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# THE CHIMADITIDA FEN (W. MACEDONIA, GREECE): A PEAT DEPOSIT LOST

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## SUMMARY

The Chimaditida fen is a mire which began to form at the beginning of the Holocene on the flat marginal area of the homonymous lake, located at the northwestern edge of the Amyntaion-Ptolemaïs sub-basin in Western Macedonia, Greece. In this limnotelmatic environment, peat generally accumulated with low sedimentation rates, due to the periodical fluctuations in the lake level, which caused desiccation, oxidation, and subsequent loss of deposited organic matter. The fen once covered 28 km². Between 1930 and 1950, about 89% of the area, i.e. 25 km², was drained. Since then, it has been intensely cultivated, resulting in subsidence of the peat surface layer of up to 2.0 m.

## ZUSAMMENFASSUNG

Das Niedermoor Von Chimaditida (West-Mazedonien, Griechenland): Eine Torflagerstätte Bereits Verloren
Das Niedermoor von Chimaditida entwickelte sich seit dem Beginn des Holozäns im flachen Verlandungsbereich des gleichnamigen Sees, welcher an der nordwestlichen Ecke des Teilbeckens von Amyntäon-Ptolemais in West-Mazedonien, Griechenland, liegt. Der Torf wuchs unter limnotelmatischen Bedingungen mit niedrigen Sedimentationsgeschwindigkeiten; letztere sind auf die periodischen Schwankungen des See-Wasserspiegels zurückzuführen, welche die Austrocknung, Oxidierung und den darausfolgenden Verzehr des bereits abgelagerten organischen Materials hervorriefen.

Das Niedermoor nahm früher eine Fläche von 28 km² ein. Vor dem zweiten Weltkrieg sind ca. 25 km², d.h. etwa 89% der Moorfläche, trockengelegt worden, während seit der fünfziger Jahre das Gebiet intensiv kultiviert wird. In einer Zeitspanne von nur 18 Jahren führte die Kultivierung zur Senkung der Mooroberfläche bis zu 2,0 m.

Keywords: fen, peat, subsidence, Western Macedonia, Greece

## INTRODUCTION

The sub-basins of Phlorina, Amyntaion-Ptolemaïs and Kozani are parts of a major tectonic trench which extends between the town of Prilep, former Yugoslavian Republic of Macedonia (F.Y.R.O.M.) in the north (Fig. 1), and the Aliakmon river in the south. The trench is almost 120 km long and approximately 20 km wide; it contains about 64% of the Greek lignite deposits formed during Neogene and Quaternary times (Koukouzas & Koukouzas, 1995).

The Chimaditida lake with the homonymous fen is located at the northwestern edge of the Amyntaion-Ptolemaïs sub-basin. In the first part of the present century many marshes and fens existed in this sub-basin, such as those of Sarigiol, Chimaditida, Vegoritida, Petron, Zazari (Fig. 1). From 1930 until World War II, in a period marked by extensive land drainage in Greece, these marshes and fens were gradually dried-out and converted into urban and agricultural land (Bouzinos *et al.*, 1994).

The Chimaditida fen once covered an area of 28 km² (Fels, 1954; Psilovikos, 1992). An area of about 25 km² was drained before World War II and has been cultivated since the 1950's; corn and trefoil constitute the main crops. The fen and the lake suffer today from eutrophication caused by leaching of the fertilizers, insecticides and pesticides used by the

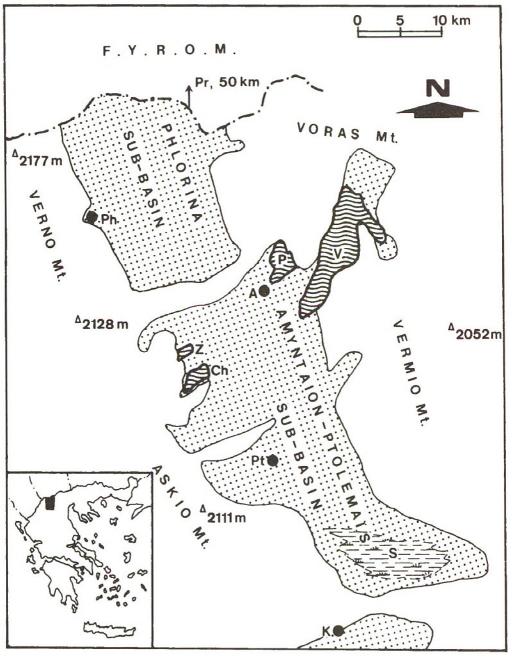


*Fig. 1. Schematic map of the sub-basins (dotted area) of Phlorina, Amyntaion-Ptolemaïs and Kozani (A: Amyntaion, K: Kozani, Ph: Phlorina, Pt: Ptolemaïs, Pr: Prilep, Ch: Chimaditida lake, P: Petron lake, S: Sarigiol mire, V: Vegoritida lake, Z: Zazari lake).*

farmers in the surrounding land (Koutsoumpidis, 1989).

Bottema (1974) carried out palynological examinations and radiocarbon datings in samples obtained from four cores in the marsh (Fig. 2). A drilling programme in 1975-77 by the Greek Geological Survey (I.G.M.E., unpublished data) revealed reserves of one million $m^3$ of peat in a 3.5 m thick formation.

## Geological and Geomorphological Settings

The intramontane sub-basin of Amyntaion-Ptolemaïs is located between the Voras and Vermio mountains to the east, and the Verno and Askio mountains to the west (Fig. 1). Geotectonically, the pre-Neogene rocks forming the basement and the margins of the basin belong to the North Pelagonian isopic zone; they consist of Palaeozoic metamorphic rocks such as gneisses, schists and phyllites (Anastopoulos & Koukouzas, 1972).

The Neogene-Quaternary sediments filling the basin overlie unconformably the Palaeozoic metamorphic rocks. The sediments can be divided into three lithostratigraphic formations (Anastopoulos & Koukouzas, 1972). The lowest formation consists of basal conglomerates which contain pebbles of metamorphic rocks and underlie marls, sandy marls, clays and lignite (xylitic type) layers. The age of this formation has been defined by palaeobotanic methods (Velitzelos & Schneider, 1973) and pollen analyses (Ioakim, 1981) as Upper Miocene-Pliocene. The middle formation consists of lignite seams alternating with clays, marls and sandy clays. Pollen analyses have established the age of this formation as Late Pliocene (Ioakim, 1981; 1982a, b). The upper formation consists of limnic, telmatic, fluvial and terrestrial sediments of Quaternary age, which overlie unconformably the Pliocene sedimentary rocks.

Basin formation and sedimentation are controlled by two groups of normal faults. The first group which strikes NW-SE characterizes the Upper Miocene-Pliocene tectonism and is responsible for the trench formation. The second group comprises NE-SW striking faults that were active during the Lower Pleistocene-Quaternary and divided the trench into sub-basins of Phlorina, Amyntaion-Ptolemaïs and Kozani (Fig. 1). Thus the NE-SW faults appear to dominate the area and control the present structure, geomorphology and symmetrical position of the four lakes, i.e. Vegoritida, Petron, Zazari and Chimaditida (Anastopoulos & Koukouzas, 1972; Karfakis, 1983; Pavlidis, 1985).

The area has a humid, Mediterranean climate. According to meteorological data obtained from the Greek Ministry of Agriculture, the mean annual precipitation rises up to 526 mm and the mean annual temperature is about +12°C. The average temperature in January is about +2.6°C and in July +22°C.

## Materials and Methods

The field work was carried out in 1992-93 during two visits to the study area. The main helophytic communities covering the present mire were identified and classified after the dominant species. The extent of the main communities was also mapped. The stratigraphy of the uppermost deposits was determined by coring. About 38 boreholes were made with an Edelman hand-driven corer up to a depth of 6 m. The cored sediments were examined macroscopically and logged on site (Merkt *et al.*, 1971). The degree of peat decomposition was estimated according to the field method of von Post, which is based on the preservation of plant remains

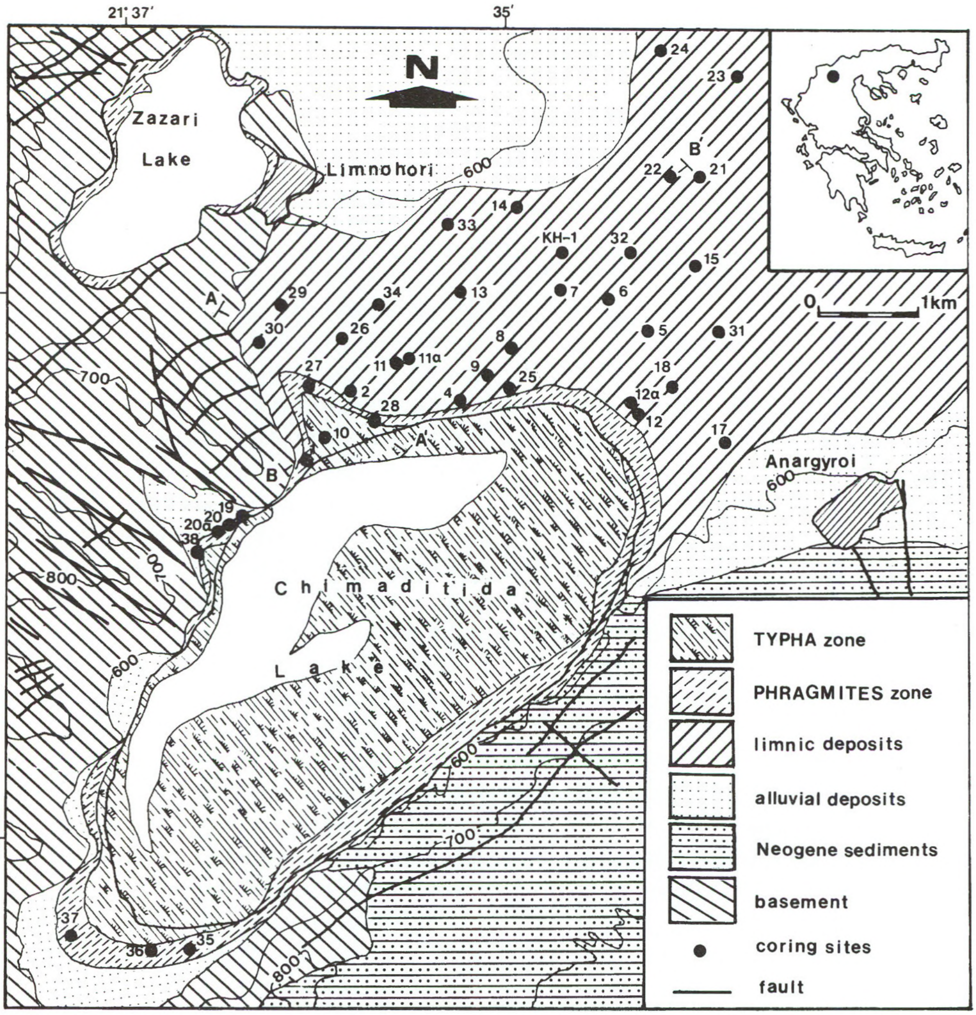


*Fig. 2. Geological map of the lake and the fen of Chimaditida (KH-1: Bottema's coring site).*

and the quantity and colour of the expressed water (Schneekloth, 1990).

Moisture and ash content of samples taken from core No 4 (Fig. 2), each representing depth intervals of 20 cm, were determined initially by oven drying at 105°C for 48 hours and then by ignition in a muffle furnace at 550°C for 4 hours. In addition, pH (in $H_2O$) and electrical conductivity measurements were carried out. The procedures used followed the guidelines given by the former Peat Institute of the Lower Saxonian Geological Survey, Germany (Goetzke, 1974).

Bottema's (1974) radiocarbon datings have been calibrated after the Radiocarbon Calibration Program REV. 3.0 (Stuiver & Reimer, 1993) in the National Centre for Scientific Research (N.C.S.R.-"Demokritos"), Athens to obtain the real ages of the samples.

## Results

The dominant helophytic, peat-forming species covering the present Chimaditida fen are *Typha angustifolia, Phragmites australis* and *Scirpus* spp., while along the shore of the Zazari lake, *Typha domingensis* forms a narrow zone with a few clusters of *Scirpus* spp. and *Cyperus longus.*

The helophytic communities show the typical zonation for mires formed under limnotelmatic conditions (Kaule & Göttlich, 1990; Christanis & Papadaki, 1992). The helophytic vegetation of the Chimaditida fen can be distinguished in two zones according to the dominant species: the *Typha* and the *Phragmites* zones (Fig. 2).

The first zone extends along the internal shore of the lake. *Typha angustifolia* predominates, but *Phragmites australis* also forms clusters. Owing to the general fall of the water-table in the basin and the eutrophication already mentioned, Typha grows today in the largest part of the lake up to a water depth of approximately 1.5 m. As a result, the lake is gradually filling in and the terrestrialization process is well advanced. Only about 30% of the lake area, located in the proximity of the western shore still remains open. Obviously, this is the deepest lake sector marked by the NE and NW striking faults, which are still active.

The *Phragmites* zone extends mainly along the external lake shore. Apart from *Phragmites australis*, this zone also includes clusters of *Scirpus* spp., *Lythrum salicaria* and isolated *Sparganium erectum*, *Cladium mariscus* and some *Carex* spp. In relatively drier places, *Juncus articulatus*, *J. effusus*, *J. hedreichianus* also occur. Aquatic plants, such as *Potamogeton pectinatus* and *Myriophyllum spicatum* dominate the shallow parts of the lake, where *Ranunculus aquatilis*, *Nymphaea alba*, *Zannichellia palustris* and *Lemna minor* form well-defined clusters (Lavrentiadis, 1956).

The peat shows a relatively homogenous matrix; roots and epidermis fragments of *Phragmites australis*, as well as fruits, seeds and leaves of trees are also observed. The peat has a dark brown, brown-greyish or brown-blackish colour. The degree of humification estimated after the field method of von Post ranges between 3 and 5, seldom 6. In the northwest and west of Chimaditida lake, peat occurs at the surface, while in the south it is covered by clastic material up to 2 m thick.

Limnotelmatic sediments (mainly gyttja) are intercalated with peat up to the cored depth. The thinness of these layers shows that interruptions of telmatic by limnic environment were of a short duration and of local significance.

The sediments underlying the peat deposit comprise two distinct formations (Fig. 3). The lower consists of mainly plastic clay layers alternating with lesser amounts of silt and sand. This formation was cored over almost the entire study area. It is characterized by the presence of muscovite flakes and has a green-greyish to grey-greenish colour (named thereafter "green horizon"), occasionally with grey-bluish hues. The roof of the "green horizon" varies between 1 and 3 m beneath the surface; its thickness remains unknown. The upper formation is between 1 and 2 m thick consisting of clay, silt, sandy clay, with plant remains and, only very rarely, muscovite flakes. It has a brown, brown-greyish to brown-blackish colour; thus, it is called "brown horizon". According to the radiocarbon dating of Bottema (1974), both the "green" and the "brown horizons" were deposited before peat started accumulating 9,345±85 yrs BP or, after calibration, some 10,350 yrs ago, an age which coincides with the Pleistocene/Holocene boundary.

The preliminary determinations of physical and chemical properties of the peat and the other organogenic sediments can be summarized as follows: The water content of the samples from core No 4 (Fig. 2) ranges between 82 and 85% of mass. The ash content (on a dry basis) lies between 24 and 39%. The pH values range between 2.6 and 3.1, while electrical conductivity lies between 1,300 and 1,900 ìS$^{-1}$.

According to the results of the physical and chemical analyses carried out by I.G.M.E. on 300 samples obtained from 84 cores, the peat has a water content of between 70% and 85%. The minimum ash content (on a dry basis) is 19.2% and the maximum 43.8%.

Limnotelmatic peat is generally richer in ash than the one formed under pure telmatic conditions (Botis *et al.*, 1993; Christanis, 1983; 1994; Christanis & Papadaki, 1992). The high ash content of the Chimaditida peat can be explained by the supply of inorganic material, which is transported fenwards by surface waters. Although according to the ASTM (1969), an organic sediment which contains ash between 25-50% (on a dry basis), is called clayey peat, Kaule and Göttlich (1990) define peat as a sediment containing less than 50% ash (on a dry basis).

In eight samples from four I.G.M.E. cores, the average fixed carbon on a dry and ash-free basis is 53.2%, the volatile matter 46.8% and the total sulphur content 1.94%. The gross calorific value ranges between 2,980 and 4,280 kcal kg$^{-1}$, while the net calorific value is between 2,780 and 4,000 kcal kg$^{-1}$.

## THE LOSS OF THE ORGANIC MATTER

Until 1930, Macedonia had a total wetland area of 986 km$^2$, the largest in Greece. Between 1930-50 about 94% of this area, i.e. 930 km$^2$, was drained for agricultural use (Psilovikos, 1992). Some peatlands have displayed subsidence phenomena after a few years of cultivation; for example in the Philippi fen, during only 15 years after drainage and intense cultivation, the peat surface subsided by about 3.5 m (van der Molen & Smits, 1962). Similarly, in the Chimaditida fen, lowering of the watertable resulted in subsidence of the peat surface. In addition, the

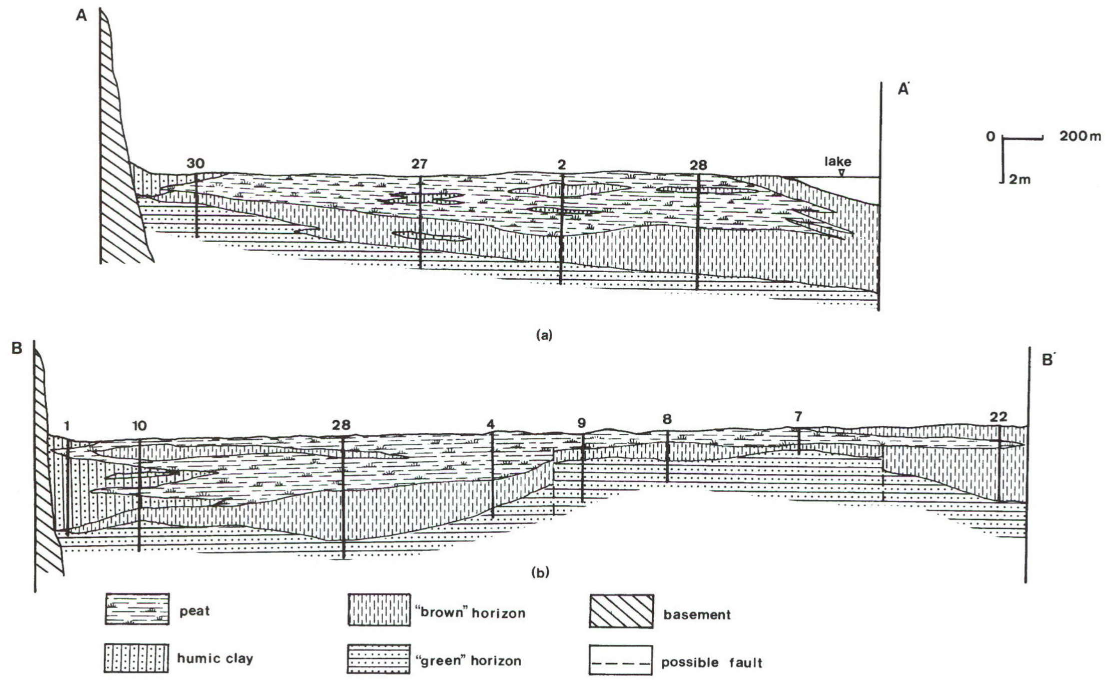


*Fig. 3. Cross-sections A-A' and B-B' (see Fig. 2) of the Chimaditida fen.*

intense cultivation caused the loss of the surface peat layer as a result of oxidation and self-ignition. In 1974-75, the I.G.M.E. drilling programme in the north and northwest of the lake revealed a peat formation with an average thickness of 3.5 m (maximum 5 m), while during our field study in 1992-93 the maximum thickness did not exceed 2 m. Furthermore, in the course of these 18 years, peat reserves in the same area were reduced from 1 million $m^3$ to a few thousand $m^3$. Evidently, these differences result from a loss of organic matter.

