (Day *et al.*, 1979) was used to determine the cation exchange capacity (CEC) of selected peat/sand mixes. Statistical analyses were performed on a Macintosh SE with Statworks software (Cricket Software, 1985). Significance levels of t-tests were set at $\alpha = 0.05$.

RESULTS

EXPERIMENT I.

The first greenhouse experiment was conducted to assess the relative suitability of variously extracted peats for use as plant growth media, and to determine the effects of removing specific fractions from peat. The media tested included whole peat (non-extracted), debituminized peat (extracted with a 2:1 azeotrope of toluene and isopropanol), dehumified peat, and strong acid hydrolyzed peat.

The effects of the extraction procedures on the physical and chemical characteristics of the peat were varied. Drying of neutralized dehumified peat resulted in the formation of hard peat clumps, which were remilled to pass through a 1mm sieve. Acid hydrolysis caused peat particle size to decrease and debituminization caused little change in the appearance of the peat, although sieve analysis revealed a slight shift to larger particle size. Debituminization and acid hydrolysis reduced cation exchange capacity by less than 7%, while dehumification caused a reduction of 40% (Table 2).

Table 2. Characteristics of peat-sand mixes used as treatment media for radish growth trials (Experiment I).

Characteristics	Whole	Debituminized	Acid Hydolyzed	Dehumified	Sand
pH (pre-trial)	4.5	4.6	5.4	5.0	8.2
pH (post-trial)	5.7	7.1	6.4	7.7	7.6
CEC(meq/100g)	11.3	10.5	10.6	6.8	0.2

The pH values of all soil mixes increased after plant growth. Irrigation waters percolated rapidly through sand and dehumified peat treatments, at a moderate rate through whole peat and debituminized peat treatments, and very slowly through acid hydrolyzed peat treatments, reflecting differences in particle size. Thus it appears that many factors could have influenced plant growth in this experiment and differences in growth probably cannot be attributed to just one variable.

All soil mixes (treatments) with extracted peat produced significantly less plant growth than the whole peat treatment (Table 3). Nutrient

Table 3. Radish growth in Experiment I after 27 days (mean above-ground biomass per radish plant). All treatments received 870mg fertilizer/l irrigation solution. Means followed by the same letter do not differ at a significance level of 5%. SE, standard error; N, number of samples; T/C, treatment mean divided by control mean.

Treatment	Biomass (mg)	SE	N	T/C
Whole peat (Control)	302.4 a	16.0	17	1.00
Debituminized	224.7 b	17.3	19	0.74
Sand	108.5 c	6.8	20	0.36
Dehumified (1% NaOH)	106.0 c	5.4	20	0.35
Acid hydrolyzed (1N HCl)	92.5 c	6.0	20	0.31

deficiency symptoms were evident in radishes from the sand, dehumified and acid hydrolyzed treatments, and there was no significant difference among them in terms of biomass produced.

Plant tissue analysis revealed high concentrations of Na in the dehumified and acid hydrolyzed treatments, and this appeared to be at the expense of K and Ca concentrations in these plants (Table 4). Almost certainly this resulted from high concentrations of Na in peats extracted or neutralized with NaOH. Cu and Ni concentrations were highest in plant tissues from the sand treatment, and were at least 8 and 3 times higher, respectively, than in other samples. Toxicity due to these metals may have been partially responsible for the poor growth in this treatment. Plants in the debituminized treatment appeared healthy with no obvious symptoms of nutrient deficiencies, but biomass production was about 26% less than that in the whole peat treatment. Plant tissue analysis revealed that concentrations of major cations (K, Ca, Mg, Na) were higher in plants from the whole treatment than in plants from the debituminized treatment, but analyses of these peats showed very little difference in the availability of nutrients or in other physical and chemical characteristics.

Table 4. Concentrations (mg/l) of selected elements in radish leaves and stems in the five soil mixes used in Experiment I.

Element	Whole Peat	Debituminized	Sand	Dehumified	Acid Hydrolyzed
P	7,900	11,406	13,312	10,436	12,914
K	59,518	46,453	51,409	14,713	21,905
Ca	15,714	10,854	4,573	6,104	5,926
Mg	6,939	4,670	2,921	3,021	6,470
Na	4,740	2,870	2,964	28,544	25,909
Fe	141	146	118	112	102
Al	44	49	47	28	33
Mn	61	161	97	104	79
Zn	49	57	80	51	65
Cu	5	8	64	7	5
B	50	61	71	74	42
Ni	0.5	0.4	1.8	0.3	0.6

EXPERIMENT II

A second greenhouse experiment was conducted to determine the effects of extracting peat with water or weak solutions of acid or alkali. This procedure minimized differences among the peats in terms of the physical characteristics and eliminated the need for neutralizing the peats. Plants were grown in extracted peat-sand mixes and half were watered with the solution extracted from that treatment (Table 5) at strength of 300 mg/l dissolved solids, plus fertilizer at the standard rate; the other half received only the standard fertilizer solution. The pH of the watering solutions ranged from 6.5 to 6.7. Two whole peat treatments were included, one receiving fertilizer solution (control) and the other receiving weak acid extract and fertilizer.

Table 5. Mild extraction conditions and yields (Experiment II), concentrations of peat extracts (filtrates), percent oven dry matter in fulvic acid (FA) and humic acid (HA) fractions, and percent ash in each fraction in parentheses.

Extractant	Slurry pH	Filtrate pH	Solids mg/l	%FA	%HA	Total nonash %	Total ash %
.01N HCl	3.84	4.14	1450	97.0(45.8)	3.0(3.5)	55.4	44.6
Water	4.37	4.74	820	95.9(35.5)	4.1(4.2)	65.8	34.2
.05% NaOH	5.12	5.54	1150	94.0(43.5)	6.0(3.1)	58.9	41.1

The extraction procedures would be expected to remove water-soluble matter including fulvic acid, some humic acid, easily extractable mineral matter and soluble non-humic organic matter. The weak acid extract was richer in acid-soluble matter than the other two, but the proportion of ash-free matter was highest in the water extract. Acid insoluble matter and, therefore, humic acid concentrations were very low in all three extracts.

Extracting peat with water, weak acid or weak alkali reduced biomass production by 20-29% compared to the control, but if the extract was returned to the treatments in irrigation waters, biomass production equalled or exceeded that in the whole peat treatment (Table 6). Differences between biomass values of whole peat and those of extracted peats that were watered with extracts were not statistically significant.

Table 6. Radish growth in Experiment II after 21 days (mean above-ground biomass per radish plant). All treatments received fertilizer (870 mg/l) and some received extract at 300 mg/l irrigation solution. Means followed by the same letter do not differ at a significance level of 5%. SE - standard error; N - number of samples; T/C - treatment mean divided by control mean.

Treatment	Biomass(mg)		SE	N	T/C
Whole + acid extract	262.5	a,b	13.4	20	1.18
Acid extracted + extract	241.0	b,c	11.9	20	1.09
Water extracted + extract	233.7	b,c	15.2	19	1.05
Whole peat (Control)	222.0	b,c	16.4	20	1.00
Base extracted + extract	215.5	c	12.1	20	0.97
Acid extracted (0.01N HCl)	177.0	d	10.5	20	0.80
Base extracted (0.05% NaOH)	163.0	d	12.8	20	0.73
Water extracted	157.0	d	15.8	20	0.71

We calculated that only 39% of the material removed from the peat through weak acid extraction was returned to that treatment in the irrigation waters. The corresponding figure for the weak base extraction was 50%, and for the water extraction 67%. Biomass production in the whole peat treatment receiving weak acid extract was 18% greater than that in the whole peat receiving fertilizer only; although this difference is not significant at the 5% level, it is significant at a level of 7% (t-test, 38 degrees of freedom).

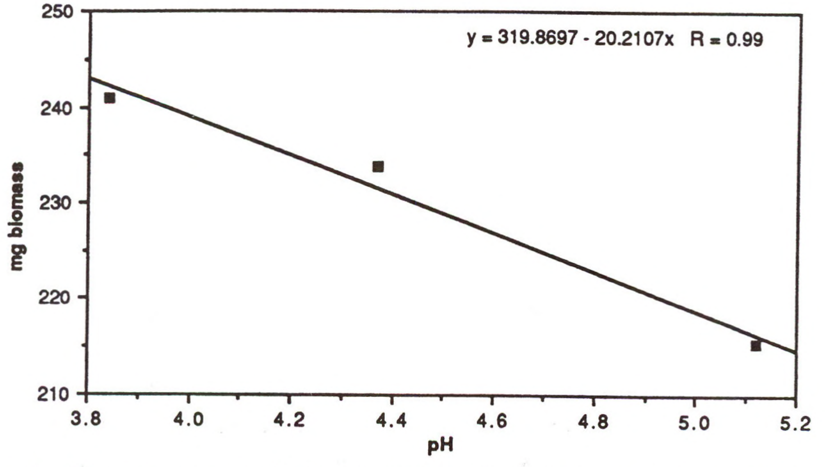

Figure 1. Biomass versus pH during extraction; extracted peats that received extract in irrigation waters.

Biomass production was inversely proportional to the pH of the original extract when diluted extract (300 ppm) was added back to the extracted peat-soil mixes in irrigation water (Fig. 1). This indicates that acid soluble fractions such as fulvic acids may have been most responsible for stimulation of radish growth in this experiment.

DISCUSSION

The suitability of peat for use as a component of plant growth media was reduced by extraction treatments. Relatively normal plant growth was evident in media containing debituminized peat, yet yields were significantly less than in media with nonextracted peat. This is in contrast with the findings of Pihlaja *et al.* (1983) and Rengo (1987) that debituminization does not worsen peat as a growth medium. This contrast may reflect differences in extraction and testing procedures, plant species, and peat type. The nutrient content of peat was lowered slightly and the proportion of larger peat particles increased after extracting with organic solvents. A reduction in nutrient content might be the cause of poor yield in the debituminized peat. It is possible that extraction with organic solvents removed some factor beneficial to plant growth that was not measured by soil analysis. Pihlaja *et al.* (1983) found that organic extractives from peat contain a lipophilic substance(s) that promotes plant growth, and they suggested that sterols or their derivatives may be the active compounds. Also, the availability or activity of stimulatory humic substances in our peats may have been reduced by debituminization.

Plant yield and health were severely reduced when plants were grown in media containing dehumified or strong acid hydrolyzed peat. We believe that this effect is partly a result of the removal of humic substances and other possible growth enhancers in peat. However, this effect also may be related to high levels of sodium in the extracted and neutralized peats, and possibly to changes in their physical characteristics. These problems severely limit the potential for using dehumified or strong acid hydrolyzed peat as components for plant growth media.

Peat extracted with water, weak acid, or weak alkali performed similarly to debituminized peat in that radish production was reduced by 20 to 30%, but apparently healthy plants were produced. It appears that these reductions were due to the removal of soluble matter that is beneficial for plant growth, not due to changes in the physical characteristics of the peat. Returning less than half of the weak acid extract to the extracted peats caused radish growth to increase by 36% and the addition of this extract to nonextracted (whole) peat caused an 18% increase in radish growth. This indicates that the extracts contained beneficial factors in a more available form than originally present in the peat. The growth stimulation caused by the extracts could be due to direct stimulation by humic substances. Others have found that humic substances can reduce the negative impacts of poor aeration (Vaughan *et al.*, 1985) and that the stimulation produced by humic substances is lower in soils with a high organic matter content (Lee & Bartlett, 1976).

