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Factors Influencing Variation in Susceptibility of Prairie Plants to an
Early Summer Frost in East-Central Minnesota

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ABSTRACT

This study was conducted to determine the factors affecting susceptibility of prairie plants to an early summer frost at Cedar Creek Natural History Area, in east-central Minnesota. Data were collected in a previously established experimental field after temperatures fell to 1.3 °C on 20 June 1992, and to 0.3 °C on 21 June 1992. The degree of frost damage to prairie plants was recorded using a scale of frost damage based on visual criteria, and possible causes of variation in frost susceptibility were examined. The degree of frost damage was independent of plant type (grass or forb), life cycle (annual, perennial, or biennial), successional status (early or late), and species origin (native or introduced). No significant correlations were noted between plant height and mean frost damage but there was a significant negative correlation between plant height and maximum frost damage. In addition, there were no significant correlations between frost damage and mean plant biomass allocated to leaves, stems, and roots, mean biomass allocations above-ground and below-ground, and total biomass. However, plants that allocated a greater proportion of biomass to leaves were more severely damaged than plants which allocated less biomass to leaves. The ratio of leaves to total biomass appears to be critical in relation to frosting events because leaves have a high surface area to volume ratio, which allows more surface area to be exposed to cold air masses, thus increasing the freezing rate.

INTRODUCTION

The effects of frost damage on natural plant communities have received little study because of the unpredictability and complexity of naturally occurring frost events. Armesto and Pickett (1985) noted that it is difficult to conduct studies examining the effects of such disturbances on plants, because experiments of this nature lack controls and information on the habitat prior to disturbance. In addition, Armesto and Pickett (1985) also noted that it is difficult to assess the environmental intensity of disturbances in a manner useful for comparison between species, and that the long term effects of the disturbance need to be monitored in order to determine the impact of the event on the community. Due to these constraints, prior research on frost damage has been restricted to examining laboratory effects on plant growth and physiology (Levitt, 1972, 1978; Armesto and Pickett, 1985; Platt and Weis, 1985; Sakai and Larcher, 1987; Bollinger *et al.*, 1991).

In determining plant survival, temperature fluctuations are considered the most critical factor because temperature directly affects physiological activity needed for growth, reproduction and survival (Treshow, 1970; Sutcliffe, 1977). After a frost, plants experience decreased enzyme and metabolic activity which reduce growth rates (Treshow, 1970). Treshow (1970) also noted that if temperatures fall below a certain critical temperature, which is species specific, plant tissues can experience visible physical damage. This damage can range from minor chlorosis of leaves, due to blanching of green portions of leaves resulting from a breakdown in chlorophyll pigments, to severe necrosis of tissues, noted by white or dark brown regions on plant tissues due to increased tannin and resin levels (Treshow, 1970; Sakai and Larcher, 1987).

Understanding the effects and severity of frost damage has economic importance when agricultural crops experience damage from unseasonably late frosts, decreasing overall crop yield. Studying the damage caused by frost also has

evolutionary significance in better understanding mechanisms of plant succession, which are based, in part, on competition for resources. Competition is important in the ecology of natural populations because physical disturbances can alter habitat resources, allowing the stronger competitors to exploit a majority of the resources, which may cause fluctuations in the existing community structure (Etherington, 1975; Grime, 1979; Armesto and Pickett, 1985; Platt and Weis, 1985). Plants compete for resources such as light (Armesto and Pickett, 1985), nitrogen (Tilman, 1986; Inouye and Tilman, 1988), water during droughts (Bollinger *et al.*, 1991), and space (Wilson and Tilman, 1991a, b), but little research has focused on changes in plant community structure after frosting events. Thus, it is important to determine the characteristics of the plant species damaged by frost, which may allow future assessments of alterations in community structure.

In this study I examined the visible, physical damage caused by an early summer frost on prairie plant species at Cedar Creek Natural History Area, in east-central Minnesota. Physical and ecological plant characteristics were analyzed in order to determine which plant characteristics increased susceptibility to frost damage.

METHODS

This study was conducted at Cedar Creek Natural History Area, which is located on a glacial sand plain approximately 45 km north of Minneapolis, Minnesota (see Inouye *et al.* 1987 for description). In June, 1992, an unseasonably-late frost occurred in east-central Minnesota. According to the weather records for the Minneapolis area, which date back to 1891, there is no record of a frost occurring as late as 21 June (National Oceanic and Atmospheric Administration, 1992). A shielded thermistor placed 1.5 m above ground at Cedar Creek laboratory headquarters recorded minimum air temperatures of 1.3 °C on 20 June 1992, and

0.3 °C on 21 June 1992. The frost damaged a variety of native and introduced prairie plants in addition to local crops of corn (Zea mays) and soybeans (Glycine max).

