Unheated and Minimally Heated Winter Greenhouse Production of Specialty Cut Flowers

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ADDITIONAL INDEX WORDS. *Anemone*, *Antirrhinum*, snapdragon, *Consolida*, larkspur, *Delphinium*, *Helianthus*, sunflower, *Lupinus*, lupine, *Matthiola*, stock, *Viola*, pansy

SUMMARY. Anemone (*Anemone coronaria* L.), snapdragon (*Antirrhinum majus* L.), larkspur [*Consolida ambigua* (L.) P.W. Ball & Heyw.], delphinium (*Delphinium* ×*cultorum* Voss.), sunflower (*Helianthus annuus* L.), lupine (*Lupinus hartwegii* Lindl.), stock [*Matthiola incana* (L.) R. Br.], and pansy (*Viola* ×*wittrockiana* Gams.) were grown in raised sandy loam ground beds in double-layered polyethylene-covered greenhouses which were either unheated (ambient) or had a 55 °F (13 °C) minimum night temperature in year 1 and 36 or 50 °F (2 or 10 °C) minimum night temperature in year 2. Results were species specific; however, the extreme low temperatures [21 °F (–6 °C)] in the unheated house limited delphinium and lupine production. The warmest greenhouses (55 and 50 °F) reduced production time for anemone, delphinium, larkspur, lupine (year 2), snapdragon (year 2),

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stock, and sunflower. The coolest greenhouses (unheated and 36 °F) increased stem lengths for anemone (year 2), delphinium, larkspur (year 1), lupine (year 2), snapdragon, stock, and sunflower. The coolest greenhouses also yielded a profit or lower net loss for all species except delphinium, lupine, and snapdragon (year 2) for which profits were highest or net losses were lowest in the warmest greenhouses.

The peak outdoor specialty cut flower marketing season of September through May does not match the typical outdoor production season of May through September in the southern Great Plains (F. Arnosky, personal communication). Field producers could increase gross sales by expanding to a year-round growing season encompassing high sales holidays such as Valentine's Day, Easter, and Mother's Day.

Although the growing season could be extended using heated greenhouses, heating expenses can be prohibitive. However, unheated or minimally heated greenhouses could profitably provide season extension for specialty cut flower producers. Winter conditions in the southern Great Plains are typically favorable for low heating expenses due to high light intensity and warm day temperatures. During the day, the greenhouse soil is heated by the sun which helps maintain night air temperatures above outdoor night air temperatures.

A number of specialty cuts can be grown at cool temperatures. Anemone yields the highest number and quality of flowers when produced at 41 to 50 °F (5 to 10 °C) night and 57 to 65 °F (14 to 18 °C) day (Ohkawa, 1987). Armitage and Laushman (1990) reported that anemone tubers planted in November and December produced higher quality flowers than those planted in January and February due to cooler growing temperatures experienced during November and December planting versus January and February planting. Harvest duration from first to last harvestable flower also decreased for plantings made after November.

Delphinium is a perennial with a spike inflorescence; cool temperatures promote stem elongation (Dole and Wilkins, 1999b; Griffiths, 1995). Delphinium flowering is reduced at temperatures above 81 °F (27 °C) (Wang et al, 1997). Forcing temperature for flowering can be as low as 55 °F (13 °C) (Dole and Wilkins, 1999b; Nau, 1993b).

Cool temperatures are required for larkspur stem elongation. Six weeks at 36 °F (2 °C) has been reported to be most effective for flower initiation and development. It was also noted that larkspur stem elongation is reduced at 55 °F (13 °C) when given long days (Dole and Wilkins, 1999b).

No published information is available on the specific cultural requirements for *Lupinus hartwegii*. However, floral initiation and days to anthesis were reduced for blue lupine (*L. angustifolius* L.), rough-seeded lupine (*L. consentini* Guss.), and yellow lupine (*L. luteus* L.) when grown at 82 / 70 °F (28 / 21 °C) (day / night) compared to 70 / 57 °F (21 / 14 °C) (day / night) (Rahman and Gladstones, 1972).

