Research Reports

Influence of Plant Age on Cold Hardiness of Three Container-Grown Herbaceous Perennials[1]

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Abstract

Overwintering container-grown perennial plants is often necessary during their production. Rooted vegetative cuttings potted at the beginning of the growing season and rooted vegetative cuttings potted at the beginning of the previous growing season, were exposed to –2, –5, –8, –11, and –14C (28, 23, 18, 12, 7F) in January then returned to a greenhouse kept at 3 to 5C (37 to 41F). In June, plants were assessed using a visual rating scale (1 = dead, 3–5 = increasing salable quality) and dry weight of foliage regrowth. For *Geranium* × *cantabrigiense* 'Karmina', studied for one year, age did not affect either rating or dry weight. For *Sedum* 'Matrona', studied for two years, age had no effect on dry weight but ratings were higher for two-year-old plants than one-year-old plants in the first year and higher for one-year-old plants than two-year-old plants in the second year. For *Leucanthemum* × *superbum* 'Becky', studied for two years, age affected both rating and dry weight, which were higher for one-year-old plants. Of the cultivars studied, overwintering one-year-old, container-grown plants resulted in more growth and higher quality than overwintered two-year-old plants.

Index words: nursery, production, cold stress, overwintering, freezing injury, root-bound, pot-bound, Shasta daisy, *Geranium*, *Sedum*, *Leucanthemum*, *Hylotelephium*.

Species used in this study: *Geranium* × *cantabrigiense* L. 'Karmina' (syn. 'Biokovo Karmina'); *Leucanthemum* × *superbum* L. 'Becky'; *Sedum* L. 'Matrona'.

Significance to the Nursery Industry

Container production of herbaceous perennials continues to be popular within the nursery industry, and consumers expect plants of certain size and quality. In northern climates, this may require multiple seasons of plant growth and 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. How long a plant has been established in a container, plant age, may affect survival of freezing winter temperatures. Research relating age of herbaceous perennials to cold hardiness is uncommon. This study demonstrated that plant age can influence the survival and quality of containerized herbaceous perennials that are exposed to freezing temperatures. For two of the three cultivars studied, plants that were one year old produced more growth and were rated higher in quality following exposure to freezing temperatures; age had no effect on the third cultivar. This information will assist growers in planning production schedules for containerized plants and in deciding which containerized plants are

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most likely to overwinter successfully, potentially reducing expenses required to protect containerized plants from freezing temperatures.

Introduction

Production of herbaceous perennial plants in containers continues to be popular within the nursery industry and accounts for the majority of ornamental plant production (8, 22, 23, 26). Herbaceous perennials and other bedding/garden plants make up over half of the value of sales for floriculture crops and is the highest valued category behind woody nursery stock of all nursery and greenhouse industries (34). 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 within the nursery, require less labor overall, and are more efficient to transport. Consumers generally prefer to purchase smaller, uniform, well-grown plants in containers that are easy to handle and transplant. Container-grown plants experience less root loss than field-harvested plants, and this allows them to better survive and establish following transplanting (8, 9, 22, 23).

Overwintering is typically the most limiting factor in production of container-grown plants for growers in northern climates (21). 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 cultivars and propagation methods require production periods longer than a single season prior to sale, again necessitating overwintering (26, 27, 32). A recent trend by consumers to grow herbaceous perennials as ornamental container plants, has led to an interest in overwintering through multiple years of growth (7). Successful methods for overwintering containerized plants are generally labor intensive and expensive (26, 33).

Plants in containers are exposed to colder air temperatures than they may experience when growing in the ground (22, 26), challenging the plants' natural survival mechanisms. Many cold-sensitive roots are found on the outer top and sides of a container where media temperature approaches this cold air temperature (21, 22, 26). These are often young roots that are first to be injured by cold temperatures (15). The smaller the container, the more rapidly media temperature will react to air temperature changes (32). It is generally accepted that an established plant with a well developed root system will better survive overwintering (26, 31) although age of the plant is not specified. The effects of plant age, how long a plant has been established in the same pot, on survival of freezing winter temperatures is relatively unstudied, particularly for herbaceous perennial container production.