Only 5 coring sites (Nos 4, 5, 9, 15, 28; see Fig. 2) could be correlated to 5 sites of the I.G.M.E. study (Z-6, M-14, H-8, 3, B-2; see Table 1) which were in close proximity. Comparison of lithostratigraphic data from these cores, common to both studies, leads to the conclusion that, over the 18 years, intense drainage and cultivation of the Chimaditida fen caused shrinkage and loss of large amounts of organic matter from the surface peat layer resulting in lowering of the original surface by between 47.4% and 77.3% (Table 1).

According to Ilnicki (1983), the subsidence (h) in cultivated fens can be calculated using the formula:

$$h = 0.14\ H + 0.33\ t + 0.05\ L - 0.53$$

where H : the initial peat thickness in metres, L : the time in years, t : the ditch depth in meters. The estimated subsidence values for the Chimaditida fen (L = 18 years, t = 1.5 m) lie between 1.14 m and 1.21 m (Table 1), i.e. about 65 mm $yr^{-1}$. This value is very high because of the intense drainage, as the ditches are extremely deep (1.5 m). The surface lowering

*Table 1: Comparison between the results of both studies (I.G.M.E. & Univ. of Patras) showing the loss of organic matter (*: the area around the coring site is not cultivated).*

| Coring sites in 1974-95 (IGME) | Initial thickness (m) | Coring sites in 1992-93 (Univ.) | Thickness remaining (m) | Surface lowering (m) | Reduction in initial thick-ness (%) | Subsidence (m) according to Ilnicki's formula |
|---|---|---|---|---|---|---|
| Z-6 | 3.80 | 4 | 2.00 | 1.80 | 47.4 | * |
| M-14 | 2.20 | 5 | 0.20 | 2.00 | 77.3 | 1.17 |
| H-8 | 2.50 | 9 | 0.70 | 1.80 | 72.0 | 1.21 |
| 3 | 2.00 | 15 | 0.70 | 1.30 | 65.0 | 1.14 |
| B-2 | 3.15 | 28 | 2.20 | 0.95 | 30.0 | * |

measured in the Chimaditida fen, however, is even higher than the calculated one, as Ilnicki's formula does not take into account the climatic influence. The Greek climate is characterized by long warm and dry seasons which contribute to increased peat oxidation. Moreover, part of the measured subsidence value can be attributed to self-ignition, to burning of dried helophytes in order to gain land for agricultural use and to subsequent wind erosion.

## DISCUSSION

According to the data obtained from the present study, the development of the Chimaditida peat formation can be reconstructed as follows:

The Chimaditida lake formed during Early Quaternary times (Pavlidis, 1985). Litho- and chronostratigraphical data of the sedimentary filling do not exist. During the Last Glacial, a lacustrine regime dominated this part of the sub-basin. The lake formed under the influence of surface waters that originated from the northwestern margins (Fig. 4a). The surface waters transported clastic material from the weathered basement rocks (schists, gneisses) which was deposited in the shallow parts of the Late Glacial lake under limnodeltaic conditions. This resulted in the formation of the "green horizon" (Fig. 3) which consists of clay, silt and sand, and is characterized by muscovite flakes.

The formation of the overlying "brown horizon" which consists of limnic clay containing few plant remains, indicates changes in the clastic material supply and the hydrogeological regime. In this period, the clastic material transported by the surface waters originated from the weathered Neogene and Pleistocene sediments located tothe northeast of the study area (Fig. 4b) while owing to the neotectonic activity, the lake extended to the north and covered a greater area than before. As a result, pure limnic conditions dominated at the northern and northwestern shores of the present lake.

With the onset of the Holocene, the terrestrialization process started at the northern shore of Chimaditida late and the Late Glacial open lake diminished drastically. Organogenic sediments formed in the deeper part of the lake, while peat accumulated at the northwestern shore of the present lake (Fig. 4c). Considering the radiocarbon dating of Bottema (1974), peat accumulated with a mean sedimentation rate of about 0.17 mm $yr^{-1}$ in the periods between 10,350-7,910 yrs BP and 4,420-920 yrs BP (calibrated ages); during the intermediate period (7,910-4,420 yrs BP) the mean rate was about 0.38 mm $yr^{-1}$. All these values are significantly lower than the sedimentation rates calculated for Holocene peat in other Greek fens (Botis *et al.*, 1993; Christanis, 1983; 1994; 1996). Small, probably seasonal fluctuations of the lake level, caused a great expansion of the fen, as the whole area to the north of the present lake is almost flat. Thus, periods of peat accumulation alternated with periods of watertable lowering which resulted in peat desiccation and oxidation and, therefore, loss of accumulated organic matter. Consequently, the apparent sedimentation rates of the limnotelmatic sequence remain low. On the other hand, the calculated rate for the last millenium (2.1 mm $yr^{-1}$) is surprising high compared with recent values for mires of the temperate zone (McCabe, 1987). Unfortunately, the lack of undisturbed peat profiles at the time of our field studies led us to avoid radiocarbon dating.

During the last two decades, drainage and intense cultivation of Chimaditida fen have resulted in subsidence of the surface peat layer of up to 2.0 m owing mainly to the oxidation of the organic matter,

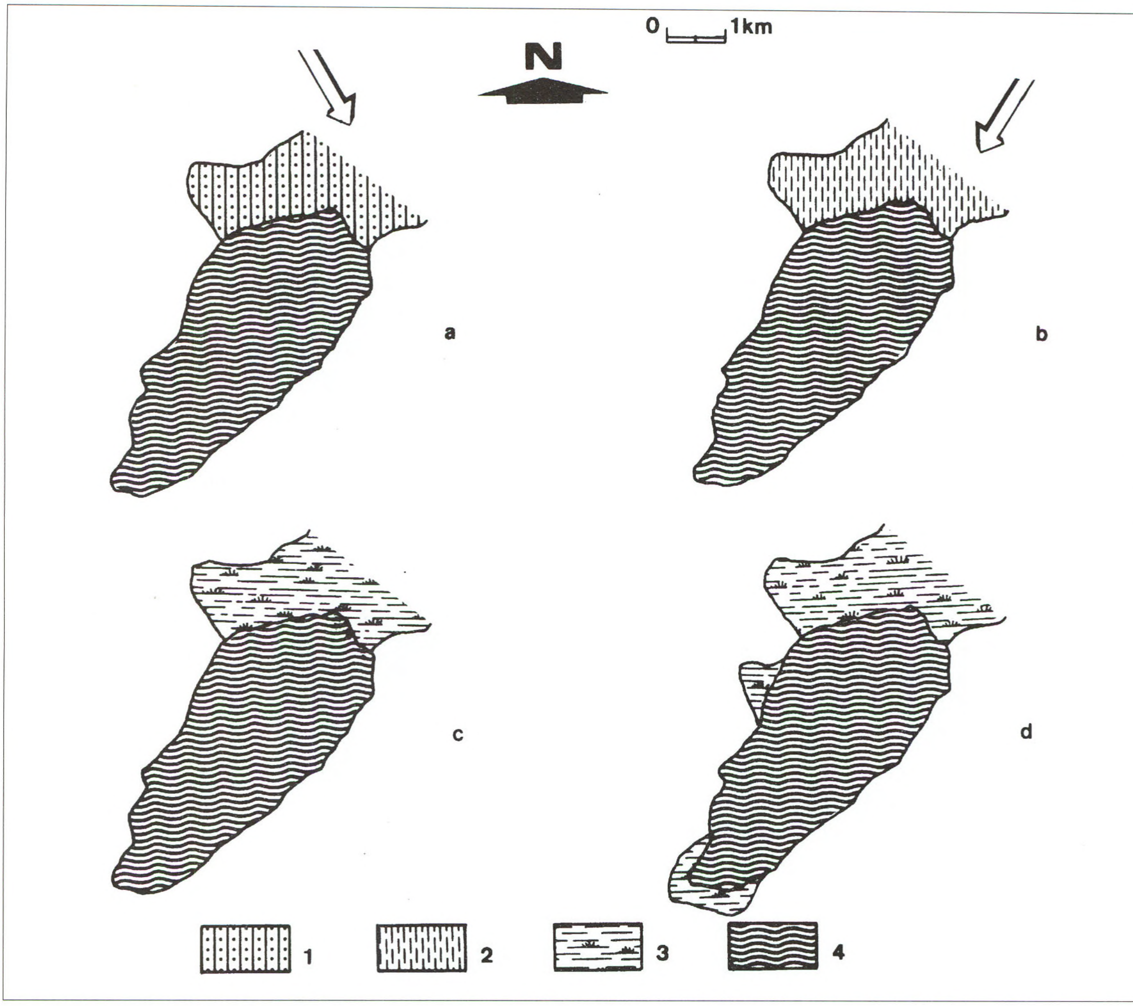


*Fig. 4. Schematic representation of the evolution of the Chimaditida fen. (a) and (b) Last Glacial, (c) Early Holocene, (d) Late Holocene. (1: "green" horizon, 2: "brown" horizon, 3: peat and limnotelmatic sediments, 4: present lake. The arrows show the direction of origin of the clastic material).*

but also to peat compression and wind and water erosion. Presently, peat accumulation takes place at the southern and, partly, the western shore of the Chimaditida lake (Fig. 4d).

If the hydrological-hydrogeological and tectonic conditions in the area remain stable for a long period, the terrestrialization process which has already started, and is accelerated by eutrophication of the lake water, will result in the gradual filling in of the lake. Thereafter, the present limnotelmatic conditions will eventually change to purely telmatic.

## CONCLUSION

In the Chimaditida fen, limnotelmatic conditions have favoured peat accumulation since the onset of the Holocene. The low peat sedimentation rates until recent historical times are associated with periodical fluctuations of the lake level which caused desiccation, oxidation and loss of the organic matter deposited.

The drainage and the intensive cultivation of the fen since the 1950's, combined with the climatic influence, have resulted in a lowering of the surface of up to 2.0 m in a period of only 18 years.

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# WETTING OF MILLED PEAT DURING STORAGE

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## SUMMARY

Milled peat (viz. peat in a particulate form) is stored over winter in large stockpiles on the bog. The average storage period is six to nine months, during which variable wetting of the peat occurs thereby reducing its value. The authors investigated the impact of the initial water content of the peat, and its bulk density, on wetting during storage.

A simulation rig was constructed in which peat samples were subjected to controlled wetting. A regression model was developed which shows that the drier the peat (at the start of the storage period) and the lower its bulk density, the less likely it is to wet during storage. Nevertheless, current peat production methods are such that wetting during storage is of greatest importance for low density peats, due to their higher initial water content.

Placing a very dry layer of peat (c.35% $H_20$ w/w) on the top of the stockpile at the end of the production season is suggested as a method of reducing stockpile wetting. This operation cannot be guaranteed, however, due to the inherent annual variability in weather conditions at the end of the production season. Further research is required to develop an integrated Stockpile Protection System (SPS).

Keywords: milled peat, peat storage, water content, bulk density.

## INTRODUCTION

Milled peat (viz. peat in a particulate form) is produced, during dry summer weather, by comminuting the surface of the bog and allowing atmospheric drying of the resultant thin layer (c.20 mm) of crumb material to take place. The end product (viz. milled peat at a water content of 45%, wet weight basis) is collected and stored over the winter in large stockpiles of triangular cross-section, typically 10 m x 3 m x 1000 m, on the bog. Some stockpiles are covered with polythene but it is only practicable to cover about half of the piles (Flood, 1972; Bord na Mona, 1984). The average storage period for the uncovered piles is six to nine months but could be as long as eighteen months, during which time the peat is exposed to the wetting effect of precipitation resulting in a reduction in its value. With current production techniques, milled peat is most valuable at 45% $H_20$(w/w) with little variability (Lynch, 1994).

The mechanism of stockpile rewetting involves the gradual saturation of the surface layer of the stockpile with water and this wet layer becomes deeper as more rain is absorbed. Kuzhman *et al.* (1953) suggested that the drier the peat the less readily it absorbs water. Therefore, covering the surface of the stockpile with dry milled peat (<35% $H_20$ w/w) reduces rewetting. Several researchers (Aganin, 1973; Daly, 1987; Daly *et al.*, 1994) have suggested that the rate of rewetting is influenced by the type of peat. Irish data (Ward, 1986) show that low density peat (viz. moss peat) absorbs less water than medium or high density peats. Russian sources show that for larger pitch angles of the stockpile face (between 30 and 60 degrees) less wetting occurs (Kuzhman *et al.*, 1953).

This paper examines the influence of both the initial water content of the peat (at the start of the storage period) and peat bulk density on the wetting propensity of milled peat stockpiles.

## EXPERIMENTS

A simulation rig was constructed in the laboratory (Fig. 1) which enabled the total water balance of the system to be determined. Rainfall was simulated by means of upward pointing nozzles from a sprayer which produced the following droplet size profile:

10% < 96μm
50% <320μm
90% <710μm

This use of upward pointing nozzles ensured that the "rain" drops free-fell onto the peat surface and provided an even pattern of droplets. The total amount of rainfall was adjusted by varying the duration of operation of a controlled pump in a cadenced manner. Run-off was determined by collecting water in channels located at the base of the piles (Fig.1). Evaporation was kept at a very low level (<0.5 mm $d^{-1}$) in order to mimic the low evaporation values of winter (when most rewetting is reported to occur). This was achieved by containing the atmosphere within a plastic canopy and raising relative humidity to 90%. The degree of evaporation was monitored by placing two evaporimeters within the enclosed atmosphere and monitoring air temperature (range: 5-10 ºC).

## RESULTS

Various peat types were subjected to a controlled rainfall pattern similar to a three-month winter storage period on the bog. The depths of the resultant wet layers on the surface of the piles were measured, and an empirical model, relating the depth of these wet surface layers (DWL mm) to both the initial water content ($\theta_i$) and the bulk density of the peat $\rho_B$ (g $l^{-1}$), was developed as follows:

$$DWL = 5(\theta_i) + 0.6(\rho_B) - 274 \text{ mm} \; ; \; R^2=0.72$$

The model shows that the drier the peat the slower it is to wet; therefore reducing the initial water content by 10% (from 50 to 40%) reduces the depth of the wet layer by an average of 50 mm. In contrast, the higher the density of the peat the greater is its propensity to rewet. For example, for an initial water content of 45%, a medium density peat ($\rho_B$ =240 g $l^{-1}$) would wet twice as fast as a low density peat ($\rho_B$=160 g $l^{-1}$) at a given $\theta_i$ thus producing 95 mm and 47 mm deep layers, respectively. In reality, however, under actual production conditions the $\theta_i$ is higher for lower density peats. Typically, a low density peat (i.e. $\rho_B$=160 g $l^{-1}$) would have an initial water content of 50%, compared with 45% for medium density ($\rho_B$=240 g $l^{-1}$) and 40% for high density ($\rho_B$=340 g $l^{-1}$) peat. Under these circumstances, the wetting propensity of the different peats can be ranked as in Table 1.

*Fig. 1: Overview of laboratory stockpile wetting apparatus*

*Table 1: The wetting propensity of peats of different bulk densities as measured by the depth of the wet layer formed on the surface of the stockpile after 3 months winter storage (simulated), and the final moisture content (MC) of the stockpile.*

| Peat density: (@ 55% $H_2O$ w/w) | Depth of wet layer mm | $\theta_t$ %w/w | Stockpile Final MC* %w/w |
|---|---|---|---|
| Low Density (160g $l^{-1}$) | 99 | 50 | 54 |
| Medium Density(240g $l^{-1}$) | 124 | 45 | 50 |
| High Density (340g $l^{-1}$) | 161 | 40 | 48 |

**Calculations are based on the impact of the depth of the wet layer (assumed to be 75% $H_2O$ w/w) on the mean water content of a typical stockpile of triangular cross section with a 10 m wide base and 3 m high at the $\theta_t$ values listed here.*

This shows that even though low density peat wets less than high density peat, its high initial water content of 50% means that the final water content of the stockpile (54%) is at the upper limit of the industry target of 55%. In contrast, while high density peat wets more, the final water content of the stockpile (48%) is still below the target "sales" value of 55%. The net effect of this is that storage protection is of more immediate concern to the industry in relation to low and medium density peats than to high density peats.

## Discussion

The model developed here shows that peat density and its initial water content $\theta_t$ affect the wetting propensity of a milled peat stockpile. Unfortunately, the industry has only limited control over these two factors. It has no direct control over peat density (as it is a fixed characteristic of the available peat resource) but it does have some control over the time of sale of various stockpiles. Therefore, using the model developed above, sales can be scheduled based on peat initial moisture content and density (viz. $\theta_t$, $\rho B$) to help reduce overall wetting losses. The producer has some control over the initial moisture content viz. % $H_2O$ of the peat at harvest. One scenario to reduce wetting, based on the model, is to place a very dry layer of peat (<35% $H_2O$ w/w) on the top of the stockpile at the end of the production season. This is of particular importance for low density peats, where stockpile rewetting is more critical, due to the higher average water content of the stockpile at the start of the storage period. In this way, the peat producer can implement a strategy that is specific to each peat density. This approach is consistent with the recommendations of Kuzhman *et al.*, (1953) who state, inter alia, that very dry peat (i.e. 30-35% $H_2O$) placed on the top of the pile can serve as quite reliable protection against rewetting. There is no guarantee of success, however, as the producer's capability to place a very dry layer of peat (<35% $H_2O$ w/w) on the stockpile at the end of the production season is tempered by weather conditions.

The model accounts for approximately three quarters of the variation ($R^2$=0.72), but the model is specific to the conditions under test and does not consider such factors as stockpile compression (rolling), pitch angle, peat chemistry or the role of peat particle size. Additional research is necessary in order to bring all of these (and other unknown) factors together in an integrated Stockpile Protection Strategy (SPS).

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# HIGH DENSITY OF MYCOBACTERIA IN THE BRYOPHYTE VEGETATION (MUSCI) OF MOORLAND

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## SUMMARY

Samples of Musci collected in different moorlands of Ireland contained large numbers of mycobacteria. Samples of *Hylocomium splendens, Thuidium tamariscinum, Breutelia chrysocoma* and *Acrocladium cuspidatum*, revealed more than $10^6$ mycobacteria per gram of pressed moss. Saprophytic, rapidly and slowly growing species (*Mycobacterium gordonae, M. terrae, M. aurum, M. gilvum* and *M. obuense*, and a new species *M. hiberniae*) have been isolated in 33.3 to 61.9 % of these samples. Favourable conditions for mycobacteria in Musci are similar to those in *Sphagnum* vegetation i.e. pH 5.4 to 5.6, and rapid accumulation of solar energy under the surface. The importance of Musci as a reservoir of environmental mycobacteria is stressed.