Our results indicate that the amount of easily hydrolysed humic matter, not the total amount of organic matter in a soil, controls stimulation of plant growth. It also appears that weak acid extract is more stimulatory to plant growth than water or weak alkali extracts. This is in agreement with a previous experiment using onion root bulbs and the same extract solutions (Rengo *et al.*, 1989).

Numerous reports in the literature document the stimulatory effects of fulvic acid on plant growth (eg Vaughan & Malcolm, 1985). Linehan (1977) has shown that water extracts from soil contain humic matter that is nearly identical to fulvic acids extracted from the same soil, and both have the same stimulatory effects on plant growth. It is likely that our extract solutions contained fulvic acids that are stimulatory to plant growth.

Rauthan and Schnitzer (1981) found that when fulvic acid was applied to cucumber, the growth of above and below ground plant components, nutrient uptake and the number of flowers produced all increased. This suggests that peat extracts may benefit plant growth and development in many ways, but further research is needed to confirm actual improvement in crop yield and quality. Further work with purified FA and HA conventionally extracted from peat is also needed to determine if these fractions are suitable plant growth enhancers.

Peat extracted with organic solvents or weak solutions of acid or alkali would not be as effective as unextracted peat for radish culture, but may be of sufficient quality for use in certain situations. A possible use would be as a soil conditioner in mineland reclamation. Previous work has demonstrated that the addition of debituminized peat to taconite tailings can significantly benefit plant growth and improve chances for successful revegetation (Rengo, 1987). Extracted peats may also have utility as cation exchange material for wastewater treatment (Spigarelli *et al.*, 1990).

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ECOLOGICAL PROBLEMS OF LAND RECLAMATION AND AGRICULTURAL UTILIZATION OF PEATLAND ON PROTECTED AREAS

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SUMMARY

The utilisation and protection of peatland in Poland is reviewed and the conflict between ecologists and the land reclamation specialists in the Leba and Narew river valleys is discussed. Compromise solutions for different situations illustrate the difficulty of the problem.

INTRODUCTION

The effect of peatland drainage on soil-forming processes leads to far reaching physico-chemical and biological changes in the peat and initiates a process that results in the gradual disappearance of the deposit. The intensity of the process is dependent on the method of utilisation. In maintaining the natural balance it is important that many peatland types are covered by protection measures. The intensive utilisation of natural resources by man increasingly evokes conflict between economic interests and the requirements of environmental protection. This paper presents methods of solving these problems, based on a study of two large peatland areas located in the valleys of the Leba and Narew rivers in Poland.

CHANGES IN DRAINED PEATLANDS

Lowering the underground water level in natural peatland not only reduces the surface level but promotes the mineralisation of organic matter. The subsidence of peatland by mechanical compaction due to the removal of uplift pressure continues for several years, decreasing the depth of the deposit by 10-30 %. The humification of peat ('moorshing' process) and the mineralisation of organic matter initiated by improved aeration continue until the peatland ceases to exist and is replaced by organo-mineral soils.

As a result of the above processes, significant changes occur in the physico-chemical and biological properties of the peat in the upper layers of the deposit. These layers show an increased ash content, bulk density and compression strength, while the porosity, available water capacity and moisture content decrease. This is followed by a decrease in the contents of carbon, nitrogen, potassium, magnesium and manganese, and an increase in the contents of phosphorus, zinc and copper (Okruszko, 1980).

The humification of the peat is intensified as shown by the increased amount of simple humic acids of the fulvo-acid type.

The amount of readily-mineralised nitrogen compounds also increases, the proportion of NH_4-N being 1.5 to 2 times greater than that of NO_3-N, with small changes in the qualitative composition of the organic substance (Walczyna, 1973).

Changes in the biology of the upper layers of peatland have received little attention. Here aeration results in a marked increase in micro-organisms promoting a rapid transformation of the peat.

The type of peat utilisation exerts a significant influence on the intensity of organic matter transformation and thereby on the global productivity of the peatland and its vitality. The investigations of Okruszko *et al* (1987) indicate that in the conditions which prevail in northeastern Poland, the mean annual decrease in peatland depth in the years 1967-1981 was 1.2cm on the meadows, 1.5cm on ley and 1.6cm on arable land. The decrease was greatest in the birch forests. These values are lower the higher the underground water levels and when the peatland is covered by a layer of mineral soil (sand or loam).

An interesting comparison of the energetistic effects of different forms of utilisation of 1m-deep peatland has been given by Bambalov *et al* (1988) for conditions in White Russia (Table 1). When the peatland is used as permanent meadow, a 17.5 fold increase in the amount of energy is obtained per ton of peat compared with that when the peat is used as fuel. That is why the utilisation of peat deposits as meadows is so useful both on account of peatland protection and for energetistic reasons.

Table 1. Energy potential in peatland (Bambalov *et al*, 1988).

Application	Annual consumption dry tons	Time in years	Phytomass accumulation, tons		Amount of energy Kcal	
			annual	total	annual	total
Fuel (25% efficiency)	300	4	-	-	3.8 10^8	1.2 10^6
Fertilizer	15	80	2.5 grain 2.5 straw	400	21.0 10^6	1.4 10^6
Grain crops	7	171	4.0 grain 4.0 straw	1368	33.6 10^6	4.8 10^6
Perennial meadows resown (5-7 years)	5	300	10.0 hay	3000	42.0 10^6	11.7 10^6
Permanent meadow	2	600	10.0 hay	6000	42.0 10^6	21.0 10^6

UTILISATION AND PROTECTION OF PEATLANDS IN POLAND

In Poland, there are about 49,000 peat deposits which cover 1,087,746 hectares or some 4% of the total area of the country. The vast majority (93%) are fens. In Poland, peatlands are used mainly as meadows and pastures (69.6%) and to a lesser degree for forests (11.7%) and arable land (0.5%) (Lipka, 1984). The rest consists of waste land, areas for nature protection and land used for drainage and roads (Table 2). The fens are

Table 2. Peatland utilisation in Poland (hectares); after Lipka, 1984.

Type	Wood	Grassland	Arable land	Waste land	Cut over mires	Total	%
Fen	91,682	743,588	5,477	129,029	42,836	1,012,582	93.1
Transition bog	10,923	8,852	27	7,056	1,582	28,440	2.6
Raised bog	24,403	4,135	27	14,396	3,763	46,724	4.3
Total ha	127,008	756,575	5,531	150,481	48,181	1,087,746	100.0
Total %	11.7	69.6	0.5	13.8	4.4	100	-

composed mainly of sedge peat (25% of the resource), reed peat (15%) and alder peat (15%); sedge-moss peats occur less frequently (2.3%). Under the peat there are significant areas of post-lake sediments called gyttjas. Among these, calcareous gyttja and organic gyttja are the most common.

Permanent existence of peatland biocenoses can only be assured by legal protection. In Poland at present there are 95 peatland reservations which cover an area of 5,448 ha. Of these reservations 42 are bogs, mainly raised and transition bogs (Jasnowski & Palczynski, 1976). In future, it is planned to protect 251 peatlands comprising 15,402 ha. Peatlands also form part of some National Parks, particularly in the Bialowieski, Wolinski, Slowinski and Wigierski park areas. Plans are also in hand to establish a large National Park in the Biebrzanski region in order to protect the vast fenlands in this area. Furthermore there are 35 landscape parks in Poland covering an area of 721,912 ha, while other areas of protected landscape cover some 3.2 milliom ha. The total area legally protected for nature and environment is 4.17 million ha or 13.3% of the area of the country. Of this total, peatlands account for about 4 to 5%. This means that, in Poland, about 20% of the peatlands are legally protected in one way or another. The degree of protection varies and except for the reservations, different forms of utilisation are usually permitted (Ilnicki, 1987).

Taking into account the results of several decades of investigation on the effects of reclamation and other forms of utilisation on peatlands, the main recommendation is to use them as meadows and pastures and to maintain the underground water level as high as possible within these areas. At present, peat processing plants utilise an area of about 4,500 ha for the production of garden peat, peat-mineral mixtures, casing soil for mushrooms and peat substrates. In Poland, the extraction of peat for fuel is prohibited.

ECOLOGICAL PROBLEMS OF PEATLAND DRAINAGE IN THE LEBA VALLEY

The Leba belongs to the greater Polish rivers (catchment area 1233 km^2) which flow into the Baltic Sea. The lower section of the Leba contains one of the largest peatland areas in Poland. Within an area of 15,800 ha, fen types (9,900 ha), transition mires (1,600 ha) and raised bogs (4,300 ha) occur. The raised bogs were formed in the part of the wide valley not subject to flooding (Fig. 1.). They form characteristic dome-like deposits of a specific type of Baltic raised bog (Jasnowski, 1978).

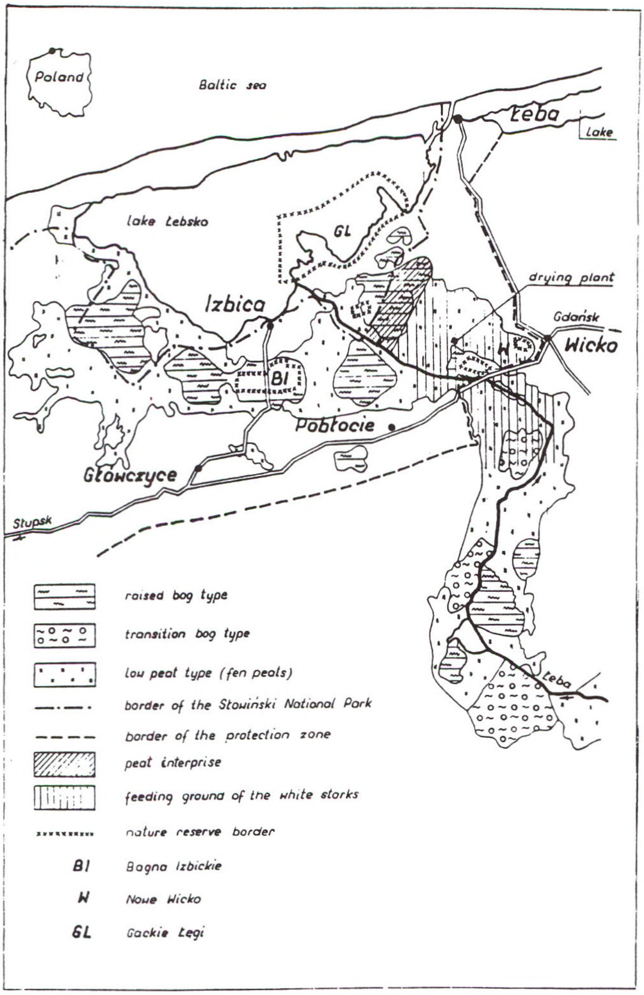

Figure 1. Peatlands in the lower section of the Leba Valley.

A section of this valley together with parts of the flat Baltic coast with its unique migrating dunes, large shallow lakes and significant areas of peatland and afforested sandy soils are included in the Slowinski National Park (about 18,000 ha) established in 1966. This park has been included by Poland in the UNESCO program: "Man and the biosphere". Within the park there are several strictly-controlled reservations including a large area for water and swamp birds "Gackie legi". The park is surrounded by a 6-8 km-wide protection zone.

