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Litter Decomposition and Nutrient Release Patterns in a Subalpine Forest in Northern Utah

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LITTER DECOMPOSITION AND NUTRIENT RELEASE
PATTERNS IN A SUBALPINE FOREST IN NORTHERN
UTAH

by

Amber Denton Johnson

Thesis submitted in partial fulfillment
of the requirements for the degree

of

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WITH DEPARTMENTAL HONORS

in

Forest Resources

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Introduction

In the arid subalpine zone of the intermountain west it is common to see patchy forests interspersed with open meadows containing scattered clusters of trees referred to as tree islands. These tree islands are often composed of subalpine fir [*Abies lasiocarpa* (Hook) Nutt.] and Englemann spruce [*Picea engelmannii* (Parry)]. In desert ecosystems, where lack of water is the most important factor limiting growth and nutrient dynamics, it is not unusual to see individual plants (especially in the shrub community) creating "islands of fertility", in which the plants collect nutrients by pumping them from deeper in the soil profile and redepositing those nutrients as litter, stemflow or throughfall (Charley and West 1975; Garner and Steinberger, 1989). Work by Richards and Caldwell (1987), Caldwell and Richards (1989), and Caldwell et al. (1991) has further shown that the root system of sagebrush (*Artemisia* sp.) communities induce hydraulic lift, a phenomenon whereby water is taken up by deep roots during the day and then released by shallow roots at night resulting in a greater amount of water available to other plants in the community. West (1991) showed that this hydraulic lift, combined with shade produced by the plant and buildup of litter underneath the plant, results in environmental conditions that are more advantageous for decomposition and nutrient release. These direct and indirect plant influences in arid environments result in a localized area around the plant that is higher in nutrient and water availability and is more conducive to plant growth and reproduction. Studies on Krummholz tree islands in the alpine zone of the Rocky Mountains in Colorado also showed that tree islands have a significant effect upon snow accumulation and redistribution (Benedict 1984) which may affect litter decomposition as well as other soil processes.

Our study investigated whether subalpine tree islands in Northern Utah have similar impacts on of nutrient and water distribution as observed in desert ecosystems that results in areas of higher nutrient and water availability or a better site conditions for tree growth and reproduction. This paper will specifically examine the influence of tree islands on litter decomposition and nutrient release. Other effects of tree islands on physical and chemical properties of soil are discussed in a companion paper (Van Miegroet et al, In Preparation)

Materials and Methods

Study Area

The study was conducted at Utah State University's T.W. Daniel Experimental Forest in the Wasatch Mountains of Northern Utah, 30 km NE of Logan at an elevation of 2600 m. The moisture regime is semiarid with an average annual precipitation of 950 mm, 80% of which accumulates as snow. Snowmelt typically occurs between mid-May to mid-June. Monthly rainfall is low between May and October, with lowest precipitation (< 2 cm) typically occurring in July. Average low temperature is around -10°C in January; highest average monthly temperature (14.5°C) occurs in July (Schimpf et al., 1980; Skujins and Klubek, 1982).

The vegetation in this area consists predominantly of spruce-fir forests of moderate age (<250 years). The periphery of the montane forb meadows consist of 20-40 m bands of quaking aspen

[*Populus tremuloides* (Michx)], followed by subalpine fir (*Abies lasiocarpa*)-dominated forest, into a climax of Engelmann spruce (*Picea engelmannii*) forest. Tree islands of mature spruce and fir occur throughout the meadows. Young spruce and fir, if present in the meadows, typically occur on the north margins of the conifer forests and in the tree islands. Summer grazing of the area by cattle and sheep has occurred since the early 1900s (Schimpf et al., 1980).

Typical tree island structure consists of a pioneering mother tree that reproduces primarily by layering (i.e. vegetative reproduction), and is surrounded by younger trees in a circular shape. As the tree island ages, the mother tree will eventually die, leaving the center of the island empty. This formation is referred to as an atoll. Atolls will continue to advance outward into the meadow, leaving the center open for regeneration by spruce-fir, and creating concentric circles of mature trees (Jean 1990).

Soils at the study area are classified as Mollisols with little profile development since the last glaciation, and contain large amounts of coarse (>2 mm) material (Skujins and Klubek, 1982). They are derived from the Knight formation of the Wasatch group, a Tertiary conglomerate of quartzite, sandstone and shale (Schimpf et al., 1980).

Plot Layout

Three tree islands were selected in Big Meadow of the T.W. Daniel Research Forest; Yellow Submarine (BY) Sweet Hillary (BS) and NeHi (BN). The islands dimensions ranged from 17 m by 23 m (BS) to 27.5 m by 38 m (BN), with the longest axis being from North to South. All had similar slope and aspect. The islands had treeless centers and surrounding clusters of trees were composed mostly of subalpine fir (*Abies lasiocarpa*) with some Engelmann spruce (*Picea engelmannii*). Many of the fir showed evidence of reproduction by layering.

In each island a north and south cluster of trees was selected as aspect was expected to have an effect on soil temperature and moisture content and ultimately on decomposition rates. The clusters were divided into a north and south hemisphere, for each hemisphere areas were designated as "below canopy" or "exposed" areas within 5 m of the canopy edge of the cluster either in the meadow or the island interior, for a total of four locations per tree cluster or eight per island (See Figure 1).

Field Methods

In October 1995, sixteen litterbags, containing similar litter material, were placed randomly in all locations in each of the three tree islands for a total of 384 bags (4 locations x 2 clusters x 3 islands x 16 bags). They were attached to the ground with aluminum nails to prevent loss by ungulates and rodents.