## ZUSAMMENFASSUNG

Hohes Vorkommen von Mykobakterien in der Laubmoosvegetation der Moore in Irland.
Die Proben von Laubmoosen (Musci) aus den Moorgebieten Irlands enthalten hohe Konzentrationen von Mykobakterien. In 1 g der gepreßten Masse von *Hylocomium splendens, Thuidium tamariscinum, Breutelia chrysocoma* und *Acrocladium cuspidatum* wurden mehr als $10^6$ Mykobakterienzellen nachgewiesen. Saprophytäre Arten, wie *Mycobacterium gordonae, M. terrae, M. aurum, M. gilvum* und *M. obuense* sowie eine neue Spezies *M. hiberniae* wurden in 33,3 bis 61,9% der Proben isoliert. Günstige Bedingungen für die Vermehrung, wie früher schon bei den Sphagnen, konnten bei den untersuchten Laubmoosen festgestellt werden (pH 5,4 - 5,6, schnelle Speicherung der Sonnenwärme unter der Oberfläche der Vegetation). Die Bedeutung von Laubmoosen als Reservoir von Mykobakterien in der Natur wird hervorgehoben.

Keywords: mycobacteria, bryophytes, moorland, Ireland

## INTRODUCTION

The mycobacteria are rod-shaped, acid-fast microorganisms, comprising a genus of more than 70 species. A small number are pathogenous, but the majority are saprophytic environmental organisms which occasionally cause disease in immunodeficient man and animals. Mycobacteria, which can provoke hypersensitivity reactions in response to the injection of tuberculin, originate in the environment. Such reactions, termed "non-specific infection" can cause difficulties with the interpretation of the tuberculin test in cattle and are common in parts of Ireland, especially in Counties Clare, Donegal and Cork (Cooney, 1991).

The occurrence of mycobacteria has been described previously in water, soil and vegetation. Most of these biotopes harbour mycobacteria but multiplication of these organisms does not normally occur. Few natural reservoirs with favorable conditions for the multiplication of mycobacteria are known. *Sphagnum* vegetation is one of the important reservoirs of mycobacteria in Germany, France, Scandinavia, North and South America, New Zealand and Madagascar (Kazda, 1977; Kazda *et al.* 1979; Müller & Kazda, 1987; Irgens *et al.*, 1981; Kazda & Cook, 1987; Müller *et al.*, 1991). Furthermore, *M.sphagni*, a species first isolated from *Sphagnum* vegetation in Sweden and Norway, has been found in all *Sphagnum* bogs examined to date (Kazda, 1980; Kazda *et al.*, 1989).

In studies designed to explain the high affinity of mycobacteria for *Sphagnum* vegetation, it was shown that these microorganisms prefer the grey layer of *Sphagnum*, situated under the active chlorophyll head region. The first stages of peat decay take place in the grey layer, and mycobacteria utilise the nutrients released during decomposition. The accumulation of solar heat (with temperatures 15 to 20°C higher than the ambient air temperature) provides optimum conditions for growth of mesophilic mycobacteria (Rudolph, 1968; Kazda, 1983) and the ion exchange properties of the cell walls of *Sphagnum* maintains an acid environment (pH 4.5 to 5.0). In such an extreme habitat, mycobacteria, unlike most other microorganisms, are capable of multiplication.

Little is known about the distribution of mycobacteria in Musci although some have been found occasionally in samples of Musci in Norway and Russia (Kazda, unpublished data). *Agrobacterium* spp. were isolated by Spiess *et al.*, (1981) from bryophytes collected in different geographical locations.

## MATERIALS AND METHODS

Through July to September 1990 and in April 1991 32 samples of *Hylocomium splendens*, 23 of *Thuidium tamariscinum*, 21 of *Breutelia chrysocoma*, 21 of *Ctenidium molluscum* and 16 of *Acrocladium cuspidatum* were collected to determine the occurrence of mycobacteria in moorlands of Counties Clare, Donegal and Cork. Furthermore, a small number of *Cratoneuron filicinum* (4 samples), *Rhytidiadelphus squarrosus* (3 samples) and *Entodon schreberi* (2 samples) were collected.

Undisturbed sites of moss vegetation were selected and samples were taken using sterile equipment and gloves to avoid contamination. The samples were transported to the laboratory and were refrigerated (0-4°C) until processed in a laminar-flow cabinet. Sterile plastic syringes (60 ml) were filled with moss, compressed and the fluid collected. The weight of the compressed moss was determined by subtraction. Dry moss samples were saturated with a minimum of sterile water, and allowed to stand for 10 min. before pressing out the fluid. The fluid was centrifuged at 1800 g for 30 min. and the sediment resuspended in 1 ml of sterile phosphate buffer pH 7.0.

The total number of acid-fast bacteria (AFB) in each sample was determined by direct microscopic enumeration of smears, stained using the Ziehl-Neelsen method. The total count procedure was a modification of that developed by Breed for enumeration of bacteria in milk (Kazda, 1977).

Rapidly growing mycobacteria were cultured in a dilution from $10^{-2}$ to $10^{-4}$ on Middlebrook 7H10 agar in plates enriched with 4% of beef serum at 31° C for 6 weeks. For isolation of slowly growing mycobacteria, a treatment with oxalic acid and NaOH (Beerwerth & Schürmann, 1969) was included and samples were cultured on Löwenstein-Jensen slants at 31°C and 37°C for 3 months. The colonies obtained were differentiated according to their morphology, smears were stained after Ziehl-Neelsen and acid-fast rods without true branching were selected for further differentiation. Single colony cultures were obtained and tested separately for fast growing (Kazda, 1980) and slowly growing mycobacteria (Kazda et al., 1990).

The three most frequently occurring moss species in the moorland of the Burren (Co. Clare), *Hylocomium splendens*, *Thuidium tamariscinum* and *Breutelia chrysocoma*, were collected in April 1991. The green head region, the grey layer and the deep brown layer were taken separately and examined for pH and numbers of AFB.

To examine the solar heat accumulation in early spring, the probe of a rotating-barrel thermograph was inserted in the grey layer of a clump of *Hylocomium splendens* association in the Carron area of the Burren and measured over a 7 day period. Air and ground (50 mm deep) temperatures were supplied by the nearest meteorological station at Shannon airport. The air and the ground temperature were recorded at hourly and six- hourly intervals, respectively.

The ability of mycobacteria to multiply in pressed fluid gained from the grey layer of *Hylocomium splendens* vegetation was tested after sterile filtration and incubation at 31°C. *M.aichiense, M.aurum and M.sphagni* isolated from moss in Ireland and *M.avium* type strain were used as test microorganisms. The turbidity at 308 nm was recorded twice weekly for 3 weeks.

## RESULTS AND DISCUSSION

The grey layer of Musci, with $10^5$ to $10^6$ AFBg$^{-1}$, showed an unusually high density of mycobacteria (Table 1). The highest mean concentrations were found in *Breutelia chrysocoma* (4.2x$10^6$ per gram), *Thuidium tamariscinum* (3.8x$10^6$ per gram), *Hylocomium splendens* (2.1x$10^6$ per gram) and *Acrocladium cuspidatum* (1.4x$10^6$g per gram). Mycobacteria were cultured in 61.9 per cent of samples of *Ctenidium molluscum*, in 52.2 per cent of *Thuidium tamariscinum* and in 50.0 per cent of samples of *Hylocomium splendens*. A total of 59 strains was isolated. Most frequent were *M.gordonae* and *M.terrae* and, occasionally, *M.aurum, M.gilvum,* and *M.obuense*. A total of 22 isolated strains could not be identified. *M.hiberniae*, described recently in Ireland (Kazda *et al.*, 1993) was often found in samples of *Ctenidium molluscum, Acrocladium cuspidatum* and *Hylocomium splendens*.

*Table 1. Density of acid-fast bacilli (AFB) and incidence of mycobacteria in moss samples from Ireland.*

| Moss species | n | Average conc. of AFB g$^{-1}$ | Incidence of mycob., % |
|---|---|---|---|
| *H. splendens* | 32 | 2.1 x $10^6$ | 50.0 |
| *T. tamariscinum* | 23 | 3.8 x $10^6$ | 52.2 |
| *B. chrysocoma* | 21 | 4.2 x $10^6$ | 33.3 |
| *C. molluscum* | 21 | 6.8 x $10^5$ | 61.9 |
| *A. cuspidatum* | 16 | 1.4 x $10^6$ | 43.8 |
| *C. filicinum* | 4 | 3.4 x $10^5$ | (25.0) |
| *R. squarrosus* | 3 | 1.0 x $10^5$ | (33.3) |
| *E. schreberi* | 2 | 3.8 x $10^5$ | ( 0 ) |

The results of the examination of the green, grey and brown layers of *B.chrysocoma, T.tamariscinum* and *H.splendens* are recorded in Table 2. As in *Sphagnum* vegetation, the highest concentration of AFB was found in the grey layer and the lowest in the green, chlorophyll active region. The pH values of the grey

*Table 2. The distribution of acid-fast bacilli (AFB) and pH values in three moss species.*

| Moss species* | Layer** | pH# | AFBg$^{-1\#}$ |
|---|---|---|---|
| *Breutelia chrysocoma* | green | 5.9 ± 0.2 | 2.2(±1.4) x $10^4$ |
| | grey | 5.4 ± 0.2 | 2.4(±1.2) x $10^5$ |
| | brown | 6.8 ± 0.2 | 1.3(±0.4) x $10^5$ |
| *Thuidium tamariscinum* | green | 5.4 ± 0.2 | 1.2(±0.6) x $10^4$ |
| | grey | 5.5 ± 0.3 | 2.8(±2.5) x $10^6$ |
| | brown | 6.7 ± 0.2 | 1.7(±1.3) x $10^5$ |
| *Hylocomium splendens* | green | 5.6 ± 0.1 | 4.5(±2.6) x $10^4$ |
| | grey | 5.6 ± 0.3 | 6.4(±1.4) x $10^5$ |
| | brown | 6.5 ± 0.2 | 4.6(±1.8) x $10^5$ |

* 6 samples of each moss species were collected

** The terms green, grey and brown layer were described previously (Kazda, 1983)

\# The pH, and AFB concentrations are given with mean value ± standard error

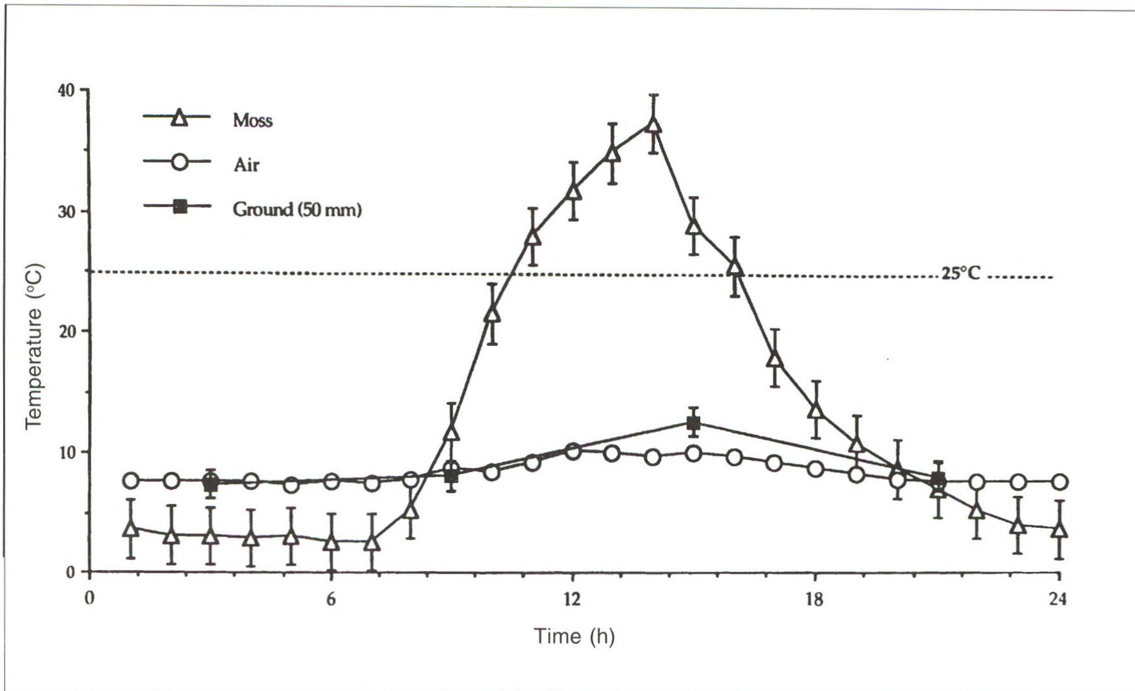


*Fig. 1. The temperature variation (mean and standard error) of moss 2 cm deep compared to the temperature variations of air and ground (0.5 cm deep) over the week 01.04.91 to 07.04.91. Moss temperatures were recorded at Carron in the Burren, Co. Clare, Ireland.*

layer in all three moss species were between 5.4 and 5.6, which is within the favourable range for mycobacterial growth (Kazda, 1983). The higher pH values recorded in the deeper brown layer of mosses probably resulted from chemical interaction with the underlying alkaline limestone present in some moorlands of the Burren.

As previously shown for *Sphagnum*, solar energy accumulates below the surface of Musci. Temperatures as high as +40°C were recorded in the grey layer of moss communities examined (Fig.1). For approximately 6 hours each day the moss temperature exceeded 25°C. At this temperature the mesophilic and "wide-range temperature groups" of environmental mycobacteria can thrive (Marks, 1976). Mycobacteria inoculated in the sterile filtered fluid from *H.splendens* multiplied during the incubation. In the first two weeks at 31°C *M.aichiense* and *M.aurum* grew rapidly whereas *M.sphagnum* and *M.avium* multiplied only to a small extent (Fig. 2). The steady state reached after 3 weeks (not shown) indicates that as nutrients become depleted no further growth takes place.

Present results show that besides *Sphagnum,* a variety of Musci also provide favorable conditions for the growth of Mycobacteria. This seems not to be restricted to Ireland. Twenty-six randomly collected samples of Musci from Germany, mainly *Rhytidiadelphus squarrosus, Acrocladium cuspidatum* and *Brachythecium rutabulum,* contained $1.4 \times 10^7$, $2.1 \times 10^7$ and $2.4 \times 10^6$ AFB per gram, respectively. Samples of Musci originating from New Zealand also revealed a high concentration of mycobacteria (data not shown). Musci are widely distributed, unlike *Sphagnum,* which requires high humidity and other conditions restricted to *Sphagnum* bogs. *Thuidium* spp and *Breutelia* spp. for example colonize a variety of biotopes worldwide (Smith, 1982).

The high concentration of mycobacteria in the moss samples examined is comparable with the unusually high density of mycobacteria in intact *Sphagnum* vegetation of New Zealand (Kazda & Cook, 1987). Apparently, it is not the taxonomic unit of moss, but the ecological form of bryophytes in general, which enables the growth of mycobacteria; the "life-form" described by Mägdefrau (cit. Smith, 1982) seems to offer favorable conditions. This life-form is described as an assemblage of moss shoots and a growth-form, modified by external conditions, which together provide suitable growth conditions. In the moorlands of Ireland, especially in the Burren the hummocks formed by *T. tamariscinum, B. chrysocoma* and *H. splendens* resemble those of *Sphagnum* vegetation.

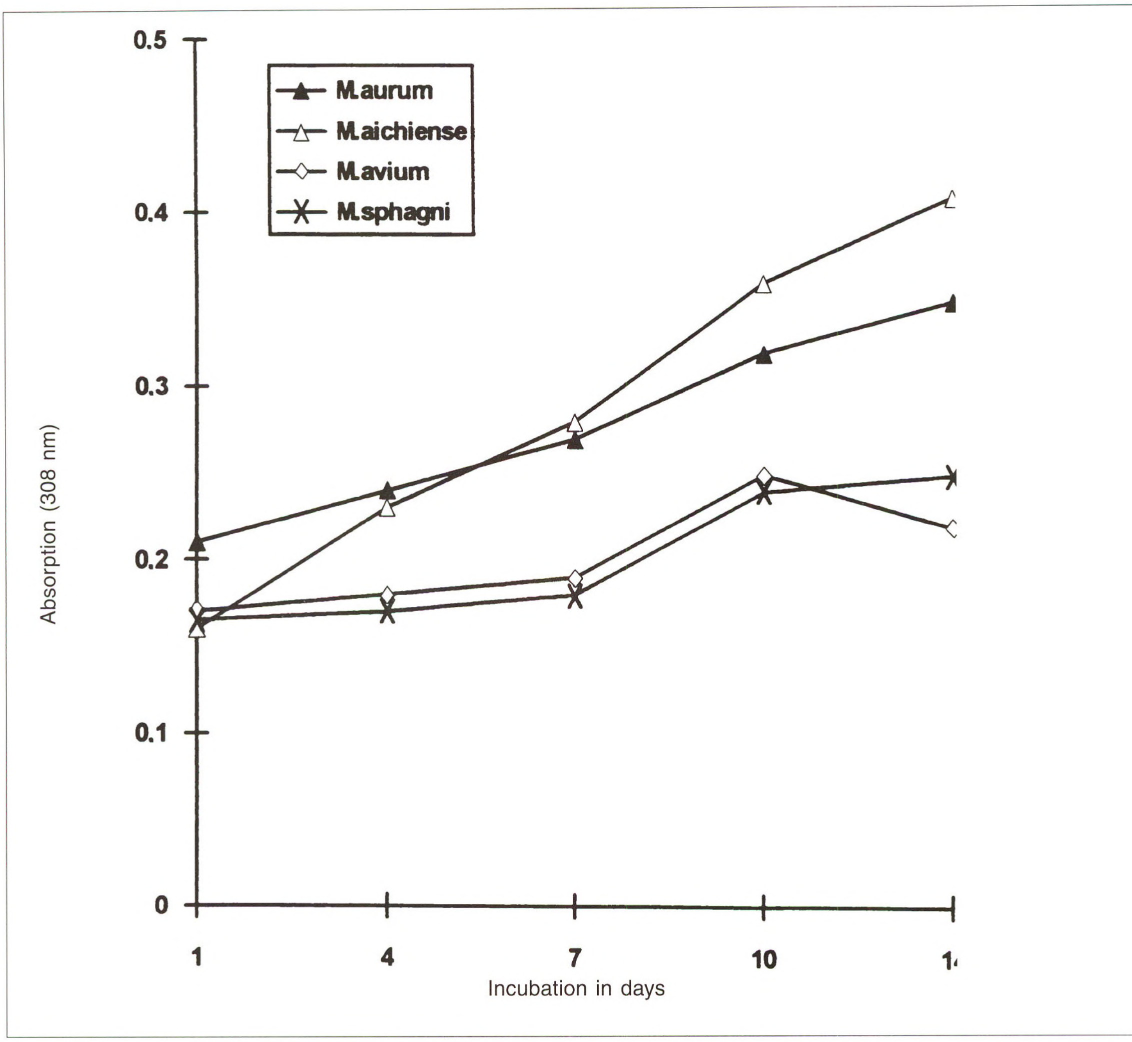


*Fig. 2. Multiplication of four species of mycobacteria in the extract from* Hylocomium splendens *incubated at 31º C.*

Little is known about the importance of microorganisms in the growth cycle of bryophyte vegetation. Agrobacteria, adhering to moss, may affect protonemal growth and gametophore initiation and thus might be an important ecological factor in regulating life cycle events at this stage of moss development (Spiess *et al.*, 1981). The mineralization of mycobacteria by autolysis of bacterial cells rich in amino acids and carbohydrates could provide nutritive substances for the growth of moss plants.

