GREENHOUSE STUDIES OF *SPHAGNUM PAPILLOSUM* FOR COMMERCIAL HARVEST AND PEATLAND RESTORATION IN MINNESOTA

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ABSTRACT

A moss species of particular commercial and ecological interest is *Sphagnum papillosum*. *S. papillosum* is the predominant moss species commercially harvested from peatlands in Wisconsin and commonly known as “top moss” or “floral moss.” Another possible use for *S. papillosum* is the restoration of harvested peatlands. The overall objective of this research was to determine, through controlled greenhouse trials, the effect of various factors on the growth and morphology of *S. papillosum* on bare peat surfaces characteristic of post-harvested Minnesota peatlands. In this study, *S. papillosum* was grown on peat substrates and water collected from three different horticultural peat harvesting sites, at three water table levels, and two moss fragment application densities. Moss morphology and tissue nutrient concentrations for the greenhouse treatments and several natural sites were also determined and compared. The results indicate that for *S. papillosum* to achieve maximum biomass accumulation, a high water table is essential, and sufficient levels of N and P should be present and in the proper proportions. Increased moss fragment application density, although significant, resulted in only a moderate increase in biomass accumulation. At the high water table level, the greenhouse treatments having the greatest biomass accumulation had significantly different moss morphology when compared to that of the lowest producing greenhouse treatments and natural sites.

Key Words: *Sphagnum papillosum*, top moss, moss fragments, peatland restoration.

INTRODUCTION

Mosses of the genus *Sphagnum*, or bog mosses, comprise a substantial amount of the world’s total plant mass (Hayward and Clymo, 1982). *Sphagnum* species are the most widespread of any of the bryophytes (Clymo and Duckett, 1986) and are a significant component of the surface vegetation in peatlands, which cover approximately 1 to 2 percent of the earth’s surface (Kivinen, 1981). In North America, *Sphagnum* species cover approximately 200 million hectares (McQueen, 1990). Minnesota’s estimated 3 million hectares of peatlands support a considerable diversity of *Sphagnum* species (Minnesota Department of Natural Resources, 1979).

A moss species of particular commercial and ecological interest is *S. papillosum*. The plants are medium to large in size, intolerant of shade, and form floating carpets or low hummocks in relatively wet, oligotrophic areas, such as poor fens (McQueen, 1990).

*S. papillosum* is the predominant moss species commercially harvested from peatlands in Wisconsin (Janssens, 1993) and commonly known as “top moss” or “floral moss.” Top moss is used for hanging floral baskets and wreaths, as a medium for seed germination, and as a packing material. Other possible uses for top moss are as a component of several hygiene products (Lévesque, 1996) and as an oil sorbent for the oil spill clean-up market (Hagen et al., 1990). In contrast to peat, the partially decomposed organic matter commonly harvested and used as a potting soil or soil amendment, top moss is the live moss actively growing on the peat surface which eventually forms Sphagnum moss peat. Unlike peat, which takes centuries to accumulate, top moss is a renewable resource currently harvested in 5-10 year rotations.

Another possible use for *S. papillosum* is the restoration of harvested peatlands. Peatland restoration is defined as the managed restoration of harvested peatlands to wetland vegetation and functional wetland status. Approximately 400 hectares of Minnesota peatland are currently managed for the harvesting of Sphagnum moss peat. These harvest sites must be restored to a natural state as required.
by state and federal regulations after harvesting has ceased. Regeneration of previously existing vegetation, such as *Sphagnum* moss, is the preferred method of restoration. The restoration of suitable post-harvested sites with *S. papillosum* may allow for future top moss harvesting, possibly providing an economic return to offset restoration costs.

Individual *Sphagnum* species vary in their optimal nutrient and water table requirements (Clymo, 1973). Many species occupy a very specific environmental niche. In general, *S. papillosum* grows well in locations with low calcium concentrations (Clymo, 1970) and a relatively high water table.

*Sphagnum* species regenerate both by vegetative means and by germination of spores. Vegetative reproduction is by far the most common, although plants do occasionally produce spores during the summer months (Darlington, 1964). The primarily vegetative regeneration of *Sphagnum* species implies the potential for establishing plants by spreading moss fragments on a suitable site. This in fact, has been done, both in the laboratory (Clymo & Duckett, 1986) and in the field (Elling & Knighton, 1984; Rochefort *et al.*, 1995; Campeau & Rochefort, 1996).

The overall objective of this study was to determine, through controlled greenhouse trials, the effect of various factors on the growth and morphology of *S. papillosum* on bare peat surfaces characteristic of post-harvested Minnesota peatlands.

