COST EFFECTIVE PRODUCTION
OF SPECIALTY CUT
FLOWERS

By

TODD JASON CAVINS

Bachelor of Science

Southwestern Oklahoma State University

Weatherford, Oklahoma

1997

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 1999

COST EFFECTIVE PRODUCTION

OF SPECIALTY CUT

FLOWERS

Thesis Approved:

Thesis Advisor

Dean of the Graduate College

ACKNOWLEDGEMENTS

The purpose of this study was to improve production methods of various specialty cut flower species. Improving production methods allows growers to reduce cost, improve plant quality and earn higher profits.

This study involved three research areas of specialty cut flowers. Partial funding was provided by a S.A.R.E. grant and Bear Creek Farm, Stillwater, OK. I would like to thank my principle advisor Dr. John Dole for his encouragement, support, honesty and perseverance.

I would like to thank Dr. Janet Cole and Dr. Jim Ownby for serving on my thesis committee. Dr. Cole offered valuable insight and direction towards the research. Dr. Ownby contributed with his wealth of knowledge in plant physiology.

A special thanks goes to Vicki Stamback and the gang at Bear Creek Farm. Vicki's experience as a specialty cut flower grower allowed me to gain personal knowledge of the cut flower industry that would not have taken place without her. Vicki's efforts and cooperation greatly improved this study.

I want to thank Randall Smith and Leah Aufill for their assistance and plant care. Tim Hooper also contributed by offering his experiences from the floriculture industry and providing stress relieving lunch breaks.

To my family: It happened because of you. Mom, Dad and Kristi always encouraged and had confidence in me to succeed. To my extended family, thank you for the support and pats on the back. To Dr. Lou Anella, you are a friend and inspiration.

Lastly, I thank Ruthie and Chloe for the hours spent collecting data, transplanting, encouraging, counseling and loving. You have made me a complete person are the reasons I continue to live. Without your beautiful smiles and twinkling eyes, flowers would have no reason to bloom. I love you both.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

In recent years demand for specialty cut flowers has increased due to their variety and uniqueness. Species of interest include new cultivars and wildflowers that were previously overlooked for the more popular roses, chrysanthemums and carnations. The floral industry has been recently flooded with new species and cultivars for which there is little information available to the growers.

According to 1997 USDA reports, domestically produced cut rose, carnation and chrysanthemum flowers increased only 5% to an estimated $447 million during 1996. However, specialty cuts soared 20% to over $250 million wholesale value. Specialty cuts now account for over half (56%) of the total wholesale value of all cut flowers produced in the United States. Of the estimated 765+ producers of cut flowers, approximately 600 grow specialty cuts (Fulton, 1997). Though the number of producers is down in recent years, the value and demand of specialty cuts is increasing.

Many specialty cut producers are relatively small operations with limited budgets. Lack of financial backing for research limits the ability of growers to add new cultivars to the variety of flowers offered. Without continually offering variety to the consumer, the demand for specialty cuts could plateau. New production methods which could enhance flower quality and reduce production expenses need to be tested. Necessary cut flower qualities include long sturdy stems, good postharvest life and economical production methods.

A major factor in determining production cost is crop time - length of time from propagation to harvesting. Extended crop time increases labor, irrigation, fertilization and pest management expenses and increases the likelihood of climatic problems. Reducing crop time while maintaining high quality would assure a profitable crop for growers.

GREENHOUSE *CAMPANULA* AND *LUPINUS* PRODUCTION

Campanula medium 'Champion Blue' and 'Champion Pink' and *Lupinus hartwegii* 'Bright Gems' are new cultivars available to specialty cut flower growers. The three cultivars have large flowers and good postharvest life (V. Stamback, personal communication). *Campanula medium* is a biennial plant requiring cold and long production time for flowering (Wellensiek, 1985). However, 'Champion Blue' and 'Champion Pink' have the ability to flower in 15 weeks without cold treatment (Sakata, personal communication).

Lupinus hartwegii 'Bright Gems' is a cultivar for which little production information is known. Relative of the famous Texas bluebonnet (*Lupinus texensis*), *L. hartwegii* is available in a variety colors making it highly desirable as a cut flower. Proper production methods to ensure a quick crop time and high quality cut flowers, thus reducing expenses and increasing profits, must be determined for these cultivars.

PHOTOPERIOD

Photoperiod is the period of darkness required for a plant to flower. Providing plants with the proper photoperiod is important to ensure flowering. Improper photoperiods may increase days to anthesis or prevent flowering. Also, combinations of photoperiods may increase plant quality.

JUVENILITY

Juvenility is the early stage of plant growth in which the plant is incapable of flowering despite exposure to reproductive conditions (i.e. inductive photoperiod). Leaf or node count is a common method used to define herbaceous plant juvenility (Cameron et al., 1996; Cockshull, 1985; Yeh and Atherton, 1997). Transferring a plant too early or too late may expedite or hinder plant growth and flower development (Damann and Lyons, 1995).

LIGHT INTENSITY

High intensity discharge (HID) supplemental lighting increases light intensity. Higher light intensities increase photosynthetic accumulation which is used for plant growth and development (Kinet et al, 1985). Increases in photosynthetic accumulation could reduce crop times, increase stem lengths, increased stem diameters and improve cut stem quality (Armitage and Tsujita, 1979; Armitage and Wetzstein, 1984; Carpenter, 1976; Carpenter and Rodriguez, 1971; Quatchak et al., 1986; Tsujita, 1987).

FIELD DUTCH BULB PRODUCTION

Hyacinthoides hispanica, *Hyacinthus* 'Gypsy Queen', *Narcissus* 'Music Hall', *Narcissus* 'Tahiti', *Tulipa* 'Couleur Cardinal', and *Tulipa* 'White Emperor' are Dutch bulbs for which there is little information for optimum production methods in Oklahoma.

Dutch bulbs require warm – cool – warm temperatures for flowering and perennialization (Rees, 1972). Poor perennialization in Oklahoma may be due to an insufficient duration of cold temperatures or excessive summer heating which promotes foliage senescence and reduces daughter bulb regeneration (Armitage, 1993, A. De Hertogh, personal communication). Improving flowering, reducing crop time, and increasing perennialization are important factors in overcoming high production costs which limit profits.

COLD PRETREATMENT

Cold pretreatments have been shown to reduce days to anthesis and promote stem elongation as well as improve rooting during unfavorable growing conditions in Dutch bulbs (Jennings and De Hertogh, 1977; Le Nard and De Hertogh, 1993). Providing bulbs with a 5°C cold pretreatment the first year may improve cut flower production.

PLANTING DEPTH

Proper planting depths are important to ensure consistent and uniform emergence of bulbs. However, shallow planting depths are believed to allow bulb temperatures to rise above optimum, leading to damaged root systems and reduced daughter bulb regeneration (Le Nard and De Hertogh, 1993). Deeper planting depths may delay summer heating and allow daughter bulb regeneration.