The existing experimental design of the site required data collection in 50 test plots, each measuring 5 m x 5 m, with varying levels of fertilizer and disturbance. Plots were previously established in a field that had last been farmed for soybeans in 1957 (Wilson and Tilman, 1991b). Data were collected from plots with four different treatment schemes: (1) high nitrogen levels (51 g · m⁻² · yr⁻¹) and no disturbance, (2) high nitrogen levels and high disturbance (initial plot was tilled to a depth of 10 cm until 100% bare ground was exposed), (3) no nitrogen and no disturbance, and (4) no nitrogen and high disturbance. The following fertilizers were added to all plot treatments: P₂O₅, 20 g · m⁻² · yr⁻¹ as commercial 0-46-0 fertilizer; K₂O, 20 g · m⁻² · yr⁻¹ as commercial 0-0-61 fertilizer; CaCO₃, 40 g · m⁻² · yr⁻¹ as fine-ground commercial lime; MgSO₄, 30 g · m⁻² · yr⁻¹ as United States Pure Epsom Salts; CuSO₄, 18 ug · m⁻² · yr⁻¹; CoCO₂, 15.3 ug · m⁻² · yr⁻¹; MnCl₂, 322 ug · m⁻² · yr⁻¹; NaMoO₄, 15.1 ug · m⁻² · yr⁻¹ (Wilson and Tilman, 1991b).

The degree of frost damage was assessed for each prairie plant species (see Appendix) using a scale of damage based on the following visual criteria: 1- No visible damage to a species, 2- Slight damage (< 5 % of a species exhibited <20% leaf discoloration), 3- Moderate damage (5-50% of a species exhibited 20-50% leaf discoloration or wilting), 4- Severe damage (> 50% of a species exhibited >50% leaf discoloration or wilting), and 5- Complete damage (death to 100% of specimens within a species). The mean and maximum frost damage (i.e., the highest frost rating given to a species across all 50 plots) were calculated for each species and then compared among the following plant characteristics: (1) plant type (grass or forb), (2) life cycle (annual, perennial, or biennial), (3) successional status (early or late), (4) species origin (native or introduced), (5) mean height of mature plants, and

(6) biomass allocation (biomass allocated to leaves, stems, roots; total biomass; the proportion of biomass above-ground and below-ground; the proportion of biomass allocated to leaves). These parameters were defined based on Fernald (1950) and on previous data collected at Cedar Creek Natural History Area (McGinley and Tilman, unpubl. data; McGinley, Tilman, and Olf, unpubl. data). Plant type was separated into categories of grass or forb, with sedges included in the grass category, while legumes were categorized as forbs. Data on plant height were the average maximum heights of mature plant species at Cedar Creek Natural History Area during the summer, 1989 (McGinley, unpubl. data). Successional status of species was divided into early successional species (plants commonly found in fields from 1-15 yrs of age) and late successional species (plants found in fields of 16 or more years of age) (Inouye *et al.*, unpubl. data; McGinley, pers. comm.). Biomass allocation data was interpreted using data from Gleeson and Tilman (1990) for specimens previously collected from various locations within Cedar Creek Natural History Area.

Statistical analyses. — Analyses were conducted for all plant species found in 10% or more (5+ plots) of the 50 test plots. One-factor ANOVA were performed to assess the affects of frost with respect to plant characteristics (Zar, 1984). In addition, Spearman rank correlations were used to determine the relation between both plant height and biomass allocations to the degree of frost damage (Zar, 1984).

RESULTS

Plant species that exhibited significant differences in frost damage due to variable fertilizer and disturbance levels were excluded from analyses (analyses not shown; see Appendix for a complete listing of frost damage ratings for all species). The degree of frost damage was independent of plant type, life cycle, successional status, and species origin (Tables 1 and 2). Plant height was not correlated to the mean frost damage, but a significant negative correlation was noted for plant height

and the maximum frost damage (Table 3). The mean biomass allocated to leaves, stems, and roots, the biomass allocated to total biomass, and the above-ground and below-ground biomass were not correlated with the degree of frost damage (Table 3). However, plants which allocated a greater proportion of their total biomass to leaves were more severely damaged than plants which allocated less biomass to leaves (Figures 1 and 2).