The specific objectives of this study were to:

1. **Determine the effect of peat/water source, water table level, and moss fragment application density on *S. papillosum* growth and biomass accumulation in greenhouse trials.**
2. **Compare moss morphology, and tissue elemental concentrations for *S. papillosum* grown on bare peat surfaces in the greenhouse to that grown at several natural sites in Minnesota.**

**MATERIALS AND METHODS**

The experiment was designed to determine the effects of peat/water source, water table level, and moss fragment application density on *S. papillosum* growth and biomass accumulation. The experimental design for this study included: three peat substrate/water treatments (old, intermediate, and new), three water table levels (1 cm above, and 3 and 9 cm below the peat surface), and two moss fragment application densities (120 and 60 fragments per container) for a total of 18 treatment combinations. Five replications of each treatment combination were established in the Natural Resources Research Institute’s greenhouse in a randomized block design resulting in a total of 90 containers.

Peat substrates and water were collected in December 1994, from three separate horticultural peat harvesting sites within a 50-mile radius of Duluth, Minnesota. These sites represent Sphagnum moss peat harvesting operations of various ages. The number of years harvesting had occurred on these sites was approximately 15 years for the oldest site, 7 years for the intermediate site, and only ditching and pre-harvest removal of surface vegetation having occurred on the newest site. These sites will be referred to in the text as old, intermediate, and new, respectively. The peat substrates were collected from the harvested or cleared surface of each peatland and sieved (6.68 mm mesh) to remove large woody material. Bog water for the study was collected from adjacent ditches or field depressions. *S. papillosum* moss fragments were collected from an undisturbed poor fen near the new site. The top 4 cm of each moss plant was collected and cut in two - 2 cm pieces, one consisting of only stem material, and the other of stem and capitula.

A system of nested containers was used to control the water table level. A 1000-ml plastic container (perforated bottom) was nested within a larger 2500-ml plastic container (sealed bottom). The smaller inside container held the peat substrate and the larger outside container served as the water reservoir. A small hole was made in the side of each outer container corresponding to the desired water level. Peat was placed in each container and compressed to a uniform density to approximate a natural peat surface. Each container was then thoroughly saturated with bog water before applying moss fragments.

The moss fragment application density of 120 fragments/container (12,500 fragments/m²) was selected to correspond with the application density for a field study established in September 1994. The second application density selected, 60 fragments/container (6,250 fragments/m²), is one-half the field study density. For restoration purposes, the fragment application density is sometimes expressed as a ratio of the natural, undisturbed bog surface area from which moss fragments are collected, to the area of bare peat surface on which they are spread (Campeau & Rochefort, 1996). Assuming each moss plant will yield two fragments, an application density of
12,500 fragments/m² (120 fragments/container) would require 6,250 moss plants/m². At the undisturbed poor fen site where the moss fragments were collected, the natural density was approximately 24,800 moss plants/m². The resulting ratio is approximately 1 part natural bog harvested to 4 parts bare peat restored, or 1:4. The ratio would be approximately 1:8 for the 60 fragments/container application density.

The greenhouse study was initiated on April 6, 1995, and continued through October 24, 1995, a period of approximately 29 weeks. Water levels were maintained daily by filling each outer container to the proper level with bog water collected from each respective site. The moss surface in each pot was also misted daily with approximately 5 ml of de-ionized water. Greenhouse temperature ranged between 15°C and 25°C. No supplemental lighting was provided.

Moss lineal growth was monitored using the cranked wire method according to Clymo (1970) in which changes in moss height are determined relative to a stationary wire. Rather than using cranked wires, where the bend in the wire holds it in place, straight stainless steel wires approximately 20 cm long, were inserted into the moss and underlying peat until they contacted the bottom of the container. The bottom of the container was used to keep the wire stationary. Three wires were placed in each container. Moss lineal growth measurements were taken every 2 weeks using a graduated glass tube placed over the wire. A flat plastic disc, approximately 3 cm in diameter, was attached to the bottom of the graduated glass tube, and in use rested on the moss surface. This better defined the moss surface level and resulted in a more accurate measurement of moss lineal incremental growth (Clymo, 1970). The median lineal growth increment from the three wires was considered the observation for that time period.

On October 24, 1995, the total accumulated biomass was collected from each container and washed of any residual peat. The number of moss stems and capitula were recorded for each sample and all moss materials were dried at 65°C for 48 hours. The total oven-dry mass of harvested moss per container was corrected to estimate accumulated biomass by subtracting the dry mass of moss fragments initially applied.

Moss samples from the 15 containers with the highest water table and fragment application density treatments (five for each of the three peat/water sources) were selected for morphology comparisons and nutrient analysis. As part of an associated field study, S. papillosum tissue samples were also collected and analyzed in October 1995 from four natural sites in Minnesota.