SHADING

Shading plants reduces irradiance which reduces temperatures. Reducing temperatures would help soils to remain cooler and allow for extended foliage life of bulbous plants. Extended foliage life is important for continuing the supply of photosynthates for daughter bulb regeneration. Although excess shading can reduce plant quality, *Hyacinthus* and *Tulipa* have been shown to flower in darkness (Armitage, 1991; Nowak and Rudnicki, 1993 and Wassink, 1965)

GREENHOUSE LOW-TEMPERATURE PRODUCTION

Winter greenhouse production may be possible despite reduced temperatures with genera such as *Antirrhinum*, *Consolida*, *Delphinium*, *Helianthus*, *Lupinus*, *Matthiola* and *Viola*. Oklahoma's winter conditions (high light intensity and warm day temperatures) favor low – temperature greenhouse production by warming soils during the day. The warmth of the soil, in turn, can lead to warmer greenhouse temperatures at night. Winter greenhouse production would allow cut flower production during the peak selling season. Reducing greenhouse temperatures during the winter would reduce heating expenses, but may extend days to harvest.

TEMPERATURE

Temperatures affect plant growth rates and morphology. Higher temperatures promote rapid growth and internode elongation in some species such as *Viola* (Pearson et al, 1995). Cooler temperatures have been shown to promote stem elongation in some species such as *Delphinium* and *Consolida* (Dole and Wilkins, 1999). Winter greenhouse production could be more cost effective if plants could be grown successfully in minimally-heated or non-heated environments which would reduce heating expenses and increase profits.

OBJECTIVES

The research has 3 objectives:

1) to determine optimum photoperiods, transplant stages and light intensity (± HID lighting) for *Campanula medium* 'Champion Blue' and 'Champion Pink' and *Lupinus hartwegii* 'Bright Gems' production;
2) to determine the effects of cold pretreatment, planting depth and shading on Dutch bulb flowering, cut stem quality and perennialization in Oklahoma;
3) to determine feasibility of minimally-heated or non-heated greenhouse temperatures on specialty cut flower production to reduce production costs and improve profits.

The information gained from this research will allow specialty cut flower producers to improve production methods, reduce crop times, improve cut stem quality and increase profits.

LITERATURE CITED

Armitage, A.M. 1991. Shade effects yield and stem length of field-grown cut-flower species. HortScience 26:1174-1176.

Armitage, A.M. 1993. *Tulipa*, pp. 311-315. In: Specialty Cut Flowers. Varsity Press, Portland, Ore.

Armitage, A. M. and M. J. Tsujita. 1979. The effect of supplemental light source, illumination and quantum flux density on the flowering of seed propagated geranium. J. Hort. Sci. 54:195-198.

Armitage, A. M. and H. Y. Wetzstein. 1984. Influence of light intensity on flower initiation and differentiation in hybrid geranium. Hortscience 19:114-116.

Cameron, A. M. Yuan, R. Heins and W. Carlson. 1996. Juvenility: your perennial crop's age affects flowering. GrowerTalks 6(8):30-32,34.

Carpenter, W.J. 1976. Photosynthetic Supplementary Lighting of Spray Pompon, *Chrysanthemum morifolium* Ramat. J. Amer. Soc. Hort. Sci. 101:155-158.

Carpenter, W. J. and R. C. Rodriguez. 1971. Earlier flowering of geranium cv. 'Carefree Scarlet' by high intensity of supplemental light treatment. Hortscience 5:183-184.

Cockshull, K.E. 1985. *Antirrhinum majus*, pp. 476-481. In: Handbook of Flowering, vol. III, A.H. Halevy, ed. CRC Press, Boca Rotan, Fla.

Damann, M.P. and R.E. Lyons. 1995. Juvenility and photoperiodic flowering requirements of *Chrysanthemum x superbum* 'G. Marconi' and 'Snow Lady' grown under short- and long-day conditions. J. Amer. Hort. Sci. 120:241-245.

Dole, J.M. and H.F. Wilkins. 1999. *Delphinium*, In: Floriculture: Principles and Species. Prentice Hall, Upper Saddle River, N.J.

Fulton, W. 1997. President's message. The Cut Flower Quarterly 9(3):4-6.

Jennings, N.T., and A.A. De Hertogh, 1977. The influence of preplanting dips and postplanting temperatures on root growth and development of nonprecooled tulips, daffodils and hyacinths. Scientia Hort 6:157-166.

Kinet, J., R. M. Sachs and G. Bernier. 1985. Control by Light, pp.64-88. In: The Physiology of Flowering. vol. III, CRC Press, Boca Raton, Fla.

Le Nard, M. and A.A. De Hertogh.1993. *Tulipa*, pp.617-682. In: The Physiology of Flower Bulbs: A Comprehensive Treatise on the Physiology and Utilization of Ornamental Flowering Bulbous and Tuberous Plants. Elsevier, N.Y.

Nowak, J. and R.M. Rudnicki. 1993. *Hyacinthus*, pp.335-347. In: The Physiology of Flower Bulbs: A Comprehensive Treatise on the Physiology and Utilization of Ornamental Flowering Bulbous and Tuberous Plants. Elsevier, N.Y.

Pearson, S., A. Parker, S.R. Adams, P. Hadley, and D.R. May. 1995. The effects of temperature on the flower size of pansy (*Viola* x *wittrockiana* Gams). J. Hort. Sci. 70:183-190.

Quatchak , D. J., J. W. White and E. J. Holcomb. 1986. Temperature, supplemental lighting and chlormequat chloride effects on flowering of geranium seedlings. J. Amer. Soc. Hort. Sci. 111:376-379.

Rees, A.R., 1972. Structure morphology development and periodicity, pp. 17-44. In: The Growth of Bulbs, vol I. J.F. Sutcliffe, ed. Academic Press, London.

Tsujita, M. J. 1987. High intensity supplementary radiation of roses, pp.171-186. In: Roses. R. W. Langhans, ed., Roses Inc., Haslett, Michigan.

United States Department of Agriculture. 1997. Floriculture Crops, 1996 Summary. SpCr6-1(97), Washington D.C.

Wellensiek, S.J. 1985. Campanula medium, pp.123-126. In: Handbook of Flowering, vol. II, A.H. Halevy, ed. CRC Press, Boca Raton, Fla.

Wassink, E.C. 1965. Light intensity effects in growth and development of tulips, in camparison with those in *Gladiolus* . Medeelingen van de Landbouwhoogeschool, Wageningen, The Netherlands, 65-15, 21 pp.

Yeh, D.M. and J.G. Atherton. 1997. Manipulation of flowering in cineraria. II. Juvenility. J. Hort. Sci. 72:55-66.