Beyond the park but within the Leba valley there are several nature reservations. The "Bagna Izbickie" reservation (281 ha) protects a relict crossed-leaved heath bog of the Atlantic type, preliminary drained and occupied by the natural vegetation of the forest community Vacciniouliginosi-Pinetum and the heath Ericetum tetralicis balticum. The "Nowe Wicko" reservation (24.5 ha) protects an overgrown lake and the location of *Myrica gale* at the south-eastern extremity of the area.

In the valley in the immediate neighbourhood of Lebsko lake, deep peat-muck soils predominate. In the raised bogs, the mean depth of peat is 4.0 to 5.5m ; in the fens it is slightly less (2.0 to 4.0m). The raised bogs are composed of *Sphagnum* peat of a medium degree of decomposition overlying reed peat; the fens consist of sedge-moss peat. The most important physical properties of the muck and peat layers are shown in Table 3.

Table 3. Physical properties (bulk density and ash contents) of muck-peat soils in the Leba valley near Izibica-Poblocie.

Bog type	Muck M_1 0.0-0.15m		Peat T_1 0.4-0.6m		Peat T_2 0.8-1.0m	
	B.D. g/dm^3	Ash %	B.D. g/dm^3	Ash %	B.D. g/dm^3	Ash %
Raised bog (western part)	259	18.4	128	4.21	103	3.75
Raised bog (central part)	331	27.7	145	6.30	116	6.50
Fen (eastern part)	388	38.5	139	13.80	130	12.60

Agricultural utilisation of raised bogs over a prolonged period has resulted in a 4 to 5 fold increase in the ash content of the peat and about a 2 to 5 fold increase in the consolidation of the upper peat layers. In the fens, the ash content and bulk density have increased 3 fold. The reaction of the upper layers is strongly acidic and the contents of assimilable phosphorus, potassium, magnesium and copper are low.

Grasslands cover 61.6% of the area followed by forest and shrubs (13.4%), cut-over peatlands (12.2%) and arable land (1.7%). On the majority of the grasslands, the level of the underground water is high, hindering agricultural utilisation.

Wet meadows and the large, shallow Lebsko lake provide favourable breeding conditions for water and swamp birds. The feeding ground of the greatest breeding colony of white stork in Pomerania is located in the vicinity of Wicko.

The concept of successive land reclamation schemes assumes drainage of most of the valley with the help of a pumping station and a systematic network of ditches and drain pipes and the construction of a network of surfaced roads and irrigation canals to supply water from Lake Lebsko to the borders of the valley. It also assumes the conversion of part of the scrub into meadow, intensive meadow production for cattle farms and the construction of a drying plant for green fodder.

A number of these reclamation proposals were opposed by the Management of the National Park, the Provincial Nature Conservator and the Provincial Land Planning Authorities in Slupsk.

The environmental protection authorities have defined the following requirements concerning land reclamation schemes:

- reclamation work must not affect moisture relationships in the National Park or in existing reservations,
- the intensity of agricultural production must be limited by reducing the level of applied fertiliser to 400kg NPK/ha, by prohibiting the use of aircraft for fertilising meadows and the establishment of large cattle farms and green fodder driers and by limiting cattle stocks to 120 to 150 head per 100 hectares,
- landscape protection should be provided by maintaining the present methods of land use, minimising the uprooting of trees near ditches and limiting the development of technical installations like roads, pumping stations and canals, the construction of which should be in sympathy with the landscape,
- the valuable refugia for water and swamp birds on the grassland should be preserved as should the existing relief and different vegetation communities; concentrations of trees on areas of open meadow should be prevented,
- extensive utilisation of part of the meadows involving the elimination of spring cultivation and postponement of the first mowing of grass until the end of June should be introduced in order to permit the hatching of eggs of birds which nest in these areas,
- the present water levels and flow in the Leba river should be maintained and underground water levels in the meadows should be kept as high as possible.

The above demands of the environmental protection authorities have induced the author to develop a new ecological concept of land reclamation in the Leba valley by changing five basic elements: the method of land utilisation, the concept of meadow irrigation, the optimal underground water levels, the protection of habitat conditions of birds and mammals and the protection of moisture relationships in the nature reservations.

The planned level of intensification of production has been limited significantly by reducing the total yields of meadow hay from 120 to 80 q/ha. It has been decided to preserve in full the present method of land utilisation, abandon the uprooting of shrubs and retain the peasant pastures. The building of two fat-cattle farms and a green fodder drier has been excluded from the plan.

The above decisions together with a detailed analysis of the climatic water balance in the vegetative period (a deficit of only 26mm), a high effective useful capacity (120mm) and a good capillary rise coupled with a simultaneous supply of subterranean water to the peatland from the upland, river and lake have resulted in the cancellation of the plan to construct an irrigation system. In the circumstances, the construction of a pumping station and of concrete canals, which would have cut off the valley from the uplands, was unnecessary. They would have spoiled the landscape, split existing biotopes and presented a trap for the animals

It has been assumed that in the vegetative period the level of underground water in the meadows and forests will oscillate between 0.6 and 0.8m depth. In the regions with gravitational drainage, there is no threat of the water level falling below the indicated value, due to back water from Lake Lebskie, and the planned drainage network is thus unnecessary. Within the polders drained by pumping, it has been decided to shallow the network of ditches and drain pipes and to switch on the pumping station at a higher water level. It is expected that the existing cut-over peatlands as well as part of the scrub will flood periodically leaving marshes in the depressions in the meadows for the needs of birds.

In order to preserve favourable conditions for the development of water and swamp birds, it has been decided to maintain the present form of land utilisation, to leave undisturbed the existing old river bed and cut-over peatland and to limit the extent of meadow drainage. It is also intended to delay the annual mowing of meadow border zones in order to leave refugia for the nesting of meadow birds. Limiting the extent of drainage will also ensure the maintenance of feeding grounds for the large colony of storks. The concept of providing drainage ditches at the border line between meadows and forests has also been abandoned. In this way, the lowering of the underground water level, which adversely affects the shallow root system of trees, has been prevented and furthermore contributes to the maintenance of the connection between the forest and meadow biotopes. Deep ditches with steep slopes (1:1) constitute traps for roe-deer and wild boar, in which they are frequently drowned. Therefore it has been recommended that the angle of slope be reduced accordingly.

For the protection of the nature reservations, hydrological buffer zones have been established in the valley. Their width depends on differences in the underground water levels in the reservations and meadows and also on the water permeability of the peat (Kuntze & Eggelsmann, 1981). In raised bog areas, the width ranges from 110 to 130m; in fens it is 60m. The construction of ditches, canals and roads has been abandoned in these zones. In this way reservations are protected according to recommendations valid in Poland since 1938 and contained in the new "Technical conditions" (Ilnicki *et al*, 1987). Such zones also afford considerable protection against the wind drift of mineral fertilisers and shield the reservation animals against noise.

ECOLOGICAL PROBLEMS OF PEATLAND RECLAMATION IN THE UPPER NAREW VALLEY

The Narew is one of Poland's largest rivers with a catchment of 28,856km^2 or 10% of the area of the country. The Upper Nerew above the mouth of the Biebrza river has a catchment of 7,291km^2 and since 1969 has been the subject of intensive land reclamation work. The regulation of 210km of the river and 30,000ha of land were covered by the development programme. However as work progressed, opposition to the technical concept of land reclamation and its destruction of the ecological system of an overflow valley unique in Europe increased.

In 1977, the results of scientific investigations and observations concerning the effects of land reclamation in this valley were presented at a special scientific conference of the Polish Academy of Sciences(Okruszko, 1980) and a decision was made to halt regulation of the river in the region of Rzedziany village. A wide natural and economic assessment carried out in the years 1978-1982 had shown that the most valuable natural section of the Narew valley is located in the region between Suraz and Rzedziany (Fig. 2). In 1985, the Provincial National Council in Bialystok decided to establish the Narwianski Landscape Park, covering an area of 22,160ha including the river valley from Suraz to the village of Zoltki. The reservation zone includes a section above Rzedziany. This decision prohibited the regulation of the river and other work which might disturb significantly terrain features or alter the water relations in the valley.

For the first time in Poland, the need was recognised to separate drained sections of a large valley from localised protected zones. The possibility and purpose of land reclamation between Rzedziany and Zoltki

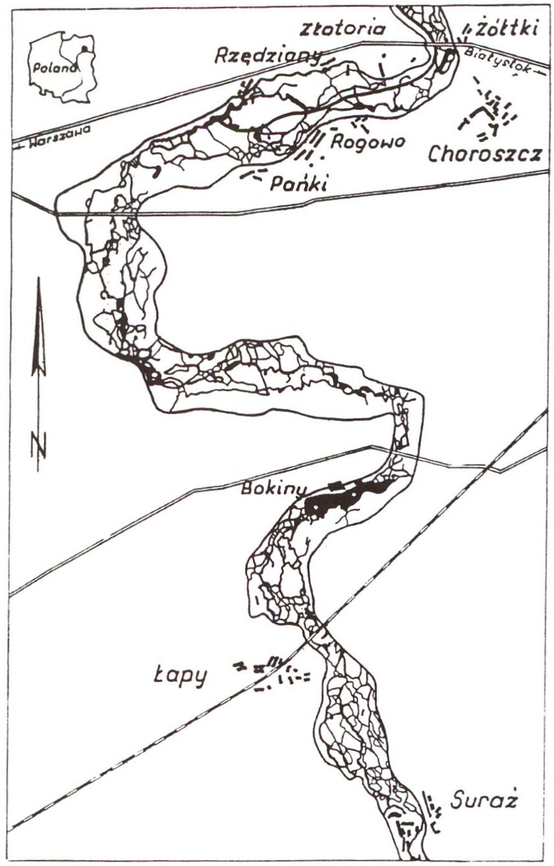

Figure 2. The Narew Valley between Suraz and Zoltki

were also questioned. This section on which river regulation had already been carried out had to act as a buffer zone for the most valuable natural part of the valley. The possibility of sustaining the supply of irrigation water at $15m^3/s$ to the drained meadows below Rzedziany from the water reservoir at the head of the Siemianowka valley was also questioned. The solution of these three problems became the subject of controversy between the environmental protection authorities and those involved in land reclamation.

Before the regulation of the Narew, the valley above Rzedziany always had an abundant supply of water which sustained its marshy character, while the downstream section was distinctly drier in summer. Here shallow (up to 1m) organic soils predominate, occupying about 70% of the valley; deeper peats (up to 2m) cover some 10% and the remainder (10-15%) comprises muck soils on sand. The upper and middle layers of the soil profile consist of weakly decomposed sedge peat of low ash content; the deeper layers comprise strongly decomposed and poorly permeable osier peat with a high ash content. The peat is separated from the sand by a shallow layer of impermeable mud.