'Oregon Giants' is a pansy cultivar with larger flowers and longer stems than cultivars used as bedding plants. High temperatures [77 °F (25 °C)] promote internode elongation and faster growth rates for pansies (Pearson et al., 1995). When pansies are produced at cool temperatures, a slow growth rate is achieved allowing a long duration for flower development, thus creating a large flower. Pansies should be grown at 39 to 55 °F (4 to 13 °C) to reduce internode elongation and ensure high quality flowers (Post, 1949).

Growth rates for snapdragon are highest when mature plants are grown at 55 to 61 °F (13 to 16 °C); media temperatures above 79 °F (26 °C) increase days to anthesis (Dole and Wilkins, 1999a; Wai and Newman, 1992). However, Miller (1962) noted snapdragon's growth rate is slower at

Table 1. Direct and indirect expenses of unheated and minimally heated greenhouse production of anemone, delphinium, larkspur, lupine, pansy, snapdragon, stock, and sunflower cut flowers.

Expense category	Year 1		Year 2	
	Minimum greenhouse temp[z]			
	Unheated	55 °F	36 °F	50 °F
	Direct expenses ($ / 9ft²)[y]			
Heating	0.00	5.44	2.91	4.36
Labor (manager)	7.50	7.50	7.50	7.50
Labor (production)	2.14	2.14	2.14	2.14
Labor (postharvest)	3.57	3.57	3.57	3.57
	Indirect expenses ($ / 9ft²)			
Fertilizer	0.24	0.24	0.22	0.22
Production supplies	3.98	3.98	3.98	3.98
Postharvest supplies	1.79	1.79	1.79	1.79
Water	0.21	0.21	0.16	0.16
Electricity	0.08	0.08	0.34	0.34
Property mortgage	2.63	2.63	2.45	2.45
Polyethylene glazing	0.49	0.49	0.46	0.46
Greenhouse	1.85	1.85	1.72	1.72
Miscellaneous[x]	1.89	1.89	1.76	1.76
Total	24.26	29.70	27.24	28.69

[z]36 °F = 2 °C, 50 °F = 10 °C, 55 °F = 13 °C.
[y]$1.00 / 9 ft² = $1.20 / m².
[x]Includes tractor, implements, vehicle, auto maintenance, and transportation expenses.

50 °F (10 °C) than at 77 °F (25 °C).

A great diversity in flower response occurs among stock cultivars. High temperatures [61 °F (16 °C) or higher] delay flowering in most cultivars (Cockshull, 1985). Heide (1963) reported that stem elongation was greatest and visible bud was reached in fewest days when plants were grown with long days (9 h or longer) at 54 to 61 °F (12 to 16 °C).

High growth rates for sunflower are achieved when grown at 65 to 75 °F (18 to 24 °C) and growth rates are reduced at lower temperatures (Armitage, 1993; Schuster, 1985). Under proper growing conditions, sunflowers can reach anthesis in as few as 8 weeks after sowing seeds (R. Sterkel, personal communication).

The objective of this study was to determine if anemone, delphinium, larkspur, lupine, pansy, snapdragon, stock, and sunflower could be economically grown in unheated, minimally heated, or heated greenhouses to produce high quality cut flowers during winter months.