CHAPTER II

PHOTOPERIOD, JUVENILITY AND HIGH INTENSITY DISCHARGE (HID) LIGHTING AFFECT FLOWERING RESPONSE AND CUT STEM QUALITY OF *CAMPANULA* AND *LUPINUS*

Todd J. Cavins and John M. Dole. Department of Horticulture and Landscape Architecture, Oklahoma State University, Stillwater, OK 74078-6027

Additional index words. *Campanula medium* 'Champion Blue', *Campanula medium* 'Champion Pink', *Lupinus hartwegii* 'Bright Gems'

Abstract. In year one, *Campanula medium* L. 'Champion Blue' (CB) and 'Champion Pink' (CP) and *Lupinus hartwegii* Lindl. 'Bright Gems' (LH) were grown in 8 or 16 h initial photoperiods, transplanted when 2-3, 5-6, or 8-9 nodes developed, and placed under 8, 12 or 16 h final photoperiods. Greatest flowering percentage (100%) for CB and CP occurred when plants with 2-3 nodes were grown in the 16 h final photoperiod. The lowest flowering percentage for CB (3%) and CP (16%) resulted from plants grown in the 8 h photoperiod continuously (initial and final) indicating that CB and CP are long day plants (LDP). Champion Blue and CP stem lengths (49.8 cm) were longest when grown in the 8 h photoperiod continuously and shortest with the 16 h initial and 8 h final

photoperiods for CB (26.5 cm) and the 16 h photoperiod continuously for CP (25.4 cm). Fewest days to anthesis, 134 d for CB and 145 d for CP, resulted from the 16 h photoperiod continuously. Longest crop time (216 d) was from plants grown in the 8 h photoperiod continuously. Champion Blue and CP exhibited full maturity at 8-9 true leaves. In year two, 8 or 16 h high intensity discharge (HID) supplemental lighting reduced days to anthesis and when supplied during the 8 h initial photoperiod improved quality ratings. Champion Blue and CP highest profits per stem were from plants grown in the initial 8 h photoperiod and transferred at 2-3 or 5-6 true leaves into the final 16 h photoperiod. *Lupinus hartwegii* plants had a high flowering percentage (96-100%) regardless of photoperiod or transplant stage. Stem lengths were longest (60.1 cm) for LH plants exposed to the 16 h photoperiod continuously and shortest (46.2 cm) when exposed to the 8 h photoperiod continuously. *Lupinus hartwegii* exhibited a curvilinear response for days to anthesis with the 16 h final photoperiod producing the shortest crop time (166 d) and the 12 h final photoperiod producing the longest crop time (182 d) indicating that LH is a facultative long day plant. Juvenility was not evident for LH in this study. In year two, HID lighting generally increased stem length; however, when plants were placed into the final 16 h photoperiod the positive effects of HID lighting diminished. High intensity discharge lighting increased quality ratings for LH and decreased days to anthesis when given to plants transplanted at 8-9 leaves into the final 16 h photoperiod. Highest profits were produced from LH plants grown in the 16 h photoperiod continuously with HID supplemental lighting during the intial photoperiod until 5-6 or 8-9 true leaves.

Introduction

A major factor in determining production cost is crop time - length of time from propagation to harvesting. Extended crop time increases labor, irrigation, fertilization and pest management expenses and increases the likelihood of climatic problems. Reducing crop time while maintaining high quality would assure a profitable crop for growers.

Two factors, juvenility and photoperiod, are important in determining economical methods to produce cut flowers. Juvenility is the early stage of plant growth in which the plant is incapable of flowering despite being exposed to the proper reproductive conditions. Determining the minimum age at which a plant is mature enough to respond to the photoperiod or other flower induction conditions will reduce crop time. Damann and Lyons (1995) showed that transferring *Chrysanthemum* x *superbum* Bergmans ex J. Ingram at the proper node count from a non-inductive photoperiod to an inductive photoperiod reduced the time to flower from 123 to 77 days. The number of true leaves (nodes) was used as an indicator of plant maturity. Leaf number, which indicates the end of juvenility, has been described for many plants including *Antirrhinum majus* L. at 18-22 leaves (Cockshull, 1985), *Coreopsis* L. 'Sunray' at 16 leaves (Cameron et al., 1996) and *Pericallis* D. Don. 'Cindy Blue' at 6-7 leaves (Yeh and Atherton, 1997).

However, if a plant with a short juvenility period is exposed to appropriate reproductive conditions before sufficient plant mass has developed, the plant may not be able to support quality flowers. Plants must attain proper photosynthetic capacity before being exposed to reproductive conditions. In addition, early exposure to flowering conditions before the end of juvenility could decrease uniformity of flowering (Cameron et al., 1996).

In addition to photoperiod (light duration), light intensity is an important factor in plant development and quality. Low light levels have been shown to increase plant height in *Anemone coronaria* L., *Centaurea americana* Nutt. , *Echinops ritro* L., *Eryngium planum* L., *Oxypetalum caeruleum* (D. Don.) Decne and *Zantedeschia* Spreng. (Armitage, 1991; Armitage et al., 1990). Plants may become taller or have longer stems but may be markedly weaker. Weak stems would not properly support the flowers and would lower the cut stem quality.

Many studies involving geranium (*Pelargonium* sp.) have illustrated the potential for reducing crop time of floral crops via the use of high intensity discharge (HID) supplemental lighting (Armitage and Tsujita, 1979; Armitage and Wetzstein, 1984; Carpenter and Rodriguez, 1971; and Quatchak et al., 1986). In greenhouse cut rose (*Rosa hybrida*) production, days to anthesis were decreased 3-10 days with the use of HID lamps (Tsujita, 1987). *Chrysanthemum moriflorum* Ramat plants increased in height and fresh weight during the vegetative stage of growth when plants were given HID lighting (Carpenter, 1976). The higher light intensity increased photosynthate production which increased carbohydrate levels for growth and development (Kinet et al., 1985).

In addition to the increased photosynthates, the light quality of the high pressure sodium (HPS) lamps may promote flowering (Wilkins and Healy, 1980). High pressure sodium lamps emit light primarily in the red, orange and yellow spectral range (Bugbee, 1994). Light quality or color also has photomorphogenic effects. When light possesses a low ratio of red to far red light, stem elongation occurs (Moe and Heins, 1990). Far red and red light (compared to blue light) have been shown to reduce days to flowering in many plants including *Campanula carpatica* Jacq., *Campanula isophylla* Moretti, *Dianthus caryophyllus* L., *Fuschia* L., and *Gypsophila* L., As reported by Blom (1998), HPS lamps have become the most commonly used HID lamp for supplemental lighting due to their light quality and quantity.

The profitability of specialty cut flower production also depends on grower ability to offer species and cultivars new to the industry. Two species that show promise as specialty cuts are *Campanula medium* L. and *Lupinus hartwegii* Lindl. *Campanula medium*, commonly known as Canterbury Bells, is a pubescent plant with rosulate lower leaves and multiple 3.5 cm long bell-shaped flowers on a terminal raceme (Griffiths, 1995). *Campanula medium* plants were previously biennials and required a cold treatment and lengthy cultivation time with short days followed by long days for flowering (Wellensiek, 1985). However, two new cultivars, 'Champion Blue' and 'Champion Pink', now offer a crop time as low as 15 weeks with no cold requirement for flower development (Sakata, personal communication). These new cultivars can produce multiple stems up to 25 cm long when spaced 25-30 cm apart or single stems of 65 cm when spaced 10-15 cm apart. The 'Champion Series' recently received a Fleuroselect gold medal for uniformity and high productivity (Sakata, personal communication).

Lupinus hartwegii 'Bright Gems' is a relative of the famous Texas bluebonnet (*Lupinus texensis*). 'Bright Gems' consists of a variety of colors including blue, pink and white. The lupine is popular in the cut flower industry because of its unique colors, especially light blue, and large inflorescence size. *Lupinus hartwegii* is an annual with pubescent stems reaching lengths of 90 cm. A native of Mexico, its inflorescence consists of 1.5 cm flowers on long racemes (Griffiths, 1995). While no published information is available on the specific cultural requirements for *L. hartwegii*, most other lupine species are long day plants (Rahman and Gladstone, 1974).

