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 km² 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 m² of material collected from the borrow site would recover 8 m² 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.)

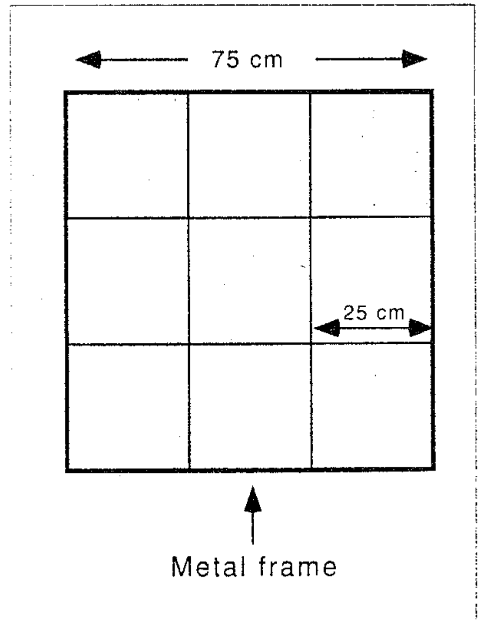

Fig. 1: Sampling field frame to evaluate percentage mire plant establishment representing 1 group of 4 quadrats

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 m² 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.]

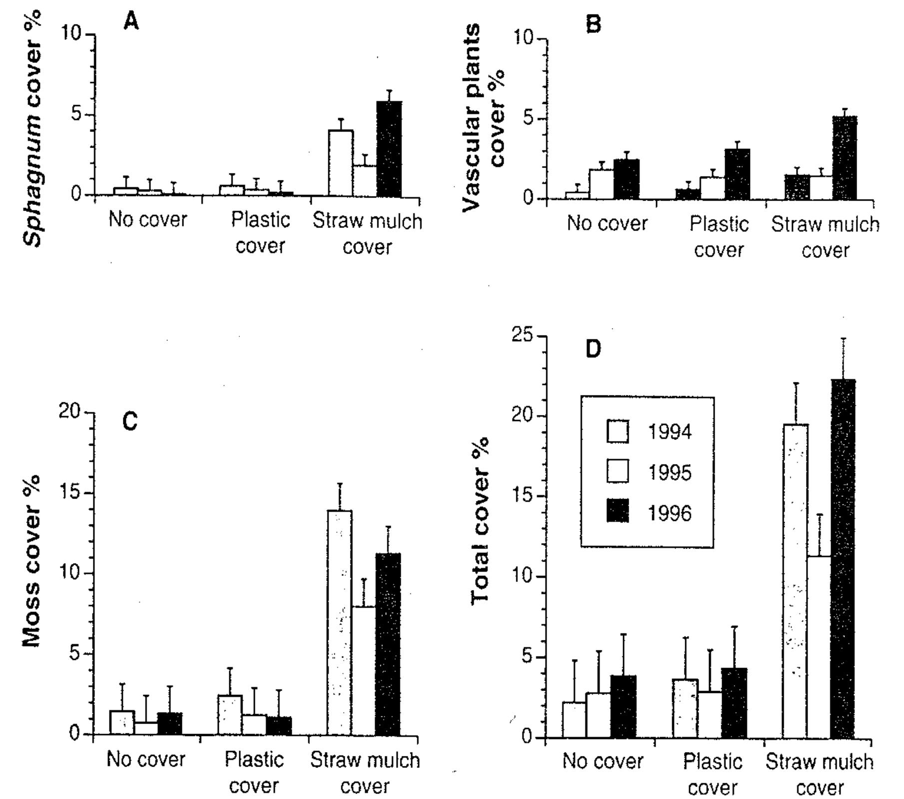

Fig. 2: Effect of straw mulch and plastic cover having similar porosity on the establishment (cover %) of different plant groups on a site being restored for 1994, 1995, and 1996 (mean ± S.E.). A - Sphagnum cover; B - Vascular plant cover; C - Bryophyte cover (excluding Sphagna); D - Total plant cover.