Generally, acidification of the environment by acid rain benefits the spread of bryophytes. The high density of mycobacteria associated with Musci should be taken into consideration in human and animal hygiene and in collecting and processing of moss for horticulture.

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# RESTORATION OF PEATLAND VEGETATION: THE CASE OF DAMAGED OR COMPLETELY REMOVED ACROTELM

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## SUMMARY

Shredded mosses and mire plants from a natural site ("borrow" sites) were spread on harvested sites to favour plant recolonisation of bare peat. Different physical protection methods (windbreaks, artificial cover and straw mulch) were tested to facilitate sphagnum establishment on peat substrates that had a partial or complete loss of the acrotelm layer. On sites where the former acrotelm layer of the mire had been completely removed by peat harvesting activities, the straw mulch spread over shredded, reintroduced mire plant material significantly enhanced the establishment of *Sphagnum* spp. and other bryophytes. On the other hand, the windbreaks and plastic artificial cover had no effect. This effect was independent of the mean water table depth underlying the peat surface to be restored. In favourable conditions (i.e. a site with a mean water table rarely below 65 cm), mire plant material that had been collected and spread mechanically reached close to a 50% cover in three seasons. Likewise, sites with a partial acrotelm remaining (mire plant borrow sites) recovered better when a straw mulch was applied in the first year. In the second year, sphagna reached nearly 60% cover with or without a straw mulch applied. Before concluding that a protecting device is not necessary in sites with partial acrotelm remaining, it would be important to verify the effect of different seasonal climatic conditions on moss regeneration success.

Keywords: revegetation; rehabilitation; Sphagnum; mire; recolonisation.

## INTRODUCTION

Recreating the functions of peatland ecosystems on post-harvested peatlands is at first problematic. On the one hand, in natural mires, the presence of an acrotelm ensures a high and stable water level which is critical to the growth and development of sphagna (Ingram, 1992). On the other hand this same acrotelm exists because of the structure created by sphagnum mosses. Peat extracting activities remove these two features: the acrotelm and the moss cover. Hence, once peat extracting activities cease, it is not easy for *Sphagnum* species to re-establish on bare peat. Even though the former drainage system for exploitation is blocked, the water table remains lower and fluctuates more than in nearby intact mires (Price, 1996), impeding the recolonisation by sphagna. Indeed, from all the abandoned peatlands that could be traced in eastern Canada, only 10 percent of the surfaces exibited partial sphagnum cover (Rochefort, unpublished data; but see Lavoie & Rochefort, 1996). Remedial measures are needed to induce and ensure sphagnum recolonisation.

Preliminary field and greenhouse studies show that the most promising approach for revegetating the moss layer is to spread sphagnum fragments (diaspores) on bare peat (Rochefort *et al.*, 1995; Campeau & Rochefort, 1996). Further studies also show that it is critical to protect diaspores against desiccation caused by wind and solar radiation (Sagot & Rochefort, 1996; Quinty & Rochefort, 1997a; Ferland & Rochefort, in press). As part of a collaborative research project in eastern Canada, physical protection methods (windbreaks, artificial cover and straw mulch) were tested to facilitate sphagnum establishment on peat substrates that had a partial or complete loss of the acrotelm layer.

## Study Sites and Methods

### 1) Site with acrotelm removed completely

The study site for this experiment is within a 15 km$^2$ mire located at Rivière-Ouelle (47°27'N, 69°58'W), about half of which is used for peat harvesting. The experiment was conducted on two fields (40 m wide by 400 m long) that had been abandoned for ten years. The drainage ditches along the fields were blocked in May 1993. The aim of the experiment was to test the effect of windbreaks and ground covers on the recolonisation success of sphagnum on a peat substrate where the acrotelm of a mire had been completely removed by peat harvesting activities. Recolonisation by sphagnum moss and other mire plants in sites subject to different protection treatments was monitored over a three year period (1994 to 1996).

*Experimental design*

The effect of windbreaks and ground covers on the recolonisation success of sphagnum species, other bryophytes and vascular plants was tested within a split-plot experiment in a completely randomized design. For windbreaks, we used wooden snow fences that were set perpendicular to the prevailing winds (see Quinty & Rochefort, 1997a). The fences were 1.2 m high with a porosity of 50%. We also expected windbreaks to work as snow traps in winter. Consequently, we had four possibilities regarding the position of the windbreak: (1) the effect of fences as windbreak in summer (to reduce desiccation effect), (2) the effect of fences as snow trap in winter (to increase stored soil moisture), (3) the combination of both effects (to ensure a moist substrate for as long as possible), (4) a control with no fences. The experimental site was divided into 12 main plot units (15 x 9 m) to which the four levels of the windbreak factors were randomized (3 replicates for each windbreak condition).

Each main plot unit was subdivided into 3 subplot units (15 m x 3 m), to which the three cover types (no cover, plastic cover and straw) were randomized. The plastic cover consisted of plastic snow fences that were unrolled on the ground. The straw was spreaded by hand at a density of approximately 1500 kg ha$^{-1}$ fresh mass (Quinty & Rochefort, 1997a). Both covers had about the same porosity (66%).

*Collection and reintroduction of mire plant material*

Living plant material was collected mechanically with a shredder to a depth of 10 to 15 cm and spread with a manure spreader onto the abandoned surfaces (Quinty & Rochefort, 1997a). The material contained pieces from 1 to a few centimeters long, with some bigger chunks. The ratio of collected surface to the surface covered by the transplanted material was 1:8. For example, 1 m$^2$ of material collected from the borrow site would recover 8 m$^2$ of the experimental fields.

*Data collection and statistical analysis*

The effect of treatments (windbreaks and cover types) on the establishment of a vegetated cover was assessed by evaluating the percentage coverage of three plant groups at the end of each growing season (October). The three groups of plants were: (1) sphagnum mosses dominated by *S. fuscum* (Schimp.)

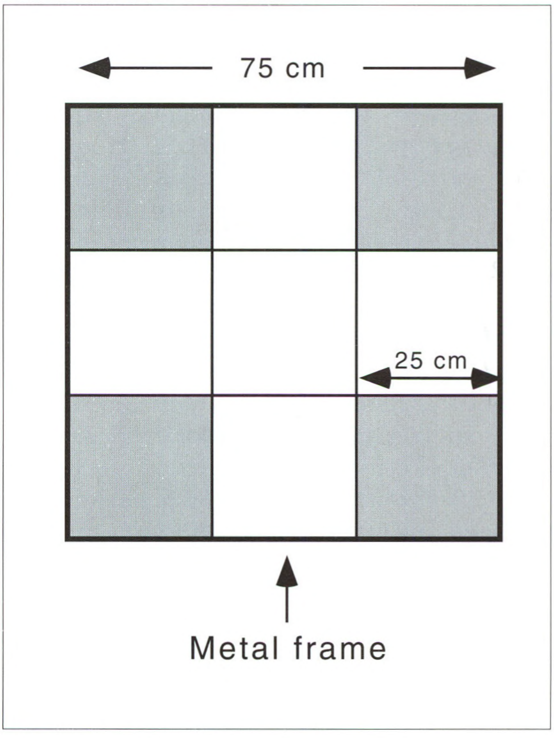


*Fig. 1: Sampling field frame to evaluate percentage mire plant establishment representing 1 group of 4 quadrats*

*Table 1: Repeated measures ANOVA analyses on plant cover (%) for the Rivière-Ouelle experiment (acrotelm removed completely) for years 1994, 1995 and 1996 on rank transformed data.* df *means degree of freedom; F is the F statistic; P means probability and N.S. is for non significant.*

| | *Sphagnum* | | | *Other mosses* | | | *Vascular plants* | | | *Total cover* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Source | df | F | P | df | F | P | df | F | P | df | F | P |
| Main plots | | | | | | | | | | | | |
| **Windbreaks** | 3 | 0.32 | N.S. | 3 | 0.32 | N.S. | 3 | 0.64 | N.S. | 3 | 0.45 | N.S. |
| **Error a** | 8 | | | 8 | | | 8 | | | 8 | | |
| Subplots | | | | | | | | | | | | |
| **Cover** | 2 | 19.54 | <0.001 | 2 | 39.40 | <0.001 | 2 | 9.72 | <0.01 | 2 | 33.37 | <0.001 |
| **Cover x Windbreaks** | 6 | 0.61 | N.S. | 6 | 1.10 | N.S. | 6 | 1.78 | N.S. | 6 | 0.49 | N.S. |
| **Error b** | 16 | | | 16 | | | 16 | | | 16 | | |
| Repeated measures | | | | | | | | | | | | |
| **Year** | 1 | 48.97 | <0.001 | 1 | 13.05 | <0.001 | 1 | 6.95 | <0.05 | 1 | 0.50 | N.S. |
| **Year x Windbreaks** | 3 | 0.59 | N.S. | 3 | 0.18 | N.S. | 3 | 0.42 | N.S. | 3 | 0.08 | N.S. |
| **Year x Cover** | 2 | 3.12 | N.S. | 2 | 0.37 | N.S. | 2 | 0.78 | N.S. | 2 | 0.51 | N.S. |
| **Year x Windbreaks xCover** | 6 | 1.11 | N.S. | 6 | 1.00 | N.S. | 6 | 0.93 | N.S. | 6 | 0.49 | N.S. |
| **Error c** | 24 | | | 24 | | | 24 | | | 24 | | |

Klinggr. and *S. capillifolium* (Ehrh.) Hedw. with a minor component of *S. magellanicum* Brid., (2) other bryophytes dominated by *Polytrichum strictum* Brid., *Dicranum polysetum* Sw., *Mylia anomala* (Hook.) S. Gray and *Pohlia nutans* (Hedw.) Lindb. and (3) vascular plants, by order of abundance *Betula papyrifera*[1] (Marsh.), *Larix laricina*[1] (DuRoi) K. Koch, *Chamaedaphne calyculata* (L.) Moench, *Vaccinium oxycoccos* L., *Vaccinium angustifolium* Ait., *Drosera rotundifolia* L. and *Ledum groenlandicum* Retzius. Three groups of 4 quadrats of 25 x 25 cm (Fig. 1) were randomly placed on each subplot to evaluate percentage cover.

Numbers obtained for each sampling quadrat were averaged for each subplot. Those values were used in analyses of variance with repeated measures (year) according to a split-plot design (factors: windbreaks and artificial covers), following rank transformations to reduce heterogeneity of variances (SAS, 1990). Box's conservative correction was applied to correct for the nonrandomisation of the " year " factor (Box, 1954).

## 2) Site with partial acrotelm remaining

Restoration techniques currently developed in eastern Canada require the removal of mire surface vegetation on some small natural surfaces to provide source material for Sphagnum reintroductions on former exploited and abandoned areas. As a result, the acrotelm of these " borrow " sites is partially damaged by machinery when chipping and collecting the first top 10 cm of living plant material for the reintroductions. The collection work is done in the spring when the underlying peat is still frozen, minimizing soil disturbance. Regeneration of borrow sites was studied at Ste-Marguerite-Marie (48°47'N, 72°10'W) in two different sphagnum communities; one was a lawn dominated by *S. angustifolium* while the other was dominated by *S. fuscum* hummocks and ericaceous shrubs. Plant material was collected in the spring of 1995, after which, 10 plots of 40 $m^2$ were delineated at the borrow sites to evaluate recovery from these superficial disturbances. Half of the plots in each community were covered with a straw mulch (which could be composed of barley, oat or wheat straw) to

[[1] *Betula* and *Larix* are two species that established spontaneously.]

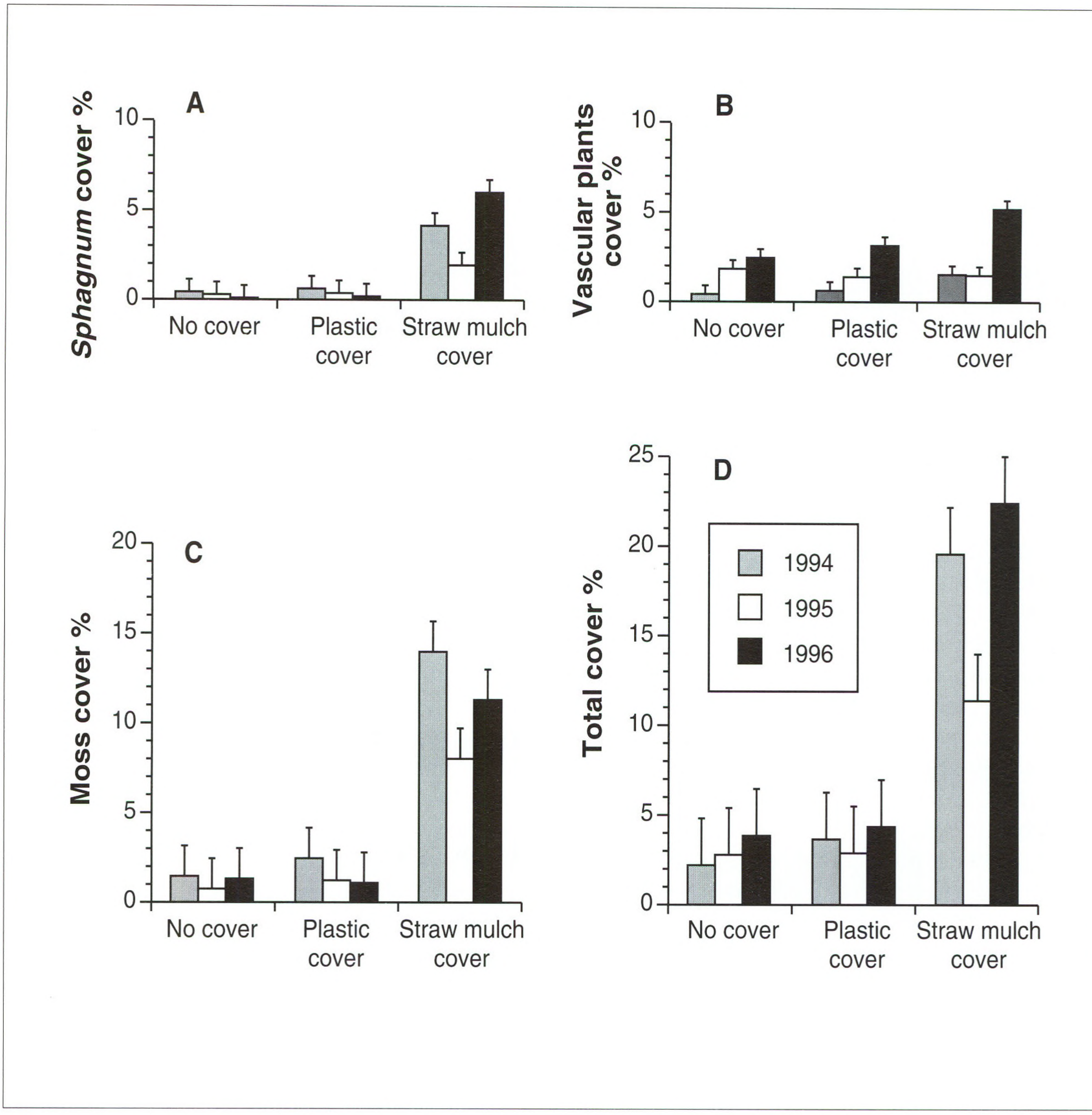


*Fig. 2: Effect of straw mulch and plastic cover having similar porosity on the establishment (cover %) of different plant groups on a site being restored for 1994, 1995, and 1996 (mean ± S.E.). A - Sphagnum cover; B - Vascular plant cover; C - Bryophyte cover (excluding Sphagna); D - Total plant cover.*

determine if an artificial cover would assist the regeneration process. At the end of each growing season, the percentage cover of Sphagnum moss was estimated in a series of quadrats (20) in each plot. Data were analysed using analysis of variance in which rank transformation was used to reduce heterogeneity of the variances (SAS, 1990).

## RESULTS AND DISCUSSION

### Site with acrotelm removed completely

*Effect of windbreaks*

Abandoned peatlands form vast flat areas of denuded peat and are exposed to extreme environmental conditions compared to natural ecosystems. The use of wooden snow fences to simulate natural tree windbreaks could help prevent evaporation and desiccation of the soil surface during the summer and thus ameliorate the establishment conditions for Sphagnum diaspores. Also, flat surfaces are not conducive to snow accumulation over the winter. Windbreaks could be a passive means of increasing accumulation of snow during winter and help to dampen the site to be restored.

The presence of windbreaks had little effect on Sphagnum establishment (Table 1). Windbreaks did increase snow accumulation (data not shown), but this greater snow depth had no measurable effect on the local water table. To detect an effect, it may be necessary to install a large number of windbreaks on all sections of the peatland where the drainage system has been blocked.

### *Effect of a protecting cover*

Straw mulch placed on top of the sphagnum diaspores greatly facilitated their implantation (Fig. 2; Table 1). Moss establishment (sphagnum and other bryophytes) was three to five times greater than when the diaspores were protected by a plastic cover or implanted without any protection. The effect was not as strong for the vascular plant group reintroduced, but still significant ($P<0.01$). The difference is explained by the fact that mosses are poikilohydric organisms which are very dependent on atmospheric moist conditions for survival and growth compared to vascular plants. Thus, the effect of a straw mulch covering the moss diaspores was pronounced.

### *Season effect*

The success of establishment varied between the different growing seasons (year term significant for the 3 plant groups reintroduced; Table 1), but in a different manner for each group of plants. The vascular plant cover (Fig. 2B) increased from year to year, independently of climatic condition, once they were established. On the other hand, bryophytes (Fig. 2A and 2C) responded directly to the pluviometry of the particular growing season. For the region of the experimental study, 1995 was a very dry year. This was generally the case for all eastern Canada and the industry registered a record year of peat harvesting. Mosses then had little chance to develop further or increase their colonisation in 1995. With a straw mulch, the surface colonized by the mosses was at least maintained over that dry summer. In comparison, under the plastic cover or without cover, part of the sphagnum individuals and bryophytes that had established in 1994 were lost. The 1996 season, which was characterised by wet July and August months (little peat harvesting done by the company), permitted a recovery of the colonisation process.