The main characteristic feature of the Narew valley in the Suraz-Zoltki section is the overall predominance of marshland and the fragmentation of the river into a dense network of waterways that frequently change their course. The numerous and vast areas of flood water are overgrown with aquatic vegetation, reeds and rushes. A unique arrangement of ecosystems was created here characterised by the coexistence of very diferent habitats: water, water-land and land-swamp. The plant cover is characterised by great richness and diversity, consisting mainly of aquatic, marsh and rush (sedge) vegetation, while willow shrubs, alders and xerothermic vegetation covers small areas. The area is little exposed to industrial contamination and at present is the best location in Poland for marshy herbs (*Menyanthes trifoliata, Acorus calamus*). It is also the settlement for the largest Middle-European population of numerous water and swamp birds, the breeding groud of 117 species, an important resting and feeding area for migratory birds, one of the most important breeding grounds in Poland for game birds (mallard and 'garganey') and several other already rare species as well as being a lair for beaver and elk. The area is exceptionally rich in open waters which lie adjacent to the main river in the form of lateral streams, old river beds, flood waters and lakes. These contribute to a quantitative and qualitative wealth of fish and create perfect conditions for angling.

The natural valorisation, based mainly on the evaluation of the vegetation communities and the bird population, has established that the most precious areas begin some 600-1500m above the Panki-Rzedziany line and extend as far as Suraz.

As a result of significant oscillations in the natural water levels in the river, the valley can be flooded to a depth of 30-60cm, while in summer the level of the underground water can fall to 30cm (maximum 60cm) below the level of the surrounding terrain. After regulation of the river in the Rzedziany-Zoltki section, the level of the underground water dropped by 0.5 to 1.0m.

The basic problem in dividing the valley in the Panki - Rzedziany region is to manage the meadows below this line with optimal levels of underground water of 0.4 to 0.5m, while above this line maintain conditions favouring the development of sedge communities ie conditions of long-lasting floods and continuously wet ground.

The original concepts of dividing the valley were developed in 1984 at the Institute of Land Reclamation and Grassland Farming in Falenty and by Bromel (Consulting Engineering) in Warsaw, but they were not accepted by the environmental protection authorities. Taking into account the solutions previously discussed and the opinions of the authorities mentioned, the author proposed that division of the valley should incorporate two systems for the protection of the reservation zone against drainage.

The first system would be created by a weir at Rzedziany, dammed up throughout the year, a dyke or valley barrier between Panki and Rzedziany, a shallow canal along the right bank of the Nerew connecting existing and new channels via a lock and two headworks at the northern and southern extremities of the old river bed (Fig. 3). The effectiveness of the system would depend on the efficiency of the operators regulating the flow of the river at three points - the weir and the two headworks. The system would be able to maintain the water level from 0.0 to 0.2m below the surrounding terrain.

The second system, which is self-acting, involves the "stepping" of the unregulated bed of the Narew and provision ('high stills') in the dyke and at the mouth of the right bank canal to control flow. This will ensure that the underground water level in the vicinity of the dyke is maintained at 0.5 to 0.6m below the terrain and that adequately higher levels are provided further from the dyke. Due to the proposed headworks, it will be possible to lead water to the old river bed and to both sides of the valley below Rzedziany. The whole system will be based on a tight but not very high dyke providing a wide spillway for flood waters.

The raising of the underground water level in the valley below the dyke is achieved by filling the old river beds with water and damming them. This will decrease seepage under the dyke. The maintenance of water flow through the system of old right bank river beds in the reservation zone will require the construction of a shallow (not penetrating the sands underlying the peat), wide canal on the right bank, which has the character of an old river bed and connects all existing old beds above the dyke.

The method of carrying out particular drainage work in the Rzedziany-Zoltki section is also controversial. The projects already prepared assumed the construction of a network of ditches at 130m intervals and 1.2 to 1.3m deep, connected into a drainage-irrigation system. The weir situated 5km below Rzedziany in Babino permits the raising of the water level in the river and in the valley. The damming of the main old river beds was planned at several points in order to enable gravitational

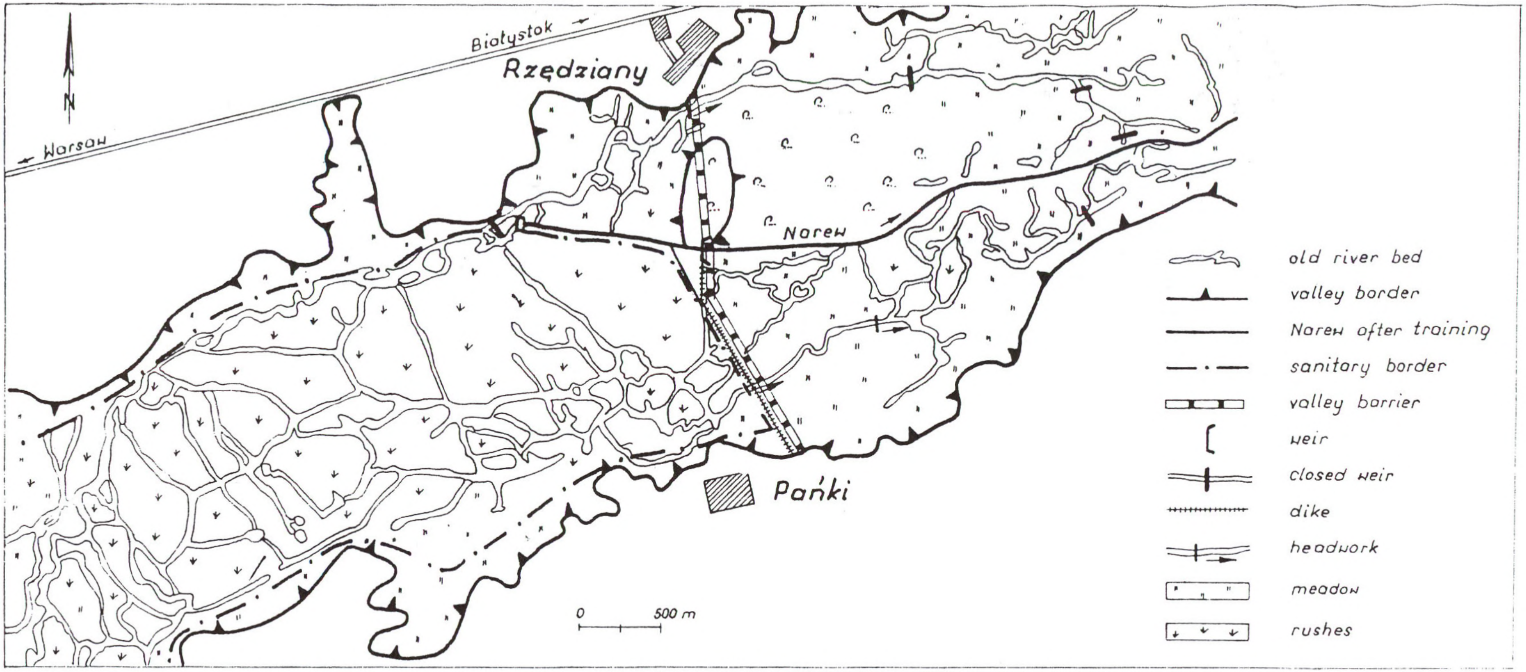

Figure 3. Valley division in the Panki - Rzedziany region.

irrigation of the meadows. As a result of the regulation of the river, the underground water levels have been lowered significantly. According to measurements carried out on a cross-section of the valley at Rogowo the water levels during the vegetation period are at depths of 0.5 to 1.0m. In these conditions it is impossible to maintain the natural sedge communities and to be able to utilise the meadows. The small natural value of the valley when modified by river regulation must also be considered. Based on these facts, the author's proposal is to utilise the maximum damming potential of the weir at Babino and to construct a series of closed weirs and headworks in the old river beds in order to channel water through headworks in the dyke at Panki-Rzedziany and maintain the underground water level in the vally at a depth of 0.4 to 0.6m. This will enable intensive production on the meadows and remove the need for a network of ditches and the uprooting of trees along the old river beds. The shallow layers of peat and the permeable sandy substrate associated with the dense, branched network of old river beds will enable regulation of the water level in the valley which varies in width from 1 to 25 km.

The possibility of concentrating in the Siemianowka reservoir the water supply for the drained meadows below Rzedziany in the Narew valley is basically important for the effectivity of land reclamation work already carried out. Can this be done without any regulation work in the Suraz-Rzedziany section or will it be necessary to undertake considerable earthworks in the reservation zone?

The natural scientists strongly oppose any work that will disturb the present state of the river bed whereas the design office staff maintain that it is absolutely necessary locally to deepen and widen the river bed along 38% of the section. At the same time the influence of the marshy valley on water flow is problematic.

The Suraz-Rzedziany section (7,700ha) is flooded every year. Assuming a mean depth of flood water of 0.6m, then 46.2 million m^3 of water are stored, usually for several months but gradually flowing into the river. In the dry period, the water level in the valley falls to 0.3m below the surface. During this period, the 480ha of existing surface water (the river,old river beds, small lakes) discharge 1.4 million m^3, while the flow from a 0.3m layer over 7,220ha of peatland amounts to about 2.16 million m^3 (10% of soil volume). Therefore the total storage capacity of the valley is about 50 milliom m^3, ie almost as much as the Siemianowka reservoir can accommodate.

In the period February-May, the flow in the river measured on the gauges at Suraz and Zoltki show that in the natural river bed the rate is $15m^3/s$ whereas at Zoltki it is $20.3m^3/s$.

In this situation, the utilisation of the reservoir from May-June to the end of August should ensure that the rate of water flow to Suraz is at least $15m^3/s$. With full saturation of the Suraz-Rzedziany section at the end of May, minimal water loss would occur in this area and high spring flows would be maintained in the period critical for agriculture. The flow of water through the 35km unregulated river section would be slow but its effects would be imperceptible. The present flows in the Narew higher than $15m^3/s$ are proof of the permeability of the section. The correctness of this concept and the result of change in the roughness coefficient of the river bed in summer should be checked by measurement in the vegetative period.

CONCLUSIONS

The conflict between ecologists, environmental protection authorities and land reclamation specialists results in a considerable degree from inadequate knowledge of natural conditions, inexact presentation of the claims of natural scientists, lack of understanding of the significance of marsh and aquatic ecosystems by land reclamation specialists and difficulties in finding compromise solutions. The widening of technical knowledge in the circle of natural scientists and increasing familiarity with natural science among technical experts as well as the acceptance of the principle of precisely defined postulates are the basic conditions for the introduction of ecological land reclamation principles and compromise solutions to relevant disputes. Considerable help is provided by the "Technical conditions for work in the field of land reclamation and water management on areas with particular natural value" published by the Polish authorities (Ilnicki *et al*, 1987).

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RELEASE OF PLASMINOGEN ACTIVATOR BY NATURAL HUMIC ACIDS AND SYNTHETIC PHENOLIC POLYMERS

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SUMMARY

The influence of natural humic acids and synthetic phenolic polymers on the release of plasminogen activator was studied in isolated perfused vascular preparation (pig ear). Of the phenolic polymers tested, caffeic acid oxidation product (COP) and 3,4-dihydroxyphenylacetic acid oxidation product (3,4-DHPOP) at a concentration of 50 µg/ml perfusion solution were able to increase the t-PA activity by 70%. The oxidation products of the chlorogenic acid (CHOP), hydrocaffeic acid (HYCOP), pyrogallol (PYROP) and gallic acid (GALOP) at the same concentration exerted no influence on the release of t-PA.

