Research Reports

Effect of Artificial Substrate Depth on Freezing Injury of Six Herbaceous Perennials Grown in a Green Roof System

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SUMMARY. A green roof system was installed on an existing 35-year-old building. The purpose of the study was to evaluate the effect of three substrate depths on low-temperature injury of six herbaceous perennials: bugleweed (*Ajuga reptans*), sandwort (*Arenaria verna* 'Aurea'), sea pink (*Armeria maritima*), whitlow grass (*Draba aizoides*), creeping baby's breath (*Gypsophila repens*), and stonecrop (*Sedum xhybridum*). Plants in 4-inch (9-cm) pots were transplanted into three substrate depths: 2, 4, and 6 inches (5, 10, and 15 cm) and evaluated over a 3-year period. The analysis of the results showed that the species have different winter hardiness, therefore some species were subject to more freezing injury than others. Stonecrop had significantly more damage at 2-inch than 4- or 6-inch depths during the two winters. Bugleweed and creeping baby's breath showed more damage at 2 inches in 1996–97, not in 1995–96. Substrate temperatures were measured from Oct. 1995 to May 1997. Low temperature injury was more pronounced at 2 inch than at 4 or 6 inch depths. Minimum daily temperature and temperature variations measured in fall and spring of these 2 years were also higher at 4- and 6-inch depths.

Green roof systems are defined as a complex for growing plants that includes a variety of specific materials with particular functions. The components are layered in the following order: waterproofing, drainage material, filter, growing medium, vegetation and edge protection (Boivin and Challies, 1998). Green roof systems have been widely used in many European countries during the last 20 years for several environmental reasons: enhancement of air quality and urban climate, sound insulation, temperature regulation, creation of microclimates and as a way to create green spaces in densely populated cities (Peck et al, 1999). A limitation to the use of rooftop greening systems is the weight added to the dead load capacity of a building structure. Therefore, it is important to minimize the weight of each of these components while providing adequate growing conditions for plants.

Many container-grown herbaceous perennials require winter protection to survive low temperatures and wide temperature fluctuations (Iles et al., 1993; Perry, 1990). In northern latitudes (43 to 60 °N), survival of hardy perennials depends on their degree of hardiness, which protect them from freezing injury (Bigras, 1993; Kacperska-Palacs, 1978; Kacperska, 1985; Kacperska, 1989). 'Brilliant' stonecrop (*Sedum spectabile*) and 'Autumn Joy' stonecrop (*Sedum spectabile xtelephium*) were killed in January at –5.8 and –16.6 °F (–27 and –21 °C) respectively, while both cultivars were killed at 10.4 and 26.6 °F (–12 and –3 °C) in September before hardening was completed (Iles and Agnew, 1995). In another study (Levitt, 1980), sedge grass (*Carex firma*), winter heath (*Erica carnea*), saxifrage (*Saxifraga aizoon*) and hens and chickens (*Sempervivum glaucum*) plants were killed at 23 to 42.8 °F (–5 to 6 °C), 26.6 to 24.8 °F (–3 to –4 °C), 24.8 °F (–4 °C), 26.6 (–3 °C), respectively, when hardening was not completed; whereas plants were killed at –20.2 to –22 °F (–29 to –30 °C), –0.39 to –2.2 °F (–18 to –19 °C), –2.2 °F (–19 °C) and –13 °F (–25 °C) when hardening is fully reached. Cold acclimatization was also measured for many grass species (Gusta and Fowler, 1977; Hope and McElroy, 1990) and hardy shrubs (Havis, 1976; Imanishi et al., 1998; Steponkus et al., 1976). In October to November (fall) and April (spring), when snow protection is lacking, daily temperature variations can be more damaging to perennials than low temperatures. Temporary rise of temperatures can reverse the hardening process and cause freezing of perennial plants (Sasaki et al., 1998).

Environmental conditions on rooftops in Québec are often characterized by presence of high winds and lack of snow. Winter protection of the plants is not commonly used in green roof systems. The winter survival of the plants must then rely only on the growing substrate depth. Therefore, our objective was to evaluate the effect of three substrate depths on low-temperature injury of six herbaceous perennials.