DISCUSSION

Plant type. — Plant type is an important characteristic in considering frost damage within a community of coexisting grasses and forbs. Grasses tend to influence the large scale distributional pattern of forbs, confining forbs to spaces between dense grasses (Collins and Pinder, 1990). Such a phenomenon was observed at Cedar Creek Natural History Area. Prairie grasses are known for their extensive root systems (Weaver, 1954), which may crowd out forb roots, accounting for the dispersal of forbs between grass clumping. Sakai and Larcher (1987) found that dense vegetation traps heat, protecting surrounding plants from frost damage. Thus, when forbs occur between dense patches of grasses, they may also gain shelter from frost from the surrounding biomass and experience less frost damage. However, plant type was independent of the degree of frost damage, which suggests there was insufficient biomass around forbs to shelter from them the frost.

Both grasses and forbs are composed of approximately 80-90% water (Sutcliffe, 1979; Kramer, 1983). According to Levitt (1972), plants with higher concentrations of water are more likely to freeze and are more prone to damage than plants with lower water levels. Because grasses and forbs received similar degrees of frost damage, protection from frost may be determined by a more complex physiological mechanism than by just basic water concentrations. One such physiological mechanism is the process of plant cold hardening, noted by an increase in solute number in the cellular fluids of plants, especially of carbohydrates, fats and proteins,

which decreases the freezing point of the solution (Treshow, 1970; Levitt, 1972, 1980; Larcher, 1973; Sutcliffe, 1977; Sakai and Larcher, 1987; Alscher and Cumming, 1990;). These solutes act as an anti-freeze to protect against cellular freezing, while allowing grasses and forbs to maintain high water concentrations.

Life cycle. — Annuals are typically weedy, introduced, early successional species which are known to withstand fluctuations in temperature (Bazzaz, 1979). Likewise, perennials have developed mechanisms to protect against regional temperature fluctuations in order to survive (e.g., an increase in below-ground structures to protect against frost) (Sutcliffe, 1977). Bollinger *et al.* (1991) noted that annuals have greater resilience but less resistance to stress when compared to perennial-dominated plant communities. However, there was no significant difference between plant life cycle and the degree of frost damage, which suggests that the severity of plant frost damage may depend on the stage of vegetational development (i.e., growth or reproductive stages) in conjunction with various life cycles (Sakai and Larcher, 1987). In circumstances such as unseasonably late frosts, plants may have shifted their energy toward reproductive investments and away from frost protection techniques. The plants within this study were either in late growth stages or had already entered the reproductive stage and had begun to flower. Plants in rapid growth and reproduction phases are the most susceptible to physical disturbances, such as frost, and experience an increased likelihood of death (Larcher, 1973; Sutcliffe, 1977; Levitt, 1980; Willson, 1983). In this study, some plant species may have also delayed development until seasonal temperatures had increased, to avoid damage by early frosts, but leaving themselves vulnerable to unseasonable late frosts (Sakai and Larcher, 1987). Therefore, such an episodic frost may have harmed plants from all life cycles because they were not physically or physiologically prepared for unseasonably low temperatures.

Annuals only have one reproductive effort in their life time, so avoiding frost damage should be crucial in preserving reproductive investments. In contrast, damage by late frosts may not be as threatening to the lifetime reproductive investments of biennials and perennials, because if hit by a frost, biennials and perennials have two or more growing seasons to recover from damage (Grime, 1979). As a result, investment in frost prevention techniques may not be as critical for biennials and perennials as for annual species. Plant life cycles may also play a significant role in frost recovery because plants may lose a season for propagation by decreasing their allocations to reproduction in order to rebuild damaged structures (Sakai and Larcher, 1987). However, not all life history strategies can afford this decrease in reproductive output. In cases of severe nutrient stress, Willson (1983) noted that annuals allocated more energy to reproductive efforts, whereas perennials increased energy allocations toward growth while cutting back on reproductive structures. Grime (1979) noted that if biennials were disturbed during their second growth season, they shifted their energy away from growth and toward reproductive investments, a strategy similar to annual species.