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

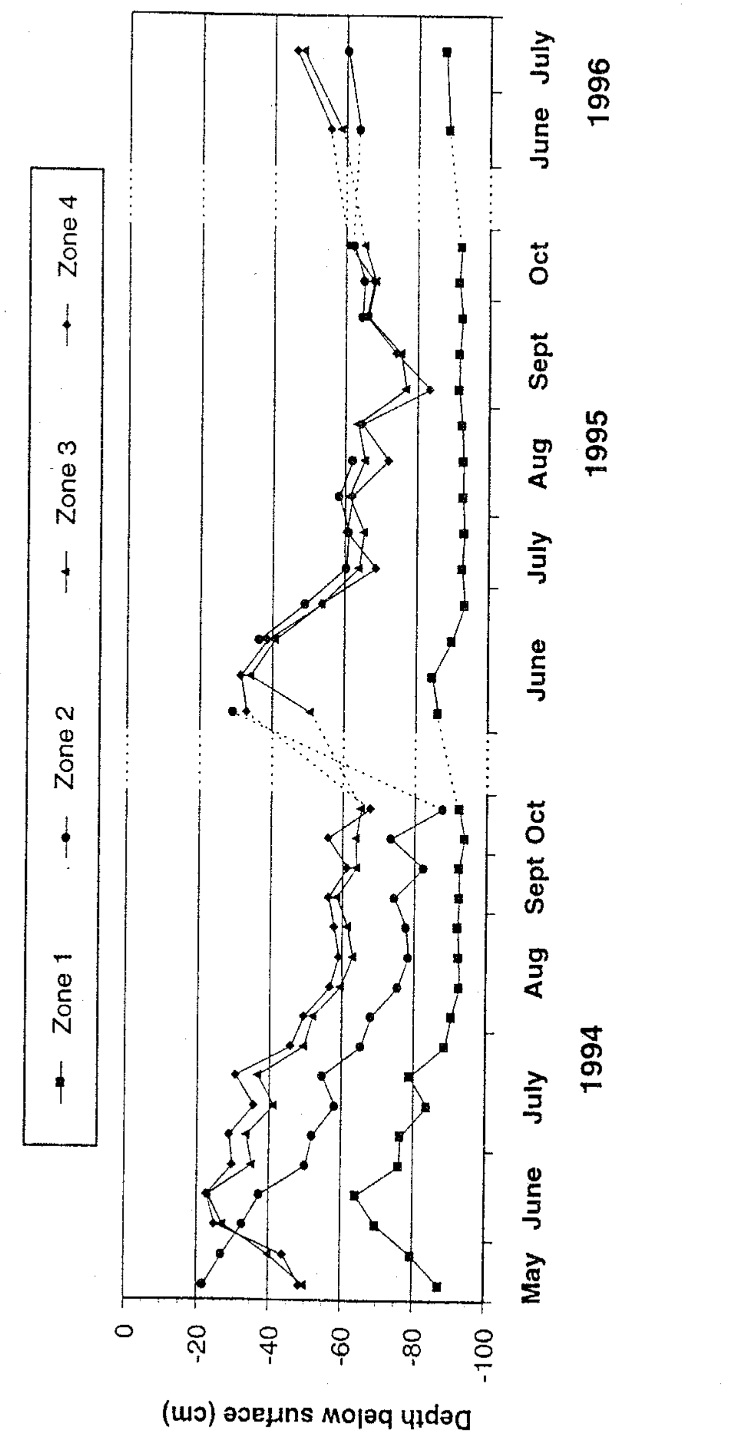

Fig. 3. Water table depth (cm) measured usually once a week during the summers of 1994 and 1995 and two times in 1996. Values represent the mean of two water wells for each experimental site. Site 1 was definitively a drier site than the others. Site 2 was intermediate in the drier years (1994 and 1996).

