

Development of Construction Method of *Sphagnum* Wetland for Landscape Use: With Focus on Planting Method, Planting Base, and Nitrogen Treatment

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ABSTRACT: Construction of green zones in urban areas is of great importance in urban environment. Various vegetation and substrates have been suggested, but little information is available about moss as a target vegetation for green zones including rooftop greening. This study aims to test the feasibility of construction of *Sphagnum* wetlands in urban ecosystems by collecting basic information about *Sphagnum* growth and decomposition. We constructed 12 groups of *Sphagnum* microcosms (1m x 1m) with three replicates. A factorial design with two types of plating bases (Plain planting base and planting base with water reservoir), two types of planting methods (Capitulum without stem and Capitulum with stem), and three levels of nitrogen additions (Control, 2 g N m⁻² yr⁻¹, and 6 g N m⁻² yr⁻¹) was prepared. The changes in length, dry mass and decomposition rates of *Sphagnum* were monitored over a growing season. Net primary production ranged between 175 – 260 g m⁻² yr⁻¹ for dry mass, and 12.1 - 26.5 mm/yr for the length. These values are comparable to those from natural bogs over N48 ° in latitude. Decomposition rates measured by a litter-bag method exhibited 10.9 - 21.4% mass loss per year, which are within the ranges of decomposition rates reported from natural bogs. Overall results of this study indicate that construction of *Sphagnum* wetlands can be successfully employed as a greening technology in urban ecosystems even in mid-latitude.

Keywords: Bog, *Sphagnum*, Productivity, Decomposition rate

1. INTRODUCTION

Recent years have witnessed increased concerns about urban environmental problems including reduction in green areas, a heat island effect, and ‘tropical night’. To

solve such problems, various eco-friendly techniques and regulations have been introduced. For example, rain water reuse, expansion of permeable surface, and enhancement of photosynthesis have drawn much attention. Construction of wetlands

could be an effective approach to achieve many goals both aesthetically and environmentally, because wetlands have functions of high productivity, biodiversity, and water retention (Mitch and Gosselink, 2002). However, previous studies on construction of wetlands as a greening matrix mostly focused on marshes, while little attention was given to peatland such as bogs. Bogs are a unique ecosystem in a way that decomposition is much slower than production (Clymo, 1992). As such, they accumulate undecomposed organic matter as peat, which are estimated to contain 1/3 of soil organic matter globally (Gorham, 1991; Clymo, 1998). In general, bogs are dominated by *Sphagnum* mosses, which play a key role in carbon accumulation. Various factors are known to affect the growth of *sphagnum*. For example, water level and nutrient availability have been noted as some of key driving forces for *Sphagnum* growth. Because *Sphagnum* grows apically from capitulum (Clymo, 1970), distances between water level and capitulum determines water and nutrient availability, which then regulate the growth of *Sphagnum*. Each species of *Sphagnum* has different resistance to drying and nutrient uptake rates (Hayward and Clymo, 1983; Wagner and Titus, 1984; Luken, 1985), and hence different species of *Sphagnum* develop along a microtopography (Rydin, 1986; Rydin, 1993). In general, productivity of *Sphagnum* shows a positive correlation with water level (Ratcliffe and Walker, 1958; Hayward and Clymo, 1982, 1983), but other factors may be more dominant when water table reaches a certain level (Weltzin *et al.*, 2001). For instance, nitrogen availability is one of the general limiting factors. However, excessive N input through increased atmospheric deposition has been noted to affect *Sphagnum* growth negatively (Rocheffort *et al.*, 1990; Malmer and Wallen, 2005). In pristine conditions, added N is effectively absorbed to capitulum (Gunnarsson and Rydin, 2000). However, if nitrogen additions exceed a certain threshold,

N absorption capacity decreases exponentially, and may result in inhibition of growth (Bragazza *et al.*, 2005). Another important factor would be the transport of water and nutrient through *Sphagnum* tissues. Because *Sphagnum* does not have vascular tissues, external capillary networks play a key role (Ingram, 1982; Hayward and Clymo, 1982; Rydin, 1985). However recent studies have suggested that dead tissues are still involved in nutrient transport (Rydin and Clymo, 1989; Skre *et al.*, 1983; Aldous, 2002), and production of *Sphagnum* bogs (Gerdol *et al.*, 2006).