However, we suspected that the colonisation process was partly dependent on the position of the mean water table underlying the peat surface to be restored because it varied substantially from one end of the experimental site to the other (Fig. 3). The experimental site can be divided into four distinct zones perpendicular to the water table gradient (Fig. 3). Each zone was divided into three main plot units, for a total of twelve main plots units over the site to which the windbreak factor was initially randomized. As windbreaks had no effect on the establishment success of vegetation we decided *a posteriori* to reconduct an ANOVA that did not include the windbreak factor but compared sphagnum recolonisation under a cover of straw mulch only (three plots per zone). The resulting design was factorial (4 zones x 3 years), replicated 3 times, and no data transformation was needed. The analysis revealed a strong zone effect whereby the success of establishment was better when the water table was nearer the surface (Table 2 and Fig. 4). As this is only *a posteriori* observation, we do not want to further discuss the success of establishment in relation to mean water table. However, it is possible to say that after 3 years of monitoring mire plant material that has been reintroduced mechanically, close to 50% of the surface can be successfully recolonized under favourable conditions.

## Site with partial acrotelm remaining

After one growing season (1995), our results showed that the application of a straw mulch on the borrow sites significantly enhanced their natural recovery (Fig. 5, Table 3), enabling the *S. fuscum* to regenerate from about a 5% loose material left from the collecting operation to a 40% cover. The *S. angustifolium* community did not regenerate as well (5% after the first growing season) as the *S. fuscum*. Perhaps the looser growth habit of *S. angustifolium* left fewer regenerants in the field for propagation, but

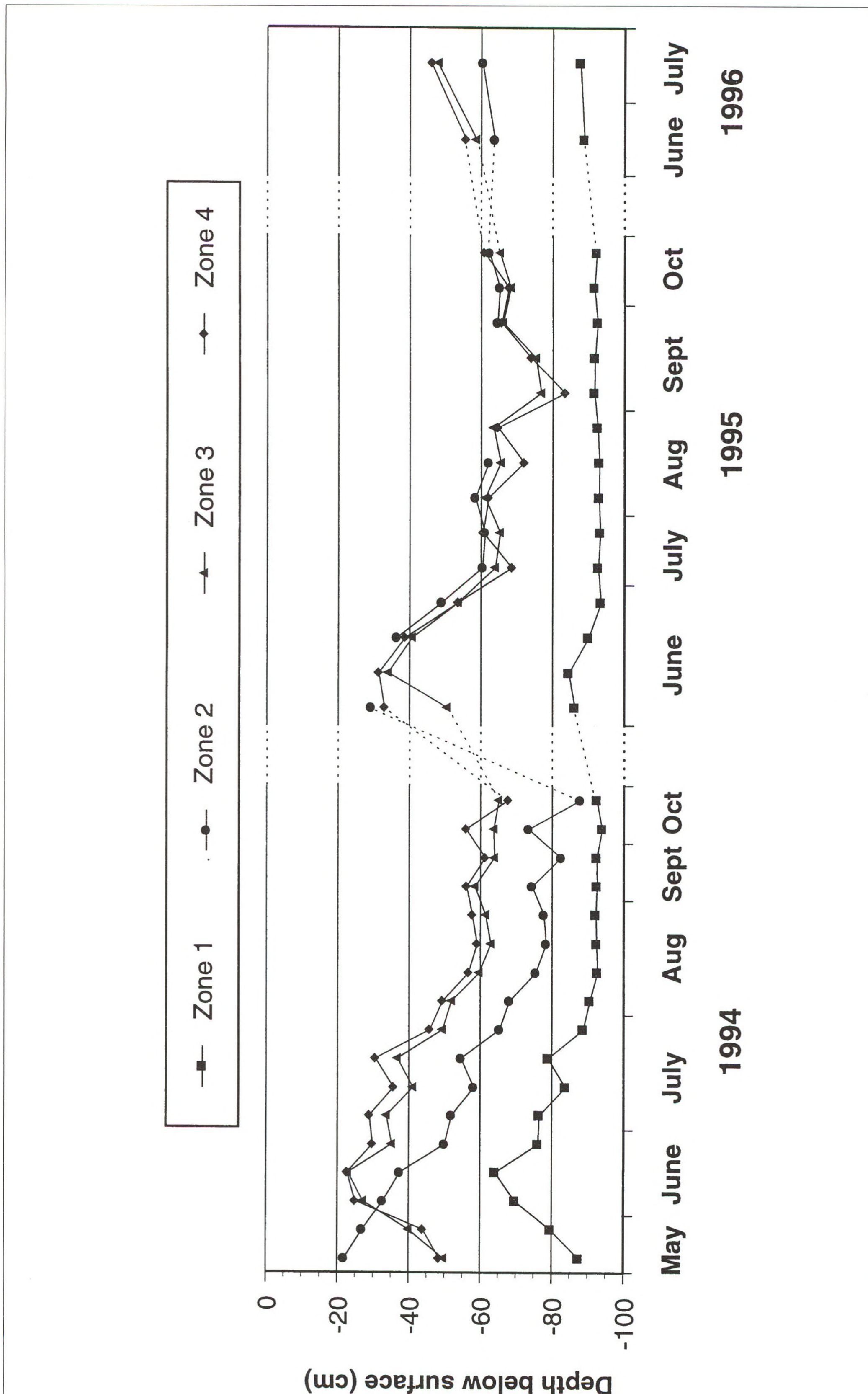


*Fig. 3: Water table depth (cm) measured usually once a week during the summers of 1994 and 1995 and two times in 1996. Values represent the mean of two water wells for each experimental site. Site 1 was definitively a drier site than the others. Site 2 was intermediate in the drier years (1994 and 1996).*

*Table 2: Factorial ANOVA analyses on plant cover (%) for the Rivière-Ouelle experiment (acrotelm removed completely) for years 1994, 1995 and 1996.* df *means degree of freedom; F is the F statistic; P means probability and N.S. is for non significant.*

| | *Sphagnum* | | | Other mosses | | | Vascular plants | | | Total cover | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Source** | **df** | **F** | **P** | **df** | **F** | **P** | **df** | **F** | **P** | **df** | **F** | **P** |
| Main plots | | | | | | | | | | | | |
| **Zone** | 3 | 12.91 | <0.01 | 3 | 44.83 | <0.0001 | 3 | 0.65 | N.S. | 3 | 132.34 | <0.0001 |
| **Error a** | 8 | | | 8 | | | 8 | | | 8 | | |
| Subplots | | | | | | | | | | | | |
| **Year** | 2 | 3.03 | N.S. | 2 | 4.04 | N.S. | 2 | 5.97 | <0.01 | 2 | 8.52 | <0.01 |
| **Year x Zone** | 6 | 5.98 | <0.001 | 6 | 4.27 | <0.01 | 6 | 1.44 | N.S. | 6 | 7.50 | <0.001 |
| **Error b** | 16 | | | 16 | | | 16 | | | 16 | | |

we have no data to subtantiate this conjecture. The ericaceaous shrubs easily recovered to a 20% cover but were not affected by the mulch treatment (data not shown). The recovery monitoring was followed in 1996, but because of particularly wet conditions in the autumn of 1996, the plots dominated by *S. angustifolium* were under water, and it was not possible to make cover estimates. Hence, it was not possible to analyse statistically the *S. fuscum* plots by themselves because they were replicated only twice. Still, judging from the mean data presented in Fig. 5 for 1996, both treatments yielded a regeneration cover close to 60%. From this second year result, one could

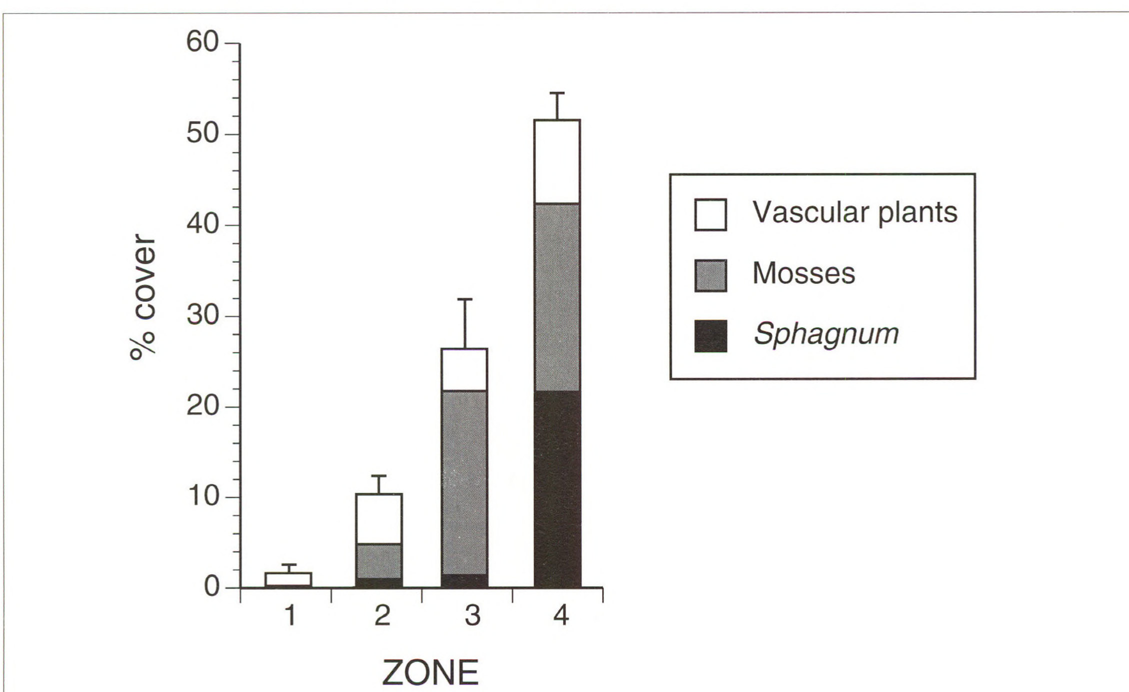


*Fig. 4: Plant establishment (mean cover % ± S.E.) on the experimental site for four zones defined by water table depth after three years of growth under a straw mulch.*

*Table 3: Split-plot ANOVA analysis on percent cover of mire plants recovery for the experiment at Ste-Marguerite-Marie (acrotelm partially removed). df means degree of freedom; F is the F statistics; P means probability and N.S. is for non significant.*

| Source | df | F | P |
|---|---|---|---|
| Main plots | | | |
| **Community** | 1 | 373.69 | 0.0003 |
| **Error a** | 3 | | |
| Subplots | | | |
| **Mulch cover** | 1 | 14.34 | 0.03 |
| **Mulch cover x Community** | 1 | 0.18 | N.S. |
| **Error b** | 3 | | |

conclude that it is unnecessary in the long run to use a protecting cover in the first place to facilitate regeneration of the sphagna although 1996 was a relatively wet season, and the impact impact of the presence of the straw mulch may have been lessened compared to what it could be in a drier year. We are presently testing, for the 4 years to come, the regenerating capacity of different sites with relation to climatic variability, that is repeating the same experiments year after year.

Overall, the use of a straw mulch on sphagnum diaspores appears to greatly enhance the establishment of a sphagnum moss layer which is critical to restoring a peat-forming ecosystem. In eastern Canada, it is now common practice to use this technique (Quinty & Rochefort, 1997b), sometimes in combination with other restoration techniques (water management, implantation of companion species or creation of a topography) to regenerate mire

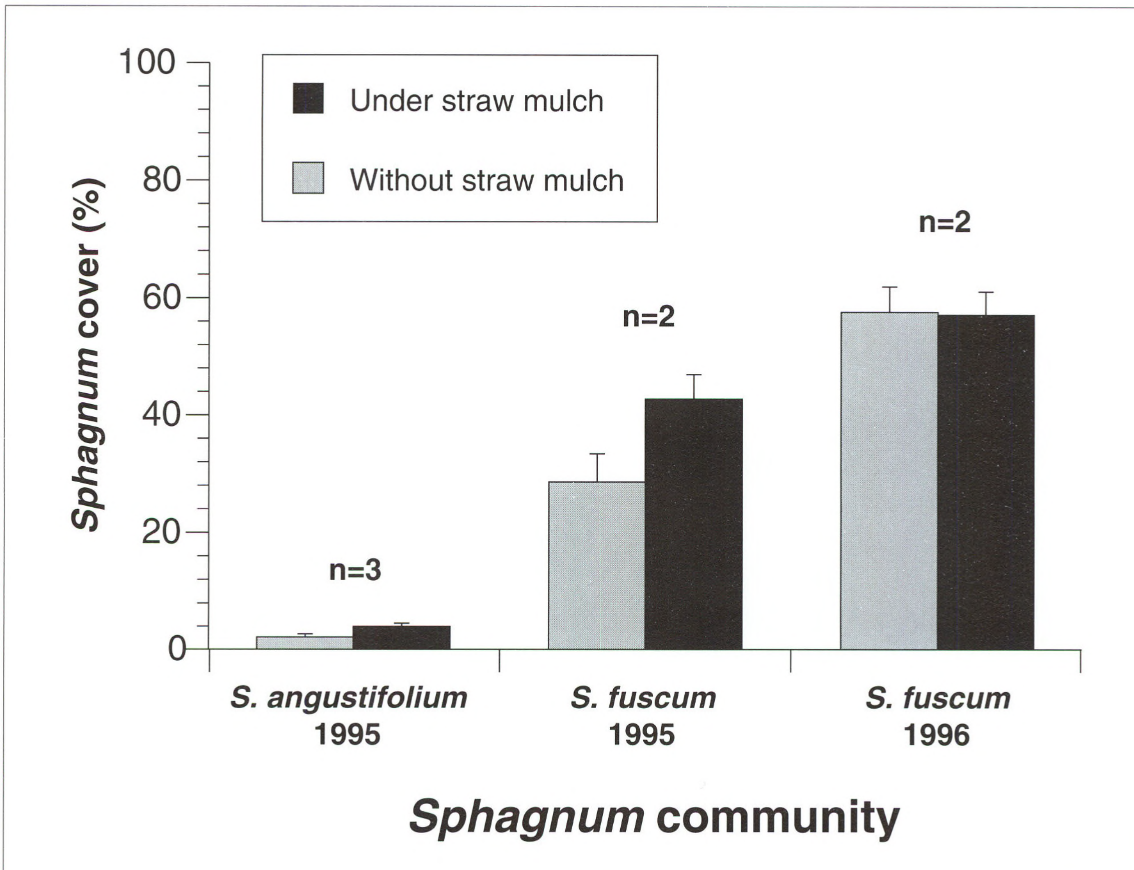


*Fig. 5: Sphagnum recovery (mean cover % ± S.E.) after chipping and removal of the top 10 centimeters of vegetation in a bog. Recovery was evaluated after one season for* S. angustifolium *community and two growing seasons for* S. fuscum *community. The* S. angustifolium *dominated community could not be evaluated at the end of the second growing season as the sites were under water in autumn 1996.*

ecosystems, either when the acrotelm has been completely or partially destroyed.


## ACKNOWLEDGEMENTS

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# IMPACT OF DIFFERENT FERTILIZERS ON THE BOUND AMINO ACIDS CONTENT IN SOILS

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## SUMMARY

The composition of bound amino acids was investigated in soils treated with different fertilizers. All fertilizers increased the total amount of bound amino acids in soils. It was found that in all soil samples, amino acids with neutral net charge showed the highest concentrations. Acidic and sulfuric amino acids had the lowest concentrations in all samples of soils. Glutamic acid, glycine, leucine and 1-methylhistidine predominated in samples of soils. All fertilizers had the greatest influence on 1-methylhistidine concentrations. High concentration of â-alanine and lysine in soils may indicate higher microbial biomass, since â-alanine and lysine are typical constituent of bacterial cell walls.

## INTRODUCTION

A considerable part of soil organic matter consists of compounds which disintegrate into amino acids during hydrolysis (Stevenson, 1985). Root exudates supply the soil with considerable amounts of organic substances containing amino acids (Claudius & Merhotka, 1973). Soil amino acids may be produced from the decomposition of plant biomass or they may be formed by transamination of the respective ketoacids. Most of the amino acids in soils occur in bound form in the humin fraction. It is commonly assumed that the bound amino acids in soil are in the form of proteins or peptides (Stevenson, 1985). Peptides or proteins react via $NH_2$ - groups with phenolic lignin degradation products or phenols formed from metabolic reactions of micro-organisms (Szajdak & Zyczynska-Baloniak, 1994). Phenolic acids are known to inhibit plant growth. The negative effects of phenolic acids are manifest in the inhibition of seed sprouting and root growth. Inhibition of mitotic cell divisions has also been reported (Szajdak & Zyczyñska-Baloniak, 1994; Wójcik-Wojtkowiak *et al.*, 1990). Decomposition of organic matter and autolysis of microorganisms in soil liberates some amino acids favourable to plant growth and serves to explain, in part, how organic matter increases soil productivity. Thus, interest in the study of amino acids in soil has increased. Little information is available on the factors which may influence the nature of the amino compounds of the soil. Among those which would be expected to exert an influence are the plant species occupying the soil, the cropping system and fertilization.

This paper presents the results of an investigation on the bound amino acids in soils treated with different fertilizers. The total amino acids were determined qualitatively and quantitatively.

## MATERIALS AND METHODS

The composition of bound amino acids was investigated in soils treated with different fertilizers and in untreated soils (Sokolov *et al.*, 1995). The following fertilizers "BALANCE ORGANIC MINERAL FERTILIZERS (BOMF)" were used: $BOMF_p$ (peat + cow manure + NPK), $BOMF_s$ (sapropel + cow manure + NPK), $BOMF_{bc}$ (brown coal + cow manure + NPK). BOMF mixtures were specially prepared and applied for the cultivation of potatoes. The study was performed on experimental fields at Experimental Station "Ducora", 50 km south-east of Minsk, belonging to the Institute for Problems of the Use of Natural Resources and Ecology, Academy of Sciences of Belarus, Minsk. This area has been investigated with regard to soil,

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hydrology and meteorology. The potato crop was fertilized with BOMF 60 t $ha^{-1}$.; farmers normally use 35-40 t $ha^{-1}$ of BOMF. BOMF was applied to soils ploughed in April 1994. The potatoes were planted in May 1994 and soil samples for testing were taken in July 1994. The experimental fields contain a medium sandy loam podsolic soil with 3 % of humus, H+ 3.15 meq $100g^{-1}$ of soil, $V_{sorptive\ capacity}$ 77.07 %, $N_{total}$ 0.15 %, $P_2O_5$ (extract 0.2 N HCL) 49.6 mg $100g^{-1}$ of soil and $K_2O$ (extract 0.2 N HCl) 20.3 mg $100g^{-1}$ of soil. The pH value, determined in 0.1 mol×$l^{-1}$ KCl, was 6.05. During the growing season, the activity of catalase enzyme ranged from 4.5 to 6.7 $cm^3$ of $O_2$ per gram of soil per 2 minutes and that of the dehydrogenase enzyme from 0.47 to 1.01 mg of 2,3,5 - triphenyltetrazolium chloride per 10 g of soil per 24 hours.