Materials and methods

Delphinium 'Casa Blanca', larkspur 'Giant Imperial Mix', lupine 'Bright Gems', pansy 'Oregon Giant', snapdragon 'Animation Mix', and stock 'Cheerful White' seeds were sown in seed flats [29 inches^3 (475 cm^3) / cell] containing a peat-lite commercial medium (Redi Earth, Scotts-Sierra Horticultural Products Company, Marysville, Ohio). At the appearance of the first true leaves, plants were transplanted into bedding plant flats [3 inches^3 (49 cm^3) / cell] using a commercial peat-based root substrate (BM1, Berger Peat Moss, Saint-Modeste, Quebec). After establishment in flats, plants were transplanted into raised sandy loam ground beds in double-layered polyethylene-covered greenhouses. Anemone tubers were kept at 41 ± 1 °F (5 ± 0.6 °C) for 30 d, until the other species were planted, to provide the floral initiation and development cold treatment (Ohkawa, 1987). Tubers were planted 6 inches (15 cm) from the soil surface to the bottom of the tuber. Larkspur, lupine, pansy, and snapdragon plants were spaced at 3 × 6 inches (8 × 15 cm) and anemone, delphinium, and stock plants at 6 × 6 inches. In year 2, delphinium and pansy were eliminated from the study due to low consumer demand and sunflower, spaced at 6 × 12 inches (15 × 30 cm), was added.

Data collected included number of stems harvested, harvest date, stem length, flower sales price, and direct and indirect expenses (Table 1). Stems possessing high retail market qualities (sufficient stem length, diameter, flower size, and color) were harvested and sold direct to retail florists. Profit or loss was calculated as sales price minus direct and indirect expenses (Table 1). Results were expressed in profit or loss per sample area, about 9 ft^2 (0.84 m^2) per species sample. Other data collected included daily air and soil temperatures. The design was a modified split plot. The greenhouses were the main plots and there were four samples of 72 plants / sample for larkspur, lupines, pansy and snapdragon; 36 plants / sample for anemone, delphinium, and stock; and 18 plants / sample for sunflower. Data were analyzed by general linear model procedure (SAS Institute, Cary, N.C.).

In year 1, plants were grown in two greenhouses: 1) unheated (ambient) with average daily high / low temperatures of 84 / 48 °F (29 / 9 °C) and average soil temperature of 59 °F (15 °C); 2) heated with a minimum night temperature of 55 °F (13 °C), average daily high / low temperatures of 84 / 59 °F (29 / 15 °C) and average soil temperature of 63 °F (17 °C) (Fig. 1).

In year 2, greenhouses were set at minimal night temperatures of either 36 or 50 °C (2 or 10 °C). The 36 °F greenhouse average daily high / low temperatures were 73 / 46 °F (23 / 8 °C) with an average soil temperature of 57 °F (14 °C). The average daily high / low temperatures for the 50 °F greenhouse were 77 / 54 °F (25 / 12 °C) with an average soil temperature of 59 °F (15 °C) (Fig. 2).

Results

Anemone 'Jerusalem Mix'

