Influence of Moisture on Cold Hardiness of Six Container-Grown Herbaceous Perennials[1]

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Abstract

Overwintering container-grown plants is often necessary during production. Plants maintained in pots at growing medium moisture levels above ('wet') and below ('dry') 10% volumetric water content were exposed to –2, –5, –8, –11, and –14 C (28, 23, 18, 12, 7 F) in January, then returned to a greenhouse kept at 3 to 5 C (37 to 41 F). In June, plants were assessed using a visual rating scale (1 = dead, 3 to 5 = increasing quality) and shoot dry weight of new foliage growth. Quality rating and shoot dry weight of *Coreopsis* L. 'Tequila Sunrise' and *Carex morrowii* Boott. 'Ice Dance' were not affected by moisture level. Quality ratings were higher for *Geranium* × *cantabrigiense* L. 'Cambridge' 'wet' plants than for 'dry' plants and for *Heuchera* L. 'Plum Pudding' 'dry' plants than for 'wet' plants. Shoot dry weight was higher for 'dry' plants of *Carex laxiculmis* Schwein. 'Hobb' (Bunny Blue™) and *Carex oshimensis* L. 'Evergold' exposed to most temperatures. Of the cultivars studied, effects of moisture level on overwintering container-grown plant growth and quality are cultivar-specific and a universal effect could not be established.

Index words: nursery, production, cold stress, overwintering, freezing injury, irrigation, moisture, sedge, tickseed, cranesbill, coral bells, *Carex*, *Coreopsis*, *Geranium*, *Heuchera*.

Species used in this study: sedge (*Carex oshimensis* L. 'Evergold', *Carex morrowii* Boott. 'Ice Dance', *Carex laxiculmis* Schwein. 'Hobb' (Bunny Blue™)); tickseed (*Coreopsis* L. 'Tequila Sunrise'); cranesbill (*Geranium* × *cantabrigiense* L. 'Cambridge'); coral bells (*Heuchera* L. 'Plum Pudding').

Significance to the Horticulture Industry

Container production of herbaceous perennials continues to be popular within the nursery industry, and consumers have come to expect plants of certain size, quality and bloom. In northern climates, this may require multiple seasons of plant growth or vernalization events during which plants are subjected to freezing temperatures. Additionally, growers may wish to overwinter propagation stock, plants not sold within a season, or newly potted plants prepared for the following season. The conditions a plant has been grown under, including drought stress, may affect survival with freezing winter temperatures. Research relating soil moisture to cold hardiness and acclimation to cold temperatures has been extensive yet not always specific to herbaceous perennial container production. This study demonstrated growing medium moisture as a possible factor in container-grown herbaceous perennial survival and salable quality, depending on cultivar, following exposure to freezing temperatures. *Heuchera* L. 'Plum Pudding', *Carex laxiculmis* Schwein. 'Hobb' (Bunny Blue™), and *Carex oshimensis* L. 'Evergold' either produced more growth or rated higher in quality following exposure to freezing temperatures when grown under 'dry' conditions. *Geranium* × *cantabrigiense* L. 'Cambridge' rated higher in quality following exposure to freezing temperatures when grown under 'wet' conditions. Moisture level had no effect on *Coreopsis* L. 'Tequila Sunrise' and *Carex morrowii* Boott. 'Ice Dance'. This information will assist growers in planning container-grown plant irrigation practices and in deciding which container-grown plants are most likely to overwinter successfully, potentially reducing expenses required to protect container-grown plants from freezing temperatures.

Introduction

Potted herbaceous perennial plants and other bedding garden plants are the largest contributors to total value of sales and make up nearly half of the wholesale value of all floriculture crops (USDA 2014). Growing plants in containers allows growers to produce more plants in less space with more control over propagation, culture, and pests than traditional field production. Plants in containers are easier to handle and are more efficient to transport. Container-grown plants experience less root loss than field-harvested plants, which allows them to better survive and establish following transplanting. Irrigation is a requirement in production of container-grown plants, whereas it is supplemental in field production (Perry 1998, Diver and Greer 2008, Eaton and Appleton 2009).

