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Regrowth Performance of Field-grown Herbaceous Perennials following Bare-root Storage between –10 and +5C

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Abstract. **Field-grown plants of *Alcea rosea* (L.) Cav. (hollyhock), *Asparagus officinalis* L., *Coreopsis grandiflora* Hogg ex Sweet 'Sunray', *Dicentra spectabilis* (L.) Lem. (bleeding heart), *Gaillardia ×grandiflora* Van Houtte 'Baby Cole', *Lupinus polyphyllus* Lindl. 'Russell Hybrids', and *Phlox subulata* L. 'Emerald Pink' harvested as bare-root crowns in late fall were packaged in polyethylene-lined crates and stored for 6 months. There were no significant differences in the regrowth performance of any of the perennials following storage at 0 or –2C. The amount of surface covered by fungal hyphae (surface mold) increased more than 2-fold between 4 and 6 months of storage at 0 or –2C on all species. *Dicentra spectabilis* and *Alcea rosea* were most susceptible to mold growth during storage. *Alcea rosea* and *Coreopsis grandiflora* stored poorly at all storage temperatures. In a second experiment, the regrowth performance of *Artemisia schmidtiana* Maxim 'Silver Mound', *Asclepias tuberosa* L., *Aster novae-angliae* L., *Centranthus ruber* (L.) DC., *Chrysanth*emum *×superbum* Bergmans ex. J. Ingram, *Dicentra eximia* (Ker-Gawl.) Torr., *Dicentra spectabilis*, *Geum quellon* Sweet 'Mrs. Bradshaw', *Hosta* 'Honeybells', and *Lupinus polyphyllus* was tested following 6 months of storage at temperatures between –10 and +5C. Regrowth performance was generally similar at –2, 0, and 5C for most species. The results indicated, however, that *Centranthus ruber* and *Chrysanthemum ×superbum* should not be stored at temperatures of –2C or below. Sufficient etiolated growth developed for most species when stored at 2C or above to cause problems during shipping, handling, and potting. In general, mold growth on crowns during storage did not reduce regrowth performance of the species tested.**

The increase in popularity of herbaceous perennials has led to continued efforts to improve the efficiency of production and handling techniques. Although numerous herbaceous perennials are produced in containers, many are field-grown and harvested in the fall. Plants are usually trimmed and stored bare-root for up to several months until marketed in the winter or spring. Bare-root plants are commonly containerized after storage and regrown before retail sales.

Some commercial growers have had considerable success packing bare-root plants in polyethylene-lined crates and storing them at –2C, although certain species can be difficult to store (Walters, 1983). Although many factors could contribute to poor storage survival and regrowth, some growers have questioned whether –2C is necessarily the optimal storage temperature for all herbaceous perennials. Little has been published on the effect of storage temperature on regrowth performance of herbaceous ornamental perennials other than a review by Mahlstede and Fletcher (1960). They cited unpublished work conducted in 1953 by George Rose of the Henry Field Seed and Nursery who stored perennial species at three storage temperatures: –2.2 to –1.1C, 1.1 to 4.4C, and 10 to 18C. The results were variable; i.e., *Eupatorium coelestinum* (L.), *Convallaria majalis* (L.), and *Platycodon* spp. were successfully stored in sealed polyethylene bags held at all of the storage temperatures tested. However, *Coreopsis* spp., *Chrysanthemum ×superbum*, and *Stokesia* sp. were difficult to handle under any of the packaging and storage conditions. General recommendations for storage temperatures were given by Mahlstede and Fletcher (1960) and later summarized by Lutz and Hardenburg (1968) for some herbaceous perennials. Recommended temperature for storage of bare-root strawberry crowns, a herbaceous perennial, is generally –1.1C, although differences have been noted between years and cultivars (Anderson, 1982; Guttridge et al., 1965; Worthington and Scott, 1970).