Litterbags were constructed of 1 mm² fiberglass mesh with a liner of nylon tulle (1 mm² mesh size) to prevent the short fir and spruce needles from falling out of the bags. The bags were 20 cm by 20 cm and were filled with approximately 10 grams of air-dried litter. The litter was

collected in July and August of 1995 in litter traps placed in the islands and in the nearby forest, as well as by brushing senescent needles from branches into paper sacks. The needles were brought back to the laboratory, picked over to remove any other substrate, air dried and thoroughly mixed before filling the litterbags. Subsamples were dried at 65°C for at least 24 hours to derive the air-dry to oven-dry weight ratio.

In July of 1996, 5 bags were removed from each location (9 months), and were replaced by 5 new bags as part of a second one-year decomposition assay. In October of 1996, 5 more bags were removed per location (12 months); in July of 1997 the remaining six bags (21 months) were removed as well as the replicate set put in July of 1996 (12 months).

Soil temperature was measured periodically in the BY island from December 1994 through June 1995 and from June to October 1996 using probes installed at 5 cm depth (SoilTest Model MC-310), and in all three islands in June and July 1997 using dial thermometers. Measurements were taken in the "below canopy" locations (halfway between the stem and canopy edge) and in the "exposed" locations (within 5 m of the canopy edge) of each cluster-hemisphere combination, roughly the same locations used for litterbag placement. Soil moisture was measured gravimetrically on soil samples taken in close proximity to the temperature measurements (Gardner, 1986). Additional temperature measurements were also taken during one winter (1994-1995) and two consecutive summers (1995, 1996) in the BY island and additional tree islands not included in this study (Van Miegroet et al., In Preparation).

In June of 1997, snow depth was measured in and directly around the islands to track the pattern of spring snowmelt. Measurements were taken 5 meters beyond the islands to the north and south and in the interior of the island near the north and south canopies. During the winter of 1995, snow accumulation was measured around 3 islands to determine if the tree islands had an effect on snow accumulation patterns in and around the islands as was found in Krummholz tree islands in Colorado (Benedict, 1984; Holtmeir and Broll, 1992). This was done by periodically measuring snow depth at 2 m intervals on four 20 m transects (N, S, E and W) extending from the tree island edge. At the same time snow depth was also measured in each direction around each cluster at a distance from the canopy edge equal to half the canopy diameter in that direction (Van Miegroet et al., In Preparation).

Laboratory Procedures

The litterbags were returned to the laboratory and dried at 65°C for 24-48 hours and weighed to determine moisture content and weight loss of the samples. Samples were ground using a Wiley mill (20 μ m mesh screen), and were composited into two samples per location (combination of 2 or 3 samples out of five replicates) prior to chemical and laboratory analysis. Because of a large amount of dust accumulation in many of the samples, litter was dry ashed to determine loss on ignition and ash-free dry weight (Nelson and Sommers, 1996). All weight loss numbers are based on ash-free dry weight units. The composite samples were digested using a nitric acid/ hydrogen peroxide method and analyzed for phosphorus (P), potassium (K), sulfur (S), magnesium (Mg) and other nutrients not discussed in this paper by ICP-AES (inductively coupled plasma atomic emission spectrometry) at the Utah State University Soil and Water Testing Laboratory (Jones et

al., 1991). The composite samples were also analyzed for total nitrogen (N) by standard Kjeldahl methods (Jones et al., 1991).

Statistical Analysis

Simple means were computed using SAS analytical software, and location effects on the rate of weight loss and nutrient release were determined by one-way ANOVAs followed by Duncan multiple range tests.

Results and Discussion

Snow accumulation and distribution

Tree islands in the study area did not affect snow accumulation and distribution during the winter months. There was not a significant difference in snow depth between the four transects extending from the tree island in February, 1995, although there was less snow in the interior of the island and between 0-2 meters outside of the island as compared to meadow locations (Table 1, Table 2). Studies on Krummholz tree islands in Colorado's alpine zone have shown an effect of tree islands on snow accumulation and redistribution (Benedict 1984, Holtmeir and Broll 1992). However, these tree islands are in a very different climatic system that is greatly impacted by wind. In Krummholz, trees tend to die off on sides exposed to the wind, and survive on the protected side of the tree island. Tree islands generally have snow blown away from the side facing the general direction of the wind and accumulation of snow on the leeward side of the islands. The large build up of snow drifts on their leeward side not only increase the spring soil moisture, but tends to promote dependence on clonal layering as a reproductive strategy by burying low branches with snow and litter, and creating a favorable environment for adventitious roots to form (Benedict 1984, Holtmeir and Broll 1992). The snow drifts persist into the spring growing season, which may help to suppress surrounding forbs and grasses that compete with the Krummholz tree island for limited nutrients. In Northern Utah wind is not a limiting factor at this elevation. Snow is not redistributed around the tree islands, and the tree islands expand in a somewhat concentric circular pattern, not in a flag pattern as in Colorado. We do see evidence of reproduction by layering, but the degree to which the tree islands depend on it in this system is not known.

During spring snowmelt the islands in our study did have an effect on snow depth by controlling the rates of snowmelt in and around the islands. In 1997 snow was gone from the south side of the islands and most of the west side by the first week in June, and did not melt off from the center, north side or the east side of the islands until 3 to 4 weeks later. These differential snowmelt patterns between below-canopy, exposed meadow and exposed island interior sites had a direct impact on soil moisture content in early summer (especially in the first half of June) (Figure 2).