Overwintering is typically the most limiting factor in production of container-grown plants for growers in northern climates (Pellett et al. 1985). Inevitably, all plants will not be sold within a single growing season, resulting in the necessity of disposing, field planting or overwintering container-grown stock. Additionally, many propagation methods require production periods longer than a single season prior to sale, again necessitating overwintering (Pilon 2006, Svendsen and Tanino 2006, Pyle 2009). Successful methods for overwintering container-grown plants are generally labor intensive and can be expensive (Taylor et al. 1983, Pilon 2006).

Maintaining adequate moisture in overwintering plants is necessary to prevent freeze-drying (Pilon 2006). Steps to maintain moisture in overwintering plants include irrigating thoroughly prior to storage under cover and regular monitoring and irrigating when plants are stored within an accessible structure (Smith 2004, Hulme 2010). Regular watering can alleviate plant injury from buildup of soluble

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salts in the growing medium due to water loss (Hulme 2010). Maximizing water content of a growing medium has been shown to regulate duration of temperature extremes of plants stored under cover during freezing periods (van de Werken 1987). Sufficient water content will provide a source of heat and thus slow freezing of the growing medium, although too much water can foster diseases (Smith 2004). Plant loss due to overly wet conditions is the leading reason for plant loss during overwintering (Pilon 2006). The effects of soil moisture levels in the period prior to freezing winter temperatures on survival has been extensively studied yet not always particularly for container production. However, it is a common concept that withholding water during acclimation can increase cold hardiness, provided thorough watering occurs prior to freezing conditions (Pilon 2006).

A reduction in available water can occur during both drought and freezing periods (Verslues et al. 2006). Certain physiological effects in plants during water drought closely resemble those that occur during cold acclimation of plants. These effects include an accumulation of abscisic acid, proteins, and carbohydrates (Pagter et al. 2008), decrease in tissue water content (Brule-Babel and Fowler 1989, Iles and Agnew 1995, Gusta et al. 2004), and reduced shoot growth (Herzog 1987, Arnott et al. 1993, Pagter et al. 2008). With the assumption that plants experiencing water drought have already acquired the factors necessary for freezing tolerance, attempts to relate drought stress to increases in cold hardiness have been widely researched.

Water deficit stress during the growing season has been shown to increase ability to survive exposure to freezing temperatures in Austrian winter pea (*Pisum sativum* subsp. *arvense* (L.) Poir.) (Kephart 1984) in the field, chicory (*Cichorium intybus* L. 'Grasslands Puna') and narrow-leaf plantain (*Plantago lanceolata* L. 'Ceres Tonic') in the field (Skinner and Gustine 2002), and narrow-leaf plantain (*Plantago lanceolata* L. 'Grasslands Lancelot') in a growth chamber (Skinner 2005). Water deficit stress did not affect freezing tolerance of European varieties of winter faba beans (*Vicia faba* L.) in a growth chamber at a constant temperature but improved freezing resistance when combined with a day/night temperature difference (Herzog 1987). Lower tissue water content has been shown to increase ability to survive exposure to freezing temperatures in field-grown strawberry (*Fragaria* × *ananassa* Duch. 'Earliglow') (Warmund and Ki 1992) and may have been a contributing factor in *Sedum spectabile* × *telephium* L. 'Autumn Joy' cold tolerance grown outdoors in containers (Iles and Agnew 1995). Conversely, water deficit stress during the growing season has not been shown to increase ability to survive exposure to freezing temperatures in chicory (*Cichorium intybus* L. 'Grasslands Puna') in a growth chamber (Skinner 2005).

An increase in available water during the growing season is less commonly studied than drought situations. However, plentiful water supports plant processes during the growing season and encourages development of strong root systems to better survive overwintering (Pilon 2006). Growing media with high water content do not immediately reach the lower temperatures during freezing periods that dry media do (van de Werken 1987, Smith 2004).