Of the naturally-occurring humic acids, the influence of sodium humate (Na-HA) was within the same order of magnitude as COP and 3,4-DHPOP. Ammonium humate was able to increase t-PA release only at a concentration of 100 µg/ml perfusate. In rats, t-PA activity increased and t-PA inhibitor activity decreased after i.v. application of 10mg Na-HA/kg.

INTRODUCTION

Naturally-occurring humic acids and synthetically-prepared phenolic polymers belong to a group of anionic compounds with similar physico-chemical properties.

One of these polyanionic compounds, heparin, contributes to the release of tissue-type plasminogen activator (t-PA) which is present in endothelial cells of the vascular system and plays an important role in dissolving thrombi (Markwardt & Klöcking, 1977). This finding stimulated us to investigate naturally-occurring humic acids as well as synthetic phenolic polymers with regard to their influence on t-PA release.

MATERIALS

The materials used in the study and their source were as follows:-

1. **Naturally-occurring humic acids:** sodium humate (Na-HA, m.w. 7900) and ammonium humate (NH_4-HA, m.w.7500) isolated from high-moor peat collected near Rostock in the Baltic coastal region (Klöcking *et al*, 1977).

2. **Phenolic polymers:** polymeric oxidation products from caffeic acid (COP, m.w. 6500); hydrocaffeic acid (HYCOP, m.w. 10 000); chlorogenic acid (CHOP, m.w. 12 000); gentisinic acid (GENOP, m.w. 5900); pyrogallol (PYROP, m.w. 6500); gallic acid (GALOP, m.w. 6000) and 3,4-dihydroxyphenylacetic acid (3,4 DHPOP, m.w. 8600) were synthesised by oxidation of the basic compounds with sodium metaperiodate (Helbig & Klöcking, 1983). COP, HYCOP, GENOP, PYROP and GALOP are also available from SERVA Fine Biochemicals GmbH, Heidelberg, Germany.

3. **COA-SET^R t-PA/PAI:** for the determination of t-PA and t-PA inhibitor in plasma (Kabivitrum, Stockholm, Sweden).

METHODS

The release of t-PA plasminogen activator was studied in isolated perfused pig's ear (for details of the test see Klöcking *et al*, 1976). Both t-PA and its "fast" inhibitor PAI-1 were determined in rats according to the method of Chmielewska and Wiman (1986).

RESULTS

The percentage increases in t-PA release induced by naturally-occurring humic acids and by some selected synthetic phenolic polymers are shown in Table 1. At a concentration of 50 µg/ml perfusion solution, the increases in t-PA activity of 65%, 70% and 73%, induced by Na-HA, COP and 3,4 DHPOP, respectively, were statistically significant.

At a concentration of 100 µg/ml, NH_4-HA also produced a significant increase in t-PA activity.

In rats, the t-PA activity increased and the PAI-1 level decreased after intravenous application of 10 mg/kg Na-HA (Figure 1.).

DISCUSSION

Fibrinolysis (Astrup & Permin, 1947; Collen, 1987; Bachmann, 1987) is the major defence against the deposition of fibrin on vessel walls. The fibrinolytically - active enzyme, plasmin, is formed from its inactive precursor, plasminogen, by plasminogen activators (PAs). Two types of PAs

Table 1. Influence of humic acids and synthetically-prepared phenolic polymers on plasminogen activator release in isolated perfused pig ear.

Compound	Concentration ($\mu g/ml$ perfusion solution)	Release enhancement (%)	Number of experiments (n)
Na-HA	50	65 ±28	6
	100	111 ±54	4
NH_4HA	50	0	4
	100	58 ±19	4
COP	50	70 ±17	4
	100	136 ±91	4
CHOP	50	30 ±21	4
3,4-DHPOP	50	73 ±4	4
HYCOP	50	24 ±18	6
PYROP	50	0	4
GALOP	50	7 ±7	4
control	–	12 ±10	33

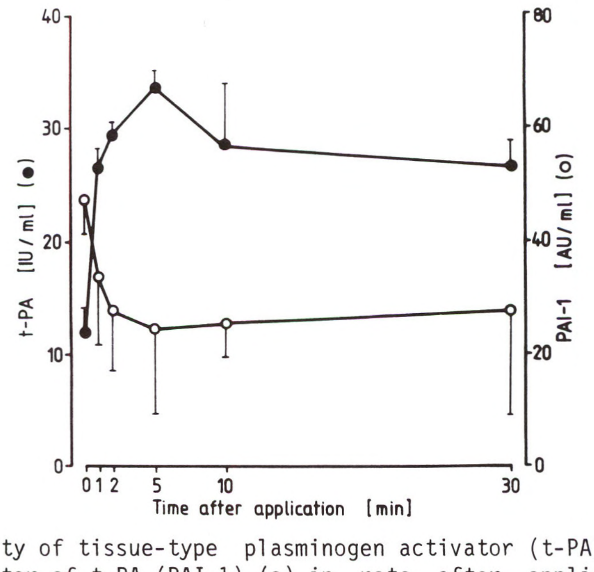

Figure 1. Activity of tissue-type plasminogen activator (t-PA) (•) and inhibitor of t-PA (PAI-1) (o) in rats after application of sodium humate (10 mg/kg i.v.). n = 3.

are presently known: tissue-type Pa (t-PA) and urokinase-type PA (u-PA). Among these distinct types of PAs, t-PA is thought to be of prime importance in initiating fibrinolysis and thrombolysis. Endothelial cells are the principal and probably the only source of t-PA in the blood. Besides providing a basal level of circulating t-PA, endothelial cells can release t-PA temporarily by exercise, venous occlusion or the administration of drugs (Prowse & Cash, 1984). The increase is due to the release of t-PA from vascular endothelial cells into the circulation system. Indeed, in isolated perfused vascular "beds", the release of t-PA from the vessel wall can be induced by various drugs (Emeis, 1983; Klöcking, 1979; Klöcking *et al*, 1976, 1985, 1987; Markwardt & Klöcking, 1977, 1978).

According to the results obtained in the present study, it is concluded that naturally-occurring humic acids and some synthetically-prepared phenolic polymers have a direct influence on t-Pa release from the vessel wall. Since t-PA is involved in the regulation of fibrinolysis (Wiman & Collen, 1978), the release of t-PA by humic acids may explain the use of peat in the treatment of thrombophlebitis (Lachman, 1964).

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A RAIN WARNING SYSTEM FOR PEAT PRODUCTION USING RADAR TECHNOLOGY

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SUMMARY

The occurrence of precipitation can be estimated on a probability basis using data from conventional weather services. In peat production, there is a need for local real time information concerning the time and intensity of rainfall events. For this purpose, marine radar and advanced weather radar were tested during the summer of 1990 and the economic advantages estimated simultaneously.

From the economic point of view, the feasibility of the rain-warning system depends on the number of rainfall events. On average we have 10 significant rain periods during the season which interrupt peat harvesting. The statistical value of the advantages of the system are estimated at around 300 Fmk/hectare/season for the production company and about a tenth of this for the contractor. The pay back time for the rain-warning system is between 1 and 5 years.

INTRODUCTION

The occurrence of precipitation can be estimated on a probability basis using data from conventional weather services. In peat production, however, there is a need for local real time information concerning the time and intensity of rainfall events. For this purpose, marine radar has been tested during the summer of 1990 and the economic advantages of using it estimated simultaneously.

Normal peat production is very dependent on the occurrence of rain during the whole production season. Normally, the occurrence of rain is predicted by the so-called peat production weather services which forecast the time and probability of each event.

A principal improvement in weather services would be a shift from probabilistic forecasts to real time knowledge. This improvement would be especially valuable in enabling the adaptation of production plans to the approaching weather disturbance, the rain.

In this paper, some recent findings concerning the application of weather radar to rain warning in peat production are presented. It appears that, technically, both marine radar and advanced weather radar are suitable for real time warnings in peat production. The economic feasibility must also be tested but preliminary calculations suggest that adoption of these technologies should be seriously considered.

BASIC CONCEPTS

The occurrence of precipitation controls the production rate and yield of peat. With regard to the larger weather fronts, their advance can be forecast quite reliably from normal weather services. However, more local precipitation can also disturb peat winning and eliminate considerable segments of available production time. Real time knowledge of the advance of precipitation is important for optimal adaptation of peat-winning processes to incoming rain.

Examples of the occurrence of different precipitation types in peat production areas can be seen in Figure 1.

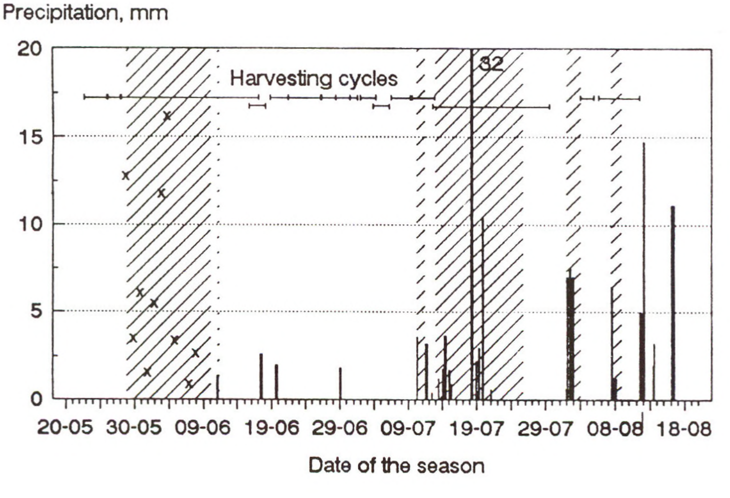

Figure 1. Occurrence of rain on some peat production areas in Northern Finland (Ahonen *et. al.*, 1990).

The figure shows that during the season peat production is interrupted several times by different rain periods. This means that the real time system would have to operate as many times in order to provide a consistent warning to production operators.

From the economic point of view, the feasibility of the warning system depends on the number of rainfall events which occur ie number of warnings issued and acted upon. When estimating the profitability of a warning system theoretically, the return is regarded as insignificant in two extreme cases, when there is no rain and when there is constant rain.

On average in Northern Finland there are 10 significant rain periods which interrupt peat production during the season. In all of these cases safe ridging can be used (Table 1). Three times on average during the season, precipitation is so high (> 20mm) that all the production is lost and work must start from the beginning. Seven times on average during the season, precipitation is such (2..20mm) that all production processes (milling, turning) are interrupted.

Table 1. The occurrence of different kinds of precipitation according to observations at Jyväskylä airport 1971-1989.

	Precipitation		
	2...20mm	> 20mm	Total
Average events per season	7.20	2.9	10.1
Standard deviation	1.45	1.81	1.57

ESTIMATION OF ECONOMIC FEASIBILITY FOR RAIN WARNING

A comparison of the production costs with and without a warning system will show the feasibility of the system. Additionally, the capital and maintenance costs of the system have to be taken into account. Thus the gross annual advantage(GAA) resulting from the use of the warning system is the sum of expenses avoidable by improved information (AE) and the value of the yield saved from wetting, denoted by YS:

$$GAA = AE + YS \qquad (1)$$

where: GAA = Annual gross advantage of using the warning system
AE = Expenses avoidable by use of the warning system
YS = Value of peat yield saved from wetting

Subtracting the capital and maintenance costs gives the net annual advantage of using the warning system, the NAA.

$$NAA = GAA - ACC - AMC \qquad (2)$$

where: NAA = Annual net advantage of using the warning system
ACC = Annual capital cost of the system
AMC = Annual maintenance costs of the system

The above expressions follow the general principles of feasibility calculations where the net annual advantage of using a system has to be positive and, in practice, high enough to justify establishment of a new investment.