Storage much above 0C can induce etiolated growth of plants during storage (Boontjes, 1982) or potentially increase the incidence of fungal growth (Hanchek et al., 1990). Certain fungi can grow on the crowns during storage, although this may not always be detrimental to the regrowth performance (Hanchek et al., 1990). To our knowledge, no one has tested herbaceous perennial storage at temperatures less than –2.

The following experiments were conducted to observe effects of postharvest storage temperatures on the regrowth performance of several bare-root herbaceous perennials.

Materials and Methods

Storage at 0 or –2C (Expt. 1). Plants of *Alcea rosea*, *Asparagus officinalis*, *Coreopsis grandiflora* 'Sunray', *Dicentra spectabilis*,

Table 1. Visual mold rating[z] on the surface of bare-root herbaceous perennials after 4 and 6 months of storage at –2 or 0C. The average percent increase in visual mold rating was calculated between 4 and 6 months of storage.

Perennial	Storage duration (months)	Storage temp (°C) –2	Storage temp (°C) 0	Avg increase from 4 to 6 months (%)
		Mold rating[z]		
Alcea rosea	4	1.4	1.3	
	6	3.0	2.5	104***
Asparagus officinalis	4	1.1	1.2	
	6	1.8	1.5	43*
Coreopsis grandiflora	4	2.0	1.7	
	6	4.1[y]	2.6	81***
Dicentra spectabilis	4	2.0	1.7	
	6	3.9	3.8	108***
Gaillardia grandiflora	4	1.3	1.5	
	6	2.1	2.4	61***
Lupinus polyphyllus	4	1.5	1.8	
	6	1.8[x]	2.6	33*
Phlox subulata	4	1.3	1.3	
	6	1.8	1.9	42*

[z]Mold rating scale from 1 = no to little observable mold growth to 5 = greater than 75% covered with fungal growth.
[y]4- and 6-month mold ratings significantly different at $P \leq 0.0001$
[x]4- and 6-month mold ratings significantly different at $P \leq 0.05$
*, ***Significant at $P \leq 0.01$ or 0.0001, respectively.

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Table 2. Average 3-week visual regrowth rating and percent survival of herbaceous perennials when grown following 6 months of storage at –2 or 0C. There was no significant effect of temperature on regrowth rating.

Perennial	Regrowth rating[z]	Survival (%)
Alcea rosea	1.6	53
Asparagus officinalis	2.8	100
Coreopsis grandiflora	1.0	37
Dicentra spectabilis	2.3	83
Gaillardia grandiflora	3.3	93
Lupinus polyphyllus	2.6	90
Phlox subulata	3.8	100

[z]Regrowth rating scale from 0 = no regrowth to 5 = excellent regrowth.

Gaillardia grandiflora 'Baby Cole', *Lupinus polyphyllus* 'Russell Hybrids', and *Phlox subulata* 'Emerald Pink' were hand-harvested on 18 Nov. 1983 at a commercial nursery (Walters Gardens, Zeeland, Mich.). *Alcea rosea*, *Asparagus officinalis*, *Coreopsis grandiflora*, and *Lupinus polyphyllus* were 1-year crowns grown from seed. *Dicentra spectabilis* and *Phlox subulata* were 1-year crowns and plants, respectively, grown from cuttings taken the previous spring. After harvest, plants were transported to East Lansing, and any remaining soil was removed from the roots and crowns by agitation. All shoots of *Alcea rosea*, *Asparagus officinalis*, *Dicentra spectabilis*, and *Lupinus polyphyllus* and green tops of *Coreopsis grandiflora* and *Gaillardia grandiflora* were removed to within 3 to 5 cm of the crown. Plants of *Phlox subulata* were not trimmed, as it is an evergreen ground cover. Five plants of each species were packed in 75-µm-thick low-density polyethylene bags and put into wooden celery crates (30 × 30 × 45 cm), with three crates (replications) per treatment. Plants were cooled at 2C for 24 h with the bags open. The tops of the polyethylene bags then were folded over but not sealed and the crates placed into controlled-temperature chambers at either 0 or –2C (both ±1C). Plants were removed from storage after 4 months and visually rated for the percentage of surface covered by mold: 5 = approximately >75%; 4 = approximately 50% to 75%; 3 = approximately 26% to 50%; 2 = approximately <25%; and 1 = none visible. No attempts were made to identify the fungal species that infected the crowns in these experiments. We have previously identified some of the organisms that may have been present (Hanchek et al., 1992). Plants were returned to their respective storage temperatures after mold rating.