Alfalfa (*Medicago sativa* L.) has been shown to increase survival following exposure to freezing temperatures as field soil saturation increased (Van Ryswyk et al. 1993). In studies of container-grown herbaceous perennials *Coreopsis* L. 'Tequila Sunrise' and *Geranium* × *cantabrigiense* L. 'Cambridge' comparing growing medium moisture level stresses during the growing season followed by a freezing event, higher moisture levels resulted in larger plant size, although *Coreopsis verticillata* L. 'Moonbeam' in the same study did not show any effect on plant performance following a freezing event from growing medium moisture level stresses (Luchini and Perry 2004). Water saturation stress did not affect freezing tolerance of European varieties of winter faba beans (*Vicia faba* L.) in a growth chamber at a constant temperature but improved freezing resistance when combined with a day/night temperature difference. This same effect was also observed with water deficit stress as noted above (Herzog 1987).

The purpose of this study was to examine how continuous drought or saturation growing medium moisture levels during the entire growing season and acclimation period affected survival and salable quality following exposure to freezing temperatures for six herbaceous perennial cultivars grown in containers. *Coreopsis* L. 'Tequila Sunrise', *Geranium* × *cantabrigiense* L. 'Cambridge', *Heuchera* L. 'Plum Pudding', *Carex oshimensis* L. 'Evergold', *Carex morrowii* Boott. 'Ice Dance', and *Carex laxiculmis* Schwein. 'Hobb' (Bunny Blue™) were used in the study. These cultivars, with varying moisture requirements, are readily available and information on their culture will be of value to growers.

The genus *Coreopsis* perform best in well-drained soil in full sun (Armitage 2008). *Coreopsis* L. 'Tequila Sunrise' may reach a height of 41 cm (16 in). Hardiness is listed for U.S. Zones 6 to 9 (Anonymous 2010b), although the cultivar is known to lack vigor and be short-lived (Armitage 2008). Hardy perennial geraniums prefer full sun to partial shade and moist soil (Armitage 2008). *Geranium* × *cantabrigiense* L. 'Cambridge' is a low growing [up to 30 cm (11.8 in)] groundcover (Yeo 2002) with hardiness listed for U.S. Zones 5 to 9 (Hogan 2003), yet has proven hardy in Zone 4 field conditions in Vermont (Perry 2010). *Heuchera* L. 'Plum Pudding' (aka 'Plum Puddin') has a compact growth habit, up to 41 cm (16 in) in height (Anonymous 2010c), and prefers moist, well-drained soil in full to partial shade. Hardiness is listed for U.S. Zones 3 to 8 (Hill and Hill 2003), Zones 4 to 9 (Anonymous 2010b), or Zones 5 to 9 (Anonymous 2010a). *Carex oshimensis* L. 'Evergold' prefers good drainage in moist soils and can reach a height of 38 cm (15 in). Hardiness is listed for U.S. Zones 5 to 8 (Anonymous 2010a) or Zones 5 to 9 (Anonymous 2010b). *Carex morrowii* Boott. 'Ice Dance' is adaptable to many soil types and can be drought tolerant once established. Hardiness is listed for U.S. Zones 3 to 8 (Anonymous 2010a) or Zones 5 to 9 (Anonymous 2010b). *Carex laxiculmis* Schwein. 'Hobb' (Bunny Blue™) prefers moist soil in partial shade and can reach a height of 20 cm (8 in) (Darke 2007). Hardiness is listed for U.S. Zones 5 to 9 (Anonymous 2010a).

Materials and Methods

In the study, 60 plants were established for each cultivar. Plants were obtained as rooted cuttings in liners of 36 (166 ml (10 in^3)) to 72 (83 ml (5 in^3)) individual plants per flat depending on cultivar or as divisions of previously established potted plants (existing in American National Standards (ANS) container class #SP4 (900 ml (55 in^3)) or ANS #SP3 (400 ml (24 in^3)) plastic pots) (Anonymous 2014). All plants used in the study were potted in July into ANS #SP4 (900 ml (55 in^3) pots with ProMix BX growing medium (Premier Horticultural Products, Red Hill, PA) and allowed four weeks to establish prior to initiating treatments.

After the establishment period, plants were randomly divided into two treatments with half then grown under 'wet' and half under 'dry' conditions. Moisture level within the growing medium was monitored daily for volumetric water content (VWC) using a Field Scout TDR 100 soil moisture meter (Spectrum Technologies, Plainfield, IL). Plants designated as 'wet' were maintained above 10% VWC, and plants designated as 'dry' were maintained below 10% VWC. Seasonal average was 16.5% VWC for all 'wet' plants and 6.6% for all 'dry' plants. Moisture levels were maintained throughout the remainder of the growing season and acclimation period, stopping prior to controlled freezing events in January. The intent was to stress the plants without excessively affecting growth.