The objective of this study was to determine optimum photoperiods and transplant stages for *Campanula medium* 'Champion Blue', *Campanula medium* 'Champion Pink' and *Lupinus hartwegii* 'Bright Gems' and to determine if high intensity discharge supplemental lighting can aid in producing high quality cut flowers with minimal crop time.

Materials and Methods

Year one. *Campanula* ‘Champion Blue’ and ‘Champion Pink’ and *Lupinus* seeds were direct sown into 1206 bedding plant flats (50 cm^3/cell) using a peat-lite commercial media (Redi Earth, Scotts-Sierra Company, Marysville, Ohio) on 12 September 1997.

Seedlings were placed into the respective photochambers upon the appearance of the first true leaves. Two initial photoperiods of eight and sixteen hours were used. The 8 h photochamber received 8 h of natural light concurrent with 8 h of incandescent light (654 $\mu mol \cdot m^{-2} \cdot s^{-1}$). The 16 h photochamber received 8 h of natural daylight and an additional 8 h of day extension provided by incandescent lights. Thus, both treatments received 8 h of natural daylight and 8 h of incandescent light.

Plants were transplanted into 1801 (260 cm^3/cell) bedding plant flats with a commercial soilless media (BM1, Berger, Saint-Modeste, Quebec) at the appearance of 2-3, 5-6 or 8-9 true leaves and placed into the final 8, 12 or 16 h photoperiods. The 8 and

16 h photochambers were lighted as described previously. The 12 h photochamber received 8 h of natural light concurrent with 4 h incandescent light and 4 h day extension incandescent light.

Plants were grown in a corrugated polycarbonate-covered greenhouse set at a 18/15°C day/night temperature. Plants were fertigated with 250 $mg \cdot L^{-1}$ N from a premixed commercial 20N-4.4P-16.6K fertilizer (Peter's Professional, Scotts Company, Marysville, Ohio).

Data collected at harvest time included stem length, stem diameter, selling price, quality rating and number of live plants per replication. Average daily temperature, monthly light levels, date of visible bud and harvest date were recorded. Total profit/loss was calculated based on: sales - production cost. Production cost was calculated as: [(Seed, flat and media expenses) + ($2.26/m^2 * 0.0086 m^2 * weeks from sowing to anthesis)]/percent of replication flowering. Seed, flat and media expenses totaled $0.097/cell. The $2.26/m^2 was determined from Brumfield (1982) for small grower servicing floral shops and adjusted by the consumer price index (U.S. Bureau of the Census, 1998). The 0.0086 m^2/stem is the area of one cell pack of an 1801 bedding plant flat.

Campanula flowers were harvested at full color of terminal flower bud and *Lupinus* when one-third of florets were open. A 2 x 3 x 3 factorial treatment combination was used with two initial photoperiods, three transplant stages, and three final photoperiods. Four samples (1801 flat) of 18 plants were used for each treatment combination. Data were analyzed by the general linear model procedure (SAS Institute, Cary, NC)

Year two - 8 h HID duration. *Campanula* 'Champion Blue' and 'Champion Pink' were sown on 2 December 1998 and placed into 8 or 16 h photoperiods upon the appearance of the first true leaves as described in year one. In addition, one half of plants were given 8 h of supplemental lighting (740 $\mu mol \cdot m^{-2} \cdot s^{-1}$; P. L. Light Systems, Beamsville, Ontario) concurrent with the 8 h of incandescent lighting for both photoperiods. The other half of plants did not receive HID supplemental lighting. Plants were transplanted into the final 16 h photoperiod (incandescent lighting only) at 5-6 true leaves resulting in a 2 x 2 factorial treatment combination with 2 initial photoperiods and two light intensities from supplemental lighting. Four samples (1801 flats) with 18 plants per sample were used. All other procedures were the same as described for year one.

Year two - 8 and 16 h HID duration. *Campanula* 'Champion Blue' and 'Champion Pink' were sown 27 August 1998 and placed into 8 or 16 h photoperiods upon appearance of the first true leaves as described in year one. The 8 or 16 h was supplied by natural lighting and incandescent lighting only or natural lighting and incandescent lighting plus HID supplemental lighting (740 $\mu mol \cdot m^{-2} \cdot s^{-1}$; P. L. Light Systems, Beamsville, Ontario). Plants were transplanted into the final 16 h photoperiod upon appearance of 2-3, 5-6 or 8-9 true leaves. A 2 x 2 x 3 factorial treatment combination was used with two initial photoperiods, two supplemental light intensities and three transplant stages. There were four samples (1801 flats) with 15 plants per sample.

Year two - Lupinus. Seed were sown 14 October 1998. Plants were placed into a 16 h photoperiod, with or without concurrent HID supplemental lighting upon appearance of the first true leaves. Plants were transplanted at the appearance of 2-3, 5-6 or 8-9 true leaves into the final 8, 12 or 16 h photoperiods using 1801 bedding plant flats as described previously for year one final photoperiods.

Results

Cultivar differences were observed between *Campanula medium* 'Champion Blue' and 'Champion Pink'; consequently, the two cultivars were discussed separately. 'Champion Blue' reached visible bud ($p=0.0001$) and anthesis ($p=0.0001$) in fewer days than 'Champion Pink'. However, 'Champion Blue' required a longer duration between visible bud and anthesis ($p = 0.0233$) and had narrower stems ($p = 0.0025$) than 'Champion Pink'. 'Champion Blue' and 'Champion Pink' plants had similar stem lengths and quality ratings.

CAMPANULA MEDIUM 'CHAMPION BLUE'

Percent plants flowered. *Year one.* Initial photoperiod interacted with final photoperiod affecting flowering percentage (Table 2.1). The 16 h initial photoperiod produced higher flowering percentages than the 8 h initial photoperiod. The greatest percentage (99-100%) of plants flowered when they received the 16 h final photoperiod, regardless of initial photoperiod and the lowest percentage (3%) was produced by the plants in the 8 h initial photoperiod and 8 h final photoperiod. *Year two.* All treatments received the 16 h final photoperiod and produced similarly high flowering percentages (Tables 2.2 and 2.3).

Stem length. Stems were longer when plants received the 8 h initial photoperiod compared to the initial 16 h photoperiod (Tables 2.1, 2.2 and 2.3). *Year one.* Stem length increased as both initial and final photoperiod duration decreased resulting in the 8 h initial and 8 h final photoperiod producing the longest stems and the 16 h initial and the 16 h final photoperiod the shortest stems. Final photoperiods showed a curvilinear response with the 8 h final photoperiod resulting in the shortest stems and the 12 and 16 h final photoperiods resulting in longer stems (Table 2.1). Transplant stage did not affect stem length.

Year two, 8 h HID duration. Light intensity and initial photoperiod interacted such that plants receiving HID supplemental lighting in the 16 h photoperiod had shorter stems than without HID lighting while plants receiving HID lighting in the 8 h initial photoperiod had longer stems than without HID lighting (Table 2.2).