Litter decomposition

Temporal patterns

There was not a significant difference between decomposition rates from nine months to one year (Table 3), suggesting that during the summer months not much additional decomposition occurred. Most moisture in this system falls as snow in winter, and most soil moisture is derived from snowmelt and early spring rains. Winter and early spring, when the soils are saturated, seem to be very important for decomposition. Stark (1972) found that in Nevada most litter decomposition occurred under the snowpack. Because litterbags were not removed before snowmelt in our study, it is not possible to verify whether this is also the case in this ecosystem. However we can conclude that most decomposition occurred between October and June and decrease towards the end of July when the soils became dry.

It is interesting to note the large difference in decomposition rates from one one-year period to another. The rate of weight loss from October 1995 to October 1996 was considerably lower than in the 12 month period from July of 1996 to July of 1997, which had decomposition rates comparable to the 21 month period (October 1995- July 1997, Table 3). One possible explanation for the greater decomposition of samples left in the field until July 1997(12' months) was the greater amount of precipitation during the second winter (1997). There was a deeper snowpack during the winter of 1996-1997 (Hebertson, 1997) and the soils were consequently moist longer into the summer season possibly allowing for a longer period of decomposition.

Even though there were significant differences in soil temperature and moisture content among the different locations inside and outside the tree islands (Figure 2) (Van Miegroet et al., In Preparation) they were not sufficient to explain differences in decomposition among locations. Across the entire dataset, we could not find a strong correlation between decomposition rates and either soil temperature or moisture content. The strongest correlation we found was between percent weight loss in the 12 month period from July of 96 to July of 97 and soil moisture content on June 21, 1997 at $r^2=0.37$ ($p = 0.01$) (Figure 3).

Aspect

For the first twelve months (9 and 12 months) organic matter decomposition was occurring fastest in the island interior compared to exposed sites or sites under direct canopy cover. By twenty-one months decomposition rates were highest in the south meadow exposed locations and slowest in the north meadow exposed locations.

At 9 months there was not a significant difference in litter decomposition rates between north meadow exposed sites ($21.2\% \pm 2.3$ loss, b) and south meadow exposed sites ($21.1\% \pm 2.1$ loss, b), but by 12 months differences were emerging and by 21 months litter samples at the south meadow exposed sites ($33.3\% \pm 7.6$, a) had lost an additional 6% of biomass over those in the north meadow exposed sites ($27.3\% \pm 6.4\%$, b) (Table 3).

It is possible that most of the decomposition occurred under the snowpack which would help explain why soil moisture and temperature in late spring and early summer is hard to link with decomposition rates. Soil temperatures stay at or near 0°C from November through March allowing a constant if cold environment for decomposition. These conditions would exist at all locations inside and outside tree islands irrespective of canopy cover (Figure 4a, 4b). Hence,

differences in decomposition rates must be due to differences in other factors among locations, possibly not measured in this study. Soil moisture and temperature may be more closely related to nutrient release patterns than to the actual weight loss of the substrate.

Nutrient Release

For the first 12 months of decomposition all locations showed high net P immobilization suggesting that P was a limiting nutrient. The interior of the islands had a tendency for lower relative P immobilization at 12 months (-83.8%) while the meadow exposed location at the south side of the islands exhibited the highest percent of P immobilization (-137.12%). There were, however, no statistically significant differences in P immobilization between locations.

Nitrogen dynamics were more variable among locations, and some broad trends emerged from our study: exposed locations outside the tree islands showed net N release (4-7% after 9 months, 11-12% after 12 months), whereas locations inside the tree islands (exposed island center or below tree canopy) generally exhibited N immobilization (except for the northern canopy location which showed some N release after 9 months). This N immobilization pattern may be related to the higher accumulation of carbon rich material in the island interior (Figure 5) (Van Miegroet et al., In Preparation). We could not find a significant correlation at 12 months between percent N release and percent weight loss indicating that N dynamics were operating somewhat independent of carbon turnover.

Within the first year litter samples lost between 17% and 40% of their Mg pool. Magnesium release followed decomposition trends and was significantly positively correlated with weight loss for all time periods. The highest correlation coefficient was measured for the period of October 1995-October 1996 ($r^2 = 0.34$, $p = 0.0001$). Starting at 9 months there was a significant effect ($p = 0.0001$) of location on Mg loss. The highest Mg release occurred in the island interior ($41.6\% \pm 6.9$) and the south meadow exposed locations ($34.5\% \pm 7.5$). There was not a significant difference between these two locations, but Mg release rates were significantly different from the other locations. Mg release rates were not statistically different between the two below-canopy locations and the northern exposed meadow sites. By 12 months, the highest Mg release occurred in the south meadow exposed locations ($37.1\% \pm 9.6$) and in the island interior locations ($36.1\% \pm 8.4$), but now the south canopy location showed slightly higher Mg release rates ($22\% \pm 9.2$) than the north canopy ($16.4\% \pm 8.1$) and the north meadow exposed ($15.3\% \pm 9.0$). Differences between the latter locations were not statistically significant.

Potassium release followed expectations with the highest percent release occurring in the initial stages of decomposition, and no statistically different patterns among locations.

Other nutrient release data is forthcoming.

Conclusions

Our observations support the hypothesis that the presence of tree islands alter decomposition and nutrient release patterns, however, these patterns change over time and do not necessarily follow the classic island of fertility concept. We hypothesized that the presence of the tree islands would increase the moisture content of the soil, increase decomposition rates, and provide more available nutrients to the trees resulting in a more favorable site for tree growth and reproduction. What we observed was that although the tree islands influenced soil moisture content and temperature those changes were not necessarily tied to decomposition. Early on, the tree island interiors provided the most favorable conditions for organic matter decomposition and the release of Mg, but with time decomposition and Mg release in the warmer exposed sites to the south of the tree islands caught up.