Young plants and plant parts have shown certain biological traits that help them to withstand freezing temperatures. Young, uniform tissue will freeze more uniformly and is more flexible than mature, differentiated tissue that may have developed structural rigidity that could lead to mechanical injury from ice formation (20). Younger, smaller plants may have fewer nucleation sites where ice forms during freezing events since the frequency of these sites appears to increase with mass (4). Studies with cucumber showed that young plants produced antioxidants that prevented damage to protein and DNA during low temperature events (13). In alfalfa, older plants were 'consistently associated with markedly lower levels of expression of cold-regulated genes' (6).

Older plants may have an advantage of prior exposure to freezing events. Faults and anchorage points in cells, regions where tissue is arranged to accommodate formation of extracellular ice, may not develop until initial exposure to freezing temperatures (16). It is generally accepted that a well developed root system will better survive freezing temperatures (26, 31). A larger shoot-to-root ratio has not been shown to affect survival of freezing temperatures in studies of *Plantago lanceolata* (30). This would suggest that a mature plant with full root system that has been exposed to prior freezing events may overwinter at least as effectively as a younger plant with a less established root system.

Plant age can have positive or negative effects on survival following a freezing event. Seedlings of onion (35) and the woody plant *Phellodendron sachalinense* were less cold hardy than mature plants (17). On the other hand, seedlings of various legumes were more cold hardy when they were younger (18) as were younger alfalfa plants (6). Studies of container-grown herbaceous perennials generally found younger plants to be more marketable than established plants following freezing events although results varied by cultivar. Younger plants of *Tiarella*, *Dianthus* and *Geranium* 'Cambridge' rated better in salable quality following freezing, whereas older plants of *Geranium* 'St. Ola' fared better following freezing (5, 14).

The purpose of this study was to examine how the duration that a plant had been established in a container, plant age, affected survival and salable quality following exposure to freezing temperatures for three herbaceous perennial cultivars. The species and cultivars used in this study are different from those examined previously (5, 14).

Materials and Methods

Plants that had been in pots for two different lengths of time were studied. 'One-year' plants were obtained as rooted vegetative cuttings in liners of 36–72 individual plants per flat [56 × 28 cm (22 × 11in)] depending on cultivar and transferred into #SP3 [10 cm (4 in), 400 ml (24 in^3)] plastic pots at the beginning of the study growing season. 'Two-year' plants had been established from rooted vegetative cuttings in liners into #SP3 plastic pots for one prior growing season and were a year old at the beginning of the study. Two complete growing seasons in the same pot represents an extreme condition that may occur for various reasons. All plants were potted with ProMix BX medium (Premier Horticultural Products, Red Hill, PA).

The study was conducted over two years. In the first year, *Leucanthemum* × *superbum* 'Becky', *Sedum* 'Matrona', and *Geranium* × *cantabrigiense* 'Karmina' were used. In the second year, *Leucanthemum* × *superbum* 'Becky' and *Sedum* 'Matrona' were used. These recently introduced cultivars are readily available and information on their culture will be of value to growers.

Shasta daisies are vigorous and easy-to-grow perennial plants (11) that tend to be short lived, 2–3 years (3) but are easily propagated by division. The cultivar *Leucanthemum* × *superbum* 'Becky' has 8–10 cm (3–4 in) white flowers (11) on 91 cm (3 ft) stems that are desirable as cut flowers. The foliage is particularly tolerant of heat and humidity. Hardiness is listed for U.S. Zones 4–9 in one reference (1) and Zones 5–9 in another (2).

Sedum (syn. *Hylotelephium*) have distinctly fleshy leaves, are relatively easy to grow, and perform best in well-drained soil in full sun (3). *Sedum* 'Matrona' was formerly listed under the species *Sedum telephium* (28) and is now listed with no specific epithet (29). This robust and sturdy plant reaches heights of 61–91 cm (2–3 ft) with purple-red stems bearing pink flowers in autumn. Hardiness is listed for U.S. Zones 3–9 (1, 2).

Hardy perennial geraniums, also known as cranesbill, are native to temperate regions worldwide (36). They grow under a range of conditions but prefer full sun to partial shade and moist soil (3). The cultivar *Geranium* × *cantabrigiense* 'Karmina', (syn. 'Biokovo Karmina'), exhibits flowers of a red-raspberry color (3) with aromatic, seemingly glabrous, light-green foliage, forming a low growing [up to 30 cm (11.8 in)] groundcover (36). Hardiness is listed for U.S. Zones 4–8 (2) and Zones 5–7 (1). This cultivar has proven hardy in Zone 4 field conditions in Vermont (24).