Plants were grown in a glass greenhouse at the University of Vermont, Burlington, VT. Temperatures in the greenhouse were maintained at 3 C (5 F) warmer than ambient outdoor temperatures by direct venting and radiant heat as needed. Water-soluble fertilizer was applied once per week throughout the growing season (Jack's Professional 17-4-17, J.R. Peters, Inc., Allentown, PA) delivered at 150 ppm nitrogen and Peters Professional S.T.E.M. soluble trace elements (The Scotts Company, Marysville, OH) delivered at 5 ppm boron, 12 ppm copper, 28 ppm iron, 30 ppm manganese, 0.15 ppm molybdenum, 52.5 ppm sulfur, and 16.9 ppm zinc. In October, when greenhouse temperatures were 16 ± 3 C (60 ± 5 F) during the day, temperatures in the greenhouse were reduced 3 C (5 F) per week until temperatures of 3 to 5 C (37 to 41 F) were reached at the end of November. This low temperature was maintained in the greenhouse until spring when the temperature was increased by the same increments beginning in April of each year until ambient temperature was reached.

During January, the 30 plants in each treatment were randomly divided into five, six-pot groups, pruned back to within 2.5 cm (1 in) above the level of the pot rim, and evenly watered. Controlled freezing of each six-pot group to –2, –5, –8, –11, and –14 C (28, 23, 18, 12, and 7 F) was performed as developed in previous studies (Luchini 2005). Plants were randomized by target freezing temperature and placed in heavy-weight open-mesh flats (56 by 28 cm (22 by 11 in)). Flats were loaded into the freezer alternately stacked with wooden supports to allow air flow around pots to achieve uniform temperature within the freezer. Plants with the lowest target freezing temperatures were loaded first, followed by the second-lowest, and so on until the highest target temperature plants were loaded on the top level within the freezer. Loading by target freezing temperature minimized the amount of time that the freezer was open while removing plants, in turn minimizing temperature fluctuations, during the course of the freezing event.

Temperature in the insulated chest freezer (Model VWC15-ZL/E, W.C. Wood Co., Guelph, Canada) was controlled using a Dyna-Sense Mk III Versa-Lab Microprocessor Temperature Controller (Scientific Instruments, Skokie, IL) and monitored separately using a digital thermocouple (Model HH611P4C, Omega Engineering, Stanford, CT) with a probe suspended within the freezer and a probe placed within a pot with the lowest target temperature. An 8 cm (3 in) cooling fan (Radio Shack, Fort Worth, TX) was placed on the floor of the freezer to circulate air within the freezer. A thermocouple-based temperature recorder with internal temperature sensor (TC4000, Madgetech, Contoocook, NH) was placed alongside the pots with the lowest target temperature to record temperatures during the course of the freezing event.

Freezer temperatures were held at –2 C (28 F) for 24 hours prior to loading plants then maintained at that temperature for 48 hours following loading of plants to achieve a uniform growing medium temperature among the plants. At that point, a six-pot group of each cultivar and treatment was removed from the freezer. The freezer air temperature was then set to –5 C (23 F), which was achieved within 30 minutes, and then held for 2 hours. It took 2 hours for the growing medium to reach the new temperature, and pots were kept at that temperature for 30 minutes. After this period, a six-pot group of each cultivar and treatment was removed. The freezer was then set to –8 C (18 F) and the process continued, with subsequent removal of pots at the –11 C (12 F) and –14 C (7 F) target temperatures. Following removal from the freezer, plants were returned to the 3 to 5 C (37 to 41 F) greenhouse where they were maintained through the return to ambient temperatures in spring as described above.

In June, plants were assessed for survival, growth and vigor. A visual rating scale of 1 to 5 was used with specific growth parameters defined for each cultivar. A quality rating of 3 or more was considered satisfactory for retail sale for most cultivars. Following the visual rating, plant regrowth from each pot was harvested to within 2.5 cm (1 in) above the level of the pot rim. Harvested growth was dried at 60 C (140 F) for one week prior to recording shoot dry weight with a digital electronic balance.