Contrary to the observations in Krummholz tree islands in Colorado, tree islands had little direct effect on snow distribution. The presence of such snowpack around and within the islands may have created a stable albeit cold environment favorable for decomposition.

Even though the mere existence of tree islands either through the presence of tree canopies or differential shading as a function of location and aspect, causes alterations in the soil microclimate (e.g., rate of snowmelt, drying out of soil, soil temperature, etc) and these microclimatic changes are likely to affect physical, chemical and biological processes in the soil, our study results did not allow us to clearly connect microclimate changes to litter decomposition and nutrient release patterns. However, water availability and the role of snowmelt rates thereupon may be more critical to regeneration and growth than differences in the rate of nutrient supply from the decomposing litter. Furthermore, even if the relative nutrient release rates from the decomposing litter were the same among locations, locations inside tree islands would be able to supply more nutrients simply based on the greater litterfall and the amount of O horizon material accumulated within the tree islands. Thus, tree islands may create favorable conditions for development and reproduction but the exact mechanisms are not easy to explain.

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Appendix - Figures and Tables

Figure 1. Plot Layout.

Figure 2. Soil Moisture Content by location.

Figure 3. Soil Moisture Content and Decomposition.

Figure 4a. Temperature flux over time in the BY island below canopy locations.

Figure 4b. Temperature flux over time in the BY island exposed locations.

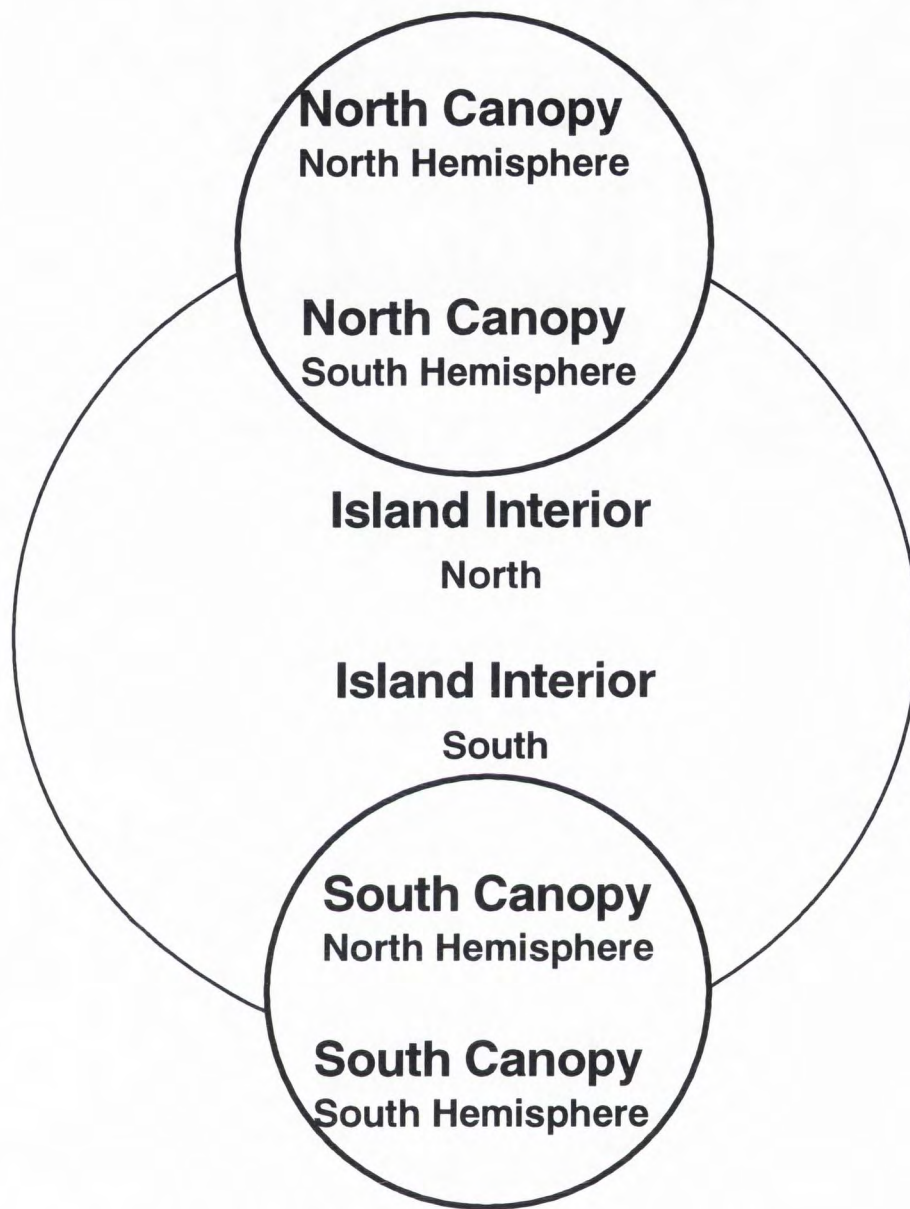
Figure 5. N immobilization by location.

Table 1. Snow Depth around islands.

Table 2. Snow Depth around clusters.

Table 3. Decomposition by location and time.

North Meadow/Exposed



South Meadow/Exposed

Figure 1. Plot Layout

Figure 2.