In each year of the study, 30 plants per cultivar were established for each plant age group. Plants were allowed to establish over a normal growing season in a glass greenhouse at the University of Vermont, Burlington. Temperatures in the greenhouse were maintained at 3C (5F) warmer than ambient outdoor temperatures by direct venting and radiant heat as needed. Water soluble fertilizer was applied once weekly throughout the growing season: Jack's Professional 17-14-17 (J.R. Peters, Inc, Allentown, PA) delivered at 150 ppm nitrogen and Peters Professional S.T.E.M. soluble trace elements (The Scotts Company) 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 of each year, when greenhouse temperatures were 16 ± 3C (60 ± 5F) during the day, temperatures in the greenhouse were reduced 3C (5F) per week until temperatures of 3 to 5C (37 to 41F) 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 the month of January, the 30 plants in each age group 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 watered. Controlled freezing of each six-pot group to –2, –5, –8, –11, and –14C (28, 23, 18, 12, 7F) was performed as developed in previous studies (5, 10, 14, 19). Plants were randomized by target freezing temperature and placed in heavy-weight standard open-mesh flats ['1020', 56 × 28 cm (22 × 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 entire 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 thermometer (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. A 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 freezing event.

Freezer temperatures were held at –2C (28F) for 24 hours prior to loading plants then maintained at that temperature for 48 hours following loading of plants to achieve a uniform soil 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 –5C (23F), which was achieved within 30 minutes, and then held for 2 hours. During this time, the pot soil temperatures achieved target temperature 2 hours after the initial temperature setting and remained at the target temperature for 30 minutes. After this period, a six-pot group of each cultivar and treatment was removed. The freezer was then set to –8C (18F) and the process continued, with subsequent removal of pots, at –11C (12F) and –14C (7F) target temperatures. Following removal from the freezer, plants were returned to the 3 to 5C (37 to 41F) 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 1–5 was used with specific growth parameters defined for each cultivar (*Geranium*: 1 = Dead, no regrowth, 2 = No flowering stems and minimal regrowth, 3 = 0–2 flowering stems and regrowth extending over edge of pot, 4 = 3–5 flowering stems and regrowth equal to or greater than above, 5 = 6 or more flowering stems and regrowth as above; *Sedum*: 1 = Dead, no regrowth, 2 = Foliage regrowth of less than or equal to 15 cm (6 in), 3 = 1 flowering stem, regrowth over 15 cm (6 in), 4 = 2 flowering stems, regrowth over 15 cm (6 in), 5 = 3 or more flowering stems, regrowth over 15 cm (6 in); *Leucanthemum*: 1 = Dead, no regrowth, 2 = No flowering stems and minimal regrowth, 3 = 1 flowering stem and minimal regrowth, 4 = 0–1 flowering stems and vigorous regrowth, 5 = 2 or more flowering stems and vigorous regrowth). A rating of 3 or more was considered satisfactory for retail sale. Following 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 from each plant was placed in an individual paper bag and stored in a drying oven at 60C (140F) for one week before weighing to 0.01 g on an electronic balance for determination of dry weight. Salable quality, which takes into account attractive factors such as flowers, is more important than quantity of growth, as reflected in dry weight, to growers and consumers (25).

The data from each cultivar were analyzed for each year of the study to compare effects of plant age on susceptibility to freezing temperatures. Visual ratings and dry weights were assessed using SAS 9.1 for analysis of variance (ANOVA) and standard error of the mean (12). Tukey's procedure was used for mean separation when appropriate.