Plants were again removed from storage after 6 months, similarly rated for mold development, planted in 540-ml clay pots (10 cm in diameter) in a 1 peat : 1 perlite (v/v) mix (Baccto, Michigan Peat Co., Houston), and grown in a greenhouse with set points at minimums of 20C days and 15C nights. The height of each plant was measured weekly, and regrowth performance was rated based on density of the foliage, vigor, and amount of new growth where 5 = excellent regrowth performance; 4 = very good; 3 = good; 2 = poor; 1 = very poor; and 0 = no observable growth. Height was not measured for *Phlox subulata*. Only regrowth performance data collected at 3 weeks are presented.

Storage at –10 to +5C (Expt. 2). On 8 Nov. 1984, plants of *Artemisia schmidtiana*, *Asclepias tuberosa*, *Aster novae-angliae*, *Centranthus ruber*, *Chrysanthemum ×superbum*, *Dicentra eximia*, *Dicentra spectabilis*, *Geum quellon*, *Hosta* 'Honeybells', and *Lupinus polyphyllus* were harvested and processed commercially by Walters Gardens. Plant material was cooled unpackaged for 24 h at 2C. Plants were weighed separately. The approximate starting water content of the crowns was close to 70% for all species tested (data not shown). Five plants of each species were packed in 75-µm, low-density polyethylene liners and placed into wooden celery crates (30 × 30 × 45 cm). The crates were then placed at –10, –5, –2, 2, or 5C (all chambers ±1C). There were two replications (crates) with five plants per replicate. Crowns were removed from storage and reweighed individually after 6 months. The presence or absence of etiolated growth was noted on a plant-by-plant basis, and the percentage of plants with etiolated growth of any length was calculated. The extent of mold growth and plant performance was measured as described for Expt. 1. The percent weight loss was calculated based on the difference in weight before and after storage. Regrowth performance was measured as described for Expt. 1, except data were only collected on week 3. Statistical analyses were conducted using SAS (SAS Institute, Cary, N.C.).

Results and Discussion

Storage at 0 or –2C. Surface mold increased significantly for all perennial species tested between the fourth and sixth months of storage in the first experiment, with an overall rating increase from 1.5 to 2.5 (Table 1). This is equivalent to ≈10% to 20% mold coverage after 4 months and ≈30% to 40% after 6 months. Molds covered 50% of *Dicentra spectabilis* and *Coreopsis grandiflora* crowns after 6 months.

A significant difference in the extent of mold growth between 0 and –2C was noted

Table 3. Visual mold rating[z], 3-week regrowth rating[y], and percent survival of herbaceous perennials when grown following 6 months of storage at different storage temperatures. $LSD_{0.05}$ was calculated from analysis of variance for each species.