The data from each cultivar was analyzed separately to compare independent variable effects of growing medium moisture level and susceptibility to freezing temperatures. Quality rating and shoot dry weight were assessed separately for each cultivar using SAS 9.1 (Statistical Analysis System, Version 9.1, SAS Institute Inc., Cary, NC) for a 2 by 5 factorial, two-way analysis of variance (ANOVA) with Tukey's procedure used for mean separation when appropriate ($p = 0.05$). Where an interaction between growing medium moisture level and temperature occurred, the growing medium moisture level effect was analyzed separately for each target freezing temperature and each growing medium moisture level was analyzed separately for a temperature effect.

Results and Discussion

No interaction was observed between moisture level and temperature for either quality rating or shoot dry weight for *Coreopsis* L. 'Tequila Sunrise' and *Carex morrowii* Boott. 'Ice Dance' (data not shown). Growing medium moisture level had no effect on either quality rating or shoot dry weight for either cultivar. Extreme lack of overall vigor of the *Coreopsis* plants used in this study undoubtedly contributed decreased hardiness (all means were below salable quality) and the lack of moisture effects. In comparison to a study of *Coreopsis* showing a preference for 'wet' moisture level (Luchini and Perry 2004), further study is necessary to reach definitive conclusions on the effects of moisture level on this cultivar. *Carex morrowii* Boott. 'Ice Dance' plants above –11 C achieved minimal salable quality (rating ≥ 3) suggesting that it may be possible to reduce irrigation and still obtain satisfactory overwintering survival for this cultivar.

Table 1. Effect of growing medium moisture level and freezing temperatures on quality rating and dry weight of regrowth of container-grown *Geranium* × *cantabrigiense* L. 'Cambridge'.

	Quality rating[z]			Shoot dry weight (g)		
Temp C	Wet[y]	Dry	Mean[x]	Wet	Dry	Mean
–2	2.83	3.50	3.17a	0.66	0.48	0.57a
–5	3.83	3.17	3.50a	0.47	0.54	0.50a
–8	3.50	2.83	3.17a	0.56	0.47	0.51a
–11	3.50	2.83	3.17a	0.54	0.57	0.55a
–14	3.50	3.00	3.25a	0.51	0.63	0.57a
Mean[w]	3.43A	3.07B		0.55A	0.54A	

[z]Quality rating scale 1 = dead, no regrowth, 2 = no flowering stems and minimal regrowth, 3 = 0 to 2 flowering stems and regrowth extending over edge of pot, 4 = 3 to 5 flowering stems and regrowth equal to or greater than above, 5 = ≥ 6 flowering stems and regrowth as above.

[y]Plants designated as 'wet' were maintained above 10% volumetric water content and plants designated as 'dry' were maintained below 10% volumetric water content during the growing season.

[x]Temperature means with a different lowercase letter are significantly different according to Tukey's procedure (p = 0.05).

[w]Growing medium moisture level means with a different capital letter are significantly different according to Tukey's procedure (p = 0.05).

Table 2. Effect of growing medium moisture level and freezing temperatures on quality rating and dry weight of regrowth of container-grown *Heuchera* L. 'Plum Pudding'.

	Quality rating[z]			Shoot dry weight (g)		
Temp C	Wet[y]	Dry	Mean[x]	Wet	Dry	Mean
–2	2.67	3.00	2.83ab	5.53	5.75	5.64a
–5	2.67	4.67	3.67a	4.83	5.95	5.39a
–8	3.17	3.17	3.17ab	5.49	5.69	5.59a
–11	2.17	3.17	2.67ab	4.80	5.40	5.10ab
–14	2.33	2.67	2.50b	4.38	4.06	4.22b
Mean[w]	2.60B	3.33A		5.01A	5.37A	

[z]Quality rating scale 1 = foliage dieback evident and 0 to 1 flowering stems, 2 = foliage dieback minimal and 2 flowering stems, 3 = foliage healthy and 3 flowering stems, 4 = foliage healthy and 4 flowering stems, 5 = foliage healthy and ≥ 5 flowering stems.