In the case of radar-based systems, the estimation of actual values for the above expressions involves some practical approximations but allows a rough estimation of the following feasibility ratio, denoted by FR:

$$FR = (NAA/ACC) \qquad (3)$$

In practice, it is expected that the above ratio would be of magnitude 0.2 to 1.0 in order to be reasonable from the payback point of view. If the FR falls into this value range, the payback time for the system roughly lies between 1 and 5 years.

EVALUATION OF ECONOMIC VALUES

The actual values for estimating the feasibility characteristics of radar application for rain warning have to be estimated according to the preceding equations (1)...(3). Based on peat production costs the following estimates were derived:

AE = Expenses avoidable by the use of a warning system
= Contractors' costs which are lost in the case of rainfall
= 30 Fmk/hectare/season (Karjalainen & Kiukaanniemi, 1990)

YS = Peat yield saved from wetting by use of the system
= The value of safe ridging of peat during the season
= 300 Fmk/hectare/season (Karjalainen & Kiukaanniemi, 1990)

These two advantages are directed differently, the AE to the contractor and the YS to the production company. If we assume that both recipients of the advantage participate in the payback of the radar system, both advantages can be added together to give the annual gross advantage. Thus we obtain a rough measure that three hectares would, on average, correspond to an annual payback contribution of 1000Fmk*. For an area of 300 hectares the expected payback value would be 100,000Fmk on average.

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*1Fmk = 0.2407 USD (June 3, 1991)

The marine radar used in Haapavesi (Karjalainen & Kiukaanniemi, 1990) would represent an investment of about 60,000 Fmk, with current running cost of some 30-40,000 Fmk. Hence, as a first approximation, the NAA for a 300 hectare production site would be zero.

The feasibility ratio FR would increase linearly with the size of the controlled production area. Thus, for a controlled area of 1000 hectares within the range of radar, the feasibility ratio would be about two. This would indicate a worthwhile investment.

FAULT SOURCES IN FEASIBILITY ESTIMATES

Feasibility calculations usually involve different kinds of uncertainties. These are due to the annual advantage estimates; the annual cost estimates are in fact quite precise.

The first source of uncertainty will be the estimation of the advantage of rain warning associated with safe ridging. The amount of material that can be safe ridged depends on the ridger capacity of the site and also on the warning time. The present estimate for the warning time would be about one hour. Inside this time interval precise information on the rainfall and the practical advantages of real time rain warning can be obtained.

EXPERIENCES FROM SUMMER 1990

MARINE RADAR

The possibilities of marine radar as a basis for rain warning systems were tested in Haapavesi in 1990. The radar unit, a normal marine type used on ships, was placed at a height of 25 metres above ground level so that it was able to operate freely. An extra monitor was located in the site office. The equipment was maintained by the fire guard.

The suppliers' technical specifications for the radar were as follows:

Peak power:	10kw
Operating frequency:	9410 +/- 30 mhz
Radiator length:	4ft
Horizontal beam width	1.9^{o}
Vertical beam width	25^{o}
Rotation speed:	24 rpm
Range scale:	0.25 - 72 nm
Display presentation:	raster-scan, ppi (14 inch)

A photograph of the radar's monitor can be seen in Figure 2. The large area in the middle of the monitor screen is caused by radio waves reflecting from the ground and nearby trees. All echoes outside this range are caused by rain clouds. The previous locations of a moving rain cloud can be seen as black shadows, because the radar was in plot mode. The movement of rain clouds can easily be tracked and their arrival at the peat harvesting site estimated.

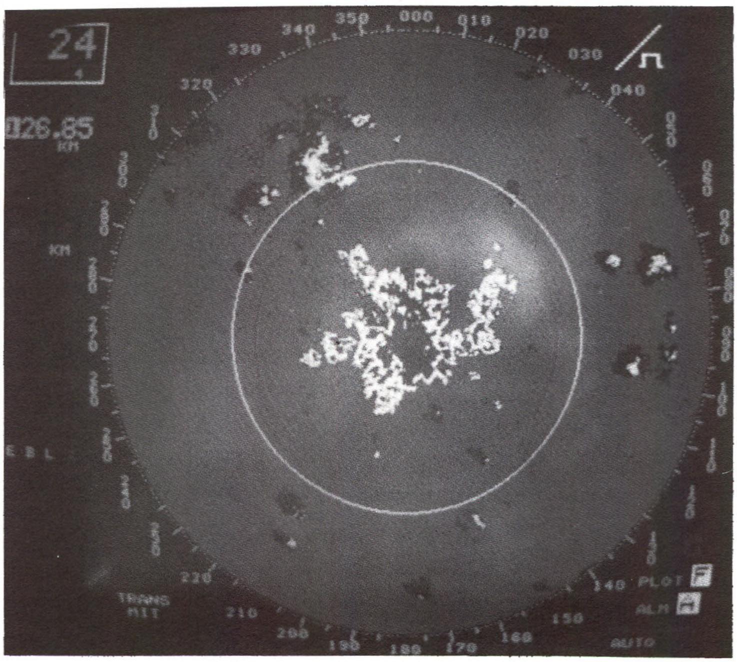

Figure 2. Photograph of the radar screen.

It seems that at a distance of about 100 kilometres it is technically possible to locate rain clouds, follow their movement and direction and estimate their time of arrival at a production site. However there are still problems which cannot be solved by the system. For example, a rain cloud could develop so fast that early warning might not be possible or rainfall might cease before reaching the site as predicted. Nevertheless, according to our experiences, a local marine radar is also useful in these cases and provides weather forecast information for peat production.

WEATHER RADAR

Modern weather radar was tested during summer 1990 using doppler radar equipment provided by the University of Helsinki. The purpose of the test was to establish how exact rain forecasts are obtained using modern weather radar. Another objective was to obtain practical experience in servicing large areas by one radar unit. Forecasts were made for a harvesting site in Riihimäki, 70 km from the radar location. Meteorologists raised the alarm immediately they observed rainfall approaching the peat production site. Forecasts were sent to the site office by telefax.

During the experiment, there were seven rainy days in Riihimäki. The results showed that the meteorologists had succeeded in forecasting the timing of rain. However the warnings were not always received within one hour and the rain mostly came later than forecast.

In Finland, weather radar systems do not cover all peat production areas sufficiently, especially in western Finland. Production areas must be large enough to pay back the cost of using weather radar. There is also the technical question of how best to serve a large group of sites equally.

FEASIBILITY OF THE INVESTMENT

Figure 3 illustrates the relationships between feasible investment and production area. The figure shows the minimum production area required

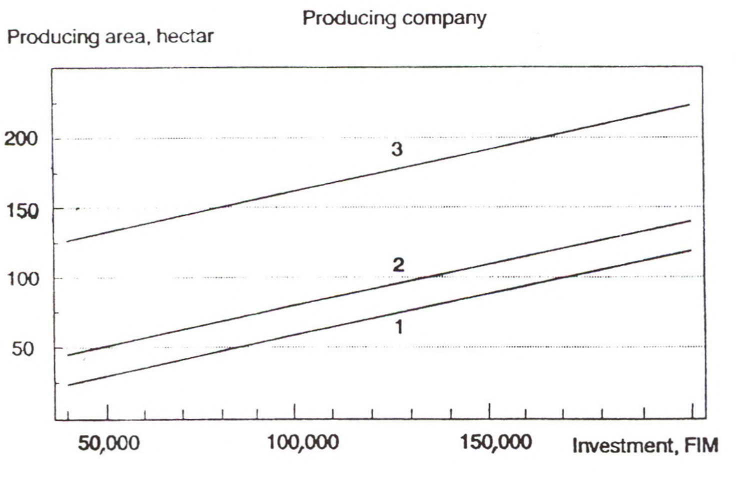

Figure 3. The ratio of investment in a rain warning system to production area according to company profits.

for feasible investment in a warning system. Line 1 depicts the situation where only the radar investment is taken into account. If conditions are bad and further investments have to be made, for example in the erection of a tower for the radar antenna, the minimum production area is shown by line 2. Line 3 shows the situation where staff have to be engaged to take care of the system, thus involving current maintenance costs. Estimates of profitability for Figure 3 are derived from the expected number of rainfall periods and the consequent advantage of safe ridging in the Oulu region of Finland.

From the above estimates it is concluded that investment in local marine radar is attractive in rather small production areas especially if there is no need to engage personel to operate and maintain the warning system. However, a lot of practical meteorological experience is required to use the warning system optimally.

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Zusammenfassungen in Deutsch

McAFEE, M. & LINDSTROM, J.: Belüftungsversuch auf Moorböden. 2. Die Auswirkungen von Bodennutzung und Klima.

Ein zweijähriger Feldversuch wurde auf einem Moorboden durchgeführt, dessen Nutzung als Grasbrache, Anbau von Gerste und offenes Brachland erfolgte, um die Veränderungen in Belüftung, Bodentemperatur und Grundwasser-Flurabstand zu bestimmen und mit der Torfsackung in Zusammenhang zu bringen. Der gewählte Zeitraum war kälter und feuchter als die Jahre 1987 und 1988, und das erlaubte einen Vergleich der Parameter bei unterschiedlichen Wetterbedingungen. Die Bodentemperatur unter Brachland war deutlich höher als unter Gras; die beim Getreide lag in der Mitte. Die Unterschiede waren in der trockenen Jahreszeit höher. Die Grundwasserflurabstände waren unter Brache am geringsten, am höchsten unter Gerste nach Auflaufen. Das Verhältnis des Sauerstoffgehaltes zum Bodenwassergehalt und zur Bodentemperatur wurde bestimmt. Bei hohem Wassergehalt und hohem Respirationsbeträgen wurden geringe O_2- und CO_2-Werte beobachtet. Die Sackung war am geringsten unter Grasbrache (0,3 cm/a), höher unter Gerste (1,2 cm/a) und offener Brache (1,6 cm/a). Die Unterschiede gehen auf die bessere Belüftung und Austrocknung nach der Bodenbestellung und auf stärkere mikrobielle Atmung in dem warmen blanken Moorboden zurück.

SCHOUWENAARS, J. M. & VINK, J. P. M.: Hydrologische Eigenschaften von Torfresten in einem Torfgewinnunsgebiet und Möglichkeiten des Wiederaufwuchses von Sphagnen.

Über die hydrologischen Kenngrößen von stehengebliebenen Torfresten in einem Torfgewinnungsgebiet, das in ein Naturschutzgebiet umgewandelt wird, wird berichtet. Hauptzweck der Untersuchung ist, diese Eigenschaften in Relation zu den Aufwuchsbedingungen von Sphagnen zu bringen. Kenntnisse über die Evapotranspiration und das Wasserspeichervermögen wurden auf dem Wege über Lysimetermessungen ermittelt. Wasserhaltevermögen, Durchlässigkeit und kapillare Steighöhe wurden untersucht.

In lebenden Hochmooren sind die Wasserspiegelschwankungen sehr gering und betragen unter 30 - 40 cm.