Successional status. — Bazzaz (1979) suggested that early successional species should possess the ability to acclimate to a wide range of temperature variations. Peterson and Bazzaz (1978) also noted that early successional species contain a large percentage of fugitive annual species which are well adapted for disturbed, open environments, which would expose them to frost events. However, there was no significant difference in frost damage for early or late successional species. Although, it was noted that frost damage for early successional species ranged from no damage to death of 100% of plants within a species, whereas the maximum damage experienced by late successional species was only slight damage. This variability in the degree of frost damage for early successional species indicates that some early successional species were able to resist frost damage, whereas, others did

not possess such an ability. In contrast, late successional species did not experience any severe frost damage which suggests that any resulting frost damage to late successional species was only slight.

Species origin. — Introduced species are typically early successional plants that need to be resilient in order to out-compete native varieties (Bazzaz, 1979). Conversely, native species should be adapted to regional temperature fluctuations. However, species origin was not related to the degree of frost damage which may be due to the nature of the frost. During the summer, when temperatures are normally high, plants are increasingly susceptible to low temperatures due to seasonal changes in plant physiology which do not provide protection against such drastic changes in temperature (Levitt, 1972; Sutcliffe, 1977). Thus, both native and introduced plants may have not been physiologically prepared for such an unseasonably late frost.

Height. — Plant height is a critical characteristic in susceptibility to frost, because temperature depressions of 3-6 °C can occur at the tops of dense vegetation, and heat readily dissipates at these peripheral locations (Treshow, 1970; Larcher, 1973; Sakai and Larcher, 1987). In addition, taller plants shelter axial leaves and shorter plants from direct contact with cold air masses. As a result, taller plant species should experience increased heat dissipation and be more susceptible to frost damage. However, in this study plant height was not correlated to the mean frost damage, but was negatively correlated to maximum frost damage. Thus, shorter plants experienced more severe maximum levels of frost damage than did taller plants. Frost protection with respect to plant height is associated with the amount of horizontal distribution of vegetation of the taller plants, which provide a canopy effect to shelter shorter plants (Treshow, 1970; Sutcliffe, 1977; Sakai and Larcher, 1987). Thus, tall plants with an increased vertical distribution of biomass (e.g., grasses) may be less effective at trapping heat dissipated from the soil, which may

adversely affect shorter plants. Soil type may have also contributed to the increase in maximum frost damage experienced by shorter plants. Soils that are dry and sandy tend to cool faster because moisture is not trapped between the loose inorganic components of sandy soils (Treshow, 1970; Larcher, 1973; Searle, 1973; Sutcliffe, 1977; Sakai and Larcher, 1987). This study site was located on a sand plain which may have further depressed the air temperatures at ground level. Due to the increased rate of heat dissipation from the soil, and the possible lack of sheltering by plants with vertical distribution of vegetation, shorter plants may have experienced more severe frost damage than previously predicted.

Biomass allocation. — Treshow (1970) noted that all plant structures are susceptible to frost damage, but the extent of the damage depends on the duration and depth of penetration of the frost. In addition, objects with a large surface area to volume ratio freeze more readily than objects with a smaller surface area to volume ratio, because freezing rates are proportional to the number of molecules which are in contact with the cold air (Treshow, 1970; Sutcliffe, 1977; Sakai and Larcher, 1987). Frost did cause more damage to plants with a greater proportion of leaf biomass, yet the proportion of the plant above-ground was independent of frost damage, indicating that stems are not as susceptible to frosts as leaves. Levitt (1972) noted that cells with low water concentrations are more resistant to frost damage because fewer water molecules are present to crystalize and damage the tissues. Thus, stems may protect against frost damage by having lower levels of water or by utilizing rigid colenchyma and sclerenchyma tissues for added support in protecting against cellular damage. Soil and litter layers may protect below-ground biomass by insulating roots when cold temperatures do not persist long enough to freeze the soil (Sutcliffe, 1977; Sakai and Larcher, 1987). According to Sutcliffe (1977), perennial plants typically allocate more of their biomass to below-ground structures and therefore have a high inherent resistance to frost. However, this relationship was

not demonstrated in this study (see Life cycles). Root depth may also be an important factor in determining plant susceptibility to frost damage, although this characteristic was not measured.

The effects of frost damage on leaves is critical because most of the energy exchange for growth and reproduction occurs within leaf tissues (Sutcliffe, 1977). Leaves exhibit increased susceptibility to frost because the surface area to volume ratio increases at narrowing leaf tips and margins (Treshow, 1970; Larcher, 1973; Sakai and Larcher, 1987), and increased heat dissipation is most rapid on broad flat leaves (Treshow, 1970). The increased damage to plants with increased allocations of biomass to leaves supports the contention that plants with a larger surface area to volume ratio are more susceptible to freezing stresses than plants with a smaller surface area to volume ratio (Treshow, 1970; Sutcliffe, 1977; Sakai and Larcher, 1987).