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

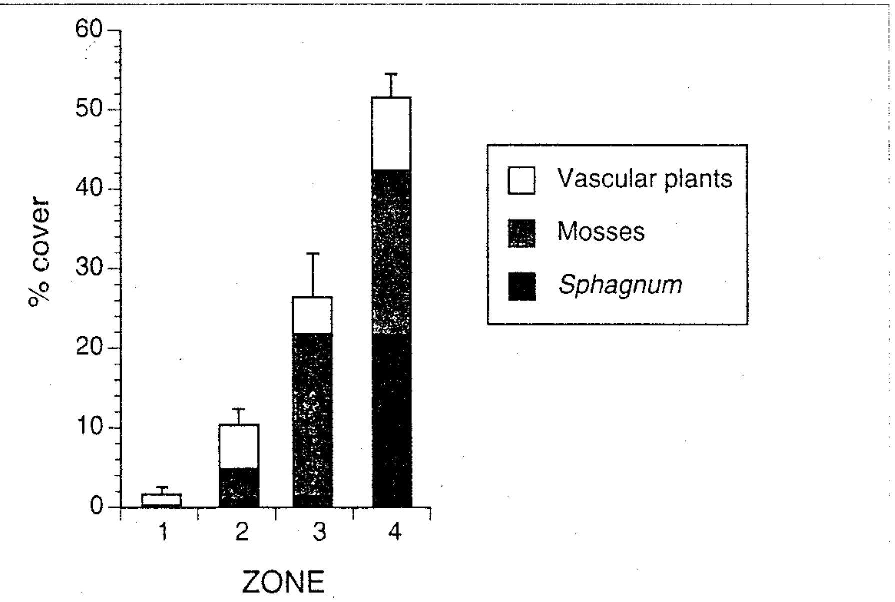

Fig. 4: Plant establishment (mean cover % ± S.E.) on the experimental site for four zones defined by water table depth after three years of growth under a straw mulch.

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

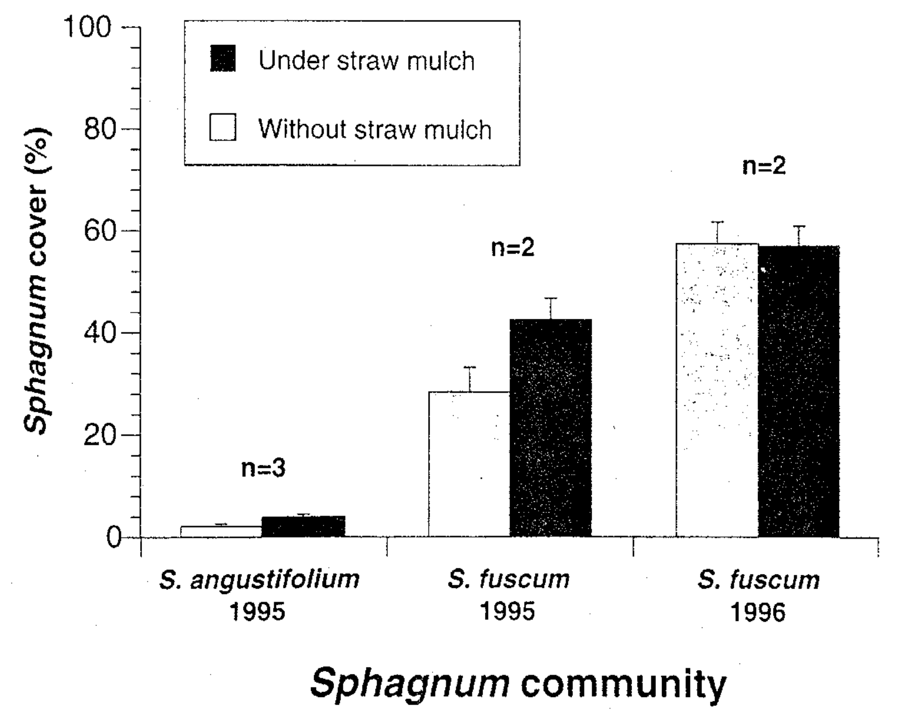

Fig. 5: Sphagnum recovery (mean cover % ± S.E.) after chipping and removal of the top 10 centimeters of vegetation in a bog. Recovery was evaluated after one season for S. angustifolium community and two growing seasons for S. fuscum community. The S. angustifolium dominated community could not be evaluated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

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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 & Zyczyńska-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), $BOMF_c$ (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.

The paper was presented during Peat Organic Matter International Symposium, Minsk 15 ... 1995