Results and Discussion

Neither age nor temperature had any effect on either quality rating or dry weight for *Geranium* × *cantabrigiense* 'Karmina' [data not shown (12)]. No interaction was observed between plant age and temperature for either rating or dry weight and all plants achieved at least minimal salable quality (rating of 3) following all freezing temperatures. Cultivars

Table 1. **Effect of plant age and freezing temperatures on salable quality rating and dry weight of regrowth of *Sedum* 'Matrona'.**

	Salable quality rating[z]					
	2005–2006			2006–2007		
Temp C	**One-year**	**Two-year**	**Mean**	**One-year**	**Two-year**	**Mean**
–2	2.5	2.8	2.7a[y]	3.5	2.7	3.1
–5	2.5	2.3	2.4a	4.0	3.2	3.6
–8	2.2	2.5	2.3a	4.0	2.7	3.3
–11	1.7	2.8	2.3a	4.0	2.0	3.0
–14	1.0	1.7	1.3b	4.2	1.8	3.0
Mean	2.0B[x]	2.4A		3.9A	2.5B	
	Dry weight (g)					
	2005–2006			**2006–2007**		
Temp C	**One-year**	**Two-year**	**Mean**	**One-year**	**Two-year**	**Mean**
–2	1.33	1.64	1.49a	3.75	3.30	3.53
–5	0.84	0.75	0.80ab	5.85	3.81	4.83
–8	1.07	0.87	0.97ab	3.68	2.03	2.85
–11	0.87	1.51	1.19a	2.14	4.34	3.24
–14	0.00	0.21	0.11b	2.79	2.30	2.54
Mean	0.82	0.20		3.64	3.15	

[z]Rating scale 1 = Dead, no regrowth, 2 = Foliage regrowth of less than or equal to 15 cm (6 in), 3 = 1 flowering stem, regrowth over 15 cm (6 in), 4 = 2 flowering stems, regrowth over 15 cm (6 in), 5 = 3 or more flowering stems, regrowth over 15 cm (6 in); A rating of 3 or more considered satisfactory for retail sale.

[y]Treatment temperature means with a lowercase letter in common are not different according to Tukey's procedure (p = 0.05).

[x]Where no interaction present between factors, plant age means with a capital letter in common are not different according to Tukey's procedure (p = 0.05).

of *Geranium* × *cantabrigiense* are known to be very hardy from previous studies (5, 14, 19).

Sedum 'Matrona' (Table 1) quality ratings were higher for two-year plants than one-year plants in the first year and higher for one-year plants than two-year plants in the second year. Powdery mildew across all study plants inhibited plant vigor but not salable quality parameters. In both years, however, age had no effect on dry weight. No interaction was observed between plant age and temperature for either rating or dry weight. Ratings included both mass and number of flowers which may explain how ratings showed differences between two-year and one-year plants when dry weight did not. The reversal of results between two-year and one-year plants in the two years is presumably due to plant loss following lower temperatures by one-year plants in the first year whereas ratings for two-year plants were consistent from year to year.

For *Sedum* 'Matrona' in the first year, temperature effects on rating (–14C lower than other temperatures) and dry weight were observed (–14C lower than –2 and –11C; –5 and –8C not different from any other temperature). No temperature effects were observed on either rating or dry weight in the second year.

The reason for the higher plant loss for *Sedum* 'Matrona' in the first year among one-year plants is uncertain, given that plants were established in the same manner both years and greenhouse temperatures did not vary significantly from one year to the next. This succulent species is not tolerant of wet soils (1) and can be sensitive to overwatering (3). Possible watering regimen differences by greenhouse staff may have affected establishment and acclimation from year to year and contributed to plant loss in the first year. Dry weights were higher in the second year for both one-year and two-year plants. This indication of more vigorous growth lends more credence to the rating results from the second year of the study.

While some individual *Sedum* 'Matrona' plants achieved at least minimal salable quality (rating of 3, disregarding disease presence) in the first year, means following each temperature for either plant age indicate that a majority of plants were below salable quality. No individual plants were of salable quality following –14C for either plant age in the first year. In the second year, all one-year plants following all freezing temperatures and all two-year plants following –5C achieved at least minimal salable quality. Means indicate that a majority of plants were below salable quality for two-year plants following all other freezing temperatures, although some individual two-year plants achieved at least minimal salable quality.