Due to high water holding capacity and carbon accumulation function, *Sphagnum* could be a good substrate for urban greening technique. However, little information is available on an effective way to grow *Sphagnum* successfully in temperate regions, urban areas in particular. Of various conditions, we selected that water availability, nutrient transport through *Sphagnum* tissues, and nitrogen availability would be the key controlling variables for successful growth of *Sphagnum*.

This study aims to fill the gap in this knowledge by conducting a manipulation experiment. We manipulate water level, N concentrations, and way of planting in replicated sphagnum microcosm and determine productivity and decomposition rates.

2. MATERIALS AND METHODS

Experimental settings were placed on roof top of a building in Yong-In, Kyeonggi Province (N37°19'). The manipulation experiment was conducted during growing season (April - November, 2007). Atmospheric temperature varied between 6.8 °C and 33.2 °C, and annual precipitation was 1268 mm.

Sphagnum palustre and *Sphagnum imbricatum*, which had been cultivated for 2 years, were placed in each microcosm of 1 m x 1 m x 0.1 m. Two types of planting

bases were employed. The first one was 'plain planting base (P1)' where fresh *Sphagnum* was placed on top of dried *Sphagnum* of 10 cm. The other one was 'planting base with water reservoir (P2)', where dried *Sphagnum* was placed to 5 cm depth, and below was filled with water (Fig. 1).

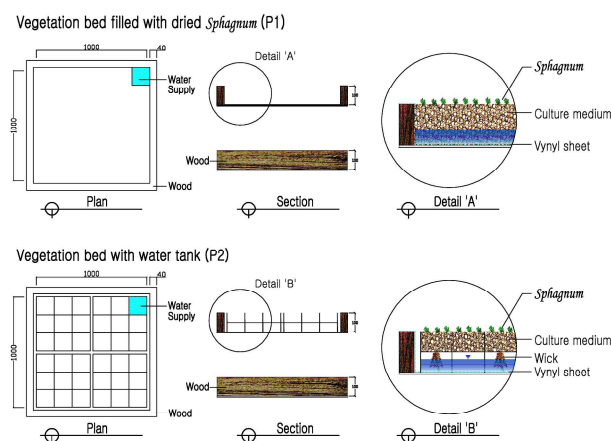


Figure 1: Two types of planting bases. Above: Plain Planting Base (P1). Below: Planting Base with Water Reservoir (P2)

Two types of planting methods were considered in relation to nutrient transport. One is to plant *Sphagnum* with stem of dead subsurface tissues (7 cm), which may allow both internal and external transport (+D). The other setting is to plant capitulum of 1 cm only without stem (-D).

For nitrogen additions, we prepared control without any N addition (N0), low N addition ($2 \text{ g N m}^{-2} \text{ yr}^{-1}$; N1), and high N addition ($6 \text{ g N m}^{-2} \text{ yr}^{-1}$; N2). Total 12 treatments (2 planting bases x 2 planting methods x 3 N additions) with 3 replicate microcosm were prepared by a multi-way factorial design.

Lengthy growth was determined on a monthly basis using 5 cranked wires installed in each microcosm. Dry mass of *Sphagnum* was determined by drying subsample at 75°C for 3 days. Decomposition rates were determined by a litter bag, where we placed dry *Sphagnum* litter in 0.8 mm

mesh bags (10 cm x 10 cm) and noted changes in dry mass.

N contents in capitulum were determined by a Kjeldahl method.

Changes in dry mass and decomposition rates were analyzed by 3-way ANOVA, while lengthy growth was analyzed by repeated measures ANOVA (SPSS, v12).

3. RESULTS

I II III IV V VI

3.1 Productivity in the Plain Planting Base (P1)

Lengthy growth ranged 15.5 – 25.8 mm for capitulum only (-D), while that for with stem (+D) varied between 23.3 – 26.5 mm (Table I). N additions induced different responses to +D and -D (Table I).

For dry mass, -D and +D ranged $187\text{--}260 \text{ g m}^{-2} \text{ yr}^{-1}$, and $227\text{--}247 \text{ g m}^{-2} \text{ yr}^{-1}$, respectively (Table I). For -D, high N addition increased dry mass substantially, but such enhancement was absent for +D (Table I).

Table I: Net annual growth in dry mass and length of each combination subjected to the Plain Planting Base (P1).