Materials and methods

A green roof was installed in Nov. 1994 on the rooftop of a one story existing 35-year-old building, the Pavillon des Services (Université Laval,

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Fig 1. Sopranature green roofing system installed in November 1994 on a one story existing building at Université Laval, Québec. The 12 experimental plots on each side of the walkway form six experimental units. Each experimental unit consists of two plots of the same depth, 2, 4, or 6 inches (5, 10, or 15 cm), placed side by side.

Québec) (lat. 46°48'N, long. 71°23'W), with the Sopranature green roofing system (Soprema Canada, Québec) (Fig. 1). The underlayer waterproofing consisted of a elastomeric bitumen membrane, Sopralene Flam Jardin which contains a root repelling agent. Concrete curbs were then installed to surround the experimental plots. Perforated styrofoam drainage panels (Sopradrain) were placed on top of the waterproofing to direct excess water to roof top drains. A geotextile filter (Soprafiltre) was placed on top of drainage panels to prevent fine substrate particles from passing through and blocking drainage panel holes. A growing substrate (Sopraflor) was then placed on top of the geotextile filter. The growing substrate, a special mix for green roof culture, is composed of mineral aggregates (60%) and organic matter (40%).

Six herbaceous perennial species (USDA hardiness zone 4b) were used: bugleweed, 'Aurea' sandwort, sea pink, whitlow grass, creeping baby's breath and stonecrop. Plants in 4-inch pots were brought to the site in September 1994 and transplanted at the end of November 1994 into 3 × 5-ft (1 × 1.5-m) plots created by placing concrete blocks on rubber spacers. Each experimental unit consisted of two plots of the same depth, 2, 4, or 6 inches, placed side by side, with three rows of five plants of half of the six species planted 10 inches apart in each plot. Substrate temperatures were monitored at four locations in each treatment replicate at 1.5 ft (0.5 m) from the sides of the plot, with one thermocouple placed at the crown level of the plants and another at the root level at 2, 4, and 6 inches deep. Thermocouples connected to a AM416 multiplexer and a datalogger (CR10; Campbell Scientific, Logan, Utah) that recorded temperatures every 2 min. Minimum, maximum, mean temperature and daily variations were calculated four times per day.

A nonwoven polyester geotextile [0.04 inch (1 mm) thick], Soprafiltre, was placed over the plants from November 1994 to May 1995 for winter protection only the first year. The plants were watered manually four times during the summer dry periods of 1995 to 1997, twice in May, once in June and once in July.

Winter damage was evaluated on 31 May in 1996 and 1997. These damages can be described as follows: leaf browning or drying, partial or total death of the plant. Winter damage in 1995 was evaluated but not included since plants were protected by the geotextile covering. Winter damage severity was evaluated for each species and rated visually on a scale of 1 to 5 for winter damage severity: 1 = leaves 100% green (no damage); 2 = leaves 75% green (25% damage symptoms); 3 = leaves 50% green (50% damage symptoms); 4 = leaves 25% green (75% damage symptoms); 5 = leaves 0% green (100% damage symptoms, plant dead).

Statistical analysis of climatological data was carried out during the month of the year where the temperature was sufficiently low to damage the plants with no snow protection. Fall corresponds to October and November while spring corresponds to April.

Five plants of each species in each substrate depth were used per replicate, with four replicates by treatment in a randomized complete block design. The blocks were oriented east west. Replicated means were used for LSD 5% protected analysis of variance with SuperAnova program (Abacus Concepts, Berkeley, Calif.). The same analysis was used for temperature fluctuation variance (SAS System, SAS Institute Inc., Cary, N.C.).

Results and discussion

The analysis of the results showed that the species have different winter hardiness, therefore some species were subject to more freezing injuries than others (Table 1). Stonecrop had significantly more damage at 2-inch than 4- or 6-inch depths during the two winters. During Winter 1996–97 the damage to bugleweed and creeping baby's breath was greater at 2 inch than 4- or 6-inch depths; however, no differences were observed for these two species during 1995–96. Medium depth did not affect the amount of cold damage occurring on sandwort, sea pink, whitlow grass during either of the two winters.