[y]Plants designated as 'wet' were maintained above 10% volumetric water content and plants designated as 'dry' were maintained below 10% volumetric water content during the growing season.

[x]Temperature means with a different lowercase letter are significantly different according to Tukey's procedure (p = 0.05).

[w]Growing medium moisture level means with a different capital letter are significantly different according to Tukey's procedure (p = 0.05).

No interaction was observed between moisture level and temperature and no temperature effects were observed for either quality rating or shoot dry weight for *Geranium* × *cantabrigiense* L. 'Cambridge' (Table 1). Growing medium moisture level had no effect on shoot dry weight but quality ratings were significantly higher for 'wet' plants. Quality means averaged across moisture level and temperature for both moisture levels achieved at least minimal salable quality (rating ≥ 3) although means at some temperatures were slightly below minimal salable quality. This is consistent with a previous study, in which significant effect of moisture level on shoot dry weight favored 'wet' growing conditions with similar salable quality (Luchini and Perry 2004). From these two studies, 'wet' moisture level during the growing season appears beneficial to *Geranium* performance following exposure to freezing temperatures, although the modest impact on salable quality may not justify additional irrigation input. Furthermore, it may be possible to reduce irrigation and still obtain satisfactory overwintering survival.

No interaction was observed between moisture level and temperature for either quality rating or shoot dry weight for *Heuchera* L. 'Plum Pudding' (Table 2). Growing medium moisture level had no effect on shoot dry weight but quality ratings were significantly higher for 'dry' plants. Temperature effects were observed on quality rating (–14 C significantly lower than –5 C) and shoot dry weight (–14 C significantly lower than –2, –5, and –8 C). The quality rating scale did not include a rating for dead plants so a quality rating of 2 or more was considered of salable quality. Plants achieved salable quality (rating ≥ 2) after exposure to all freezing temperatures. The higher salable quality and higher shoot dry weights for 'dry' plants suggests that it may be possible to reduce irrigation of *Heuchera* and still obtain satisfactory overwintering survival.

Interaction was observed between moisture level and temperature within quality rating but no interaction was observed within shoot dry weight for *Carex oshimensis* L. 'Evergold' (Table 3). Growing medium moisture level had no effect on shoot dry weight but quality ratings were significantly higher for 'dry' plants only after exposure to the –8 C freezing temperature. Temperature effects were observed for quality rating and shoot dry weights (–14 and –11 C significantly lower than other temperatures, –8 C

Table 3. Effect of growing medium moisture level and freezing temperatures on quality rating and dry weight of regrowth of container-grown *Carex oshimensis* L. 'Evergold'.

	Quality rating[z]			Shoot dry weight (g)		
Temp C	Wet[yx]	Dry	Mean	Wet	Dry	Mean[w]
–2	4.00a	4.00b	4.00	3.24	2.85	3.04a
–5	4.00a	3.83b	3.92	2.32	2.95	2.63a
–8	4.00aB	5.00aA	4.50	2.14	2.69	2.42a
–11	2.00b	1.67c	1.83	0.89	0.52	0.71b
–14	1.17c	1.33c	1.25	0.06	0.27	0.16b
Mean	3.03	3.17		1.73A	1.86A	

[z]Quality rating scale 1 = dead, no regrowth, 2 = dieback evident and regrowth < 15 cm (6 in), 3 = minimal regrowth < 15 cm (6 in), 4 = vigorous regrowth ≥ 15 cm (6 in), 5 = vigorous regrowth ≥ 15 cm (6 in) and filling or extending over edge of pot.

[y]Plants designated as 'wet' were maintained above 10% volumetric water content and plants designated as 'dry' were maintained below 10% volumetric water content during the growing season.

[x]Where interaction occurred, temperature means within each growing medium moisture level with a different lowercase letter are significantly different and growing medium moisture level means within each individual temperature with a different capital letter are significantly different according to Tukey's procedure (p = 0.05).

[w]Where no interaction occurred, temperature means with a different lowercase letter are significantly different and growing medium moisture level means with a different capital letter are significantly different, both according to Tukey's procedure (p = 0.05).

significantly higher than all other temperatures only for 'dry' quality rating). Some individual plants at –11 C and all plants at higher temperatures achieved minimal salable quality (rating ≥ 3) with 'dry' plants having higher shoot dry weight after exposure to most temperatures. This suggests that it may be possible to reduce irrigation and still obtain satisfactory overwintering survival for this cultivar.