Planting Base	Planting Method	N addition	Length (mm/yr)	Dry mass ($\text{g m}^{-2} \text{ yr}$)
P1	-D	N0	15.47	206
		N1	23.33	187
		N2	25.80	260
	+D	N0	23.33	247
		N1	26.47	227
		N2	23.33	237

※ -D: capitulum without stem, +D: capitulum with stem, P1: Plain Planting Base, N0: no addition of nitrogen, N1: Nitrogen Addition of low concentration ($2 \text{ g N m}^{-2} \text{ yr}^{-1}$), N2: Nitrogen Addition of high concentration ($6 \text{ g N m}^{-2} \text{ yr}^{-1}$).

3.2 Productivity in the Planting Base with Water Reservoir (P2)

Lengthy growth for -D varied 12.07 – 24.13 mm, while that for +D ranged 12.93–18.00 mm. N addition increased growth for both planting methods (Table II). Dry mass

changes by N additions exhibited a similar pattern as lengthy growth for -D. However, dry mass decreased by N additions for +D (Table II).

Table II: Net annual growth in dry mass and length of each combination subjected to the Planting Base with Water Reservoir (P2).

Planting Base	Planting Method	N addition	Length (mm/yr)	Dry mass (g/m ² yr)
P2	-D	N0	12.07	187
		N1	16.33	209
		N2	24.13	240
	+D	N0	12.93	201
		N1	16.60	191
		N2	18.00	175

※ -D: capitulum without stem, +D: capitulum with stem, P2: Planting Base with Water Reservoir, N0: no addition of nitrogen, N1: Nitrogen Addition of low concentration (2g N m⁻² yr⁻¹), N2: Nitrogen Addition of high concentration (6g N m⁻² yr⁻¹).

3.3 Decomposition rate

In plain planting base (P1), decomposition rates for -D ranged between 10.9-14.0%, while that for +D varied between 11.0-14.7%. N additions increased decomposition rates for both -D and +D, but differences between low N and high N were minimal (Table III).

Table III: Net annual decomposition rate of each combination subjected to the Plain Planting Base (P1).

Planting Base	Planting Method	N addition	Average (%)	SD
P1	-D	N0	10.89	4.41
		N1	14.04	3.00
		N2	13.11	2.80
	+D	N0	11.01	2.61
		N1	14.72	3.72
		N2	14.00	4.57

※ -D: capitulum without stem, +D: capitulum with stem, P1: Plain Planting Base, N0: no addition of nitrogen, N1: Nitrogen Addition of low concentration (2g N m⁻² yr⁻¹), N2: Nitrogen Addition of high concentration (6g N m⁻² yr⁻¹).

In contrast, planting base with water reservoir (P2) exhibited a different response

in a way that N additions did not affect decomposition rates substantially in general (Table IV).

Table IV: Net annual decomposition rate of each combination subjected to the Planting Base with Water Reservoir (P2).

Planting Base	Planting Method	N addition	Average (%)	SD
P2	-D	N0	18.49	2.85
		N1	20.29	2.13
		N2	19.23	3.66
	+D	N0	21.37	2.54
		N1	15.92	2.67
		N2	18.31	4.00

※ -D: capitulum without stem, +D: capitulum with stem, P2: Planting Base with Water Reservoir, N0: no addition of nitrogen, N1: Nitrogen Addition of low concentration (2g N m⁻² yr⁻¹), N2: Nitrogen Addition of high concentration (6g N m⁻² yr⁻¹).

3.4 Nitrogen concentration in capitulum

For P1, nitrogen additions resulted in different responses for -D and +D. N additions increased N content in capitulum in -D. However, N additions did not affect N content in +D (Table V).

Table V: Nitrogen concentration in the capitulum subjected to the Plain Planting Base (P1).

Planting Base	Planting Method	N addition	Nitrogen Concentration (mg/g)
P1	-D	N0	9.14
		N1	9.87
		N2	10.28
	+D	N0	10.09
		N1	10.71
		N2	10.63

※ -D: capitulum without stem, +D: capitulum with stem, P1: Plain Planting Base, N0: no addition of nitrogen, N1: Nitrogen Addition of low concentration (2g N m⁻² yr⁻¹), N2: Nitrogen Addition of high concentration (6g N m⁻² yr⁻¹).

In contrast, N additions did not change N content in capitulum for P2. N content for -D ranged between 10.6-10.9 mg/g, while that

for +D varied between 9.9-11.8 mg/g (Table VI).

Table VI: Nitrogen concentration in the capitulum subjected to the Planting Base with Water Reservoir (P2).