Other factors affecting plant susceptibility to frost. — Due to the complex interactions between biotic and abiotic factors, it is difficult to accurately predict the severity of frost damage. In this study, the recorded air temperature may have been even lower at plant level in the field than recorded at the lab headquarters. Plants radiate heat during the night and thus, resulting surface temperatures may be 3-6 °C cooler than the surrounding air temperatures of approximately 0.0 °C when frosting events occur (Treshow, 1970; Searle, 1973; Etherington, 1975; Sakai and Larcher, 1987).

Many other physical and environmental factors may have also influenced the actual temperatures during the periods of frosts within this study. Cloud cover and wind velocity, both of which were not recorded in this study, are also important factors in determining the severity of a frost because increased cooling rates are observed on calm, clear nights (Treshow, 1970; Sakai and Larcher, 1987). The elevation of the study site may have also affected the degree of frost damage observed, because cold, dense air flows downhill and settles in the lowest point

where it causes more severe frost damage (Searle, 1973). The study site was sloped, therefore, the variation in frost damage may have been partly due to the cold air mass settling in a specific region of the field (elevation surveying data was not collected at the study site). Sakai and Larcher (1987) noted that plant height and vegetation density also affected cooling rates by trapping moisture and reducing conduction of cold air masses. Thus, to accurately determine the temperature and potential freezing stress on individual plants, the actual height of plants damaged by frost and the surrounding density of vegetation would have been useful to analyze.

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LITERATURE CITED

- ALSCHER, R. G. AND J. R. CUMMING. 1990. Stress responses in plants: adaptation and acclimation mechanisms. Wiley-Liss, New York. 407 p.
- ARMESTO, J. J. AND S. A. PICKETT. 1985. Experiments on disturbance in old-field plant communities: impact on species richness and abundance. Ecology, 66:230-240.
- BAZZAZ, F. A. 1979. The physiological ecology of plant succession. Annu. Rev. Ecol. Syst., 10:351-372.
- BOLLINGER, E. K., S. J. HARPER, AND G. W. BARRETT. 1991. Effects of seasonal drought on old-field plant communities. Am. Midl. Nat. 125:114-125.
- COLLINS, B. S. AND J. E. PINDER. 1990. Spatial and distribution of forbs and grasses in a South Carolina oldfield. J. Ecol., 78:66-76.
- ETHERINGTON, J. R. 1975. Environment and plant ecology. John Wiley and Sons, New York. 347 p.
- FERNALD, M. L. 1950. Gray's manual of botany. American Book Co., New York. 1632 p.
- GLEESON, S. K. AND D. TILMAN. 1990. Allocation and transient dynamics of succession on poor soils. Ecology, 71:1144-1155.
- GRIME, J. P. 1979 Plant strategies and vegetation processes. John Wiley and Sons, London. 222 p.
- INOUYE, R. S. AND D. TILMAN. 1988. Convergence and divergence of old-field plant communities along experimental nitrogen gradients. Ecology, 69:995-1004.
- , N. J. HUNTLY, D. TILMAN, J. R. TESTER, M. STILWELL, AND K. C. ZINNEL. 1987. Old-field succession on a Minnesota sand plain. Ecology, 68:12-26.
- KRAMER, P. J. 1983. Water regulations of plants. Academic Press, New York. 489 p.