In teilweise abgebauten Mooren unterscheiden sich die meist älteren und zesetzten Torflagen in dieser Hinsicht stark von denselben Lagen in ungestörten Mooren.

Wenn nach der Wiedervernässung von teilweise abgetorften Hochmoortorfen (Regeneration, Rehabilitierung) Sphagnen wieder aufwachsen, erreicht die entstandene Torflage nach einigen Dekaden nur Mächtigkeiten von bis zu 30 cm. Während dieser ersten Regenerationsphase sind die Sphagnen sehr empfindlich gegen Austrocknung, weil die geringe Mächtigkeit der Torflage noch nicht ausreicht, selbstregulative Puffer-Mechanismen gegen die Absenkung des Wasserspiegels zu entwickeln. Diese Mechanismen stehen in enger Abhängigkeit zu den hydrologischen Kerngrößen der oberen Torflagen.

GRIFFITHS, P.: Über Brenntorf-Trocknungsversuche

Die unterschiedlichen Korngrößenklassen von Brenntorf wurden, in dünne Schichten gebracht, in bezug auf ihre Trocknungsfähigkeit untersucht, wobei dem Zusammenhang zwischen Korngröße und relativem Wassergehalt mit der Trocknungsgeschwindigkeit nachgegangen wurde.

Es zeigte sich, daß Größenzunahme und Steigerung der relativen Feuchtigkeit die Trocknungsgeschwindigkeit herabsetzt. Feuchtigkeitsabnahmekurven wurden in dimensionslose Wassergehaltskurven übersetzt, welche durch die Gliederung $MR = \exp(-Kt^n)$ beschrieben werden. Der Faktor K ist abhängig von der Korngröße und dem Wassergehalt des Torfes, der Faktor n nur von der Korngröße. Daten für die größte Kornklasse (Torfsoden) zeigten, daß ein hoher anfänglicher Feuchtigkeitsgehalt mit einer geringeren Trocknungsdauer verbunden ist. Diese Ergebnisse konnten in ein Modell eingegeben werden, welches erlaubt, die Trocknungsrate von Brenntorf unter verschiedenen Ausgangsbedingungen vorherzusagen.

BAKKER, T. W. M.: Die Form von Mooren aus hydrologischer Sicht.

Zwei mathematische hydrologische Modelle werden vorgestellt, welche den Wasserspiegel in Hochmooren zeigen. Das eine gilt für einen homogenen Torfkörper, das andere für einen Torf mit einem Akro- und einem Katotelm, wobei das letztere den größten Teil des Abflusses übernimmt. Da die Oberfläche eines Hochmoores und sein Wasserspiegel eng beieinanderliegen, können diese Modelle benutzt werden, um die Form eines Hochmoores zu beschreiben. Besondere Aufmerksamkeit wird auf die Beziehung zwischen der Höhe des Moores (hm) und seinem Durchmesser gelegt. Die Rolle offener Wasserflächen, von Moortümpeln, "meerstallen", Mooraugen, Sümpfen und anderen Gegebenheiten wird diskutiert. Eine hauptsächliche Folgerung ist, daß die offenen Wasserflächen abflußerhöhend und nicht rückhaltend für Trockenperioden wirken.

PUUSTJÄRVI, V.: Problematische Struktur-Normen für Torf im Gartenbau.

Es ist wohlbekannt, daß die Strukturnormen für Torf, welcher im Gartenbau eingesetzt wird, wegen der starken Schwankungsbreite der Analysedaten nur geringen Wert besitzen. Die Gründe dafür werden gewöhnlich bei den Untersuchungsverfahren gesucht, doch liegen sie nach Aussage des Verfassers im wesentlichen in Veränderungen der Torfkolloide begründet, die bei der Trocknung, Förderung und Lagerung der Proben entstehen. Je stärker der Torf austrocknet, umso mehr verändern sich die kolloidalen Eigenschaften und je größer die Auflösung der Struktur ist, umso weniger kommt es auf die Untersuchungsmethoden an. Eine klare Unterscheidung ist nötig zwischen reversiblen Kolloiden in unzersetztem Weißtorf und den irreversiblen Humussubstanzen, die meist Zersetzungsprodukt von holzigen Pflanzen sind.

SCHOUWENAARS, J. M., AMERONGEN, F. VAN & BOOLTINK, M.: **Hydraulische Widerstand von Torflagen und abwärtsgerichteter Abfluß in Resttorfvorkommen.**

In vielen beim Abbau stehen gebliebenen Resttorfvorkommen Nordwesteuropas ist versucht worden, die frühere Moorvegetation wiederzubeleben. Um brauchbare ökologische und hydrologische Bedingungen für diese ombotrophe Vegetation zu schaffen, muß man sich bemühen, Feuchtigkeitsverlusten entgegenzuwirken. Um die Wirkung unterschiedlichen Wasser-Managements abzuschätzen, ist v. a. die Quantifizierung der Infiltration bzw. des abwärts gerichteten Abflusses von Torfresten in darunterliegende Aquifere wichtig.

Im Engbertsdijksveen (Niederlande) wurde der Wasserhaushalt von drei kleinen Einzugsgebieten -- Größe 15 - 25 ha) untersucht. Im Winter betrug der unterirdische Abfluß aus 2,5 m mächtigem, stark zersetzten Torf zwischen 0,2 - 1,4 mm/d aus Moortümpeln mit im Durchschnitt 20 cm mächtigen Torflagen an der Basis. Es wurde festgestellt, daß die Durchlässigkeit von stark zersetzten Schwarztorflagen nahezu eine lineare Funktion ihrer Mächtigkeit ist. Die festgestellten Werte liegen in einer Größenordnung von 3.500 - 4.000 d/m, was einem Kf-Wert von 0,25 - 0,30 mm/d entspricht.

SPIGARELLI, S. A. & RENGO, J. J.: Rettich-Aufzucht auf Torfextrakten.

Das Wachstum von Rettichen in Bodensubstraten aus reinem Torf oder Torf-Extrakt-Lösungen wurde untersucht. Torfe, denen das Wasser, schwach saure oder basische Lösungen entzogen wurde, erbrachten eine um 20 - 30 % geringere Biomasseproduktion, solche, aus denen stark saure oder basische Extrakte hergestellt wurden, 65 - 75 % geringere Produktion als reiner Torf. Bei Zufügung von schwachen Extrakten zu dem vorher behandelten Torf führte zu einer Biomasseproduktion in Höhe der von unbehandeltem Torf. Die Zuführung schwacher Extraktwasser zu normalem Torf erbrachte eine Produktionssteigerung um 18 %, generell war die Biomasseproduktion am höhesten bei solchen Extraktzusätzen zu normalem Torf; die Produktion stieg linear mit der Abnahme des pH-Wertes.

Diese Ergebnisse zeigen, daß stark entwässerte Torfe nicht für die Verbesserung des Rettichwachstums geeignet sind, während die Behandlung mit schwach sauren oder alkalischem Wasser oder organischen Lösungen vorteilhaft ist. Schwach saure Lösungen (300 ppm) stimulieren das Torfwachstum in Torf- oder Torf-Bodensubstraten und sind daher als Wachstumsverbesserer im Gartenbau geeignet.

ILNICKI, P.: Ökologische Probleme der Bodenverbesserung und landwirtschaftlichen Nutzung von Moorschutzgebiete.

Nutzung und Schutz von Mooren in Polen werden diskutiert, vor allem im Hinblick auf die Konflikte zwischen Ökologen und Bodenverbesserungs-Fachleuten, die in den Flußtälern der Leba und des Narew tätig sind. Die Schwierigkeiten dieses Problems werden an Hand von Kompromißversuchen unter unterschiedlichen Bedingungen diskutiert.

KLÖCKING, H. P., KLÖCKING, R. & HELBIG, B.: Die Freisetzung von Plasminogen-Aktivatoren durch natürliche Huminsäuren und synthetische phenolische Polymere.

Der Einfluß von natürlichen Huminsäuren und synthetischen Phenolkörperpolymerisaten auf die Freisetzung von Plasminogenaktivator zu wurde am isoliert durchströmten Gefäßpräparat (Schweineohr) geprüft. Von den getesteten Phenolkörperpolymerisaten waren Kaffeesäureoxydationsprodukte (KOP) und 3,4 Dihydroxyphenylessigsäure-Oxydationsprodukte (3,4-DHPOP) bei einer Konzentration von 50 µg/ml Perfusionslösung fähig, die Aktivität des Plasminogenaktivators (t-PA) um 70 % zu steigern. Die Oxydationsprodukte von Chlorogensäure (CHOP), Hydrokaffeesäure (HYKOP), Pyrogallol (PYROP) und Gallussäure (GALOP) zeigen bei der gleichen Konzentration keinen Einfluß auf die Freisetzung vom t-PA. Von den natürlichen Huminsäuren erwies sich Natriumhumat (Na-HA) von der gleichen Größenordnung wie KOP und 3,4-DHPOP. Ammoniumhumat bewirkte erst bei einer Konzentration von 100 µg/ml Perfusionslösung eine Steigerung der t-PA-Freisetzung. Nach i.v.-Applikation von 10 mg Na-HA/kg bei Ratten stieg die t-PA-Aktivität an, während die Aktivität des t-PA-Inhibitors abfiel.

Kiukaanniemi , E. & Karjalainen, T.: Regenwarnsystem für die Torfproduktion unter Verwendung der Radartechnologie

Das Auftreten von Niederschlägen kann auf verlässlicher Grunglage durch Verwendung von Daten konventioneller Wetterdienste vorhergesagt werden. Bei der Torfproduktion besteht jedoch ein Bedarf nach lokalen Realzeitinformationen zu Zeitpunkt und Intensität von Regenfällen. Zu diesem Zweck wurden im Sommer 1990 Marineradar- und entwickelte Wettervorhesageradargeräte getestet und parallel dazu der dafür notwendige wirtschaftliche Aufwand untersucht.

Von wirtschaflichen Gesichtspunkten her gesehen hängt die Anwendbarkeit von Regenwarnsystemen von der Anzahl der Regenfälle ab. Durchschnittlich treten während der Erntesaison 10 bedeutende Regenfallperioden ein, die die Tornfernte unterbrechen. Der statistische Wert der Nutzung des Systems beläuft sich auf rund 300 FIM pro Hektar und Saison für die Produktionsgesellschaft und etwa ein Zehntel davon für den Subunternehmer. Die Ammortisationszeit für das Regenwarnsystem liegt zwischen einem und fünf Jahren.

МкАФИИ М и ЛИНДСТРОМ Я.
ИЗУЧЕНИЕ АЭРАЦИИ ТОРФЯНОЙ ПОЧВЫ. ВОЗДЕЙСТВИЕ ОБРАБОТКИ И КЛИМАТА

Для определения изменений почвенной аэрации, температуры почвы и уровня грунтовых вод и установления взаимосвязи этих параметров по отношению к норме снижения в торфе, был выполнен 2-х летний полевой эксперимент на торфяной почве поля под паром, покрытого дерновым слоем после урожая зерновых культур (ячмень) и вспаханным паром.