Soil Moisture Content by Location Spring 1997

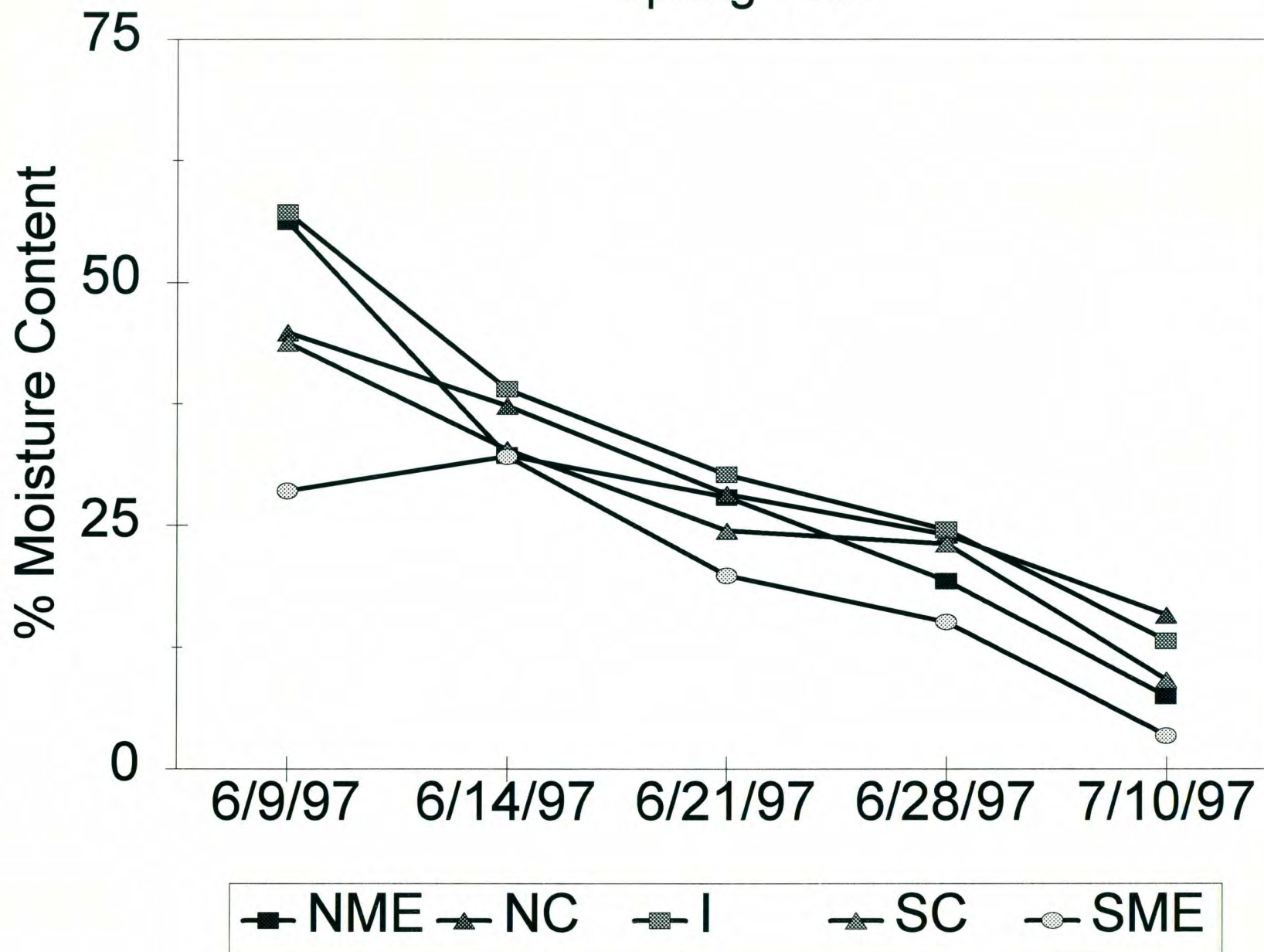


Figure 3.