- LARCHER, W. 1973. Physiological plant ecology. Springer-Verlag, New York. 252 p.
- LEVITT, J. 1972. Physiological ecology and responses of plants to environmental stress. Academic Press, New York. 697 p.
- . 1978. An overview of freezing injury and survival, and its interrelationships to other stresses. *In*: P. H. Li and A. Sakai (eds.). Plant cold hardiness and freezing stress: mechanisms and crop implications. Academic Press, New York. 415 p.
- . 1980. Responses of plants to environmental stresses: chilling, freezing, and high temperature stresses. Academic Press, New York. 497 p.
- NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION. 1992. Climatological data: Minnesota, vol. 98. Department of Commerce, Environmental Data Service, National Climatic Center.
- PETERSON, D. L. AND F. A. BAZZAZ. 1978. Life cycle characteristics of Aster pilosus in early successional habitats. *Ecology*, 59:1005-1013.
- PLATT, W. J. AND I. M. WEIS. 1985. An experimental study of competition among fugitive prairie plants. *Ecology*, 66:708-720.
- SAKAI, A. AND W. LARCHER. 1987. Frost survival of plants: responses and adaptation to freezing stress. Springer-Verlag, Germany. 321 p.
- SEARLE, S. A. 1973. Environment and plant life. Faber and Faber, London. 278 p.
- SUTCLIFFE, J. 1977. Plants and temperature. Edward Arnold Publishers Ltd., London. 57 p.
- . 1979. Plants and water, 2nd ed. Camelot Press Ltd., Great Britain. 122 p.
- TILMAN, D. 1986. Nitrogen-limited growth in plants from different successional stages. *Ecology*, 67:555-563.
- TRESHOW, M. 1970. Environment and plant response. McGraw-Hill, U.S.A. 421 p.
- WEAVER, J. E. 1954. North American prairie. Johnsen Publication Co., Nebraska. 348 p.

WILLSON, M. F. 1983. Plant reproductive ecology. John Wiley and Sons, U.S.A.
282 p.

WILSON, S. AND D. TILMAN. 1991a. Components of plant competition along an
experimental gradient of nitrogen availability. Ecology, 72:1050-1065.

———AND ———. 1991b. Interactive effects of fertilization and disturbance on
community structure and resource availability in an old-field plant
community. Oecologia, 88:61-71.

ZAR, J. H. 1984. Biostatistical analysis, 2nd ed. Prentice-Hall, Inc., New Jersey, 718 p.

TABLE 1. — Results of ANOVA tests for plant type, life cycle, successional status, and species origin with respect to mean frost damage for prairie plants at Cedar Creek Natural History Area in June, 1992.

<u>Characteristics</u>	<u>Mean Frost Damage</u>			
	$\bar{X} \pm SE$	df	F	p
<u>Plant Type</u>				
forb	1.36 \pm 0.11	1, 22	0.14	0.709
grass	1.46 \pm 0.32			
<u>Life Cycle</u>				
annual	1.71 \pm 0.27	2, 26	1.13	0.338
biennial	1.13 \pm 0.08			
perennial	1.38 \pm 0.16			
<u>Successional Status</u>				
early	1.51 \pm 0.20	1, 18	0.73	0.405
late	1.20 \pm 0.10			
<u>Species origin</u>				
native	1.39 \pm 0.18	1, 18	0.07	0.796
introduced	1.48 \pm 0.28			

TABLE 2. — Results of ANOVA tests for plant type, life cycle, successional status, and species origin with respect to maximum frost damage for prairie plants at Cedar Creek Natural History Area in June, 1992.

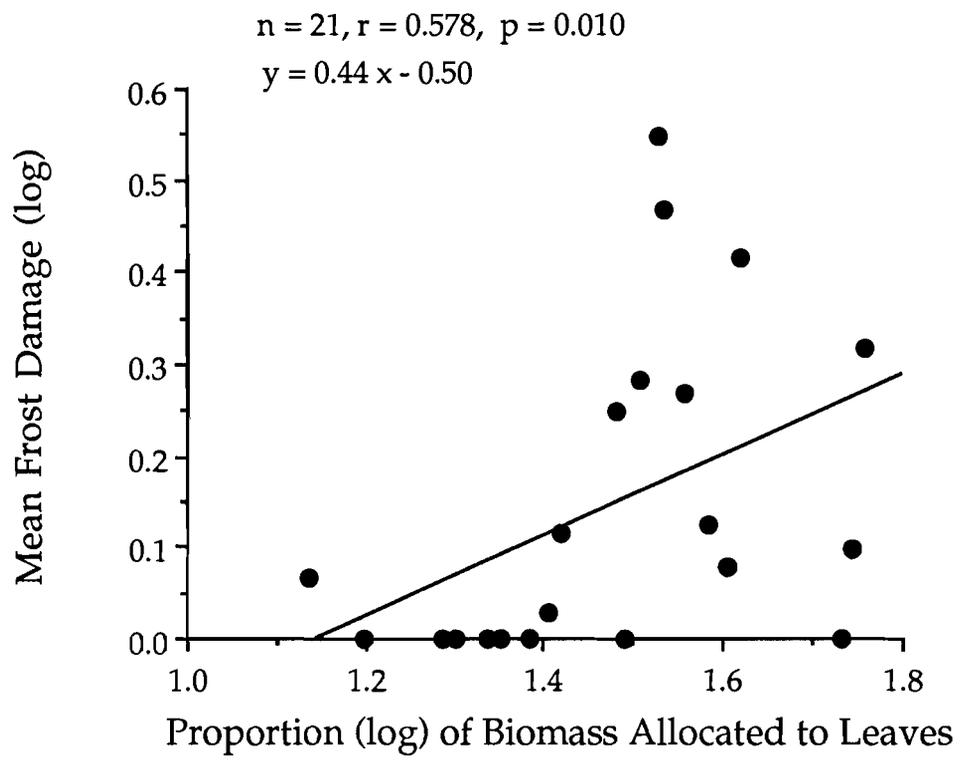
<u>Maximum Frost Damage</u>				
<u>Characteristics</u>	$\bar{X} \pm SE$	df	F	p
<hr/>				
<u>Plant Type</u>				
forb	2.06 \pm 0.25	1, 22	0.19	0.667
grass	1.83 \pm 0.48			
<u>Life Cycle</u>				
annual	2.57 \pm 0.48	2, 26	1.03	0.370
biennial	1.75 \pm 0.48			
perennial	1.89 \pm 0.27			
<u>Successional Status</u>				
early	2.20 \pm 0.34	1, 18	0.95	0.343
late	1.60 \pm 0.55			
<u>Species origin</u>				
native	2.00 \pm 0.44	1, 18	0.03	0.871
introduced	2.09 \pm 0.34			