Year two, 8 and 16 h HID duration. Light intensity, initial photoperiod and transplant stage interacted affecting stem length (Table 2.3). Plants given HID supplemental light during the 8 h initial photoperiod and transplanted at the 8-9 true leaf stage produced the longest stems. However, the treatment combination that produced the next longest stems was 8 h initial photoperiod without concurrent HID supplemental lighting and transplanted at 8-9 leaves.

Stem diameter. Plants receiving the 8 h initial photoperiod had greater stem diameters than those receiving the 16 h initial photoperiod (Tables 2.1, 2.2 and 2.3). *Year one*. A three way interaction occurred among initial photoperiods, transplant stages and final photoperiods (Table 2.1). The 8 h initial photoperiod, 2-3 leaf transplant stage and the 12 h final photoperiod produced the widest stem diameter. The narrowest stem diameter was produced on plants grown continuously in the 16 h photoperiod and transplanted at the 5-6 leaf stage.

Year two, 8 h HID duration. Light intensity interacted with initial photoperiod such that HID supplemental lighting during the 8 h initial photoperiod increased stem diameter compared with no HID lighting. During the 16 h initial photoperiod HID lighting reduced stem diameter (Table 2.2).

Year two, 8 and 16 h HID duration. Several interactions affected stem diameter (Table 2.3). Initial photoperiod interacted with light intensity such that the 8 h initial photoperiod and HID supplemental lighting produced wider stems than the 16 h initial photoperiod and ambient light intensity. Light intensity interacted with transplant stage producing wider stems when plants were given HID supplemental lighting and transplanted at the 8-9, 5-6 and 2-3 leaf stage, respectively. Initial photoperiod interacted with transplant stage such that the 8 h initial photoperiod and the later transplant stages increased stem diameter.

Quality rating. Higher quality ratings were generally produced by plants in the 8 h initial photoperiod than plants in the 16 h initial photoperiod (Tables 2.1, 2.2 and 2.3). *Year one.* A curvilinear response was obtained with the final photoperiod such that ratings for the 12 and 16 h final photoperiods were higher than the 8 h final photoperiod ratings (Table 2.1).

Year two, 8 h HID duration. The highest quality ratings were produced when HID supplemental lighting was given to plants in the 8 h initial photoperiod (Table 2.2). However, when HID supplemental lighting was given to plants in the 16 h initial photoperiod, the lowest quality rating was produced.

Year two, 8 and 16 h HID duration. The best cut stem quality was a result of a three way interaction among initial photoperiod, light intensity and transplant stage

(Table 2.3). Plants receiving the 8 h initial photoperiod, HID light intensity and the 8-9 leaf transplant stage produced the highest quality ratings.

Days from sowing to visible bud. Overall, plants in the 8 h initial photoperiod took longer to reach visible bud than the 16 h initial photoperiod plants (Tables 2.1, 2.2 and 2.3 *Year one*. A three way interaction occurred among initial photoperiod, transplant stage and final photoperiod such that the plants receiving the 8 h initial photoperiod, 8-9 leaf transplant stage and the 8 h final photoperiod took longest to reach visible bud (Table 2.1).

Year two, 8 h HID duration. Days to visible bud decreased when plants were subjected to HID supplemental lighting (Table 2.2). Plants reached visible bud in fewest days when HID supplemental lighting was combined with the 16 h initial photoperiod and the most days with 8 h initial photoperiod and without HID supplemental lighting.

Year two, 8 and 16 h HID duration. The interaction of initial photoperiod, transplant stage and light intensity affected days to visible bud (Table 2.3). Days to visible bud was generally reduced when plants were grown in the 16 h initial photoperiod with HID supplemental lighting and transplanted at the later stages.

Days from sowing to anthesis. Overall plants in the 8 h initial photoperiod took more days to reach anthesis than the 16 h initial photoperiod plants (Tables 2.1, 2.2 and 2.3). *Year one*. A three way interaction occurred among initial photoperiod, transplant stage and final photoperiod such that the plants receiving the 8 h initial photoperiod, 8-9 leaf transplant stage and the 8 or 12 h final photoperiod took longest to reach anthesis (Table 2.1). The 8 h final photoperiods took longer to reach anthesis than either the 12 or 16 h photoperiods.

Year two, 8 h HID duration. Days to anthesis were reduced when plants were subjected to HID supplemental lighting (Table 2.2). Combining HID supplemental lighting with the 16 h initial photoperiod produced anthesis in the fewest days while the 8 h initial photoperiod with only ambient light intensity took the greatest amount of time to reach visible bud.

Year two, 8 and 16 h HID duration. A three way interaction among the treatments affected days to anthesis (Table 2.3). The 16 h initial photoperiod, HID lighting and 2-3 leaf transplant stage generally reduced days to anthesis.

Days from visible bud to anthesis. *Year one.* The interval between days from visible bud to anthesis was affected by initial photoperiod such that the 8 h initial photoperiod resulted in a shorter interval than the 16 h initial photoperiod (Table 2.1). A curvilinear response was attained with the final photoperiod such that the 8 h final photoperiod had the fewest days between visible bud and anthesis as compared the 12 and 16 h final photoperiod.

Year two, 8 h HID duration. Light intensity affected the number of days from visible bud to anthesis (Table 2.2). Plants receiving HID supplemental lighting produced the longest interval while plants in the ambient light levels produced the shortest interval from visible bud to anthesis.

Year two, 8 and 16 h HID duration. Initial photoperiod and transplant stage interacted to affect days from visible bud to anthesis (Table 2.3). Plants grown in the 16 h initial photoperiod and transplanted at the 2-3 leaf stage generally reduced the interval from visible bud to anthesis compared to plants grown in the 8 h initial photoperiod and transplanted at the 8-9 leaf stage.

Profit per flower harvested. In year one, lowest profits were from plants grown continuously in the 8 h photoperiod. Highest profits were from plants grown in the initial 8 h photoperiod and then transferred at 2-3 or 5-6 leaves into the final 16 h photoperiod (Table 2.1). In year two, highest profits were from plants grown continuously in the 16 h photoperiod with HID supplemental lighting (Tables 2.2 and 2.3).

Campanula medium 'Champion Pink'

Percent plants flowered. Initial and final photoperiod affected flowering percentage (Table 2.4). The greatest percentage (100%) of plants flowered when they received the 16 h final photoperiod. The lowest percentage of plants flowered when they received the 8 h initial and final photoperiod (16%). During year two all treatments produced similarly high flowering percentages (Tables 2.5 and 2.6).

Stem length. *Year one.* Interactions occurred with initial photoperiod and transplant stage such that the plants receiving the 8 h initial and 8-9 leaf transplant stage produced the longest stems (Table 2.4). Plants receiving the initial 16 h photoperiod and 8-9 leaf transplant stage produced the shortest stems. An interaction of transplant stage and final photoperiod was noted such that plants transferred to the 8 h final photoperiod at the 2-3 leaf transplant stage produced the longest stems.

Year two, 8 h HID duration. Initial photoperiod and light intensity interacted producing the longest stems when plants were grown in the 8 h initial photoperiod and given HID supplemental lighting (Table 2.5). The shortest stems were produced by the plants in the 16 h initial photoperiod subjected to HID supplemental lighting.