Litter Decomposition Rate vs. Soil Moisture Content Spring 97

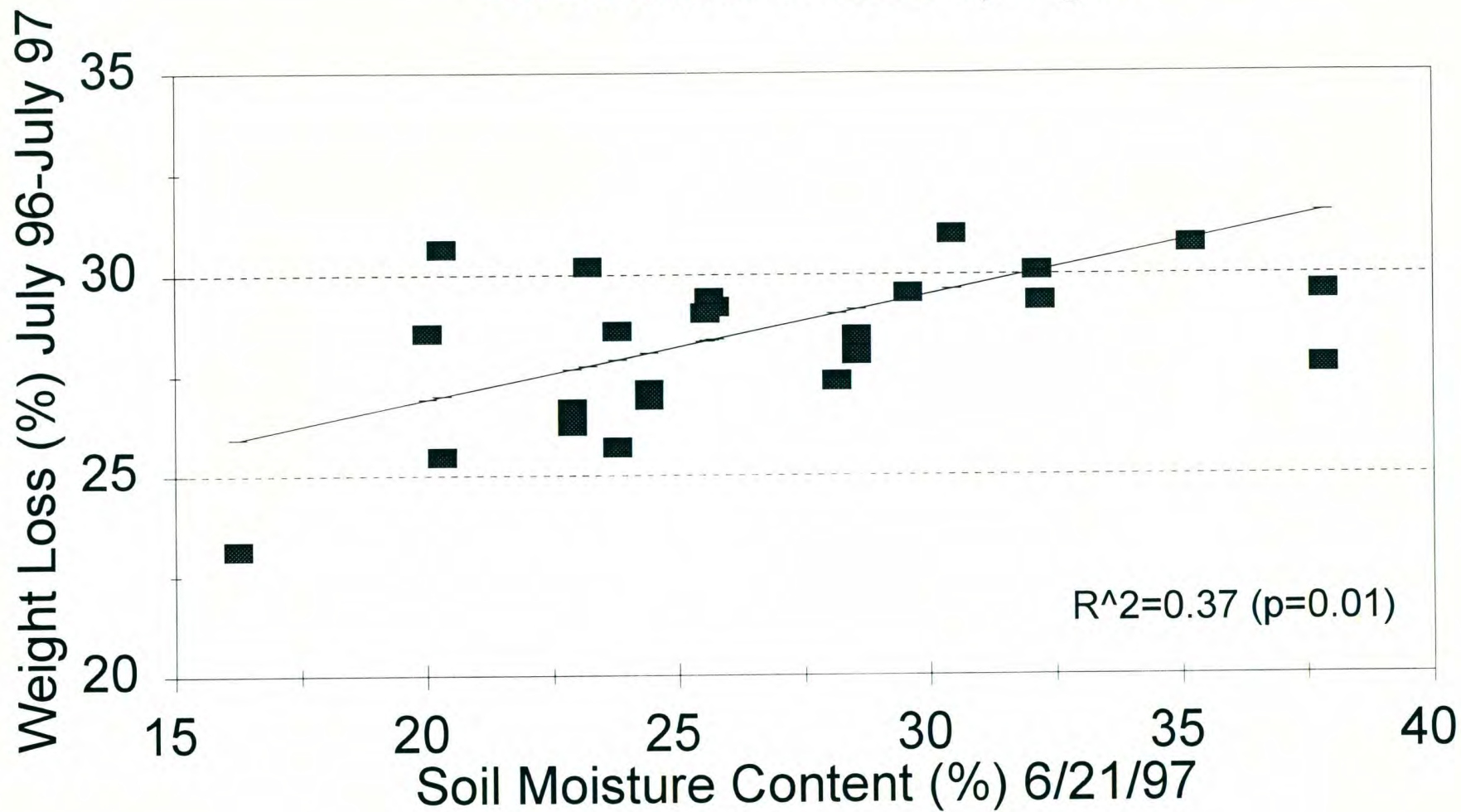


Figure 4a. Temperature flux over time in the BY island below canopy locations.