Planting Base	Planting Method	N addition	Nitrogen Concentration (mg/g)
P2	-D	N0	10.86
		N1	10.56
		N2	10.70
	+D	N0	10.56
		N1	9.85
		N2	11.75

※ -D: capitulum without stem, +D: capitulum with stem, P2: Planting Base with Water Reservoir, N0: no addition of nitrogen, N1: Nitrogen Addition of low concentration ($2\text{g N m}^{-2}\text{ yr}^{-1}$), N2: Nitrogen Addition of high concentration ($6\text{g N m}^{-2}\text{ yr}^{-1}$).

Relationship between dry mass of *Sphagnum* and N content in capitulum exhibited a hyperbolic type in a way that higher dry mass was found around 10.1-10.3 N mg/g (Fig. 2).

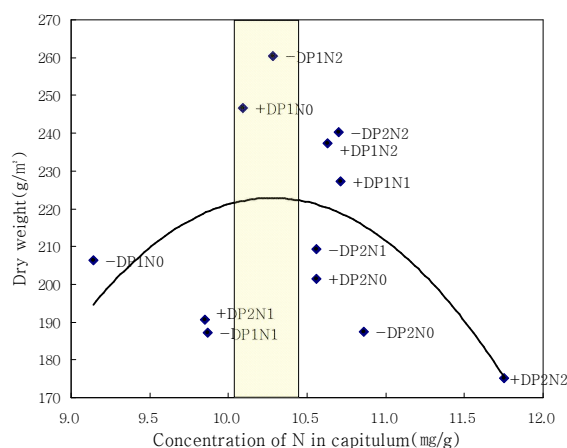


Figure 2: Relationship between dry mass and N concentration in capitulum

4. DISCUSSION

The lengthy growth and dry mass reported in the present study is comparable to those found in natural bogs in the northern peatlands (Wieder and Lang, 1983;

Gunnarsson, 2005). Considering the fact that productivity in *Sphagnum* bogs increases toward lower latitude (Damman, 1979; Wieder and Lang, 1983), and that this study was conducted at 38°N , the productivity noted in this study may be lower than that in natural bogs. The reasons would be found in the location of the microcosm. The experimental settings were placed on a rooftop of a building in an urban area. As such, wind, longer durations of sunlight, and radiant heat from concrete base could affect the production of *Sphagnum* negatively.

Comparing N control treatments, it is suggested that P2 rather than P1, and +D rather than -D would be a better design for higher productivity. This result indicates that a planting base and a planting method facilitating water and nutrient transport would enhance primary production of *Sphagnum* (Table I, II). In addition, higher production in -DP1 (i.e., planting without stem and plain planting base) than that in +DP2 (i.e., planting with stem and planting base with water reservoir) suggests that planting bases may be more important than planting methods in determining production. However, N additions interfere with these results, indicating that effects of extra nitrogen differ with types of planting bases or methods.

N contents in capitulum observed in this study are higher than the values reported by previous studies. For example, Aerts *et al.*, (1992), Gunnarsson *et al.*, (2000) reported that 4.5 – 7 mg/g is a threshold range for N content in capitulum, while Bragazza *et al.*, (2005) reported 13 mg/g as a critical concentration. Other studies have reported a higher concentration (20 mg/g) where a negative effect would appear from N addition (Ferguson and Lee, 1983; Ferguson *et al.*, 1984). It is estimated that 10.1 – 10.3 mg/g is a critical concentration where positive effects of N on growth turn into negative ones (Fig. 2).

Unlike previous reports of higher decomposition rates in nutrient rich

wetlands (Wieder and Lang, 1983; Johnson and Damman, 1991; Verhoeven and Toth, 1995), our results exhibited lower decomposition in +DP1, and higher decomposition in +DP2. Johnson and Damman (1991) and Hogg (1993) reported that aerobic conditions would induce higher decomposition rates than that in anaerobic conditions. Because P2 exposes to air both from top and bottom, it is speculated that P2 would be more aerobic than P1, and consequently exhibit faster decomposition.

Overall results of this study indicate that the combination of P1, +D, and N0 is an effective design for high production and low decomposition of *Sphagnum*. Even if the combinations of P2 and other factors exhibited lower productivity and higher decomposition rate than those of combinations of P1, +D, and N0, P2 still has high potential of applicability to urban environment in terms of rain water reuse. Development of *Sphagnum* wetland with water reservoir is also needed through the technical solution in the future.

In general, N addition may interfere with this in this experiment, and the longer term monitoring is warranted to reveal clear mechanism for that.

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