In the first year, *Leucanthemum* × *superbum* 'Becky' (Table 2) age had an effect on both quality rating and dry weight with better quality and more growth for one-year plants. No interaction was observed between plant age and temperature for either rating or dry weight. In the second year, there was interaction between plant age and temperature for both rating and dry weight. Age had an effect on rating in the second year following exposure to –2, –8, and –11C, for which means were higher for one-year plants. For –5 and –14C there was no significant difference between ages. Age also had an effect on dry weight in the second year with means higher for one-year plants following every temperature. The difference in rating following –2C is certainly due to an unusual lack of salable

Table 2. **Effect of plant age and freezing temperatures on salable quality rating and dry weight of regrowth of *Leucanthemum* 'Becky'.**

	Salable quality rating[z]					
	2005–2006			2006–2007		
Temp C	**One-year**	**Two-year**	**Mean**	**One-year**	**Two-year**	**Mean**
–2	3.0	2.5	2.8a[y]	4.3Aa	1.5Bc	2.9
–5	3.2	2.3	2.8a	3.8ab	3.7a	3.8
–8	2.5	1.7	2.1ab	3.7Ab	3.0Bb	3.3
–11	1.7	1.5	1.6bc	4.0Aab	3.0Bb	3.5
–14	1.0	1.3	1.2c	2.0c	1.7c	1.8
Mean	2.3A[x]	1.9B		3.6	2.6	

	Dry weight (g)					
	2005–2006			2006–2007		
Temp C	**One-year**	**Two-year**	**Mean**	**One-year**	**Two-year**	**Mean**
–2	1.61	0.75	1.18a	3.67Aa	0.62Bb	2.14
–5	1.50	0.78	1.14a	3.32Aa	1.36Ba	2.34
–8	0.87	0.24	0.56b	2.53Ab	1.01Bab	1.77
–11	0.29	0.09	0.19bc	3.10Aab	0.94Bab	2.02
–14	0.00	0.07	0.03c	1.23Ac	0.35Bb	0.79
Mean	0.86A	0.39B		2.77	0.86	

[z]Rating scale 1 = Dead, no regrowth, 2 = No flowering stems and minimal regrowth, 3 = 1 flowering stem and minimal regrowth, 4 = 0–1 flowering stems and vigorous regrowth, 5 = 2 or more flowering stems and vigorous regrowth; A rating of 3 or more considered satisfactory for retail sale.

[y]Treatment temperature means with a lowercase letter in common are not different according to Tukey's procedure (p = 0.05).

[x]Where no interaction present between factors, plant age means with a capital letter in common are not different according to Tukey's procedure (p = 0.05); Where interaction present between factors, means between plant age for a single treatment temperature with a capital letter in common are not different according to Tukey's procedure (p = 0.05).

quality in all two-year plants following this temperature. The mean ratings following –11C for both one-year and two-year plants are above salable quality and the difference is of no particular practical value. The overall tendency of age on both rating and dry weight was for means of one-year plants to be higher than that of two-year plants.

For *Leucanthemum* × *superbum* 'Becky' in the first year, temperature effects on rating (–14C lower than –2, –5, and –8C; –11C lower than –2 and –5C) and dry weight were observed (–14C lower than –2, –5, and –8C; –8 and –11C lower than –2 and –5C). In the second year for one-year plants, similar temperature effects on both rating and dry weight were observed (–14C lower than other temperatures; –8C lower than –2C; –8C also lower than –5C for dry weight). In the second year for two-year plants, temperature effects on rating (–14 and –2C lower than the other temperatures; –8 and –11C lower than –5C) and dry weight were observed (–2 and –14C lower than –5C). The low rating following –2C for two-year plants was again likely due to an unusual lack of salable quality in all plants following this temperature. Rating and dry weight for both years were observed to generally decrease with decreasing temperature.

In the first year, nearly all one-year *Leucanthemum* × *superbum* 'Becky' plants achieved at least minimal salable quality (rating of 3) following –2 and –5C. While some individual plants achieved at least minimal salable quality, means indicate that a majority of plants were below salable quality following –8C for one-year plants and following all freezing temperatures for two-year plants. No individual plants were of salable quality following –8C for two-year plants or following –11 or –14C for either plant age.

In the second year, all *Leucanthemum* × *superbum* 'Becky' plants achieved at least minimal salable quality following –2, –5, –8, and –11C for one-year plants and following –5 and –11C for two-year plants. Following –8C for two-year plants the mean indicated that a majority of plants achieved salable quality although some individual plants were below minimal salable quality. No individual plants were of salable quality following –2C for two-year plants or following –14C for either plant age. The poor performance of two-year plants following –2C is unusual and cannot be explained when one-year plants performed very well following the same temperature and other two-year plants also performed well following similar temperatures under the same experimental conditions.