During the last 47 years, the average minimum daily air temperatures in Quebec city were 29.3 °F (–1.5 °C), 35.6 °F (2.0 °C) and 24.6 °F (–4.1 °C) for the months of April, October, and November respectively (Environment Canada, 1993). In October and November 1995, minimum daily temperatures were significantly lower in 2-inch plots [31.3 °F (–0.4 °C)] than those measured at 4-inch [33.6 °F (0.9 °C)] and 6-inch [34.9 °F (1.6 °C)] depths. Daily temperature fluctuations also were significantly different at 2 inches [46.9 °F (8.3 °C)] than at 4 inches [42.6 °F (5.9 °C)] or 6 inches [40.5 °F (4.7 °C)] (Table 2). In April 1996, the minimum temperature measured in the root zone

Table 1. Influence of substrate depth on the winter damage severity of six perennials during Winter 1995–96 and 1996–97.

	1995–96			1996–97		
	Depth [inches (cm)]					
Species	2 (5)	4 (10)	6 (15)	2 (5)	4 (10)	6 (15)
Bugleweed	3.15 a[zy]	2.25 a	2.55 a	4.65 a	3.00 b	1.75 b
Sandwort	2.20 a	2.25 a	3.00 a	2.30 a	1.50 a	1.80 a
Sea pink	4.20 a	2.65 a	2.60 a	4.55 a	3.90 a	2.60 a
Whitlow heath	3.95 a	3.95 a	3.40 a	4.40 a	4.05 a	3.20 a
Creeping baby's breath	2.75 a	1.90 a	1.65 a	2.60 a	1.70 b	1.10 b
Stonecrop	4.00 a	1.60 b	1.65 b	4.00 a	1.60 b	1.60 b

[z] Winter damage severity expressed on a scale of 1 to 5 with 1 = leaves 100% green (no damage); 2 = leaves 75% green (25% damage symptoms); 3 = leaves 50% green (50% damage symptoms); 4 = leaves 25% green (75% damage symptoms); 5 = leaves 0% green (100% damage symptoms, plant dead).

[y] Mean of 20 plants of each species. Means within the same row, for the same year, with the same letter are not significantly different according to LSD protected test ($\alpha = 0.05$).

Table 2. Daily minimum temperature and temperature variation registered throughout the experimental period 1995–97.

Depth	Min temp °F (°C)		Temp variation °F (°C)[x]	
[inches (cm)]	Oct.–Nov. 1995[z]	Oct.–Nov. 1996[y]	Oct.–Nov.1995	Oct.–Nov. 1996
2 (5)	31.3 (–0.4) a[w]	21.4 (–5.9) a	46.9 (8.3) b[w]	40.1 (4.5) a
4 (10)	33.6 (0.9) b	24.3 (–4.3) b	42.6 (5.9) a	42.6 (5.9) a
6 (15)	34.9 (1.6) b	27.5 (–2.5) c	40.5 (4.7) a	45.1 (7.3) a
	Apr. 1996	Apr. 1997	Apr. 1996	Apr. 1997
2 (5)	31.3 (–0.4) a[w]	31.6 (–0.2) a	50.9 (10.5) a	43.5 (6.4) b
4 (10)	33.1 (0.6) b	32.4 (0.2) a	45.5 (7.5) a	40.3 (4.6) a
6 (15)	33.8 (1.0) b	32.9 (0.5) a	42.6 (5.9) a	38.7 (3.7) a

[z] 23 Oct. to 14 Nov. 1995 mean.

[y] 12 Oct. to 30 Nov. 1996 mean.

[x] Difference between daily maximum and minimum temperatures.

[w] Means of the same column, within the same year, with the same letter are not significantly different according to LSD protected test ($\alpha = 0.05$).

was still significantly lower at 2 inches [31.3 °F (–0.4 °C)], but above the freezing point at 4 inches [33.1 °F (0.6 °C)] and at 6 inches [33.8 °F (1.0 °C)].

During Fall 1996, there was a significant difference in daily minimal temperature in the three depths of soil (Table 2). Minimum temperature was as low as 21.4 °F (–5.9 °C) at 2 inches, 24.3 °F (–4.3 °C) at 4 inches and 27.5 °F (–2.5 °C) at 6 inches. Fluctuations between daily minimal and maximal temperatures were similar regardless of substrate depths. In Apr. 1997, roots of plants at 2 inches were exposed to significantly greater daily temperature fluctuations [43.5 °F (6.4 °C)] than plants at 4 inches [40.3 °F (4.6 °C)] or 6 inches [38.7 °F (3.7 °C)].