Interaction was observed between moisture level and temperature within quality rating but no interaction was observed within shoot dry weight for *Carex laxiculmis* Schwein. 'Hobb' (Bunny Blue™) (Table 4). Growing medium moisture level had an effect on shoot dry weight with means significantly higher for 'dry' plants but quality ratings were significantly higher for 'wet' plants only after exposure to the –8 C freezing temperature. Temperature effects were observed for quality rating and shoot dry weights (–14 and –11 C significantly lower than other temperatures, –8 C significantly higher than all other temperatures only for 'wet' quality rating). All plants above –11 C, achieved minimal salable quality (rating ≥ 3) with 'dry' plants having higher salable quality and shoot dry weight after exposure to most temperatures. Despite the quality rating at one temperature favoring 'wet' plants, the better performance seen for 'dry' plants after exposure to most temperatures suggests that it may be possible to reduce irrigation and still obtain satisfactory overwintering survival for this cultivar.

From the six container-grown herbaceous perennial cultivars studied, a consistent effect of growing medium moisture level after exposure to exposure to freezing temperatures could not be established. *Geranium* × *cantabrigiense* L. 'Cambridge' grown at a 'wet' moisture level rated higher, as seen in a previous study (Luchini and Perry 2004), whereas *Heuchera* L. 'Plum Pudding' grown at a 'dry' moisture level rated higher. *Carex laxiculmis* Schwein. 'Hobb' (Bunny Blue™) and *Carex oshimensis* L. 'Evergold' plants grown at a 'dry' moisture level had higher shoot dry weights after exposure to most temperatures. *Coreopsis* L. 'Tequila Sunrise' and *Carex morrowii* Boott. 'Ice Dance' showed no effect of growing medium moisture level, with all *Coreopsis* plants below salable quality.

Tailoring of irrigation regimes to improve overwintering survival of container-grown plants could be a valuable tool to growers, potentially saving some of the expense required to protect container-grown plants from freezing temperatures. A universal recommendation of plant irrigation practices for purposes of improving survival and salable quality following overwintering cannot be recommended based on this study. However, the impact of growing medium moisture level on practical salable quality suggests that it may be possible to reduce irrigation during the growing season and still obtain satisfactory overwintering survival of *Geranium*, *Heuchera*, and *Carex* cultivars.

Table 4. Effect of growing medium moisture level and freezing temperatures on quality rating and dry weight of regrowth of container-grown *Carex laxiculmis* Schwein. 'Hobb' (Bunny Blue™).

	Quality rating[z]			Shoot dry weight (g)		
Temp C	Wet[yx]	Dry	Mean	Wet	Dry	Mean[w]
–2	4.17b	4.50a	4.33	3.14	3.73	3.43a
–5	4.00b	4.00ab	4.00	2.51	3.20	2.86a
–8	5.00abA	3.50bB	4.25	2.19	2.32	2.25b
–11	1.50c	2.00c	1.75	0.10	0.34	0.22c
–14	1.17c	2.17c	1.67	0.10	0.57	0.33c
Mean	3.17	3.23		1.61B	2.03A	

[z]Quality rating scale 1 = dead, no regrowth, 2 = dieback evident and regrowth < 15 cm (6 in), 3 = minimal regrowth < 15 cm (6 in), 4 = vigorous regrowth < 15 cm (6 in), 5 = vigorous regrowth ≥ 15 cm (6 in).

[y]Plants designated as 'wet' were maintained above 10% volumetric water content and plants designated as 'dry' were maintained below 10% volumetric water content during the growing season.

[x]Where interaction occurred, temperature means within each growing medium moisture level with a different lowercase letter are significantly different and growing medium moisture level means within each individual temperature with a different capital letter are significantly different according to Tukey's procedure (p = 0.05).

[w]Where no interaction occurred, temperature means with a different lowercase letter are significantly different and growing medium moisture level means with a different capital letter are significantly different, both according to Tukey's procedure (p = 0.05).

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