Perennial and characteristic	Storage temp (°C) –10	–5	–2	+2	+5	$LSD_{0.05}$
Artemesia schmidtiana						
Mold	1.3	2.0	2.3	2.0	2.0	0.5
Regrowth	0	1.7	4.2	5.0	4.4	1.0
Percent survival	0	70	90	100	100	
Asclepias tuberosa						
Mold	1.0	4.9	2.9	2.4	2.7	0.9
Regrowth	0	0	1.7	1.9	1.6	1.0
Percent survival	0	0	70	80	70	
Aster novae-angliae						
Mold	1.0	3.4	3.0	3.3	4.1	0.9
Regrowth	0	2.5	4.5	4.6	4.9	0.9
Percent survival	0	90	100	100	100	
Centranthus ruber						
Mold	1.0	4.9	3.8	1.7	1.8	0.5
Regrowth	0	0	0	2.0	1.6	1.1
Percent survival	0	0	0	60	70	
Chrysanthemum ×superbum						
Mold	1.0	5	4	2.4	3.5	0.8
Regrowth	0	0	1.6	3.4	1.1	1.4
Percent survival	0	0	60	90	30	
Dicentra eximia						
Mold	1.0	3.6	1.6	2.4	2.2	0.5
Regrowth	0	2.6	5.0	4.9	4.9	0.5
Percent survival	0	100	100	100	100	
Dicentra spectabilis						
Mold	1.0	5.0	2.9	3.1	2.7	0.5
Regrowth	0	0	3.9	4.2	3.1	0.8
Percent survival	0	0	100	100	100	
Geum quellon						
Mold	1.0	3.7	3.2	2.3	2.6	0.6
Regrowth	0	0	3.4	4.0	2.2	0.6
Percent survival	0	0	90	80	60	
Hosta						
Mold	1.0	2.2	2.0	2.7	2.8	0.5
Regrowth	0	1.2	4.7	4.9	4.8	0.5
Percent survival	0	80	100	100	100	
Lupinus polyphyllus						
Mold	1.0	5.0	2.4	2.6	2.7	0.6
Regrowth	0	0	3.9	4.2	4.2	1.0
Percent survival	0	0	100	100	90	

[z]Mold rating scale from 1 = no to little observable mold to 5 = greater than 75% covered with surface mold growth.
[y]Regrowth rating scale from 0 = no regrowth to 5 = excellent regrowth.

only for *Coreopsis grandiflora* and *Lupinus polyphyllus* after 6 months of storage. *Coreopsis grandiflora* had more surface covered by fungi at –2C, whereas *Lupinus polyphyllus* had slightly less at 0C.

There were no significant differences in regrowth performance following 6 months of storage at either 0 or –2C for the herbaceous perennials tested. Regrowth rating and percent survival at 3 weeks differed only between species (Table 2). Following storage at either temperature, all plants of *Phlox subulata* and *Asparagus officinalis s*urvived reestablishment, whereas *Alcea rosea* and *Coreopsis grandiflora* suffered extensive dieback. In general, surface mold growth per se did not appear to reduce regrowth. No significant differences in plant height of the surviving plants were observed 3 weeks after establishment following 6 months of storage at either of the two temperatures (data not shown).

Storage at +5 to –10C. In the second experiment, little to no mold was observed on plants stored at –10C, but all herbaceous perennials tested were dead (Table 3). Most plants, except *Artemesia schmidtiana* and *Hosta*, were covered with surface mold following storage at –5C. *Artemesia schmidtiana*, *Aster novae-angliae, Dicentra eximia*, and *Hosta* were the only plants that survived storage at –5C, but they regrew poorly. The percent survival for all but *Dicentra eximia* (Table 3) was lower at –5C than at higher temperatures, and regrowth was impaired significantly. Most perennials stored at –5 and –10C were dead coming out of storage, but only those at –5C were fully covered with molds, which suggests that growth of the molds involved was limited only below –5C.

No significant differences in mold growth were seen between most of the plants when stored at –2, 2, or 5C (Table 3). Mold development was significantly more severe at –2 and 5C than at 2C on *Chrysanthemum ×superbum* and at –2C than at 2 or 5C on *Centranthus ruber*. In general, higher temperatures did not enhance mold development in storage.

Significantly less molds grew on *Lupinus polyphyllus* at –2C than at 0C in 1983–84 (Table 1), but there was no significant difference when stored at –2, 2, or 5C in 1984–85 (Table 3). Regrowth performance of plants was similar in this species in both years (Tables 2 and 3).

Table 4. Percentage of bare-root herbaceous perennials with etiolated shoots at the end of 6 months of storage as a function of storage temperature. No plants survived storage at –10C, and there were no etiolated shoots on any plants grown at –5 or –2C.