From the three containerized herbaceous perennial cultivars studied, a consistent effect of plant age on survival and salable quality following exposure to freezing temperatures could not be established. In general however, when an effect was observed, one-year plants grew more and rated higher in quality following exposure to freezing temperatures. Only for *Sedum* did the two-year plants statistically rate higher than the one-year plants for one of the years, although in practice this difference was unremarkable as plants were largely below salable quality. The second year for *Sedum*, the first year for *Leucanthemum* and many of the second-year temperatures for *Leucanthemum* all rated higher for one-year plants. The generally better response of one-year plants suggests that overwintering plants beyond a single season in the same pot would not be an acceptable practice for maintaining salable plants. If plants are overwintered with the intent to divide and propagate in the spring, not to sell immediately, age would be less of a factor, although some losses would be expected with two-year plants. Cold hardiness of the cultivar likely plays a role as the very hardy *Geranium* (5, 14, 19) showed no effect of age whereas the other two less-hardy cultivars did show effects in this study.

Other factors related to the effects of age (root volume, condition of media, available nutrients, moisture content, level of vigor) may be of more concern than simply the chronological plant age. Dividing or repotting into larger containers to establish new growth before a second overwintering may be conducive to survival, although this will increase costs and the number and volume of plants that will require protection. A study relating the container size that plugs were potted into in mid-summer to overwintering success under insulating covers did not reach a consensus across all cultivars tested but did indicate that a larger container at least yielded a larger plant the following spring than plugs potted into and overwintered in smaller containers (32). The optimal timing of division or plug potting with the intent of successful overwintering should be performed early enough in the season to allow roots to establish. This will vary for individual species and cultivars and with local growing conditions. A study in Vermont during 2009–2010 clearly showed with *Leucanthemum* × *superbum* 'Becky' and *Achillea millefolium* 'Pink Grapefruit' that dividing late in the season did not allow for sufficient root growth and resulted in poor overwintering survival (25). The cost of labor to divide or repot will have to be considered if choosing this overwintering strategy.

Literature Cited

1. Anonymous. 2010. North Creek Nurseries Plant Catalog. Accessed March 16, 2010. http://www.northcreeknurseries.com/index.cfm/fuseaction/plants.main/index.htm.

2. Anonymous. 2010. Perennial Encyclopedia. Accessed March 16, 2010. http://www.perennialresource.com/encyclopedia/.

3. Armitage, A.M. 2008. Herbaceous Perennial Plants: A Treatise on their Identification, Culture, and Garden Attributes. Stipes Publishing, Champaign, IL.

4. Ashworth, E.N., G.A. Davis, and J.A. Anderson. 1985. Factors affecting ice nucleation in plant tissues. Plant Phys. 79:1033–1037.

5. Bruce, C.M. 2003. The effects of freezing and thawing conditions on cold hardiness of containerized herbaceous perennials. MS Thesis. Univ. Vermont, Burlington.

6. Castonguay, Y., P. Nadeau, and R. Michaud. 2002. Effect of plant age on cold acclimation and freezing tolerance of alfalfa. *In*: 38th North American Alfalfa Improvement Conf., ed. Sacramento, CA.

7. Dimke, K.C., S.K. Still, and D.S. Gardner. 2008. Effect of overwintering environment on the survival of 30 species of herbaceous perennials. J. Environ. Hort. 26:222–228.

8. Diver, S. and L. Greer. 2008. Sustainable Small-Scale Nursery Production. ATTRA — National Sustainable Agriculture Information Service.

9. Eaton, G.K. and B.L. Appleton. 2009. Getting Started in the Nursery Business — Nursery Production Options. Virginia Coop. Ext. Pub. 430-050.

10. Herrick, T.A. 1996. Influence of freezing methods and nitrogen nutrition on cold hardiness of containerized herbaceous perennials. MS Thesis. Univ. Vermont, Burlington.

11. Hill, L. and N. Hill. 2003. The Flower Gardener's Bible: Time-tested Techniques, Creative Designs, and Perfect Plants for Colorful Gardens. Storey Books, North Adams, MA.