YEAR 1. Stems in the 55 °F greenhouse were 0.6 inches (1.5 cm) longer

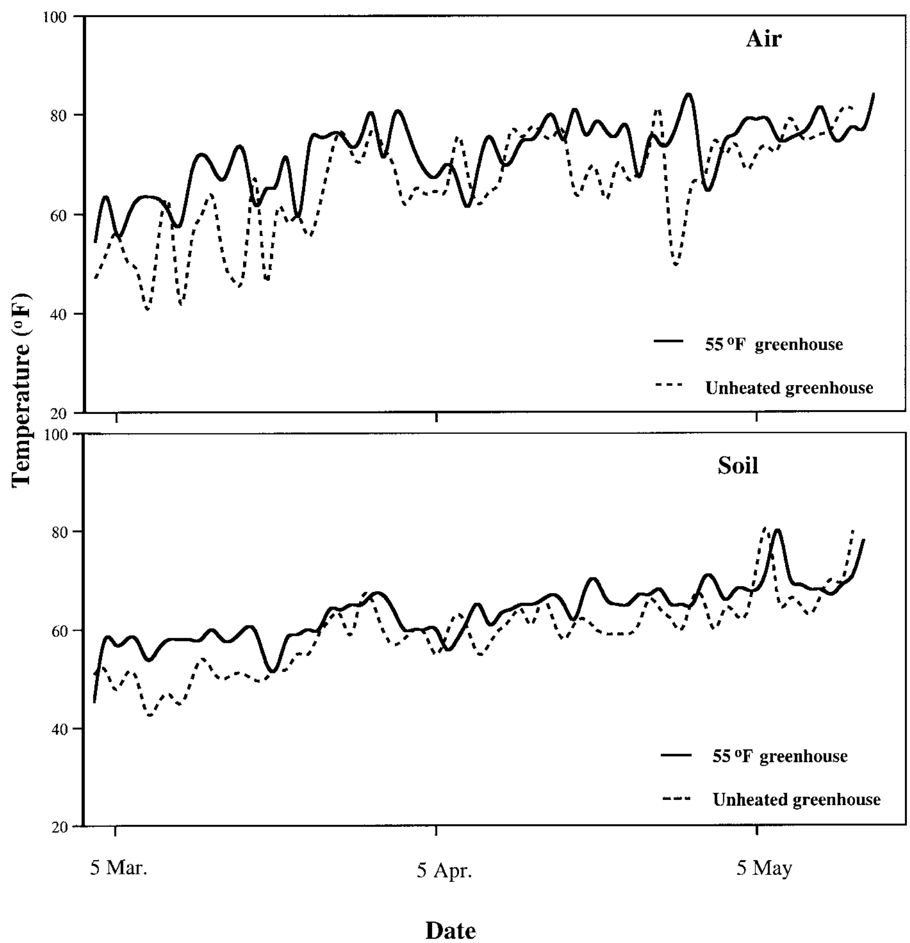

Fig. 1. Average daily greenhouse air and soil temperatures during year 1. Air thermometers were 18 inches (45 cm) above soil surface and soil temperature was recorded 5 inches (13 cm) below the surface; °C = 5/9 (°F–32)