Year two, 8 and 16 h HID duration. Initial photoperiod interacted with transplant stage such that longest stems were produced in the 8 h initial photoperiod and transplanted at the 8-9 leaf transplant stage (Table 2.6). The shortest stems were attained from plants grown in the 16 h initial photoperiod and transplanted at the 2-3 leaf stage.

Stem diameter. *Year one.* A three way interaction occurred with stem diameter (Table 2.4). Plants receiving the 8 h initial photoperiod, 2-3 leaf transplant stage and the 8 h final photoperiod produced the widest diameter stems. Overall the 16 h initial photoperiod plants produced narrower stems than the initial 8 h photoperiod. Thinnest stems were produced by the plants that received the 16 h photoperiod continuously.

Year two, 8 h HID duration. Plants in the 8 h initial photoperiod produced wider stems than those plants grown in the 16 h initial photoperiod (Table 2.5). Light intensity did not affect stem diameter.

Year two, 8 and 16 h HID duration. Initial photoperiod interacted with transplant stage (Table 2.6). Plants grown the initial 8 h photoperiod and transplanted at the 8-9 leaf stage produced the widest stem diameter. HID supplemental lighting also increased stem diameter.

Quality rating. *Year one.* Plants held in the initial 8 h photoperiod and transplanted at the later stages produced the highest quality rating (Table 2.4). The lowest quality was attained by the plants in the 16 h initial photoperiod and transplanted at the 8-9 leaf transplant stage.

Year two, 8 h HID duration. Initial photoperiod was the most influential in affecting quality rating (Table 2.5). The 8 h initial photoperiod produced higher quality cut stems than the 16 h initial photoperiod. HID supplemental lighting decreased cut stem quality for the plants grown in the 16 h initial photoperiod.

Year two, 8 and 16 h HID duration. The 8 h initial photoperiod plants produced higher quality ratings than the 16 h initial photoperiod plants (Table 2.6). Later transplanting stage linearly increased quality ratings. High light intensity from HID supplemental lighting also increased cut stem quality.

Days from sowing to visible bud. *Year one.* A three way interaction among initial photoperiod, transplant stage and final photoperiod resulted in plants receiving the 16 h initial photoperiod and a 12 or 16 h final reduced days to visible bud (Table 2.4). Plants receiving the initial 8 h photoperiod and transplanted into the 16 h final photoperiod at the 2-3 leaf stage reached visible bud in the fewest days.

Year two, 8 h HID duration The plants grown in the 16 h initial photoperiod reached visible bud quicker than the 8 h initial photoperiod plants(Table 2.5). Plants receiving the 16 h initial photoperiod with HID supplemental lighting reached visible bud quickest.

Year two, 8 and 16 h HID duration. A three way interaction among initial photoperiod, transplant stage and light intensity affected days to visible bud (Table 2.6). Plants grown in the 16 h initial photoperiod with HID supplemental lighting and transplanted at the 8-9 leaf transplant stage reached visible bud in the fewest days.

Days from sowing to anthesis. *Year one.* A three way interaction among initial photoperiod, transplant stage and final photoperiod resulted in plants receiving the 16 h initial photoperiod and a 12 or 16 h final photoperiod having fewest days to anthesis (Table 2.4). Plants receiving the initial 8 h photoperiod and transplanted into the 16 h final photoperiod at the 2-3 leaf stage reached anthesis in the fewest days.

Year two, 8 h HID duration. The plants grown in the 16 h initial photoperiod reached anthesis quicker than the 8 h initial photoperiod plants (Table 2.5). Plants receiving the 16 h initial photoperiod along with HID supplemental lighting reached anthesis quickest.

Year two, 8 and 16 h HID duration. A three way interaction among initial photoperiod, transplant stage and light intensity affected the number of days to anthesis (Table 2.6). When plants were grown in the 16 h initial photoperiod with HID supplemental lighting and transplanted at the later transplant stages, anthesis was reached in the fewest days.

Days from visible bud to anthesis. *Year one.* Significant interactions occurred between initial photoperiod and transplant stage as well as initial and final photoperiod (Table 2.4). The 8 h initial photoperiod and 5-6 leaf transplant stage produced the shortest interval from visible bud to anthesis. However, the initial 8 h photoperiod and the 8 h final photoperiod produced the longest duration from visible bud to anthesis.

Year two, 8 h HID duration. Initial photoperiod interacted with light intensity to affect days from visible bud to anthesis (Table 2.5). Plants grown in the 8 h initial photoperiod and receiving HID supplemental lighting produced the shortest interval while 8 h initial photoperiod and ambient light levels took the most days to reach anthesis from visible bud.

Year two, 8 and 16 h HID duration. Initial photoperiod interacted with transplant stage affecting the interval from visible bud to anthesis (Table 2.6). The 16 h initial photoperiod combined with the 2-3 leaf transplant stage produced the shortest interval between visible bud and anthesis.

Profit per flower harvested. In year one, lowest profits were from plants grown continuously in the 8 h photoperiod. Highest profits were from plants grown in the initial 8 h photoperiod and transferred at 5-6 leaves into the final 16 h photoperiod (Table 2.4). In year two, highest profits were from plants grown in the 8 h photoperiod and transferred at 2-3 leaves into the final 16 h photoperiod with HID supplemental lighting or grown continuously in the 16 h photoperiod with HID supplemental lighting (Tables 2.5 and 2.6).

Lupinus hartwegii 'Bright Gems'

Percent plants flowered. During year one and two all plants had high flowering percentages (96-100%) regardless of treatment (Tables 2.7 and 2.8).

Stem length. *Year one.* Stem length increased curvilinearly with increasing final photoperiod (Table 2.7). While delayed transplanting linearly increased stem length, the 5-6 true leaf stage produced the longest stems.

Year two. Transplant stage, final photoperiod and light intensity interacted to affect stem length (Table 2.8). Plants grown under ambient light levels and transplanted at the 2-3 leaf stage into the 16 h final photoperiod produced the longest stems. However, plants receiving HID supplemental lighting, 8-9 leaf transplant stage and the 16 h final photoperiod produced the second longest stems.

Stem diameter. *Year one.* Plants in the 16 h initial photoperiod had thicker stem diameters than plants in the 8 h initial photoperiod (Table 2.7). The final photoperiod produced a curvilinear response; the 8 h photoperiod produced wider stems than the 12 or 16 h photoperiods.

Year two. Transplant stage interacted with the final photoperiod such that plants transplanted at the 2-3 leaf stage into the 8 h final photoperiod had the widest stem diameter (Table 2.8). Light intensity interacted with transplant stage producing wider stems for plants receiving HID supplemental lighting and the 2-3 leaf transplanted stage compared to plants receiving no HID supplemental lighting and the 8-9 leaf transplant stage.

Quality rating. *Year one*. A significant interaction existed between initial and final photoperiod such that the 8 h initial photoperiod and the 8 h final photoperiod produced a lower quality rating than the 8 h initial photoperiod and the 16 h final photoperiod (Table 2.7). For plants grown in the 16 h initial photoperiod, the lowest quality was achieved with 12 h final photoperiod and the highest quality with the 8 h final photoperiod. The highest quality overall was achieved with plants grown in the 16 h initial and 8 h final photoperiods.