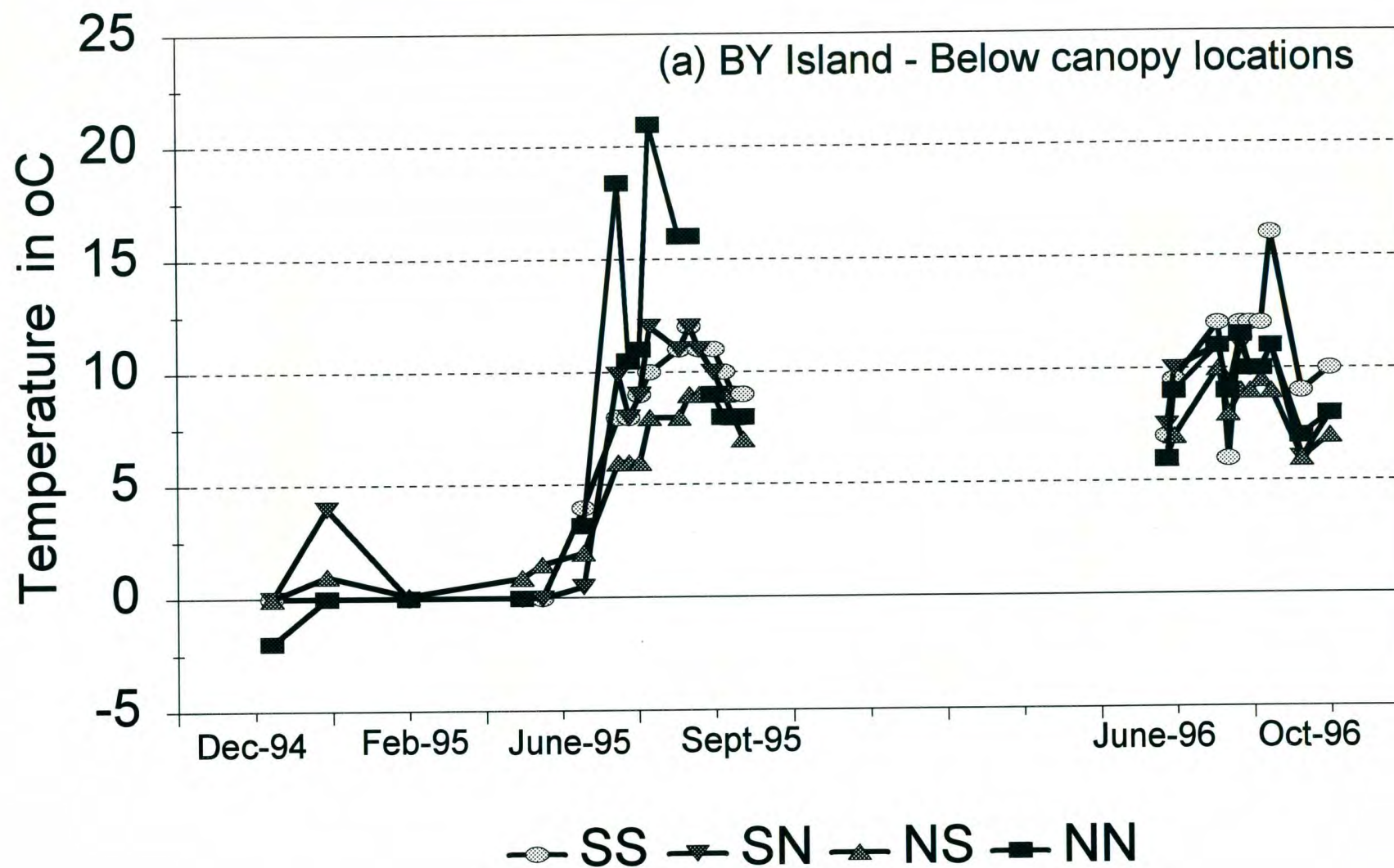
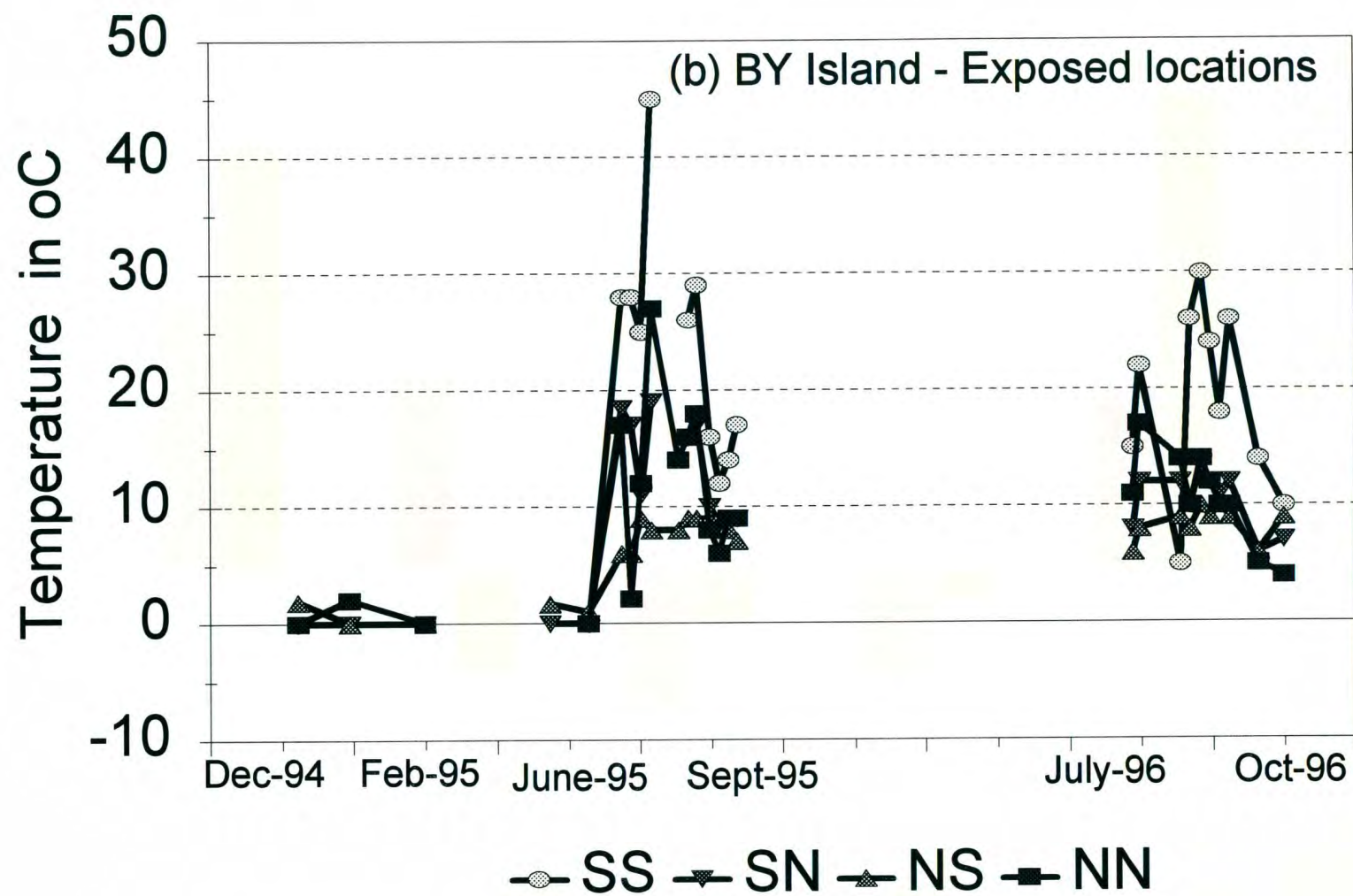


Figure 4b. Temperature flux over time in the BY island exposed locations.