Minimal temperatures recorded at the 2-inch depth were significantly lower than those recorded at 4 or 6 inches during Winters 1995–96, 1996–97 and Spring 1996, which could have increased the incidence of damage. Dates of first frost when snow cover is absent as well as the duration of cold exposure could also have caused irreparable damage to outside grown plants (Perry and Herrick, 1996). Important temperature fluctuations which occurred at 2-inch depth could have reduced water availability thus reducing minerals and phytohormones transport necessary for basic metabolism, thus limiting their capacity to acclimate in the following fall (Ali et al., 1998; Wraith and Ferguson, 1994). Hardening of perennials plants is a reversible process when plants are exposed to warm temperatures even for a short period (Eagles and Williams, 1992; Gay and Eagles, 1991; Sasaki et al., 1998). Therefore, hardening of plants in 2-inch substrate was possibly reversed since they were subjected to several temperature fluctuations.

We therefore recommend using a minimum of 4 inches of substrate depth with the Green Roof technology which was used for this research work in northern latitudes.

Literature cited

Ali, I.A., U. Kafkafi, I. Yamaguchi, Y. Sugimoto, and S. Inanaga. 1998. Response of oilseed rape plant to low temperature and nitrate-ammonium ratios. J. Plant Nutr. 21(7):1463–1481.

Bigras, F. 1993. Pépinière. Culture en conteneurs: hivernage. Conseil des Productions végétales du Québec. Publication 02-9306.

Boivin, M-A. and G. Challies. 1998. Greening the roofscape. Canadian Architect (February)37–38.

Eagles, C.F. and J. Williams. 1992. Hardening and dehardening of *Lolium perenne* in response to fluctuating temperatures. Ann. Bot. 70(4):333–338.

Environment Canada. 1993. Canadian climate normals 1961–1990. Canadian Climate Program, Québec , Canada.

Gay, A.P. and C.F. Eagles. 1991. Quantitive analysis of cold hardening and dehardening in *Lolium*. Ann. Bot. 67(4):339–345.

Gusta, L.V. and D.B. Fowler. 1977. Factors affecting the cold survival of winter cereals. Can. J. Plant Sci. 57:213.

Havis, J.R. 1976. Root hardiness of woody ornamental. HortScience 11:385–386.

Hope, H.J. and A. McElroy. 1990. Low-temperature tolerance of swtichgrass (*Panicum virgatum* L.). Can. J. Plant. Sci. 70:1091–1096.

Iles, J.K. and N.H. Agnew. 1995. Seasonal cold-acclimation patterns of *Sedum spectabile xtelephium* L. 'Automn Joy' and *Sedum spectabile* Boreau. 'Brilliant'. HortScience 30(6):1221–1224.

Iles, J.K., N.H. Agnew, H.G. Taber, and N.E. Christians. 1993. Evaluation of structureless overwintering systems for container-grown herbaceous perennials. J. Environ. Hort. 11(2):48–55.

Imanishi, H.T., T. Suzuki, K. Masuda, and T. Harada. 1998. Accumulation of raffinose and stachyose in shoot apices of *Lonicera caerula* L. during cold acclimation. Sci. Hort. 72(3–4):255–263.

Kacperska-Palacs, A. 1978. Mechanism of cold acclimation in herbaceous plants, p. 139–152. In P.H. Li and A. Sakai (eds.). Plant cold hardiness and freezing stress: Mechanisms and crop implications. Academic Press, New York.

Kacperska, A. 1985. Biochemical and physiological aspects of frost hardening in herbaceous plants, p. 99–115. In A. Kaurin, O. Junttila, and J. Nilsen (eds.) Plant production in the north. Norwegian University Press, Oslo.

Kackperska, A. 1989. Mandabolic consequences of low temperature stress in chilling-insensitive plants, p. 27–40. In P.H. Li (ed.). Low temperature stress physiology in crops. CRC Press, Boca Raton, Fla.