Year two. Transplant stage interacted with final photoperiod and transplant stage interacted with light intensity to affect cut stem quality (Table 2.8). Plant quality increased with HID supplemental lighting and the 5-6 or 8-9 leaf transplant stages. When plants were given no HID supplemental lighting, plant quality decreased with later transplant stages.

Days from sowing to visible bud. *Year one*. A three way interaction among initial photoperiod, transplant stage and final photoperiod occurred with days to visible bud (Table 2.7). Transplanting at an earlier stage to the 16 h final photoperiod reduced days to visible bud. The plants in the 16 h initial photoperiod reached visible bud quicker than the 8 h initial photoperiod plants. The fewest days to visible bud was produced by plants receiving the 16 h continuous photoperiod. Among the 16 h continuous photoperiod, an earlier transplant stage produced the fewest days to visible bud.

Year two. Light intensity and transplant stage combined to affect days to visible bud (Table 2.8). When plants were given HID supplemental lighting, the later transplant stages generally decreased the days to visible bud. However, when plants were given ambient light levels, later transplanting increased days to visible bud. The 16 h final photoperiod reduced days to visible bud.

Days from sowing to anthesis. *Year one*. A three way interaction among initial photoperiod, transplant stage and final photoperiod affected days to anthesis (Table 2.7). Transplanting at an earlier stage into the 16 h final photoperiod reduced days to anthesis. Generally, plants in the 16 h initial photoperiod reached anthesis in fewer days than the 8 h initial photoperiod. The fewest days to anthesis was produced by plants receiving the 16 h photoperiod continuously. Among the 16 h continuous photoperiod, an earlier transplant stage reduced days to anthesis.

Year two. The interaction among transplant stage, final photoperiod and light intensity affected days to anthesis (Table 2.8). Days to anthesis decreased when plants were grown under HID supplemental lighting and transplanted at the 5-6 or 8-9 leaf stages into the 12 or 16 h final photoperiods.

Days from visible bud to anthesis. *Year one*. The earlier plants were transplanted, the greater the days from visible bud to anthesis (Table 2.7). A quadratic response was observed with the final photoperiod such that the 8 h final photoperiod produced the longest interval between visible bud and anthesis.

Year two. The interaction of transplant stage, final photoperiod and light intensity affected the interval between visible bud and anthesis (Table 2.8). Plants grown under ambient light levels and transplanted at the 5-6 or 8-9 leaf stage into the 8 h final photoperiod generally produced the fewest days from visible bud to anthesis.

Profit per flower harvested. In year one, highest profits were from plants grown continuously in the 16 h photoperiod or transferred from the initial 8 h photoperiod at 2-3 leaves into the final 16 h photoperiod. In year two, highest profits were generally from plants grown continuously in the 16 h photoperiod with HID supplemental lighting.

Discussion

The 8 h final photoperiod inhibited or greatly reduced flowering for 'Champion Blue' and 'Champion Pink' plants. When plants were grown in the 8 h initial photoperiod and transplanted into the 8 h final photoperiod, flowering percentage was low for 'Champion Blue' (3%) and 'Champion Pink' (16%) (Tables 2.1, 2.2 and 2.3). In the 16 h final photoperiod 'Champion Blue' and 'Champion Pink' plants had high flowering percentages (100%) and reached anthesis in fewer days than the 12 h final photoperiod. *Campanula* 'Champion' cultivars are long day plants with a critical photoperiod between 8 and 12 h. Wellensiek (1985) also reported that *Campanula medium* is a long day plant.

The 8 h initial photoperiod was instrumental in assuring sufficient stem length and diameter for 'Champion Blue' and 'Champion Pink'. However, the 8 h initial photoperiod delayed days to anthesis compared to the 16 h initial photoperiod when plants were transplanted into a 12 or 16 h final photoperiod (Tables 2.1 and 2.2). Non-inductive photoperiods can prevent or delay floral development (Kinet et al., 1985) The 8 h photoperiod is a non-inductive photoperiod for *Campanula medium* flowering (Wellensiek, 1985). Since plants were not developing reproductive tissue, the photosynthates produced were allocated to vegetative tissue allowing for increased stem length and diameter.

The flowering percentage increased with the later transplant stages when *Campanula* were grown in the initial 16 h inductive photoperiod and transplanted into the final 8 h non-inductive photoperiod (Tables 2.1 and 2.2). ‘Champion Blue’ and ‘Champion Pink’ plants transplanted at the 2-3 leaf stage had flowering percentages of 64% and 63% respectively. However, flowering percentage increased to 100% for both cultivars when plants were transplanted at the 8-9 leaf stage. Thus, juvenility exists and plants are fully mature at the 8-9 leaf stage, which is within the range of juvenility responses from *Antirrhinum majus* at 18-22 leaves (Cockshull, 1985), *Coreopsis* 'Sunray' at 16 leaves (Cameron et al., 1996) and *Pericallis* 'Cindy Blue' at 6-7 leaves (Yeh and Atherton, 1997).

For 'Champion Blue' and 'Champion Pink' days to visible bud and anthesis were reduced by the 16 h initial photoperiod (Tables 2.1, 2.2, 2.3, 2.4, 2.5 and 2.6). Plants receiving HID supplemental lighting during the 16 h initial photoperiod reduced days to visible bud and anthesis compared to plants not receiving HID supplemental lighting (Tables 2.2, 2.3, 2.5 and 2.6). These results are similar to results obtained with *Pelargonium* (Armitage and Tsujita, 1979; Armitage and Wetzstein, 1984; Carpenter and Rodriguez, 1971; and Quatchak et al., 1986) and *Rosa hybrida* (Tsujita, 1987)

When 'Champion Pink' plants were grown in an 8 h initial photoperiod with HID lighting, stem length was increased due to increased photosynthate production for later stem elongation as compared with no HID lighting (Table 2.5). However, when grown in a 16 h initial photoperiod, HID lighting reduced stem length because the 16 h photoperiod induced flower initiation quickly which directed photosynthates to the reproductive tissue rather than vegetative growth. High light intensities promote sink strength in developing flower buds (Kinet et al., 1985). High intensity discharge lighting also reduced stem lengths in cut roses (Tsujita, 1987). High intensity discharge lighting increased cut stem quality rating in both 'Champion Blue' and 'Champion Pink' and reduced days to anthesis when given during the 16 h initial photoperiod.

The 16 h duration of HID supplemental light intensity did not affect stem length, but increased stem diameter when plants were grown in the 16 h initial photoperiod and transferred into the 16 h final photoperiod. Thus, 16 h of HID supplemental lighting was long enough to increase photosynthesis to compensate for the sink source competition of the vegetative and reproductive tissue. Although several treatments produced high profits, *Campanula* grown in the 8 h initial photoperiod and transferred at 2-3 or 5-6 leaves into the final 16 h photoperiod possessed the most consumer appeal with high profits for growers.