Nitrogen Release by Location

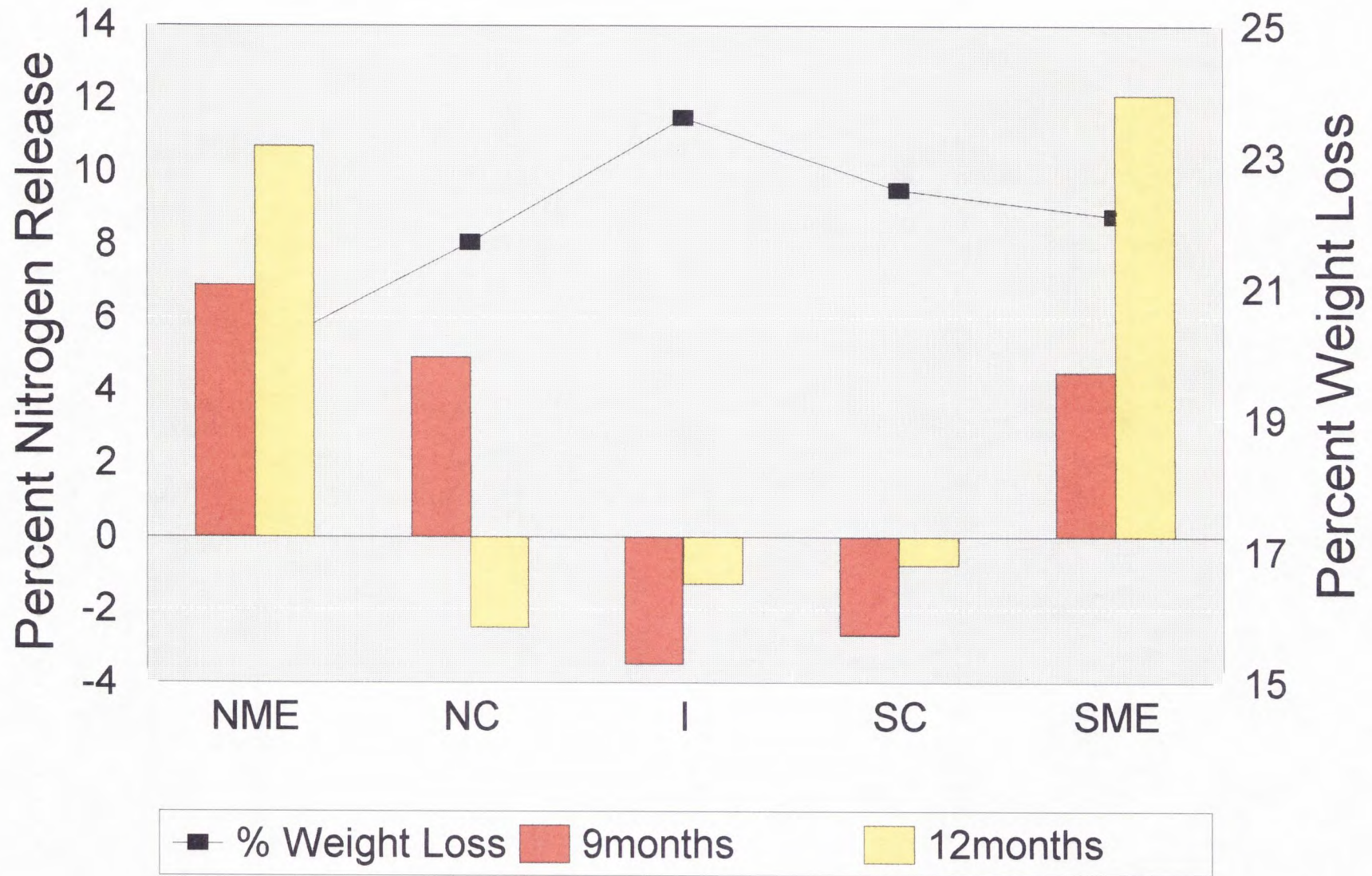


Table 1. Snow depth (cm) at the different directions around the tree islands

Measurement Point	Tree Island		
	DA	BH	BY
<u>February 1995</u>			
North	148 ± 6 a	166 ± 25 a	168 ± 12 a
East	137 ± 19 ab	163 ± 23 a	165 ± 25 a
West	137 ± 15 ab	168 ± 12 a	164 ± 19 a
South	133 ± 13 b	171 ± 11 a	168 ± 12 a
<u>April 1995</u>			
North	190 ± 18 a	176 ± 8 a	197 ± 9 a
East	179 ± 15 ab	166 ± 11 a	166 ± 27 b
West	173 ± 19 b	170 ± 10 a	174 ± 6 b
South	169 ± 21 b	174 ± 11 a	172 ± 14 b

Table 2. Snow depth (cm) at the different positions around the tree clusters

Measurement Point	Tree Island			Across ALL Islands
	DA	BH	BY	
	<u>February 1995</u>			
External (Meadow-side)	131 ± 8 a	180 ± 13 a	177 ± 13 a	163 ± 26 a
Transition (Meadow-Island)	110 ± -- a	152 ± 9 b	147 ± 17 ab	136 ± 26 a
Internal (Inside Island)	109 ± 24 a	79 ± 8 c	115 ± 2 b	99 ± 19 b
	<u>April 1995</u>			
External (Meadow-side)	172 ± 37 a	177 ± 4 a	188 ± 23 a	179 ± 21 a
Transition (Meadow-Island)	144 ± 38 a	144 ± 2 b	158 ± 33 a	149 ± 27 ab
Internal (Inside Island)	168 ± 8 a	70 ± 4 c	121 ± 23 a	120 ± 45 b

Table 3. Percent Weight Loss by Time Period and Location

Location	9 months Oct 95 - Jul 96	12 months Oct 95 - Oct 96	12' months Jul 96 - Jul 97	21 months Oct 95 - Jul 97
North Meadow Exposed	21.2% \pm 2.3 b	20.0% \pm 2.7 c	28.8% \pm 2.6 b	27.3% \pm 6.4 b
North Canopy	21.2% \pm 2.6 b	21.7% \pm 3.6 b	27.5% \pm 1.9 b	28.8% \pm 2.4 bc
Island Interior	24.0% \pm 5.0 a	23.6% \pm 2.0 a	29.9% \pm 2.2 a	30.0% \pm 3.5 b
South Canopy	21.7% \pm 2.5 b	22.5% \pm 2.2 ab	27.8% \pm 2.5 b	30.0% \pm 2.1 b
South Meadow Exposed	21.1% \pm 2.1 b	22.1% \pm 2.2 ab	27.3% \pm 5.1 b	33.3% \pm 7.6 a

(different letters indicate means that are significantly different within a given time period, Duncan Multiple Range Test $p=0.05$). No significant differences between 9 months and 12 months, significant differences between 12 months, 12' months and 21 months $p=0.05$).