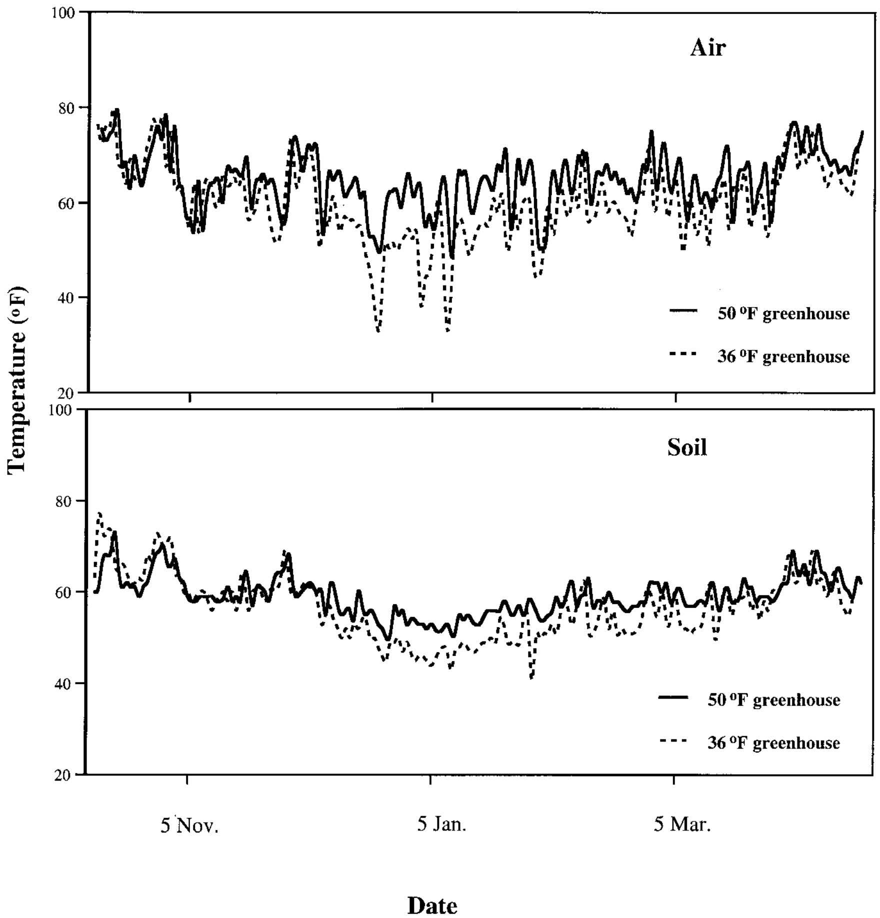

Fig. 2. Average daily greenhouse air and soil temperatures during year 2. Air thermometers were 18 inches (45 cm) above soil surface and soil temperature was recorded 5 inches (13 cm) below the surface; °C = 5/9(°F–32)

and were harvested 7 d earlier than the plants in the unheated greenhouse (Table 2). Anemone was not profitable when grown in either greenhouse due to spacing requirements for the tubers. However, the unheated greenhouse net loss / sample was $13.50 less than the 55 °F greenhouse due to lack of heating expenses and increased stem yield.

YEAR 2. The 50 °F greenhouse reduced production time 15 d compared to the 36 °F greenhouse (Table 3). However, the 36 °F greenhouse stems were 2.6 inches (6.6 cm) longer than the 50 °F greenhouse stems. While neither greenhouse was profitable, the 36 °F greenhouse net loss / sample was $9.97 less than the 50 °F greenhouse due to reduced heating expenses. In both years, stem number was unaffected by treatments.

Delphinium 'Casa Blanca'

The unheated greenhouse stems were 2.0 inches (5.1 cm) longer than the 55 °F greenhouse stems (Table 2). Plants in the 55 °F greenhouse had a shorter production time (122 d) than plants in the unheated greenhouse (149 d). Neither greenhouse was profitable for delphinium. However, the 55 °F greenhouses net loss / sample was $13.10 less than the unheated greenhouse due to temperatures [21 °F (–6 °C)] which killed plants in the nonheated greenhouse and higher stem numbers in the 55 °F greenhouse. Delphinium was not repeated the second year due to low stem production.

Larkspur 'Giant Imperial Mix'

YEAR 1. The unheated greenhouse stems were 5.3 inches (13.5 cm) longer than the 55 °F greenhouse stems (Table 2). Production time in the unheated greenhouse was 9 d longer than the 55 °F greenhouse. Larkspur was not profitable when grown at either greenhouse temperature. However, the unheated greenhouse's net loss / sample was $3.29 less than the 55 °F greenhouse due to no heating expenses.

YEAR 2. Stems in the 50 °F greenhouse were 2.9 inches (7.4 cm) longer and production time was 18 d shorter compared to the 36 °F greenhouse (Table 3). Both greenhouses were profitable with a net profit / samples of $26.42 for the 36 °F greenhouse compared to $23.21 profit or sample for the 50 °F greenhouse. In both years, stem number was unaffected by treatments.

Lupine 'Bright Gems'

YEAR 1. Stem length and production time were not significantly different between the plants in the unheated and 55 °F greenhouses (Table 2). Plants in the 55 °F greenhouse produced 26 more stems / samples than in the unheated greenhouse. Both greenhouses were profitable with the 55 °F greenhouse profiting $21.71 / sample compared to the $5.26 unheated greenhouse profit / sample. Greater profits from the 55 °F greenhouse can be attributed to greater stem numbers produced compared to the unheated greenhouse.

YEAR 2. The 36 °F greenhouse stems were 2.2 inches (5.6 cm) longer than the 50 °F greenhouse stems (Table 3). The 50 °F greenhouse plants yielded 41 more stems / sample and had a 22 d shorter production time compared to the 36 °F greenhouse. Only the 50 °F greenhouse was profitable for lupine yielding a $24.59 profit / sample due to increased stem numbers compared to a loss / sample of $3.61 for the 36 °F greenhouse.