## Methods and instruments

For analysis, samples of soils were sealed and heated with 6 N HCl for 24 h at 105°C. The solutions were then filtered, transferred to measuring flasks and made up to 50 ml with deionised water. The solutions were evaporated to dry mass under low pressure. Separation and determination of the bound amino acids were carried out on a T 339 amino acids analyser (Mikrotechna-Praha). The separation of the bound amino acids was carried out on column Ostion LGFA (0.37x20 cm). The lithium-citric buffers of the following pH: 2.90, 3.10, 3.35, 4.05 and 4.90 were in the mobile phase. The absorbances of the eluent-ninhydrin complex were monitored at 520 nm (Szajdak & Österberg, 1996). The mobile phase was pumped at a rate of 12 $cm^3$ $h^{-1}$ and developed a pressure of 2.5 MPa. All the experiments were run in triplicate and the results averaged. 23 amino acids were determined in each soil sample.

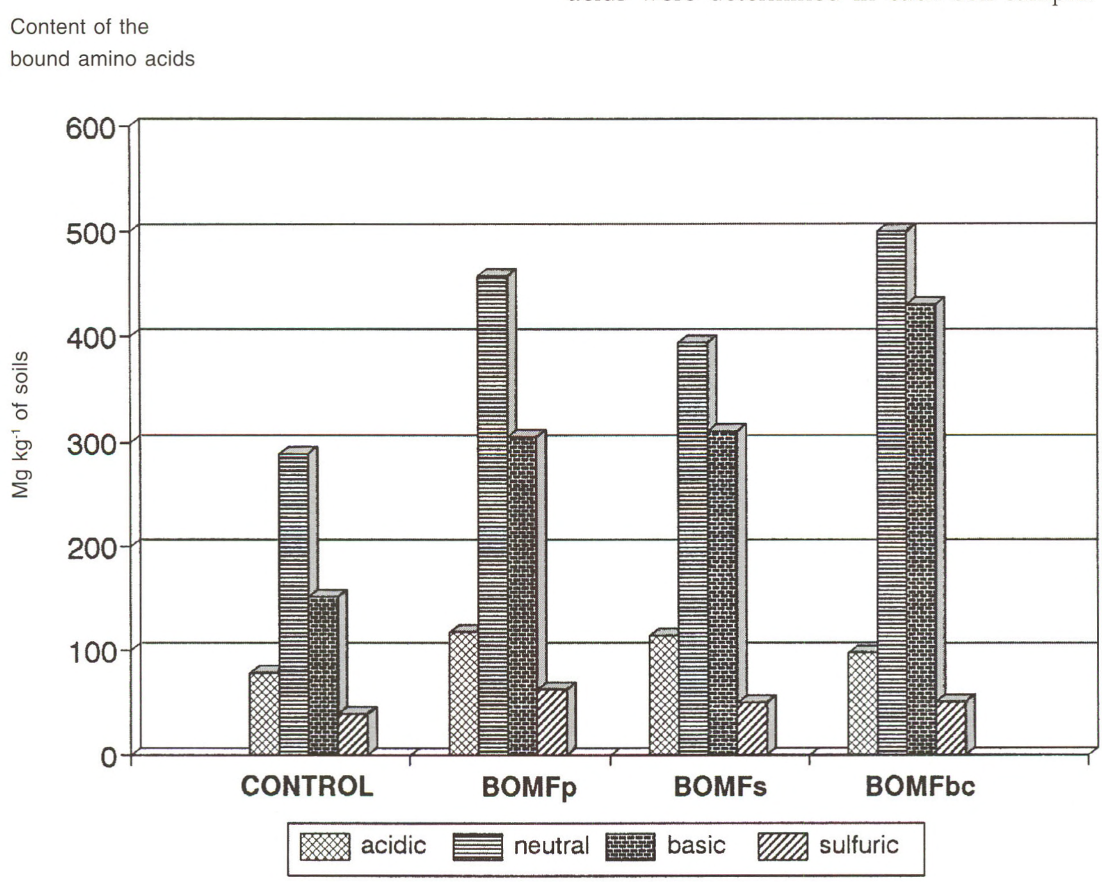


*Fig. 1. Content of the bound amino acids in soils treated with different fertlizers in mg $kg^{-1}$ of soils.*

*Table 1. The bound amino acids treated with different fertilizers in mg kg$^{-1}$ of soil.*

| Amino acids | Reference soil | Soil treated BOMF$_P$ [peat, cow manure, NPK] | Soil treated BOMF$_S$ [sapropel,cow manure, NPK] | Soil treated BOMF$_{bc}$ [brown coal, cow manure, NPK] |
|---|---|---|---|---|
| ***acidic*** | - | - | - | - |
| Cysteic acid | 9.28±0.32 | 14.20±0.49 | 12.37±0.43 | 11.16±0.37 |
| Taurine | 1.13±0.03 | 1.45±0.05 | 4.33±0.15 | 1.25±0.04 |
| Phosphoethanolamine | 5.31±0.19 | 6.72±0.23 | 2.51±0.09 | 0.54±0.02 |
| Glutamic acid | 37.14±1.29 | 67.31±2.34 | 57.74±2.01 | 41.27±1.44 |
| α-aminoadipic acid | 26.16±0.92 | 28.31±0.98 | 37.42±1.31 | 44.00±1.53 |
| ***neutral*** | - | - | - | - |
| Proline | 23.69±0.83 | 5.96±0.20 | 6.13±0.20 | 2.37±0.08 |
| Glycine | 71.14±2.48 | 103.41±3.61 | 99.18±3.46 | 97.13±3.36 |
| Alanine | 29.46±2.48 | 50.28±1.75 | 39.46±1.38 | 45.42±1.59 |
| α-aminobutyric acid | - | 8.95±0.31 | 5.92±0.21 | 0.27±0.01 |
| Valine | 33.02±1.15 | 47.54±1.67 | 53.78±1.87 | 138.12±4.82 |
| Methionine | 26.14±0.91 | 40.74±1.42 | 28.49±0.96 | 32.32±1.13 |
| Cystathionine | 2.18±0.08 | 6.04±0.21 | 4.37±0.15 | 6.51±0.22 |
| Leucine | 71.45±2.49 | 119.61±4.17 | 96.76±3.38 | 104.74±3.65 |
| Tyrosine | 7.17±0.25 | 13.02±0.45 | 11.24±0.39 | 21.34±0.75 |
| β-alanine | 32.71±1.14 | 54.83±1.91 | 39.33±1.36 | 32.11±1.12 |
| β-aminoisobutyric acid | 0.92±0.03 | 1.02±0.03 | 1.38±0.05 | 0.29±0.01 |
| γ-aminobutyric acid | 10.34±0.36 | 6.18±0.21 | 7.61±0.27 | 19.40±0.67 |
| ***basic*** | - | - | - | - |
| Ornithine | 5.44±0.19 | 8.12±0.28 | 6.60±0.23 | 6.98±0.24 |
| Lysine | 37.34±1.30 | 52.24±1.89 | 44.86±1.57 | 52.60±1.83 |
| Histidine | 13.82±0.48 | 22.08±0.77 | 14.46±0.51 | 20.65±0.72 |
| 1-methylhistidine | 11.53±0.40 | 111.47±3.89 | 129.02±4.50 | 188.55±6.51 |
| 3-methylhistidine | 70.64±2.46 | 88.92±3.10 | 96.94±3.38 | 138.20±4.81 |
| Arginine | 13.38±0.46 | 22.24±0.77 | 18.33±0.64 | 22.68±0.74 |
| **Total amount** | **519.39** | **880.51** | **818.23** | **1027.90** |

## RESULTS AND DISCUSSION

The total amount of bound amino acid in the reference soil was 519 mg kg$^{-1}$ (Table 1). All fertilizers increased the total amount of bound amino acids in the soil. The BOMF$_{bc}$ fertilizer increased it by 97.7 %, BOMF$_P$ by 69.5 % and BOMF$_S$ by 57.5 %. On grouping the amino acids into acidic, neutral, basic and sulfur types, it was found that in all soil samples, those with the neutral net charge showed the highest concentrations (Holtzlaw et al. 1980; Stevenson, 1985; Zyczyñska-Baloniak & Szajdak, 1993). Acidic amino acids were present in the lowest concentrations in the same soil samples. The highest influence of fertilizers in increasing the amount of amino acids was observed with basic amino acids. The increase of basic amino acids was from 105.1 % to 182.4 % compared with the reference soil (Table 1 and Fig. 1).

The concentrations of bound amino acids in soil treated with different fertilizers revealed that glycine and leucine were dominant among the neutral amino acids, glutamic acid among the acidic and 1-methylhistidine among the basic. All fertilizers had the highest influence on 1-methylhistidine concentrations. These concentrations in soils treated with different fertilizers were from 9.7 to 16.4-times higher than in the reference soil.

Also higher concentrations of β-alanine were found in the soils treated with different fertilizers

(Zyczyñska-Baloniak & Szajdak, 1993). With $BOMF_p$ fertilizer, the concentration of this amino acid was 67.1 % higher than that in the reference soil and 20.2 % higher in soil treated with $BOMF_s$. As a component of bacterial cell walls, β-alanine takes part in many biochemical transformations in these microbes and can indicate higher bacterial biomass in the soils treated with different fertilizers (Zyczyñska-Baloniak & Szajdak, 1993).

A higher microbiological activity in the fertilized soils is also indicated by the higher average concentration (34 %) of lysine in these soils. Lysine is formed in soil due to decarbonisation of α,ε-diaminopimelinic acid (Durska & Kaszubiak, 1980). As it is commonly known, this amino acid, like β-alanine, is a component of bacterial cell walls. The highest concentration of lysine was recorded in soil treated with $BOMF_{bc}$ and amounted to 52.60 mg $kg^{-1}$ of soil. This value was 40.9 % higher than that in the reference soil.

The studies revealed much smaller concentrations of proline in the fertilized soils than in the reference soil (Zyczyñska-Baloniak & Szajdak, 1993). Mean proline concentration was about 79.6 % lower than that in the reference soil. The smallest concentrations were observed in soil treated with $BOMF_{bc}$. In this soil, the proline content was 2.37 mg $kg^{-1}$, 89.9 % lower than that in the reference soil. Degradation of proline in the fertilized soils may be due to the fact that proline is a heterocyclic amino acid which undergoes slow microbiological decomposition. The phenomenon of proline degradation in soils treated with different fertilizers is positive since this amino acid, being a secondary amine, can form N-nitrosamine with nitrite ions if the soil is acidified. It is a potent toxin with carcinogenic, mutagenic and teratogenic effects (Kofoed *et al.*, 1981; Larson *et al.*, 1990; Pesci, 1992).

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# A FIELD INVESTIGATION INTO THE REWETTING OF MILLED PEAT IN STOCKPILES

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## SUMMARY

Understanding the rewetting of milled peat in stockpiles is necessary in order to establish possible methods of reducing the phenomenon. This paper describes the sampling of two stockpiles prior to and during the first half of a winter rewetting period. Samples were taken from both stockpile surfaces and from within the pile core to establish the patterns and magnitude of rewetting. Results indicate that before the onset of autumnal rain, the stockpile surfaces were dry and the cores were wetter with the piles having mean water contents around 0.34 g $g^{-1}$ (wet weight basis). After 3.5 months (autumn and early winter) the stockpiles increased in water content to *ca.* 0.47 g $g^{-1}$ wet weight water content. It was found that wetting was not confined to the surface wet layer but there were localised zones of high water content forming "fingers" into the core of the stockpiles. This was interpreted as indicating the development of lines of by-pass flow into the centre of the stockpiles.

## INTRODUCTION

The rewetting of milled peat in stockpiles is of importance to the peat industry because the value of the product is to some degree dependent upon the water content at which it is sold. Even when the absolute water content is not of relevance, the cost of transporting water when moving the milled peat is unwanted. In the PECO production system (Bord na Móna, 1984) long stockpiles of air-dried milled peat stretch out across the bog. These remain in place until ready for sale, and during the storage time, they are subject to prevailing meteorological conditions which in Ireland means they are exposed to significant amounts of rain (>1000 mm $yr^{-1}$, Collins and Cummins, 1996). There are currently two practical responses to this situation: accommodate it in production and sales strategies or protect the stockpiles by covering with polythene. Accommodation results in potentially high production costs and a lower product value, while covering is associated with high material costs, access problems and the need to dispose of the covering material when the peat is sold.

In order to develop and evaluate potentially cost effective and efficient methods of stockpile protection it is necessary to understand how stockpiles rewet and whether the mechanisms involved can be modified. To this end work has been undertaken to establish whether the depth of surface wet layers on stockpiles is related to the physical properties of the milled peat and their geographical location (Dykes *et al.*, 1997). It can be stated with reasonable confidence that wet layer depth is partially determined by the initial water content of milled peat in the stockpile and that orientation has a role to play. It should be noted that Dykes *et al.* assumed that the drier milled peat in the core of the stockpile was at the same water content as when the stockpile was constructed, and they assumed that wetting fronts advanced from the stockpile surface in a progressive manner determined by the porous properties of the milled peat and the amount of water applied to the surface. Such an assumption requires that water movement through milled peat conforms reasonably well to the physical principles of infiltration and conductivity of water through porous media and that their empirical relationship

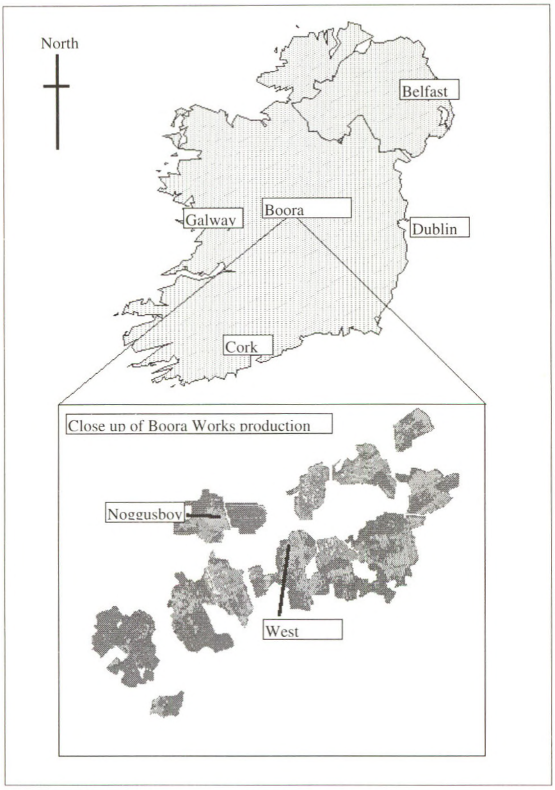


*Fig.1: The location of sample sites at Boora Works, Co. Offaly, Ireland.*

can be explained by a simple water balance, i.e. depth of wet layer would be well related to rainfall, unsaturated hydraulic conductivity, and evaporative loss.

Holden and Ward (1996a) attempted to estimate unsaturated hydraulic conductivity from one-dimensional infiltration into milled peat in the laboratory, but were confounded to some degree by changes in water content that were not progressive by depth. This meant that for some milled peat types the water content at 0.4 m depth was increasing sooner after infiltration started than the water content near the surface. A reasonable explanation for this occurrence is that water by-passed the near surface in some type of preferential flow path and started accumulating at depth.

This paper presents a field investigation into the rewetting of milled peat stockpiles through the first half of a winter period, and the implications of the findings for mechanisms of rewetting in stockpiles in general.

## METHODS

Two stockpiles were selected for investigation from the Bord na Móna Boora Works, County Offaly, Ireland. One stockpile was on a high density peat at West Boora (oriented with east-west faces - sampled on the east face) and the other on a low to medium density peat at Noggusboy (oriented with north-south faces - sampled on the south face) (Fig. 1). The physical properties of the milled peat types are summarised in Table 1. Two separate sampling strategies were pursued to establish initial water content data and the change in water content with time.

### Determining initial water content conditions

The sampling strategy for initial water content conditions was designed to provide information about variability at a relatively small scale (up to 2.0 m) and at a large scale (up to 300 m). Samples were taken (on 3-4/9/96) from six points in the stockpile: (1) three on the surface at vertical intervals of 0.5, 1.0 and 1.5 m above the ground level; (2) two from 0.5 m above the ground and within the stockpile at 0.5 and 1.0 m horizontally and (3) one at 1.0 m vertically above the

*Table 1: The physical properties of milled peats from Noggusboy and West Boora bogs, Boora Works, Co. Offaly.*

| Peat Type | Ash Content (%)[1] | Air-dry poured density (Mg $m^{-3}$) | De Boodt density (Mg $m^3$) (wet) | 2 mm ratio[2] | Saturated hydraulic conductivity (m $s^{-1}$) | Porosity (%) |
|---|---|---|---|---|---|---|
| Noggusboy (N) | 3.20 | 0.28 | 0.23 | 4.48 | 5.12E-04 | 46 |
| West Boora (WB) | 10.12 | 0.47 | 0.35 | 1.03 | 3.31E-04 | 66 |

1. By ignition at 500°C for 5 hours
2. Ratio of mass of particles > 2mm : < 2mm

ground and 0.5 m horizontally into the stockpile. Samples from the surface were taken by lifting material from 0 - 0.1 m using a trowel and samples from within the stockpile were taken using a machine screw auger mounted horizontally on a tractor. All samples were analysed for tension and water content using the filter paper method (Deka *et al.*, 1995): A 50 $cm^3$ screw lid container of known weight was half filled by pouring from the sample bag, a piece of Whatman #42 filter paper was placed on top, and the rest of the container was filled, the lid replaced and sealed. After six days the sample filled container was weighed and the gravimetric water content of both the filter paper and the milled peat determined. Using the calibration equation of Deka *et al.* (1995) the tension was calculated ($\Psi_\theta$, kPa), and using the density of milled peat in the container, the volumetric water content ($\theta_v$, $m^3$ $m^{-3}$) was calculated from the gravimetric water content using the relationship:

$$\theta_v = (\rho_b/\rho_w).\theta_g \qquad (1)$$

where $\rho_b$ = bulk density(Mg $m^{-3}$), $\rho_w$ = density of water (1.0 Mg $m^{-3}$) and $\theta_g$ = gravimetric water content (Mg $Mg^{-1}$). The filter paper method had been used with milled peat previously and had been found to be practical at high tensions (Holden and Ward, 1996b).

## Determining subsequent water content distributions

The sampling strategy used was modified from that of the initial sampling because the tractor mounted auger could not be relied upon for access during the winter months. Samples were taken on three dates (4/10/96, 31/10/96 and 9/12/96 - referred to as "sept", "oct" and "nov" in the text) at each side of the stockpile at 50 m intervals over a length of 200 m at locations near the original sampling sites. At each location 4 samples were taken from 0.5 m above ground level and about 0.5 m below stockpile height. The samples were: (1) particles from the very surface, (2) the wet layer (as determined by darkening of the milled peat), (3) 0.10 - 0.20 m below the surface but not including the wet layer and (4) 0.30 - 0.50 m into the stockpile. This set of samples was chosen because it provided information about the wet layer and the core of the stockpile approximating those samples taken initially while providing information about the effect of local elevation and orientation. Gravimetric water content was determined for all samples and is reported here, but the use of volumetric water content is more desirable because it reports the actual amount of water in the sample and permits direct comparison between samples of different density (e.g. 0.000075 $m^3$ of 0.1 Mg $m^{-3}$ milled peat with a water content of 55% (wet weight) will contain *ca.* 0.000009 $m^3$ of water. If the density was 0.4 Mg $m^{-3}$, the sample would contain *ca.* 0.000037 $m^3$ of water, the volumetric water contents would be 0.12 and 0.49 $m^3$ $m^{-3}$ respectively). Where a comparison of milled peat types is attempted, a density value of 0.28 Mg $m^{-3}$ for Noggusboy and 0.47 Mg $m^{-3}$ for West Boora have been assumed for all data (from Holden and Ward, 1996b), and volumetric water content calculated using equation 1.