Сезон в 1987 году был холодней и влажней, чем в 1988 году, и это позволило сравнить параметры в различных условиях. Температура почвы была существенно выше под парами, чем под паровым полем (после зерновых культур) и эта разность была выше в сухом сезоне. Уровень грунтовых вод был наименьшим под парами и наибольшим под зерновыми культурами, когда был установлен урозай. Было определено содержание кислорода в почвенной влаге и температура почвы. Сочетание высокого содержания влаги и высокой воздухоёмкости даёт очень низкий уровень O_2 и CO_2. Понижение влаги было меньше (0,3 см/год) под травяным покровом, возрастая до 1,2 см/год под зерновыми, и 1,6 см/год под свпаханным паром. Эти различия свидетельствуют о лучшей аэрации и сушке после обработки и более высоком соотношении микробного дыхания в нагретом открытом торфе.

СХОУВЕНААС Я. М. и ВИНК Я.П.М.
РИДРОФИЗИЧЕСКИЕ СВОЙСТВА ОСТАТКОВ ТОРФА В ВЫРАБОТАННОМ БОЛОТЕ И ПЕРСПЕКТИВЫ ПРИРОСТА СФАГНУМА

Гидрофизические характеристики слоев торфа в частично выработанной торфяной залежи природного заповедника представлены в этом исследовании. Основная цель — обсудить эти свойства в отношении условий для выращивания сфагнового типа торфа. Информация об испарении и коэффициентах сохранения влаги обеспечивалась экспериментальными измерениями по слоям. Были проанализированы водоудерживающие характеристики, гидравлическая и капилярная проводимость.

В живущих болотах колебания уровня воды очень ограничены (меньше чем 30—40 см). В частично разрабатываемых болотах, более древних и более гумифицированных, верхние слои торфа сильно отличаются от таких же в ненарушенных болотах.

Когда после частичного осушения разрабатываемых болот (восстановление, ремонт) происходит прирост сфагнума может быть не более чем 30 см после нескольких декад. В течение этой первой фазы восстановления, молодые растения сфагнума уязвимы при длительной засухе потому, что тонкий слой с этих пор также лимитируется установлением достаточно саморегулирующегося буферного механизма предотвращающего дальнейшее понижение уровня воды. Эти механизмы тесно связаны с гидрофизическими свойствами верхних торфяных слоёв.

ГРИФФИЦ Р. ЭКСПЕРИМЕНТАЛЬНАЯ СУШКА ТОРФА В ТОНКИХ СЛОЯХ

Три различных класса по размерам топливного торфа были высушены в тонких слоях при различных уровнях относительной влажности в соответствии с (1) для оценки влияния размера частиц торфа и относительной влажности на скорость сушки и (2) для установления уравнения, описывающего скорость уменьшения влаги и для спектра торфяных частиц и относительной влажности.

Результаты показали, что увеличение размера частиц торфа ведет к уменьшению скорости сушки. Кривые потери влаги были превращены, измерением потерь влаги, в коэффициент кривой, который был описан уравнением $MR = \exp(-кT^n)$. Коэффициент К зависел от размера частиц торфа и относительной влажности. Коэффициент n зависел только от размера частиц торфа. Данные для наибольшего размера частиц (кусковой торф) показывают, что увеличение содержания начальной влажности ведет к уменьшению скорости сушки. Эти результаты могут быть включены в модель в порядке предпосылки ускорения сушки топливного торфа при изменяющихся диапазонах сушки.

БАККЕР Т.В.М.
ВИДЫ БОЛОГ С ГИДРОЛОГИЧЕСКОЙ ТОЧКИ ЗРЕНИЯ

Представлены две гидрологические и математические модели, которые моделируют уровень грунтовых вод верховых болот, одно с однородным торфом, другое со смешанным и комплексным, в которых прежний переносчик основной массы освобожден от воды. Поэтому поверхности болот и уровень грунтовых вод тесно взаимосвязаны и эти модели использовались для описания вида болот. Особое внимание уделялось соотношению между высотой болота (hm) и его диаметром (B). Обсуждалась роль открытой водной поверхности водоёмов, отстойников, моховых болот, топей и других особенностей. Главный вывод состоит в том, что болота с открытой водной поверхностью являются источником, увеличивающим освобождение воды и не обеспечивают её сохранение в сухой период.

ПУУСТЬЯРВИ В.
СПОРНЫЕ СТРУКТУРЫ СТАНДАРТОВ САДОВОДЧЕСКОГО ТОРФА

Хорошо известно, что структуры стандартов садоводческого торфа в малом объёме являются высокоизменчивыми к аналитическим результатам. Причина этого обычно приписывалаь прикладным методам оценки, но согласно настоящего исследования, капилярные изменения в торфяных коллоидах являются причиной сушки торфа в течение производства и хранения и являются более существенными и основными. Чем больше торф высыхает, тем больше его коллоидные свойства изменяются и шире отклонения в структуре анализов, независимо от аналитических методов. Частые различия могут быть сделаны между обратимыми коллоидами оставшегося неразложившимся сфагнума и необратимыми гуминовыми кислотами, которые большей частью являются продуктом разложения древесных растений.

СХОУВЕНААРС Я.М., АМЕРОНГЕН Ф., ВАН и БУЛТИНК М.
ГИДРАВЛИЧЕСКОЕ СОПРОТИВЛЕНИЕ ТОРФЯНЫХ СЛОЁВ И НИЖНЯЯ ФИЛЬТРАЦИЯ В БОЛОТНЫХ ОСТАТКАХ

Во многих реликтовых болотах на Северо-Востоке Европы пробы могут быть восстановлены на основе прежней торфяной растительности. Для уменьшения потери воды необходимо создавать подходящие экологические и гидрологические условия для этой омботрофной растительности. Оценивать влияние другой воды, умением измерить её, это важное свойство нижней фильтрации из реликтовых болот, по отношению к нижележащему водоносному слою.

В Енгберртсдьюксвене (Нидерланды), были изучены водные балансы трёх небольших водосборов (15—25 га). В зимний период нижняя фильтрация изменялась от 0,2 мм/день (в более чем 2,5 метровом сильноразложившемся реликтовом торфе) до 1,1 мм/день (из небольшой залежи со средней толщиной, только 20 см слой торфа на дне). Было установлено, что вертикальное гидровлическое сопротивление нижних сильно гумифицированных слоёв сфагнового торфа, является почти линейной функцией его толщины. Значение оценивается в 3500—4000 дней/м, которое согласовывается со средним наложением гидравлической проводимости порядка от 0,25—30 мм/день.

СПИГАРЕЛЛИ С.А. и РИНГО Я.Я.
РАЗВИТИЕ РЕДИСА НА ВЫТЯЖКАХ ИЗ ТОРФА

Было исследовано развитие редиса (выращивание биомассы) в почвенных смесях, в которых содержались вытяжки торфа или растворы торфяного экстрата. Торфа, которые были экстрагированы с водой, слабой кислотой, слабым основанием или органическими растворителями, давали уменьшение биомассы на 20—30 %, чем те же торфа, в то же время эти экстраты, полученные с сильной кислотой или основанием, давали самый меньший прирост (на 65—75 % меньше чем сами торфа). Прибавление слабого экстрата к вытяжкам из торфа давало результат по биомассе равный как и в самих торфах. Прибавление слабой кислотной вытяжки, тех же самых торфов, приводит к увеличению биомассы на 18 %. В общем, биомасса редиса возрастала на торфах с добавлением слабых вытяжек, выход продукции также линейно увеличивался при уменьшении уровня pH.

Эти результаты указывают, что некоторые гидролизованные торфа не являются подходящими средами лдя поддержания развития редиса, в то же время вытяжки торфа со слабой кислотой или основанием, водные или органические растворители сохраняют некоторые преимущества самого торфа. Растворы вытяжек, полученных слабой кислотой (300 ppm), по-видимому, стимулируют развитие редиса, когда добавляются в те же торфопочвенные смеси и могут быть полезными как отдельные продукты или как ценная добавка для сельскохозяйственного торфа.

ИЛНИСКИ Р.
ЭКОЛОГИЧЕСКИЕ ПРОБЛЕМЫ МЕЛИОРАЦИИ ЗЕМЛИ И СЕЛЬСКОХОЗЯЙСТВЕННОГО ИСПОЛЬЗОВАНИЯ ТОРФЯНЫХ ЗАЛЕЖЕЙ НА ЗАЩИЩЕННЫХ ПЛОЩАДЯХ

Использование и защита торфяных залежей в Польше рассматривается и обсуждается с частичной ссылкой на конфликт между экологами и специалистами мелиораторами в долинах рек Леба и Нарев. Компромисные решения для разных ситуаций иллюстрируют трудности проблемы.

КЛОККИНГ Х.А., КЛОККИНГ Р. и ХЕЛБИГ В.
ОСВОБОЖДЕНИЕ АКТИВИРОВАННОЙ ПРОТОПЛАЗМЫ НАТУРАЛЬНОЙ ГУМИНОВОЙ КИСЛОТЫ И СИНТЕТИЧЕСКИХ ФЕНОЛЬНЫХ ПОЛИМЕРОВ

Влияние натуральных гуминовых кислот и синтетических фенольных полимеров на освобождение активированной протоплазмы было изучено в изолированном поливе предварительно подготовленных сосудов («Свиное ухо»). Испытанные синтетические фенольные полимеры, продукт окисления кофеиновой кислотой (СОР) и продукт окисления 3,4-дигидрооксид фенолоуксусной кислоты (3,4-ДНРОР) при концентрации 50 г/мл поливочного раствора увеличивают t-PA активность до 70 %. Продукты окисления хлорной кислоты (СНОР), гидрокофеиновой кислоты (НYСОР), пирогаллоновой кислоты (PYROP) и галловой кислоты (GALOP) при определенных концентрациях не проявляют влияния на высвобождение — PA. Гуминовые кислоты натурального происходления влияют на гумат натрия (Na-HA) были того же самого порядка размера, как СОР и 3,4-ДНРОР. Гумат аммония увеличивает t-PA высвобождение только при поливе с концентрацией 100 г/мл. При нормах t-PA активность увеличивается и t-PA активность усеньшается и сдерживается при применении свыше 10 мг/кг Na-HA.

...УКАННИЕМИ Е. и КАРЬЯЛАЙНЕН Т. СИСТЕМА ПРЕДУПРЕЖДЕНИЯ О ДОЖДЕ ДЛЯ ТОРФЯНОГО ПРОИЗВОДСТВА, ИСПОЛЬЗУЮЩАЯ РАДИОЛОКАЦИОННУЮ ТЕХНОЛОГИЮ

Случай выпадения осадков может быть предположен на вероятностной основе, используя обычные данные погодных служб. В торфяном производстве имеется необходимость в реальной местной информации относительно времени и интенсивности атмосферных осадков при нормальном развитии событий. Для этих целей был исследован морской радар и продвижение погоды в течение лета 1990 года совместно с предположительными экономическими преимуществами.

С экономической точки зрения, осуществимость предупреждающей системы о дожде, зависит от количества атмосферных осадков при нормальном развитии событий. В среднем мы имеем до 10 значимых дождливых периодов в течение сезона, которые прерывают добычу торфа. Статистическая оценка преимущества системы предположительно составляет около 300 фин. м./га за сезон для производственной компании и свыше десяти из них для подрячика. Период окупаемости системы предупреждения дождя составляет от 1 до 5 лет.