Pansy 'Oregon Giant'

Stem lengths and production time did not significantly differ between the 55 °F and unheated greenhouses (Table 2). Pansy was profitably grown in the unheated greenhouse, netting $6.28 / sample due to no heating expenses and 37 more stems compared to the 55 °F loss / sample of $13.09. Pansy was not repeated in the second year due to minimal consumer demand.

Snapdragon 'Animation Mix'

YEAR 1. Stems in the unheated greenhouse were 6.1 inches (15.5 cm) longer than stems from the 55 °F greenhouse (Table 2). The unheated greenhouse produced 42 more stems in 10 fewer days than 55 °F greenhouse. Plants in the unheated greenhouse netted a $22.80 profit / sample due to increased stem number and lower heating expenses compared to the 55 °F greenhouse which lost $7.16 / sample.

YEAR 2. The 36 °F greenhouse stems were 5.4 inches (13.5 cm) longer than the 50 °F greenhouse stems. The 50 °F greenhouse plants produced the most stems (117) in the shortest production time (176 d) (Table 3). Both greenhouses were profitable with a net profit / sample of $39.75 for the 50 °F greenhouse due to increased stem number compared to $31.84 profit / sample for the 36 °F greenhouse.

Stock 'Cheerful White'

YEAR 1. The unheated greenhouse stems were 5.6 inches (14.2 cm) longer than the 55 °F greenhouse stems (Table 2). Production time in the 55 °F greenhouse was 6 d less than that in the unheated greenhouse. While stock was not profitable when grown at either greenhouse temperature, the unheated greenhouse net loss / sample was $4.12 less than the 55 °F greenhouse due to heating expenses in the 55 °F greenhouse.

YEAR 2. The 36 °F greenhouse stems were 6.0 inches (15.3 cm) longer and production time 14 d longer compared to the 50 °F greenhouse plants (Table 3). Neither greenhouse was profitable for stock. In both years, stem number was unaffected by treatments.

Sunflower 'Sunrich Orange'

The 36 °F greenhouse stems were 3.4 inches (8.6 cm) longer than the 50 °F greenhouse stems (Table 3). The 50 °F greenhouse reduced production time by 28 d compared to the 36 °F greenhouse. Though neither greenhouse was profitable, the 36 °F greenhouse net loss / sample was $1.19 less than the 50 °F greenhouse due to greater heating expenses in the 50 °F greenhouse. Stem numbers were unaffected by greenhouse temperatures.

Discussion

In year 1, the air temperature inside the unheated greenhouse averaged 3.2 °F (1.8 °C) higher than the outside air temperature and the inside soil temperature 6.7 °F (3.7 °C) higher

Table 2. Effect of unheated (ambient) or 55 °F (13 °C) minimum night temperatures on stem length and production time of anemone, delphinium, larkspur, lupine, pansy, snapdragon and stock cut flowers during year 1. Means are an average of four samples per treatment for number of stems harvested and total net profit or loss and 36 to 72 plants per sample for stem length and production time.

Night temp	Stems harvested (no.)	Stem length inches (cm)	Production time[z] (days)	Total net profit/loss[y] ($)
		Anemone Jerusalem Mix		
Unheated	41	8.8 (22.4)	113	–26.92
55 °F (13 °C)	36	9.4 (23.9)	106	–40.42
Significance[x]	NS	0.0312[x]	0.0001	0.0001
		Delphinium Casa Blanca		
Unheated	8	26.6 (67.6)	149	–17.52
55 °F (13 °C)	42	24.6 (62.5)	122	–4.42
Significance	0.0008	0.0022	0.0001	0.0001
		Larkspur Giant Imperial Mix		
Unheated	35	34.3 (87.1)	151	–0.71
55 °F (13 °C)	37	29.0 (73.7)	142	–4.00
Significance	NS	0.0001	0.0001	0.0001
		Lupine Bright Gems		
Unheated	53	19.3 (49.0)	122	5.26
55 °F (13 °C)	79	19.4 (49.3)	122	21.71
Significance	0.0290	NS	NS	0.0001
		Pansy Oregon Giant		
Unheated	67	7.5 (19.1)	108	6.28
55 °F (13 °C)	30	7.0 (17.8)	105	–13.09
Significance	0.0050	NS	NS	0.0001
		Snapdragon Animation Mix		
Unheated	74	23.8 (60.5)	145	22.80
55 °F (13 °C)	32	17.7 (45.0)	155	–7.16
Significance	0.0096	0.0001	0.0001	0.0001
		Stock Cheerful White		
Unheated	35	20.6 (52.3)	117	–2.58
55 °F (13 °C)	36	15.0 (38.1)	111	–6.70
Significance	NS	0.0001	0.0001	0.0001