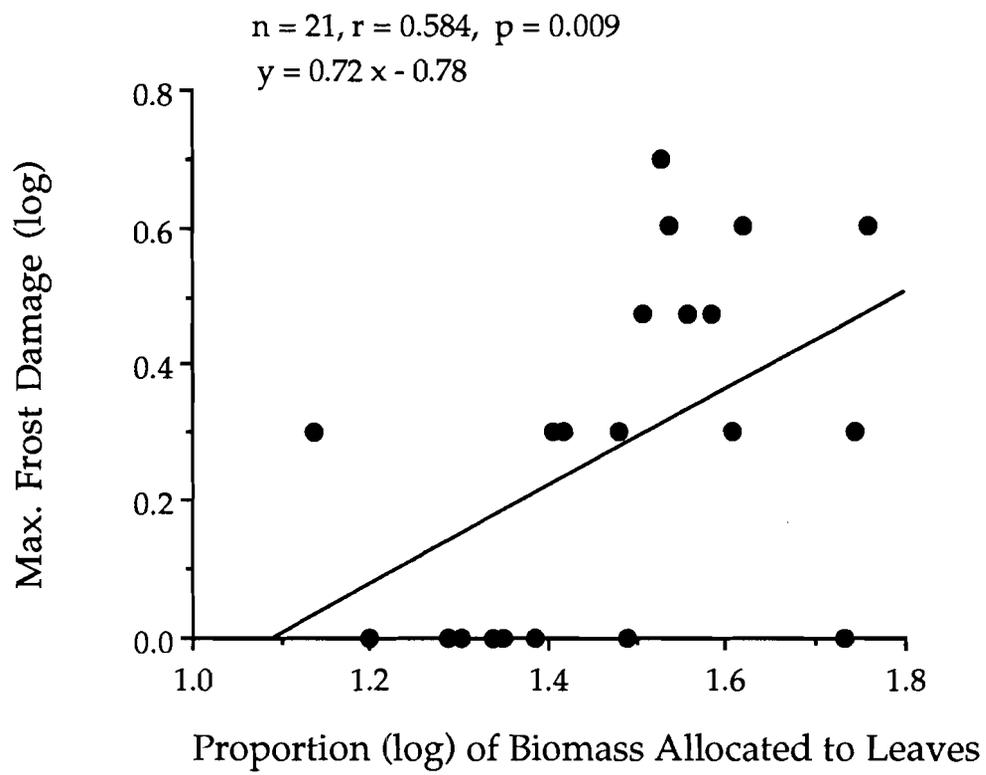
TABLE 3. -- Results from Spearman Rank Correlations for mean plant height and biomass allocations with respect to mean and maximum frost damage for prairie plant species at Cedar Creek Natural History Area in June, 1992.