To quantify differences in moss morphology, an index was developed to approximate the mean mass per unit length of stem, including capitulum, for each of the three peat/water source treatments with the highest water table and fragment application density. The total dry weight for each container was divided by its maximum lineal growth, and then divided by the number of stems. This was also done for moss collected from the four natural sites, using the top 3 cm of each stem, including capitulum.

To determine nutrient concentrations, the dried moss tissue samples from each container, and from the natural sites, were placed in a Wiley mill and ground to pass through a 0.85 mm sieve. Ground samples were sent to the University of Minnesota, Research Analytical Laboratory, to determine concentrations of seven elements (N, P, K, Ca, Mg, Fe). Total N was determined using a semi-micro Kjeldahl method. Total S was determined using an LECO Sulfur Determinator. P, K, Ca, Mg, and Fe concentrations were determined by Inductively Coupled Plasma (ICP) Atomic Emission Spectrometry (Munter, 1982).

All statistical analyses were conducted using SigmaStat® computer software. A three-way ANOVA procedure was conducted on moss biomass accumulation to determine the effects of peat/water source, water table level, and fragment density. One-way ANOVA and multiple comparison procedures were used to determine differences in moss morphology and tissue nutrient concentrations between the greenhouse treatments and natural sites. Data transformations were conducted when necessary to insure data compliance with statistical assumptions of normal distribution and equal variance. Significant treatment differences were based on a p value<0.05.

**Results and Discussion**

**Biomass accumulation**

The mean dry weight for each treatment is presented graphically in Fig. 1. Statistical analysis of the biomass data using three-way ANOVA procedures revealed significant main effects for peat/water source (p<0.001), water table level (p<0.001), and fragment density (p<0.001). It is apparent in Fig. 1 that the mean dry weight for the old peat/water
source treatment was considerably lower than the other peat/water source treatments regardless of water table level or fragment density, with the exception of the +1 cm water table/120 fragment density treatment. The significant main effect for water table level is also evident in Fig. 1, with increasing biomass resulting from an increase in water table level. This trend has also been reported in the literature for similar greenhouse studies (Campeau & Rochefort, 1996; Grosvenor et al., 1997). The high fragment density also resulted in higher biomass, although not to as great an extent as the other two factors.

There were also statistically significant interactions between peat/water source and water table level (p<0.001), peat/water source and fragment density (p=0.004), and water table and fragment density (p=0.020). The peat/water source x watertable level interaction suggests that the effects of different peat/water source treatments are dependent on the water table level, and likewise, the effects of water table level are dependent on the peat/water source. As can be seen in Fig. 1, this interaction is most evident at the highest water table level where the biomass for the new peat/water source treatment almost equals the intermediate treatment. This suggests that *S. papillosum* biomass accumulation for any given site will only reach its full potential under high water table conditions. It is likely that factors other than water table are associated with the decreased biomass for the old treatment.

The water table level x fragment density interaction indicates that the effects of water table level are dependent on the fragment density, and likewise, the effects of fragment density are dependent on water table level. Though not as significant as the other interactions, the effect of increased fragment density is most pronounced at the high water table level. Therefore, at low water level conditions, applying a high density of *S. papillosum* fragments may not result in an associated increase in biomass.

\[ \text{Fig. 1. } S. \text{ papillosum biomass accumulation (g dry weight) for three peat/water source treatments (old, new, intermediate), at three water table levels (-9 cm, -3 cm, +1 cm), at two mass fragment application densities (60 & 120 fragments/container). Means + standard error, n=5.} \]
Moss morphology

General examination of the treatments revealed several differences in moss color and morphology. Blackened capitula were observed on the intermediate and new peat/water source treatments, with brown to green colored capitula on the old treatments. The black capitula were possibly due to the uptake of humics from the bare peat surface. The capitula were also smaller, and the plants more spindly, in the intermediate and new treatments. The moss plants in the old treatments, although shorter, appeared more like S. papillosum occurring in natural bogs. In all cases, lower water table resulted in smaller capitula, with a shriveled appearance.

The morphology indexes for the three greenhouse treatments (n=5) and the combined natural sites (n=20) were compared using a one-way ANOVA procedure and Tukey multiple comparison test. Moss morphology was significantly different (p<0.001) for the four treatments tested. The multiple comparison test revealed no significant difference between the old peat/water source treatment and the natural sites. There was also no difference between the new and intermediate treatments, although they were significantly lower than the old and natural site treatments. This confirmed our observation that the old treatment resulted in moss morphology similar to that occurring at natural sites and different from the other two greenhouse treatments.