*Table 2: Initial stockpile water contents expressed as volumetric and gravimetric. (sample 1 = low surface; sample 2 = low, 0.50 - 1.00 m; sample 3 = low, 1.50 - 2.00 m; sample 4 = middle surface; sample 5 = middle 0.50 - 1.00 m; sample 6 = high surface).*

| Variable | West Boora | Noggusboy |
|---|---|---|
| mean $\theta_g$ ± S.D (g $g^{-1}$) | 0.54 ± 0.22 | 0.52 ± 0.23 |
| mean $\theta_w$ ± S.D (g $g^{-1}$) | 0.34 ± 0.09 | 0.33 ± 0.10 |
| mean $\theta_v$ ± S.D ($m^3$ $m^{-3}$) | 0.14 ± 0.05 | 0.09 ± 0.04 |
| sample 1 ($\theta_v$) | 0.12 ± 0.03 | 0.09 ± 0.04 |
| sample 2 ($\theta_v$) | 0.19 ± 0.05 | 0.09 ± 0.04 |
| sample 3 ($\theta_v$) | 0.21 ± 0.03 | 0.08 ± 0.04 |
| sample 4 ($\theta_v$) | 0.10 ± 0.02 | 0.08 ± 0.04 |
| sample 5 ($\theta_v$) | 0.14 ± 0.04 | 0.12 ± 0.02 |
| sample 6 ($\theta_v$) | 0.09 ± 0.02 | 0.08 ± 0.03 |
| sample 1 ($\theta_g$) | 0.48 ± 0.18 | 0.46 ± 0.21 |
| sample 2 ($\theta_g$) | 0.67 ± 0.18 | 0.53 ± 0.18 |
| sample 3 ($\theta_g$) | 0.79 ± 0.17 | 0.56 ± 0.26 |
| sample 4 ($\theta_g$) | 0.39 ± 0.10 | 0.42 ± 0.23 |
| sample 5 ($\theta_g$) | 0.56 ± 0.15 | 0.73 ± 0.13 |
| sample 6 ($\theta_g$) | 0.32 ± 0.08 | 0.39 ± 0.16 |

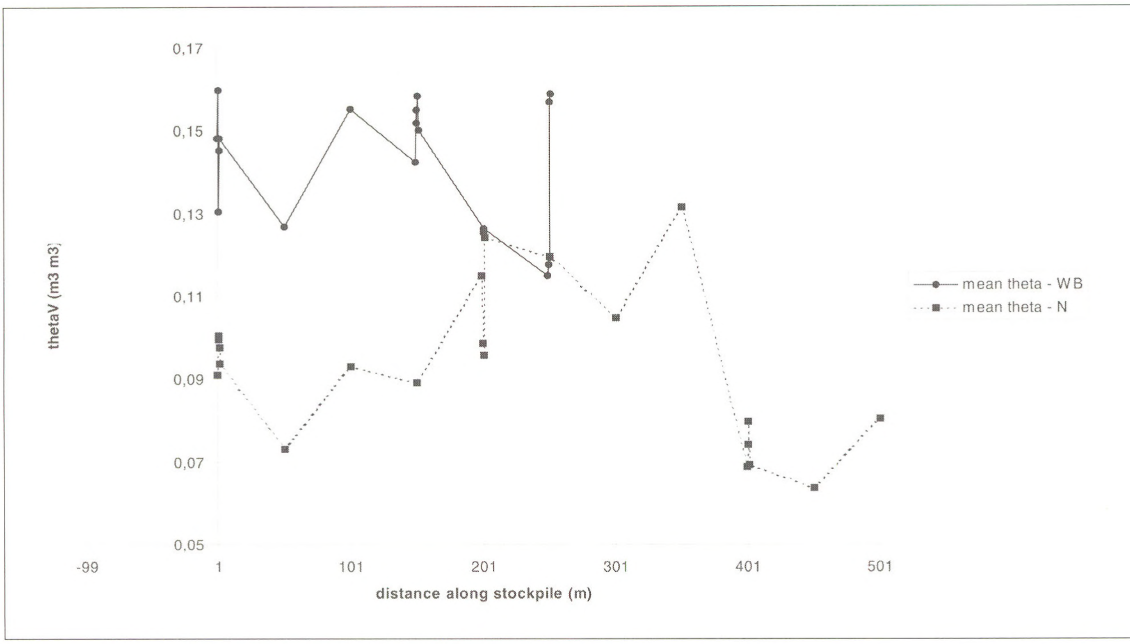


*Fig. 2. Variability in mean cross-sectional water content with location along the stockpile.*

## RESULTS AND DISCUSSION

### Initial water content conditions

The two stockpiles investigated had fairly similar average initial water contents and standard deviations (Table 2) when expressed gravimetrically, but on a volumetric basis, the West Boora stockpile contained more water (0.14 $m^3$ $m^{-3}$ vs. 0.09 $m^3$ $m^{-3}$). There was similar variability in water content for both of the stockpiles. Water content data for each of the sampling positions show significant differences in water content on the basis of sample location (using one-way analysis of variance) and indicate that for West Boora the surface layers were much drier than the core of the stockpile while for Noggusboy there was much less variability (when considered on a volume basis) with only the sample from within the stockpile at 1.0 m above the ground being significantly wetter. The samples from 1.0 m in the stockpile at West Boora were drier than those at 0.5 m elevation which could be interpreted as either water accumulating in the base of the stockpile or greater evaporative loss from the top of the stockpile. The initial sampling of the stockpile was only from one orientation so it is not possible to know for certain what the complete water content profile for each stockpile was, but it can be estimated that the north facing side at Noggusboy would have been wetter than the south facing side with perhaps little difference to be found at West Boora. If this is assumed, then the values obtained for the surface at Noggusboy are underestimates for the stockpile as a whole, and those for West Boora are nearly correct, it can be assumed that the two stockpiles were on average at very similar starting conditions prior to the onset of winter (when water content is expressed on a gravimetric basis).

There are 4 target water contents (expressed as $\theta_w$) to consider with respect to sales of milled peat for electricity supply in Ireland: (1) too dry: <0.40 g $g^{-1}$, (2) target: 0.45 g $g^{-1}$, (3) maximum desirable: 0.55 g $g^{-1}$ and (4) not economic / too wet: 0.65 g $g^{-1}$. The maximum water content on a wet weight basis ($\theta_w$) was found to be 0.55 g $g^{-1}$ at Noggusboy and 0.51 g $g^{-1}$ at West Boora, therefore both stockpiles were within the desirable range of water contents for sale as energy sources. In fact at the time of sampling the mean water contents were perhaps slightly low for optimum value. Frequency

*Table 3: Mean gravimetric water contents for sample positions on stockpiles after approximately 1, 2 and 3 months of rewetting. (sample 1 = surface particles; sample 2 = wet layer; sample 3 = 0.10 - 0.15 m; sample 4 = 0.30 - 0.50 m)*

| Variable | West Boora | Noggusboy |
|---|---|---|
| ***sept*** | | |
| mean $\theta_g \pm$ S.D (g g$^{-1}$) | 0.80 ± 0.30 | 0.88 ± 0.39 |
| mean $\theta_v \pm$ S.D (m$^3$ m$^{-3}$) | 0.38 ± 0.14 | 0.25 ± 0.11 |
| sample 1 $\theta_g \pm$ S. D. (g g$^{-1}$) | 0.98 ± 0.16 | 1.09 ± 0.38 |
| sample 2 $\theta_g \pm$ S. D. (g g$^{-1}$) | 1.06 ± 0.18 | 1.09 ± 0.38 |
| sample 3 $\theta_g \pm$ S. D. (g g$^{-1}$) | 0.52 ± 0.23 | 0.60 ± 0.32 |
| sample 4 $\theta_g \pm$ S. D. (g g$^{-1}$) | 0.65 ± 0.21 | 0.75 ± 0.22 |
| ***oct*** | | |
| mean $\theta_g \pm$ S.D (g g$^{-1}$) | 0.87 ± 0.32 | 1.07 ± 0.46 |
| mean $\theta_v \pm$ S.D (m$^3$ m$^{-3}$) | 0.41 ± 0.15 | 0.30 ± 0.13 |
| sample 1 $\theta_g \pm$ S. D. (g g$^{-1}$) | 1.05 ± 0.11 | 1.38 ± 0.33 |
| sample 2 $\theta_g \pm$ S. D. (g g$^{-1}$) | 1.12 ± 0.20 | 1.31 ± 0.45 |
| sample 3 $\theta_g \pm$ S. D. (g g$^{-1}$) | 0.65 ± 0.32 | 0.63 ± 0.33 |
| sample 4 $\theta_g \pm$ S. D. (g g$^{-1}$) | 0.67 ± 0.26 | 0.97 ± 0.29 |
| ***nov*** | | |
| mean $\theta_g \pm$ S.D (g g$^{-1}$) | 1.01 ± 0.37 | 1.12 ± 0.50 |
| mean $\theta_v \pm$ S.D (m$^3$ m$^{-3}$) | 0.47 ± 0.17 | 0.31 ± 0.14 |
| sample 1 $\theta_g \pm$ S. D. (g g$^{-1}$) | 1.07 ± 0.11 | 1.39 ± 0.50 |
| sample 2 $\theta_g \pm$ S. D. (g g$^{-1}$) | 1.33 ± 0.14 | 1.39 ± 0.46 |
| sample 3 $\theta_g \pm$ S. D. (g g$^{-1}$) | 0.87 ± 0.56 | 0.72 ± 0.28 |
| sample 4 $\theta_g \pm$ S. D. (g g$^{-1}$) | 0.97 ± 0.44 | 0.98 ± 0.37 |

histogram plots of the water content data for each stockpile (not shown) indicate that Noggusboy had a near normal distribution while West Boora was skewed towards the dry end and normal probability plots (not shown) suggested that for both stockpiles over 80% of the milled peat was at or below $\theta_w$ = 0.45 g g$^{-1}$ (the industry sales target).

An examination of the variability along the stockpiles indicated that there was significant variation in $\theta_v$ between sites at Noggusboy (F = 1.81, $F_{p^3\,0.05}$ = 1.67), but not at West Boora (F = 0.45, $F_{p^3\,0.05}$ = 1.76). Figure 2 illustrates the variability found along each stockpile and it can be seen that the small scale variability was generally within 0.02 m$^3$ m$^{-3}$ which is within the magnitude of total variability (*ca.* 0.06 m$^3$ m$^{-3}$). This seems to agree with the statement of Abakumov *et al.* (1985) who indicated that variations in water content between cross-sections of stockpiles were fairly consistent.

## Tension conditions

An examination of the tension data calculated at the start indicated that the matric potential of the surface of both stockpiles was around 212 kPa and the core matric potentials were 191 kPa (Noggusboy) and 155 kPa (West Boora). A calculation of the hydraulic gradients in the stockpile cross section indicated that in both cases the horizontal gradient was likely to have been greater than the vertical (because the direction of flow would have been core to surface while the stockpile was drying in place). Once a wet layer formed in the winter months this gradient would have been reversed.

## Water contents through the winter

A summary of the data for each stockpile for sept, oct and nov is presented in Table 3. Sept samples taken at the beginning of October indicate that there was significant wetting with average water contents for both

*Table 4: Mean wet layer depths for stockpiles by orientation and position*

| Site: | West Boora | | | | Noggusboy | | | |
|---|---|---|---|---|---|---|---|---|
| Orientation: | east | | west | | north | | south | |
| Position: | top | bottom | top | bottom | top | bottom | top | bottom |
| sept | 5 | 10 | 9 | 13 | 9 | 13 | 8 | 7 |
| oct | 13 | 18 | 15 | 16 | 18 | 20 | 18 | 21 |
| nov | 27 | 50 | 29 | 34 | 18 | 16 | 19 | 19 |

stockpiles increasing dramatically. The majority of the increase in water content can be accounted for in the surface layer where $q_g$ at least doubled. Water contents in the core of the stockpile covered a similar range to the initial conditions (*ca.* 0.5-0.7 g $g^{-1}$). Even after just one autumn/winter month the stockpile water content distribution was significantly altered with only 50 % of the milled peat being at or under the $\theta_w$ = 0.45 g $g^{-1}$ target (on the basis of the 80 samples taken to characterise the stockpile). Frequency distributions for the two stockpiles indicated that Noggusboy developed a skew with bias towards the dry end but the mode increased suggesting overall wetting and a tendency towards very wet areas in the stockpile. West Boora also showed a shift in the mode towards wetter values but did not exhibit very wet values in the same way as the Noggusboy milled peat. The percentage of peat with $\theta_w \leq 0.45$ g $g^{-1}$ decreased by the oct sampling date to 35 % at Noggusboy and by the nov to 30 %. At West Boora the probability of finding milled peat with $q_w \leq 0.45$ g $g^{-1}$ was 40 % by the nov sampling. These data are indicative of the rewetting problem but are perhaps slightly biased because an equal number of sampling points were located in the wet layer as in the core of the stockpile, and these do not represent equal volume proportions. Frequency distributions for the later sampling dates all indicate a skewed distribution with some very wet samples evident for both stockpiles.

The water content ($\theta_g$) of the wet layer appeared to have stabilised at Noggusboy at about 1.39 g $g^{-1}$ while at West Boora it was still increasing. This would suggest that there is a maximum average water content to which the stockpile surface will wet. In the core of the stockpiles there was an accumulation of water evident by the time of the oct sampling which continued to be evident by the nov sampling. This is particularly important in determining the mean water content of the stockpile because it possibly represents significant volumes of milled peat in the centre of the pile. The mean water content in the core was still at the target amount by the time of the nov sampling (for both stockpiles $\theta_w$ = 0.45 g $g^{-1}$).

Estimates of $\theta_v$ for both stockpiles suggest that the volume of water accumulating in the West Boora stockpile was greater per volume of pile than at Noggusboy which may have had the result of increasing hydraulic conductivity and thus encouraging water transport through the stockpile.

## Depth of wet layer

The depth of wet layer (Table 4) once developed was greater towards the base of the stockpile. For sept samples it was greatest on the north and west facing slopes suggesting rainfall input from the west outweighed lack of drying at West Boora but that no direct sunlight on the north face at Noggusboy led to greater wet layer depth. The oct samples show very little difference in wet layer depth by orientation or position on the stockpile surface, and this status continued to be seen for the nov samples taken from Noggusboy, but at West Boora is appeared that the wet layer depth was still increasing when samples were taken. It should be noted that the mean values quoted in Table 4 do not reflect maximum or minimum wet layer depth for each stockpile; the range of values for the nov sampling date were Noggusboy: 0.05 - 0.40 m, West Boora:

0.15 - 0.70 m. Using the data obtained in the equation of Dykes *et al.* (1997):

$$DWL = 5(\theta_i) + 0.6(\rho_b) - 274 \quad (R^2 = 0.72) \qquad (2)$$

where DWL = depth of wet layer (mm), and in this case $\rho_b$ = poured density at $\theta_w$ = 0.55 g $g^{-1}$ (kg $m^{-3}$) and $\theta_i$ is the initial water content expressed as a percentage, the predicted wet layer depths in the stockpiles are 178 mm at West Boora and 60 mm at Noggusboy. These values are significant under-estimates when compared to the measured values. If a higher initial water content is substituted by using a value of $\theta_w$ measured from sampling locations in the core of the stockpile only (not the overall initial mean provided in Table 2) as was originally done by Dykes *et al.* (1997) then the underestimation is significantly reduced. This suggests that while Equation 2 may not be particularly accurate, it does provide a useful insight into the pertinent factors to be considered when studying stockpile rewetting.

## General implications for stockpile rewetting

### *Orientation*

It is not possible to clearly establish the general role of orientation of stockpiles because there were only two milled peat types and they were oriented differently. This is not a major problem because there is little that could be practicably done to alter orientation. The arrangement of field drains dictates the orientation of the stockpile and these are placed depending upon the local topography and hydrology. In the case of most production bogs in Ireland, it is not possible to alter production arrangements therefore the question of orientation does not arise. From the data obtained it is possible to say that the north facing sites were generally wetter than the south facing and there was a slight wet bias for the west facing samples.

### *Position on stockpile*

In general the lower parts of the stockpiles were wetter but this was not always clear cut. As with orientation, there is little that can be done to alter the geometry of the stockpiles therefore the finding is perhaps of little practical importance.

### *Milled peat type*

There appears to be some differences in the rewetting response for the two milled peat types but similarities in wet weight water contents. At the time of the nov sampling the West Boora milled peat had similar mean water content ($\theta_w$ = 0.49 g $g^{-1}$) for the outer 0.50 m layer of the stockpile to the Noggusboy ($\theta_w$ = 0.50 g $g^{-1}$), but when expressed on a volumetric basis they appear quite different (0.47 $m^3$ $m^{-3}$ and 0.31 $m^3$ $m^{-3}$). A hypothetical example of the importance of these figures is that for a stockpile 3 m high, and of pitch angle of 33° a layer 0.50 m deep would account for about 38 % of the cross sectional area, therefore using the average water content data calculated for these stockpiles and assuming the outer layers are at $\theta_w$ = 0.50 g $g^{-1}$ and the core at 0.45 g $g^{-1}$ then the area weighted average water content for the stockpile would be 0.47 g $g^{-1}$ which is within the target range. Observation in the field during the last sampling period (nov) indicated that significant wetting was occurring in the centre of the stockpile therefore this would constitute an under-estimate of the actual mean water content for the stockpiles. A wet layer water content of $\theta_w$ = 0.75 g $g^{-1}$ (the value used by Dykes *et al.* (1997) for calculations) would result in a weighted mean $\theta_w$ of 0.56 g $g^{-1}$ while doubling the assumed outer layer thickness (at $\theta_w$ = 0.50 g $g^{-1}$) only increases the weighted mean $\theta_w$ to 0.48 g $g^{-1}$. From these calculations it can be concluded that absolute water content has more influence on mean water content than the wet layer thickness.

### *Water storage*

A question of interest at the outset of this investigation was whether the wet layer became progressively wetter or whether wet layers were always at a similar water content? It can be seen from the data that the wet layer became progressively wetter up to a point and that this was related positively to wet layer depth. On a storage basis, the West Boora milled peat wet layer stored more water than the Noggusboy milled peat wet layer ($\theta_v$ = 0.63 and 0.40 $m^3$ $m^{-3}$ respectively) so for a given water input the West Boora milled peat was more prone to wetting than the Noggusboy but when expressed on a mass basis this difference is not obvious.