[z]Plants were sown on 15 Dec. 1997.
[y]Sales expenses = profit for about 9 ft^2 (0.84 m^2).
[x]$P > F$.
[NS]Nonsignificant.

than the outside soil temperature. However, a minimum temperature of 22 °F (–6 °C) occurred in the unheated greenhouse one night when the outside temperature dropped to 16 °F (–9 °C). Due to soil heating and wind protection by the greenhouse, air and soil temperatures inside the greenhouse remained above freezing if outside temperatures did not go below 30 °F (–1 °C) (data not presented).

The extreme low temperatures of 22 °F (–6 °C) experienced in the unheated greenhouse greatly reduced harvestable stems for delphinium and lupine (Table 2). The low temperatures were much less than 55 to 61 °F (13 to 16 °C) which promote flower development for delphinium and flower initiation for rough-seeded lupine (*L. consentinii*) (Holcomb and Beatti, 1988; Rahman and Gladstones, 1972). Many delphinium plants were killed and did not produce stems. Lupine plants were damaged by the cold temperatures, but new growth after the damaging freeze was unaffected. Delphinium and lupine harvestable stem numbers increased when grown in the 55 °F compared to the 36 °F greenhouse.

Anemone, pansy, and snapdragon yielded more harvestable stems and delphinium, larkspur, snapdragon, and stock produced longer stems when grown in the unheated compared to the 55 °F greenhouse. The unheated greenhouse had a greater positive difference in day and night temperatures (DIF) which has been shown to promote stem elongation (Erwin et al., 1989a, 1989b). Ohkawa (1987) noted that anemone produces higher quality and number of stems at cool night temperatures [41 to 50 °F (5 to 10 °C)]. In addition, delphinium, larkspur, snapdragon, and stock produce high quality flowers when grown at 45 to 61 °F (7 to 16 °C) (Dole and Wilkins, 1999a, 1999b; Nau, 1993a, 1993b).

Anemone stems were longer when grown in the 55 °F greenhouse compared to the unheated greenhouse. The 55 °F greenhouse also reduced production time for anemone, delphinium, larkspur, and stock (Table 2). Karlsson (1997) and Pearson et al. (1995) obtained similar results with anemone and pansy.

The 55 °F greenhouse's total net loss / sample for all species combined [63 ft^2 (6 m^2)] was $54.08 compared to the unheated greenhouse's total net loss / sample for all species combined of $13.39 (Table 2). Greater net loss in the 55 °F compared to the nonheated greenhouse was due to higher heating

Table 3. Effect of 36 or 50 °F (2 or 10 °C) minimum night temperatures on stem length and production time of anemone, larkspur, lupine, snapdragon, stock, and sunflower cut flowers in year 2. Means are an average of four samples per treatment for number of stems harvested and total net profit or loss and 18 to 72 plants per sample for stem length and production time.