	<u>Mean Frost Damage</u>			<u>Maximum Frost Damage</u>		
	<u>n</u>	<u>r_s</u>	<u>p</u>	<u>n</u>	<u>r_s</u>	<u>p</u>
<u>Group</u>						
<u>Mean plant height</u>	20	-0.424	0.065	20	-0.460	0.045
<u>Biomass allocation</u>						
<u>mean</u>						
leaf	21	0.081	0.718	21	0.096	0.669
stem	21	-0.121	0.589	21	-0.124	0.597
root	21	-0.222	0.400	21	-0.241	0.282
total	21	-0.114	0.519	21	-0.148	0.507
<u>proportion</u>						
above-ground	21	-0.140	0.533	21	-0.139	0.534
below-ground	21	-0.167	0.455	21	-0.178	0.425

FIGURE 1. — Regression analysis of the proportion of biomass allocated to leaves with respect to the mean frost damage for plant species at Cedar Creek Natural History Area in June, 1992.

FIGURE 2. — Regression analysis of the proportion of biomass allocated to leaves with respect to the maximum frost damage for plant species at Cedar Creek Natural History Area in June, 1992.





APPENDIX

Mean and maximum frost damage per plot for all plant species within an experimental site at Cedar Creek Natural History Area, (n = the number of plots in which a species was found).

<u>Species</u>	<u>n</u>	<u>Mean Frost</u>	<u>Max. Frost</u>
<u>Achillea millefolium</u>	19	1.37	2
<u>Agropyron repens</u>	6	1.00	1
<u>Ambrosia artemisiifolia</u>	16	1.00	1
<u>Andropogon gerardi</u>	5	1.00	1
<u>Anemone cylindrica</u>	5	1.20	2
<u>Antennaria neglecta</u>	5	1.00	1
<u>Arabis divaricarpa</u>	9	1.00	1
<u>Aristida basiramea</u>	1	1.00	1
<u>Asclepias syriaca</u>	10	2.60	4
<u>Asclepias tuberosa</u>	1	1.00	1
<u>Berteroa incana</u>	8	1.00	1
<u>Carex sp.</u>	7	1.00	1
<u>Chenopodium album</u>	34	1.85	3
<u>Crepis tectorum</u>	3	1.00	1
<u>Equisetum arvense</u>	1	1.00	1
<u>Equisetum laevigatum</u>	23	1.00	1
<u>Erigeron canadensis</u>	6	1.00	1
<u>Erigeron strigosus</u>	3	1.00	1

<u>Species</u>	<u>n</u>	<u>Mean Frost</u>	<u>Max. Frost</u>
<u>Fragraria virginiana</u>	1	1.00	1
<u>Hedeoma hispida</u>	13	1.92	3
<u>Hieracium longipilum</u>	10	1.30	2
<u>Lepidium densiflorum</u>	6	1.17	2
<u>Lespedeza capitata</u>	17	3.53	5
<u>Liatris aspera</u>	11	1.00	1
<u>Lithospermum caroliniense</u>	9	1.00	1
<u>Lychnis alba</u>	3	1.00	1
<u>Mollugo verticillata</u>	1	1.00	1
<u>Monarda fistulosa</u>	1	1.00	1
<u>Panicum oligosanthos</u>	17	1.77	2
<u>Panicum praecox</u>	1	1.00	1
<u>Physalis virginiana</u>	9	1.33	2
<u>Poa pratensis</u>	14	1.07	2
<u>Polygala polygama</u>	7	1.29	3
<u>Polygonum convolvulus</u>	41	2.07	4
<u>Potentilla recta</u>	5	1.20	2
<u>Prunus serotina</u>	5	1.25	2
<u>Rosa arkansana</u>	2	2.00	3
<u>Rudbeckia serotina</u>	1	1.00	1
<u>Rumex acetosella</u>	15	1.33	3

<u>Species</u>	<u>n</u>	<u>Mean Frost</u>	<u>Max. Frost</u>
<u>Schizachyrium scoparium</u>	24	1.00	1
<u>Setaria glauca</u>	26	2.92	4
<u>Silene antirrhina</u>	1	1.00	1
<u>Taraxicum officinalis</u>	1	2.00	2
<u>Taraxicum sp.</u>	1	2.00	2
<u>Tradescantia occidentalis</u>	4	1.25	2
<u>Trifolium sp.</u>	1	1.00	1
<u>Urtica dioica</u>	1	1.00	1
<u>Verbascum thapsus</u>	8	1.25	2