It was assumed by Dykes *et al.*(1997) that the layer of milled peat under the wet layer was at the water content at which the stockpile was constructed. In retrospect this may not have been a good assumption because the data suggests a range of initial water contents ($\theta_w$) by this method of 0.33 - 0.50 g $g^{-1}$ for West Boora and 0.39 - 0.72 g $g^{-1}$ for Noggusboy (Dykes, 1995) which encompass a similar range to that found during later sampling for this investigation and there are explanations for the variability other than variation at time of stockpiling. The best probable explanation for the variability in core water content found during the sampling period is the occurrence of by-passing. By-passing is the preferential channelling of water through the profile to a lower depth without the wetting of upper layers that would be predicted by flow theory (also called short-circuiting by Bouma *et al.*, 1981). Observation in the field suggest that there are localised "fingers" of greater water content that are oriented near vertically in the stockpiles. These zones would have greater hydraulic conductivity and thus not only contain more water but would act as preferential by-pass channels into the stockpile. The maximum volumetric water contents determined for both stockpiles are very close to the saturated values obtained previously (Holden and Ward, 1996b) suggesting these could be significant flow paths and in addition the resistance to flow across the very steep potential gradient from near saturated to very dry would reduce the rate of expansion of such flow paths.

One implication of by-pass flow pathways is that if the water that is probably moving rapidly is permitted to drain away freely, then the mean water content of the stockpile will be maintained at a relatively low level, and variability is likely to be reduced.

## Conclusions

It can be concluded from this work that industrial practice over the last few decades has been aligned with the natural response of stockpiled milled peat to rewetting. The variability in water content along the stockpile is probably due to the occurrence of wet "fingers". It would appear that in order to reduce stockpile rewetting it is necessary to maintain wet layer water contents ($\theta_w$) at the lowest level possible (even if this results in the wet layer being deeper) and to reduce the development of by-pass channels. It should be considered however that the by-pass channels may form drainlines from the wet layer that control its maximum achievable water content, therefore further research is required to fully establish the best course of action.

## Acknowledgements

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*SHORT COMMUNICATION*

# THE WATER ABSORPTION ABILITY OF PEAT

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## SUMMARY

Different methods of determining the water absorption ability of peats were reviewed, showing characteristics of water in peat, depression of water absorption by drying and comparison of absorption ability of peat with super water absorption polymers. The effective water contents of the peat as well as its humus and fibre components were estimated from their pF curves. The fibre components in grass peat held water more effectively than either the peat itself or the peat humus fraction. Available water (pF 1.5 - 4.2) for plants is considered to comprise capillary water in the fibre components, together with the inter-particle and colloidal water over a wide pF range (more than 4.2). Although the absolutely dried grass peats showed a water absorption of 0.6 (g/g), it was found that freeze-dried peat (water content of 3.6%) retained a high value of 4.6 (g/g).

The water absorption ability of peat was inferior to that of super water absorption polymer, however, its ability with respect to increase of salt concentrations and time duration was superior. Peat might therefore improve water absorption under the severe conditions which occur in deserts

## INTRODUCTION

Several researchers have tried to apply super-absorbent polymers for desert agriculture (Aly & Letey, 1990). The water absorption ability in saline solution of polymers, however, is known to decrease markedly with increase in salt concentrations (Yamaguchi & Tsukagashi, 1991). In desert agriculture, for example, salt components can accumulate in surface soils as a result of extremely high rates of evaporation. This is the reason why stability in the absorption of water with high salt concentration is one of the key factors under such circumstances. In order to clarify this problem, the stability and ability for water absorption of peats and super-absorbent polymers in saline solutions have been compared.

## MATERIALS AND METHODS

The material investigated was of two types, peat and polymer: Group 1 comprised two basic types of peat; grass peat (Hokkaido, Japan, humus content 14 - 15 %) and sphagnum peat (Canada, humus content 45 - 48 %). Group 2 comprised three types of super water absorption polymer (SAP); SANWET IM-1000 (Sanyo Kasei Co.Ltd., Japan), AQUALIC CS & ACRYHOPE GH-2 (Nippon Shobubai Chemical Co. Ltd., Japan) and SUMIKAGEL S-SO (Sumitomo Chemical Co. Ltd., Japan).

The water absorption ability was evaluated by the "dipping" method (Masuda, 1987). Materials were immersed in water for 48 hours at 20°C. The absorbed water was calculated as the ratio of wet material/dry material (g/g). Water potential was described as pF: pF=log (-D μ) where μ is the chemical potential (cm $H_20$).

## RESULTS AND DISCUSSION

### Characteristics of Water in Peat

The quantity of each type of water in peat and its components is shown in Table 1; the

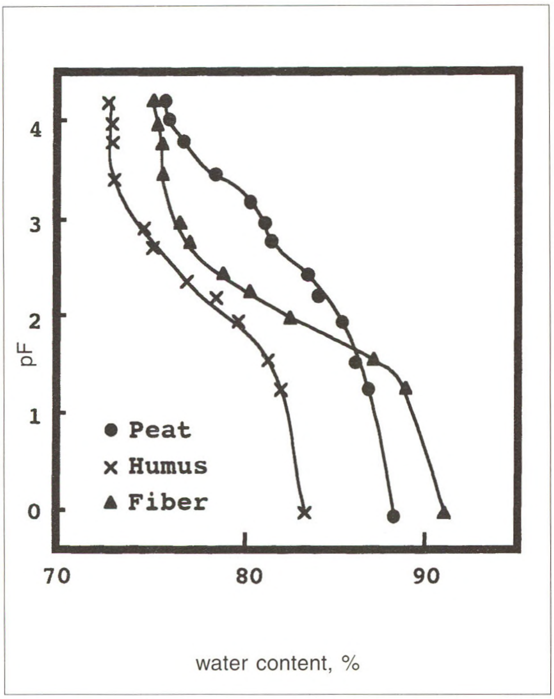


*Fig. 1. pF-water content relationships for peat, humus and fiber.*

effective water contents of the peat and its humus and fibre components estimated from their pF curves are indicated in Figure 1. The fibre component in grass peat holds water more effectively than either the peat itself or the peat humus fraction. The capillarity of both the humus and fibre components was larger than that of the peat itself.

*Table 1. Quantities of three types of water in peat and its components (g/100 g).*

| Water component | Peat | Humus | Fibre |
|---|---|---|---|
| 1. Gravitational water (pF < 1.5) | 127.1 | 64.6 | 348.7 |
| 2. Readily available water (pF 1.5-2.7) | 178.0 | 134.3 | 332.8 |
| 3. Strongly held water (pF 2.7- 4.2) | 130.1 | 34.0 | 29.7 |

The pF-water distribution curve (Fig. 2) shows that peat contains various types of water. Both gravitational and readily available water, in the fibre component increased at pF 1.5 compared to peat; non readily available water decreased at pF 2.7 - 4.2. Although gravitational water is not useful for plants, its rapid drainage from the fibre component can improve soil aeration. The balance of gas, liquid and solid phases is important for plants (Ohuchi *et al*, 1989) and might be a key factor in the use of peat in desert agriculture.

The relaxation times of each water component, as determined by Nuclear Magnetic Resonance (Minispec PC-120) analysis are shown in Table 2. These are divided into three groups: the first (0.003 - 0.005 sec) contains strongly absorbed water with restricted movement; the second (0.01 - 0.03 sec) and third (0.07 - 0.10 sec) are characterised by increasingly more mobile water. Peat humus contains two types of

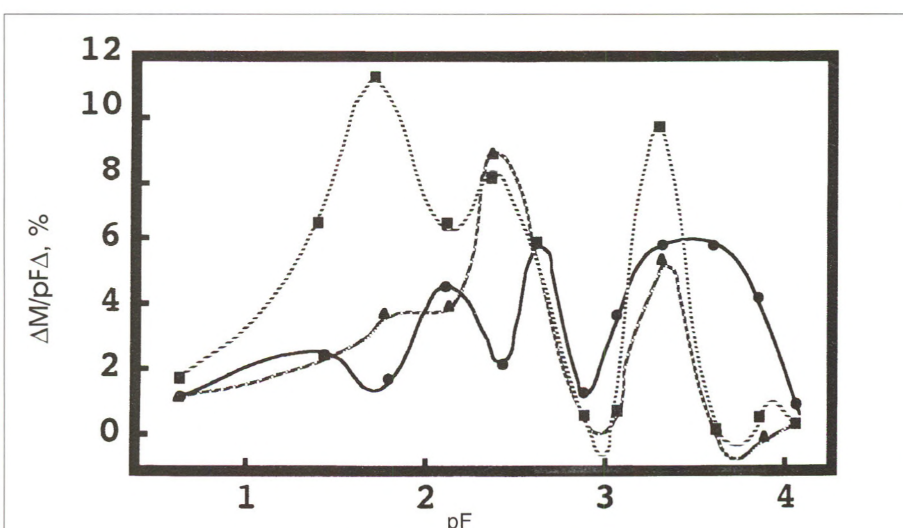


*Fig. 2. pF-water distribution curves ● peat ▲ humus ■ fiber*

water whilst peat and peat fibre contain three types.

*Table 2. NMR relaxation time of each water component*

| Component | Time/s |
|---|---|
| 1 | 0.003 - 0.005 |
| 2 | 0.01 - 0.03 |
| 3 | 0.07 - 0.10 |

It was found that components 2 and 3 (weak absorption) of peat and of peat fibre decreased with increasing pF whereas component 1 (strong absorption) increased. This tendency was most marked at pF 3.0 because of the capillary structure of the fibre. The water components of peat, humus and fibre are shown in Table 3. In general, quantities of water in peats are in the following order: capillary water > colloidal water > inter-particle water > osmotically bound water (Kawaguchi and Aomine, 1965).

It is well known that pF 3.0 is the critical point beyond which water release becomes more restricted. Available water (pF 1.5 - 4.2) for plants is considered to comprise capillary water in the fibre component, together with the inter-particle and colloidal water in the humus. Component 2 water might still remain in peat even at pF 4.2 and hence, under dry conditions, peat is more able to provide water for plants than either peat humus of fibre. It is obvious from Figure 1 (pF-water content relationship), that peat can continue to provide water over a wide pF range (more than 4.2). Water contents of the fibre and humus components are more strongly influenced by the increase of pF. The peat fibre fraction is considered to be most effective component for the absorption of water.

## Depression of Water Absorption by Drying

It is well known that the water absorption of grass peat (humus content 14 - 15 %) is depressed by thermal drying. This weighs against the use of peat as a water absorbent compared with SAP. Although absolutely dried grass peats showed a water absorption of 0.6 (g/g), it was found that freeze-dried peat (water content of 3.6 %) retained a high value of 4.6 (g/g). The absorption ability of peat may be increased by adding surfactants. Drying and re-wetting techniques for peats will be a key issue in their utilisation for improving desert agriculture.

## Stability in saline solution

The absorption ability of the polymers decreased markedly when salts were added, especially solutions containing $Ca^{2+}$ and $Mg^{2+}$. In contrast, the effect on peat was negligible. This phenomenon might be attributed to the fact that water absorption ability of peat depends on its capillary structure.

There were differences in the water absorption responses (in 0.5%NaCl and 0.5%$CaCl_2$) of peat and polymers and between the latter. SUMIKAGEL S-50 showed poor water absorption whilst those of the peats and AQUALIC CS were stable over the time period (48 hrs). SANWET IM-1000 (starch-polyacrylic acid polymer) showed good water absorption in NaCl solution but this declined markedly in $CaCl_2$.

*Table 3. Water components of peat, humus and fibre.*

| Component | Peat | Humus | Fibre |
|---|---|---|---|
| 1 | Chemically bound water<br>Osmotically bound water in cells | Chemically bound water | Osmotically bound water in cells |
| 2 | Colloidal water, capillary water, inter-particle water | Colloidal water, inter-particle water | Capillary water |
| 3 | Bulk water | | Bulk water |

In a saline solution prepared to simulate typical desert salinity (Selassie *et al.*, 1976) the results were similar to those obtained in 0.5% NaCl solution. Although the water absorption ability of peat was inferior to that of SAP its stability with respect to increase in salt concentrations and time duration was superior. Peat might therefore improve water absorption under the severe conditions which occur in deserts.

## CONCLUSION

It is well known that peats are composed of humus and fibre fractions. The fibre component plays an important role in retaining water whereas the humus fraction improves nutrient retention. Thus, peat could play an important role in the future development of desert agriculture.

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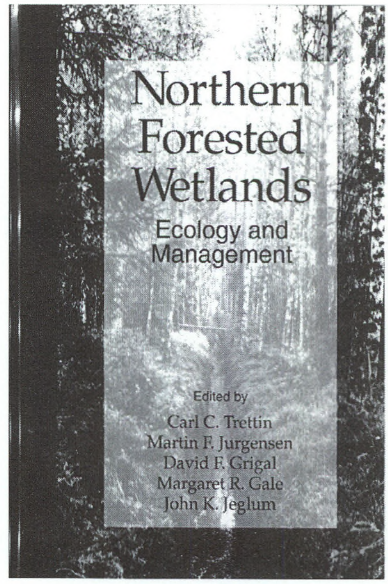
# LEARNING MORE ABOUT NORTHERN FORESTED WETLANDS

## Northern Forested Wetlands. Ecology and Management.

Edited by **Carl C. Trettin, Martin F. Jurgensen, David F. Grigal, Margaret R. Gale and John K. Jeglum**. Lewis Publishers. Boca Raton-New York-London-Tokyo. 1997. 486 pp. ISBN 1-56670-177-5. Price USD 69.95.




Forested wetlands are a major component of northern landscapes, important both for their ecological functions and their socioeconomic values. In the far past these lands were used for trapping and hunting, collecting wild forage for cattle, and picking of wild berries etc. Early in this century reclamation of wetlands for farming was an important alternative in some countries. In some other ones draining of these sites for wood production or peat harvesting during the last decades has occupied even vaster areas. Nowadays, nature conservation, restoration, and recreation aspects are more emphasized in connection with mires and other wetlands.

There are many questions about the use and management of these lands in the future, particularly with respect to wood production, hydrology and water quality, plant and wildlife ecology, landscape dynamics, and wetland restoration.

The book strives for a synthesis of current research and literature, examining the status, distribution, and use of these wetland resources. It focuses on understanding the role of the northern wetlands in the landscape and how to manage these lands and sustain their important functions. The book is based on selected papers presented in the International Symposium on the Ecology and Management of Northern Forested Wetlands held Aug. 24-31, 1994 in Traverse City, Michigan. The ecology and opportunities for sustainable management were also discussed on a pre-symposium excursion centered in Cochrane, Ontario. The book is divided into four sections: Wetland resources, Ecology and vegetation, Hydrology and biogeochemistry, and finally Wetland management. On a volume basis the book emphasises the basic characteristics of wetland resources giving a background for their - hopefully - sustainable management.

The book is well edited, illustrated and provided with a list of references for each of the chapters, and a list of index covering the whole book. The knowledge gathered covers geographically the countries possessing the bulk of the northern forested wetland resource. Most of the contributors - representing a wide range of expertise - are well known worldwide in their special fields. However, reviewing and editing must have been a tremendous effort when several of the original manuscripts were coming from other than English speaking countries. I understand that readers have to thank Dr. Elon S. Verry, not belonging to the team of editors mentioned on the cover of the book, for the skill- and time-demanding work he has put for checking especially the chapters dealing with hydrology.

The terminology connected to mires and other wetlands is not totally solid yet. However, this book gives a valuable reference to approach a common understanding of the northern forested wetlands. It will serve well e.g. to familiarize students of forestry and other environmental sciences with the basic ecological principles needed to develop an understanding of the functioning northern forested wetland ecosystems.

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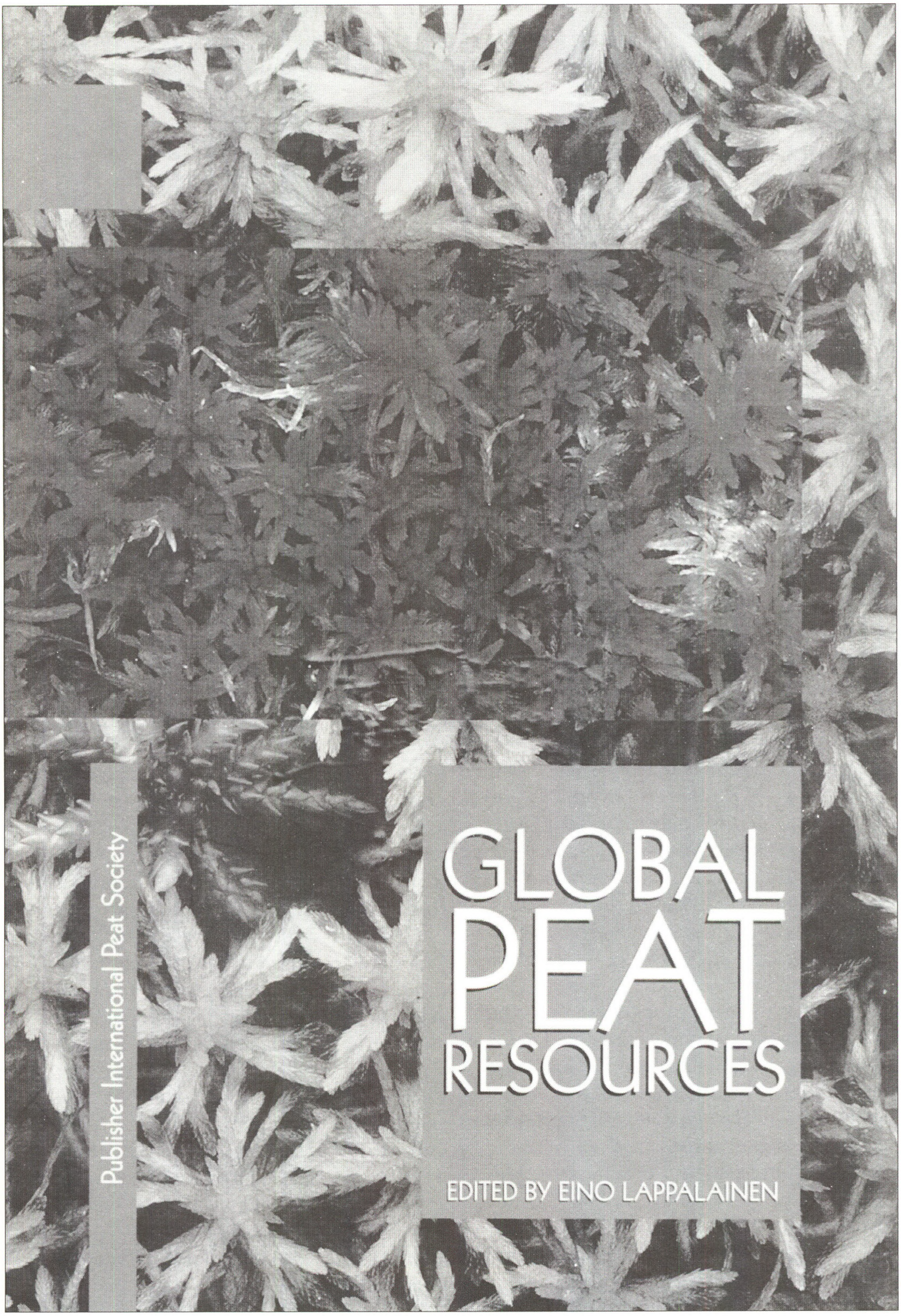
*Finland*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