12. Kingsley-Richards, S.L. 2011. Influence of plant age, soil moisture, and temperature cycling date on container-grown herbaceous perennials. MS Thesis. Univ. Vermont, Burlington.

13. Kuk, Y.I. and J.S. Shin. 2007. Mechanisms of low-temperature tolerance in cucumber leaves of various ages. J. Amer. Soc. Hort. Sci. 132:294–301.

14. Luchini, A.J. 2005. Effects of plant age and temperature fluctuations on cold hardiness of container-grown herbaceous perennials. MS Thesis. Univ. Vermont, Burlington.

15. Mathers, H.M. 2003. Summary of temperature stress issues in nursery containers and current methods of protection. HortTechnology 13:617–624.

16. McCully, M.E., M.J. Canny, and C.X. Huang. 2004. The management of extracellular ice by petioles of frost-resistant herbaceous plants. Ann. Bot. 94:665–674.

17. McNamara, S. and H. Pellett. 2000. Cold hardiness of *Phellodendron sachalinense* Friedr. Schmidt seedlings increases with age. HortScience 35:304–305.

18. Meyer, D.W. and M. Badaruddin. 2001. Frost tolerance of ten seedling legume species at four growth stages. Crop Sci. 41:1838–1842.

19. Meyer, G.A. 1999. Electrolyte leakage as a predictor of freezing tolerance and seasonal cold acclimation patterns in Aster 'Wood's Pink' and *Geranium* × *cantabrigiense* cultivars. MS Thesis. Univ. Vermont, Burlington.

20. Olien, C.R. 1964. Freezing processes in the crown of 'Hudson' barley (Hordeum vulgare L.). Crop Sci. 4:91–95.

21. Pellett, N.E., D. Dippre, and A. Hazelrigg. 1985. Coverings for overwintering container grown plants in northern regions. J. Environ. Hort. 3:4–7.

22. Perry, L.P. 1998. Herbaceous Perennial Production: A Guide from Propagation to Marketing. Northeast Regional Agricultural Engineering Service, Ithaca, NY.

23. Perry, L.P. 2006. Herbaceous Perennials — Container Overwintering and Hardiness. Accessed March 16, 2010. www.uvm.edu/pss/ppp/pubs/coh31hardy.pdf.

24. Perry, L.P. 2010. A–Z Database: Geranium. Accessed March 16, 2010. http://pss.uvm.edu/pss123/perger.html.

25. Perry, L.P. 2011. Pers. Comm.

26. Pilon, P. 2006. Perennial Solutions: A Grower's Guide to Perennial Production. Ball Publishing, Batavia, IL.

27. Pyle, A. 2009. Talking Shop: Perennial Potential. Greenhouse Grower.

28. RHS. 2006–2007. RHS Plant Finder. London, UK: Dorling Kindersley Ltd.

29. RHS. 2009–2010. RHS Plant Finder. London, UK: Dorling Kindersley Ltd.

30. Skinner, R.H. 2005. Cultivar and environmental effects on freezing tolerance of narrow-leaf plantain. Crop Sci. 45:2330–2336.

31. Smith, T.M. 2004. Overwintering Containerized Perennials. Accessed March 16, 2010. http://www.umass.edu/umext/floriculture/fact_sheets/specific_crops/overwint.html.

32. Svendsen, E. and K.K. Tanino. 2006. The effect of container size on overwintering survival and growth of herbaceous perennials. Can. J. Plant Sci. (Revue Canadienne de Phytotechnie) 86:817–820.

33. Taylor, R.D., H.H. Kneen, D.E. Hahn, and E.M. Smith. 1983. Costs of establishing and operating container nurseries differentiated by size of firm and species of plant in U.S.D.A. Climatic Zone Six. Southern Cooperative Series Bulletin 301.

34. USDA. 2007. Census of Agriculture. United States Department of Agriculture National Agricultural Statistics Service.

35. Warnock, D.F., W.M. Randle, and O.M. Lindstrom, Jr. 1993. Photoperiod, temperature, and plant age interact to affect short-day onion cold hardiness. HortScience 28:1092–1094.

36. Yeo, P. 2002. Hardy Geraniums. Timber Press, Portland, OR.