	Storage temp (°C)	
Perennial	+2	+5
Artemesia schmidtiana	50	50
Asclepias tuberosa	50	0
Aster novae-angliae	100	100
Centranthus ruber	100	100
Chrysanthemum ×superbum	100	100
Dicentra eximia	100	100
Dicentra spectabilis	100	50
Geum quellon	100	100
Hosta	20	30
Lupinus polyphyllus	100	100

Artemesia schmidtiana, Asclepias tuberosa, Aster novae-angliae, *Dicentra spectabilis*, *Dicentra eximia*, and *Hosta* all grew equally well following storage at 5, 2, or –2C, based on regrowth grade, percent survival (Table 3), and regrowth height (data not shown). However, *Chrysanthemum ×superbum* survived with acceptable quality only after storage at 2C (Table 3). *Centranthus ruber* performed poorly following storage at 2 or 5C and did not survive storage at –2C. This result suggests that these two species cannot tolerate freezing. Storage of *Centranthus ruber* and *Chrysanthemum ×superbum* crowns at 2C has improved regrowth performance compared to storage at –2C, according to one commercial grower (J. Walters, Walters Gardens, personal communication).

Low regrowth ratings for *Asclepias tuberosa* and *Centranthus ruber* may not always relate directly to poor quality because both species reestablish slowly, and our results are based on 3-week regrowth data.

Etiolated growth was common on plants following storage at 2 or 5C (Table 4). Etiolated growth was absent on plants stored at 0 or –2C in Expt. 1 or at –2C or below in Expt. 2. *Hosta* and *Asclepias tuberosa* sprouted the least during storage at above-freezing temperatures, followed by *Artemesia schmidtiana*. Only 50% of *Dicentra spectabilis* plants had etiolated shoots after 6 months at 5C compared to 100% at 2C. This difference might be related to differences in soil temperatures before harvest. Every other plant had etiolated shoots after storage at 5 or 2C (Table 4). The presence of etiolated shoots did not appear to reduce survival or regrowth performance in our studies when the plants were handled carefully. However, to avoid the possibility of injury during commercial handling and potting, it would be wise to keep storage temperatures at 0C or below to inhibit new growth once dormancy requirements have been satisfied during storage.

Cameron and Maqbool (1986) found a strong negative correlation between water loss during storage and subsequent regrowth quality. There was no significant effect of temperature on the amount of water lost during storage for any of the species tested in the current study (data not shown). Relatively little water (<3% by weight) was lost through the polyethylene liner during 6 months of storage (data not shown), which implies that the humidity was nearly 100% inside the liners.

Table 5. Recommendations for storage temperature by Mahlstede and Fletcher (1960) and revised recommendations based on the results from the current study.

Perennial	Mahlstede and Fletcher (1960)	Maqbool and Cameron (1994)
Alcea rosea	>0C	–2C[z]
Asclepias tuberosa	None	–2C[z]
Artemesia schmidtiana	Freeze[y]	–2C[x]
Asparagus officinalis	None	–2C[x]
Aster novae-angliae	Freeze	–2C[x]
Centranthus ruber	None	0C[z]
Chrysanthemum ×superbum	None	0C[z]
Coreopsis grandiflora	Freeze	–2C[z]
Dicentra eximia	None	–2C[x]
Dicentra spectabilis	>0C	–2C[x]
Gaillardia ×grandiflora	Freeze	–2C[z]
Geum quellon	Freeze[z]	–2C
Hosta 'Honeybells'	None	–2C[x]
Lupinus polyphyllus	>0C	–2C
Phlox subulata	Freeze	–2C[x]

[z]Can be difficult to store.
[y]Handle as containerized plant.
[x]Relatively easy to store.

Mahlstede and Fletcher (1960) recommended storage of *Alcea rosea*, *Dicentra spectabilis*, and *Lupinus polyphyllus* at above-freezing temperatures (Table 5). We found that *Alcea rosea* was difficult to store at all test temperatures. In our experience, *Dicentra spectabilis* and *Lupinus polyphyllus* can be stored successfully at –2C. For other species, our results generally supported the recommendations of Mahlstede and Fletcher (1960).

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