Levitt, J., 1980. Responses of plants to environmental stresses. vol. 1. Chilling, freezing, and high temperature stresses. Academic Press, New York.

Peck, S., W. Callaghan, B. Bass, and M.E. Kuhn. 1999. Greenbacks from green roofs: Forging a new industry in Canada. External Res. Program Final Rpt. Can. Mortgage and Housing Corp., Toronto, Ontario.

Perry, L.P. 1990. Overwintering container-grown herbaceous perennials in northern regions. J. Environ. Hort. 8:135–138.

Perry, L.P. and T. Herrick. 1996. Freezing date and duration effects on regrowth of three species of container-grown herbaceous perennials. J. Environ. Hort. 14(4):214–216.

Sasaki, H., K. Ichimura, K. Okada, and M. Oda. 1998. Freezing tolerance and soluble sugar contents affected by water stress during cold-acclimation and de-acclimation in cabbage seedlings. Sci. Hort. 76(3–4):161–169.

Steponkus, P.L., G.L. Good, and S.C. Wiest. 1976. Root hardiness of woody plants. Amer. Nurseryman 144(10):16,76–78.

Wraith, J.M. and A.H. Ferguson. 1994. Soil temperature limitation to water use by field-grown winter wheat. Agron. J. 86(6):974–979.

Effect of Different Fruit-thinning Patterns on Crop Efficiency and Fruit Quality for Greenhouse-forced 'May Glo' Nectarine Trees

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SUMMARY. Fruit thinning is the most effective tool in regulating fruit growth potential for early-ripening peach and nectarine (*Prunus persica*) cultivars, and the common strategy is to space fruit 25 to 30 cm (9.8 to 11.8 inches) throughout the canopy, while scarce attention to the canopy environment in which the fruit develops. It is likely that different light environments within the canopy require different thinning patterns and to test this hypothesis, an experiment was set up to evaluate various fruit thinning patterns (fruit densities) in relation to fruit location within the canopy of early-ripening 'May Glo' nectarine trees trained to Y-shape. Differentiated fruit thinning resulted in higher yield efficiency due to a higher fruit number and average fruit weight. Differentiated thinning hastened fruit harvest and shortened the harvest period. Differentiated thinning reduced fruit variability within the tree in terms of size and soluble solids content, resulting in a higher crop value.

Early-ripening peaches and nectarines often produce fruit that are small, poorly colored and low in sugar content. The variability of fruit quality of peach is caused by different sources that may act independently (Genard and Bruchou, 1992). Plant effects include crop load (Corelli Grappadelli and Coston, 1991), fruit position within the canopy and on the shoot (Marini and Sowers, 1994), shoot type, competitive growth of vegetative and reproductive sinks (Inglese and De Salvador, 1996).

Crop distribution within the canopy plays a key role in determining the fruit growth potential and final size (Caruso et al., 1998; Sansavini et al., 1984), due to differences in canopy light environments and training system (De Salvador and DeJong, 1989, Erez and Flore, 1986, Marini et al., 1991, Sansavini et al., 1984).

Caruso et al. (1998) showed that in Y-shaped trees, the size and the color of 'Spring Lady' peach fruit decreased from the tree top to its base, and most of the crop (75%) came from the upper and midcanopy.

In early-ripening peach and nectarine cultivars, fruit thinning, together with summer pruning, is the most effective tool in regulating fruit growth potential. This is because the enhanced competition between vegetative and reproductive sinks, which occurs during the whole fruit development period (DeJong et al., 1987), strongly affects fruit growth (Caruso et al., 1999), particularly under greenhouse conditions (Caruso et al., 1993).

Fruit thinning in peach is necessary to set the crop load that allows the fruit to approach its growth potential (Grossman and DeJong, 1995). The common strategy is to space fruit along the bearing shoots (25 to 30 cm), while scarce attention is devoted to the canopy environment in which the fruit develops. Appropriate timing of thinning is also essential to enhance the effect of fruit thinning (Byers, 1989).

However, it is likely that different light environments within the canopy require different thinning patterns for fruit growth to be fully supported. For example, thinning may be different within the canopy to allow different fruit spacing in relation to the environment specific light microclimate. If this hypothesis is true, one could leave more fruit in the sun-exposed position of the canopy, increasing plant efficiency and

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