Night temp	Stems harvested (no.)	Stem length inches (cm)	Production time[z] (days)	Total net profit–loss[y] ($)
		Anemone Jerusalem Mix		
36 °F (2 °C)	71	20.4 (51.8)	64	–13.49
50 °F (10 °C)	57	17.8 (45.2)	49	–23.46
Significance[x]	NS	0.0001	0.0001	0.0001
		Larkspur Giant Imperial Mix		
36 °F (2 °C)	88	17.4 (44.2)	114	26.42
50 °F (10 °C)	83	20.3 (51.6)	96	23.21
Significance	NS	0.0001	0.0001	0.0001
		Lupine Bright Gems		
36 °F (2 °C)	48	31.2 (79.2)	168	–3.61
50 °F (10 °C)	89	29.0 (73.7)	146	24.59
Significance	0.0226	0.0036	0.0001	0.0001
		Snapdragon Animation Mix		
36 °F (2 °C)	102	35.8 (90.9)	181	31.84
50 °F (10 °C)	117	30.4 (77.2)	176	39.75
Significance	0.0206	0.0001	0.0001	0.0001
		Stock Cheerful White		
36 °F (2 °C)	55	37.0 (94.0)	175	–1.42
50 °F (10 °C)	56	31.0 (78.7)	161	–1.61
Significance	NS	0.0001	0.0001	0.0001
		Sunflower Sunrich Orange		
36 °F (2 °C)	35	28.2 (71.6)	154	–10.36
50 °F (10 °C)	33	24.8 (63.0)	126	–11.55
Significance	NS	0.0053	0.0001	0.0001

[z]Plants were sown 15 Sept. 1998.
[y]Sales expenses = profit for about 9 ft^2 (0.84 m^2).
[x]$P > F$.
[NS]Nonsignificant.

expenses and lower stem numbers for anemone, pansy, and snapdragon. Lupine, pansy, and snapdragon were profitable in the unheated greenhouse. Lupine was the only species that was profitable in the 55 °F greenhouse due to greater stem numbers which overcame heating expenses.

In year 2, both greenhouses were heated; thus, plants were protected from the extreme low temperatures. The 50 °F greenhouse reduced production time for anemone, larkspur, lupine, snapdragon, stock, and sunflower compared to the 36 °F greenhouse (Table 3). High temperatures promote fast growing rates and reduce production times. Similar results have been observed with anemone, lupine, pansy, snapdragon, and sunflower (Armitage, 1993; Karlsson, 1997; Miller, 1962; Ohkawa, 1987; Pearson et al., 1995; Rahman and Gladstones, 1972; Schuster, 1985). The 50 °F greenhouse plants produced the most harvestable stems for lupine, and snapdragon and longest stems for larkspur which requires cool temperatures for stem elongation (Dole and Wilkins, 1999b).

Longer stems were measured for plants grown in the 36 °F greenhouse for all cultivars except larkspur. The 36 °F greenhouse had a greater positive difference in day and night temperatures (DIF) which has been shown to promote stem elongation (Erwin et al., 1989a, 1989b). The cool temperatures also increased production time for all cultivars. Net profit / sample for all species combined [54 ft^2 (5m^2)] for the 50 °F greenhouse was $50.93 compared to $29.38 for the 36 °F greenhouse due to more harvestable stems and reduced production time (Table 3).

Conclusion

Unheated (ambient) winter greenhouse production is not recommended in areas with minimum temperatures of 29 °F (–2 °C) or lower due to possible freeze damage within the greenhouse. However, if only frost tolerant species such as larkspur, snapdragon, and stock are grown, unheated greenhouses may be feasible in areas where the minimum temperature is less than 29 °F (–2 °C) as those species tolerated one night of 22 °F (–6 °C) with no negative effects.

In summary, minimally or unheated greenhouse specialty cut flower production is economically feasible for some species such as anemone, larkspur, snapdragon, stock, and sunflower, with the use of unheated greenhouses restricted to cold tolerant species such as larkspur and stock. Other species such as delphinium and lupine are best produced in a warm greenhouse with a minimum night temperature of 50 °F (10 °C).

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