Moss Tissue Nutrient Concentrations

Sphagnum species occurring naturally on ombrotrophic sites are usually separated from the water table and acquire most of their nutrients from the atmosphere as precipitation and dry-fall (Damman, 1990; Malmer, 1993). However, when restoring a harvested peatland, moss fragments are applied to the bare peat surface, and can acquire nutrients from peat mineralization and the water table. The same was true in our greenhouse study. As the study progressed it became evident that there was significant variation in biomass accumulation and moss morphology which could be attributed primarily to the peat/water source treatments. To ascertain if these differences were the result of varying nutrient availability and uptake, moss tissue samples were collected and analyzed. These data were compared to detect differing nutrient concentrations which may explain the inconsistencies in biomass accumulation and moss morphology.

The mean moss tissue nutrient concentrations for each of the three peat/water source treatments with the highest water table and fragment application density (n=5) and the combined natural field site data (n=20) are presented in Fig. 2. Nutrient concentration data for the natural sites were similar to that for S. papillosum collected in southern Finland (Aulio, 1980). Overall, moss tissue elemental con-
centrations were higher for the greenhouse treatments than for the natural field sites. Some notable exceptions are the P and K concentrations for the old greenhouse treatment, which are significantly lower than both the natural field sites and other greenhouse treatments.

It is known that either N or P can limit Sphagnum productivity (Malmer, 1993) and by determining the ratio of these elements in moss tissue it can be inferred which of the two is limiting (Aerts et al., 1992; Li et al., 1993). An N:P ratio of less than 10 usually indicates that growth is N-limited, higher than 10 suggests growth is P-limited. Mean ratios calculated for the data in this study were 21:1 for the natural sites, 70:1 for the old treatment, 9:1 for the intermediate treatment, and 15:1 for the new treatment. The high ratio for the old treatment is a clear indication of P-limited growth. This combined with a low K concentration could explain the reduced biomass accumulation observed for this treatment.

The old treatment also exhibited an extremely high Fe concentration, approximately 3 times that of the next highest treatment. Fe, in various forms, can precipitate P and make it unavailable for plant uptake, especially at neutral to acid pH (Brady, 1974). This phenomenon could have intensified the P-limiting effect for the old treatment.

The old treatment also has significantly higher concentrations for Ca and Mg. The Ca and Mg concentrations for the old treatment are significantly higher than the natural field sites and the new treatment, but lower than the intermediate treatment. Some studies have shown that high levels of Ca combined with high pH in bog waters can have a detrimental effect on Sphagnum growth (Clymo, 1973; Malmer et al., 1992). Malmer (1993) reports that bog water with a pH >5.5 and high Ca concentration can have adverse effects on Sphagnum growth and competitive ability. The pH of the bog waters used for this experiment were 4.7 for the new treatment, 6.9 for the intermediate treatment, and 7.4 for the old treatment. Both the old and intermediate treatments had high Ca concentrations and pH above 5.5. However, the intermediate treatment produced the most biomass, therefore, it is questionable whether these factors had a negative effect on biomass accumulation in this experiment.

Sulfur concentrations were significantly higher for the greenhouse treatments than for the natural areas. Some studies have shown that high levels of S as a result of atmospheric pollution can be detrimental to Sphagnum growth (Malmer, 1993). However, in this study, the two treatments with the highest S concentrations also had the greatest biomass. Therefore, it is unlikely that S levels were high enough to reduce Sphagnum growth in this study.

**Conclusions**

In this greenhouse study, the growth and morphology of *S. papillosum* was influenced to varying degrees by a number of factors. A water table level at or very near the peat surface is essential to maximize biomass accumulation. Increased moss fragment application densities, within the range tested in this study, resulted in only a moderate increase in biomass accumulation, dependent upon the water table level and peat/water source, and may not be worth the additional impacts on natural donor areas. The chemical characteristics of the peat substrate and associated bog water also have a significant effect on moss growth and morphology. Moss tissue analysis revealed that the old greenhouse treatment, which had consistently the lowest biomass accumulation, was likely deficient in P and possibly K. The P deficiency was conceivably aggravated by a high Fe level which may have precipitated the P and made it unavailable. Relatively high Ca levels and pH may have also contributed to the low biomass accumulation for this treatment.

Even though the new and intermediate treatments resulted in significantly higher biomass, especially at the high water table level, the moss morphology was significantly different from that of natural areas and the old treatment. Their small, spindly growth habit may be suitable for restoring ground cover to post-harvested peatland sites, but if the moss is to be harvested and sold as top moss or floral moss, product quality could be diminished.

Future research should include *S. papillosum* growth trials on a variety of post-harvested sites to determine the applicability of the greenhouse findings to actual field conditions.

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