For *Lupinus*, the 16 h initial photoperiod decreased days to anthesis compared to the 8 h initial photoperiod indicating that *Lupinus* is a facultative long day plant (Table 2.7). Flower opening can be delayed when facultative long day plants are exposed unfavorable photoperiods (Kinet et al., 1985). *Lupinus* grown in the 16 h final photoperiod resulted in longer but narrower stems and reduced days to anthesis. *Lupinus* did not exhibit juvenility in the parameters tested in this study. *Lupinus* cut stems were longer and wider when given HID lighting, especially when grown in the 8 or 12 h final photoperiod. High intensity discharge lighting reduced days to anthesis due to increased photosynthesis rates, which is similar to results obtained with *Pelargonium* (Armitage and Tsujita, 1979; Armitage and Wetzstein, 1984; Carpenter and Rodriguez, 1971; and Quatchak et al., 1986) and *Rosa hybrida* (Tsujita, 1987). Profits for *Lupinus* were generally highest when plants were grown continuously in the 16 h photoperiod with HID supplemental lighting.

Conclusion

Campanula medium 'Champion Blue' and 'Champion Pink' were long day plants with the critical photoperiod between 8 and 12 h. Plants exhibited full maturity at 8-9 true leaves.

Commercially, *Campanula* should be grown initially under the vegetative 8 h photoperiod to enhance photosynthetic capacity. Plants should then be transferred at 5-6 true leaves into an inductive 16 h photoperiod for flowering. Highest profits per stem were from plants grown in the initial 8 h photoperiod and transferred at 2-3 or 5-6 true leaves into the 16 h final photoperiod.

High intensity discharge lighting of *Campanula* for an 8 h duration during the initial photoperiods exhibited statistical significance except for percent plants flowered but did not appear to be commercially feasible. The 16 h of HID lighting during the 16 h initial photoperiod increased stem diameter and quality, but not enough to equal that obtained from plants grown in the 8 h initial photoperiod.

Lupinus was a facultative long day plant as it flowered in significantly fewer days under the 16 h photoperiod compared to the 8 and 12 h photoperiods. However, flowering percentage was high (100%) regardless of photoperiod. Juvenility was not apparent within the parameters tested in this study.

Commercially, *Lupinus* should be grown in a continuous 16 h photoperiod to reduce crop time. Transplanting at an early stage (2-3 true leaves) reduced crop time compared to transplanting at later stages probably due to decreased stunting from transplant shock. Direct sowing into the final growing container is recommended.

High intensity discharge supplemental lighting increased *Lupinus* stem length and stem diameter and decreased days to anthesis. The benefits of increased light intensity warrant the use of HID lighting to improve crop quality and profitability.

Literature Cited

Armitage, A.M. 1991. Shade effects yield and stem length of field-grown cut-flower species. HortScience 26:1174-1176.

Armitage, A. M. and M. J. Tsujita. 1979. The effect of supplemental light source, illumination and quantum flux density on the flowering of seed propagated geranium. J. Hort. Sci. 54:195-198.

Armitage, A. M. and H. Y. Wetzstein. 1984. Influence of light intensity on flower initiation and differentiation in hybrid geranium. Hortscience 19:114-116.

Armitage, A.M., N.G. Seager, I.J. Warrington and D.H. Greer. 1990. Response of *Oxypetalum caeruleum* to irradiance, temperature and photoperiod. J. Amer. Soc. Hort. Sci. 115:910-914.

Blom, T. J., 1998. Light Fixture Maintenance. AERGC Greenhouse Newsletter 11:1-3.

Brumfield, R.G. , P.V. Nelson, A.J. Coutu, D.H. Willits and R.S. Sowell. 1982. Overhead Cost and Greenhouse Firms Differentiated By Size of Firm and Market Channel. N.C. Agr. Res. Ser. Tech. Bul. No. 269.

Bugbee, B., 1994. Effects of Radiation Quality, Intensity, and Duration on Photosynthesis and Growth, pp. 39-50. In: Proceedings of International Lighting in Controlled Environments workshop. NASA-CP-953309.

Cameron, A. M. Yuan, R. Heins and W. Carlson. 1996. Juvenility: your perennial crop's age affects flowering. GrowerTalks 6(8):30-32,34.

Carpenter, W. J. and R. C. Rodriguez. 1971. Earlier flowering of geranium cv. 'Carefree Scarlet' by high intensity of supplemental light treatment. Hortscience 5:183-184.

Carpenter, W.J. 1976. Photosynthetic supplementary lighting of spray pompon, *Chrysanthemum morifolium* Ramat. J. Amer. Soc. Hort. Sci. 101:155-158.

Cockshull, K.E. 1985. *Antirrhinum majus*, pp. 476-481. In: Handbook of Flowering, vol. III, A.H. Halevy, ed., CRC Press, Boca Rotan, Fla.

Damann, M.P. and R.E. Lyons. 1995. Juvenility and photoperiodic flowering requirements of *Chrysanthemum x superbum* 'G. Marconi' and 'Snow Lady' grown under short- and long-day conditions. J. Amer. Hort. Sci. 120:241-245.

Griffiths, M. 1995. Royal Horticultural Society Index of garden plants. Timber Press, Portland, Ore.

Kinet, J., R. M. Sachs and G. Bernier. 1985. Control by light, pp.64-88. In: The Physiology of Flowering. vol. III, CRC Press, Boca Raton, Fla.

Moe, R. and R. Heins. 1990. Control of Plant Morphogenesis and Flowering by Light Quality and Temperature. Acta Hort. 272:81-89.

Quatchak , D. J., J. W. White and E. J. Holcomb. 1986. Temperature, supplemental lighting and chlormequat chloride effects on flowering of geranium seedlings. J. Amer. Soc. Hort. Sci. 111:376-379.

Rahman, M.S. and F.S. Gladstone. 1974. Effects of temperature and photoperiod on flowering and yield components of lupin genotypes in the field. Austral. J. Exp. Agric. Anim. Husb. 14:205-213.

Tsujita, M. J. 1987. High intensity supplementary radiation of roses, pp.171-186. In: Roses. R. W. Langhans, ed., Roses Inc., Haslett, Michigan.

United States Bureau of the Census, Statistical Abstract of the United States: 1998 (118th edition) Washington, DC, 1998.

Wellensiek, S.J. 1985. Campanula medium, pp.123-126. In: Handbook of Flowering, vol. II, A.H. Halevy, ed. CRC Press, Boca Raton, Fla.

Wilkins, H.F. and W. E. Healy. 1980. Influence of low light on rose branching. Roses Inc. Bulletin May p.75.

Yeh, D.M. and J.G. Atherton. 1997. Manipulation of flowering in cineraria. II. Juvenility. J. Hort. Sci. 72:55-66.

Table 2.1. Effect of 8, 12 and 16 h photoperiods and transplant stages[z] on flower quality and crop time for *Campanula medium* 'Champion Blue'. Plants were moved from initial to final photoperiod at the time of transplanting. Means are an average of data from 64 to 72 plants per treatment. Year one.

Initial photoperiod	Transplant stage[z]	Final photoperiod	Plants flowered (%)	Stem length (cm)	Stem diameter (mm)	Quality rating[y]	Sowing to visible bud[x] (days)	Sowing to anthesis (days)	Visible bud to anthesis[x] (days)	Profit per flower harvested[w] ($)
8	2-3	8	7	-[v]	-	-	234	250	-	-0.05
		12	90	42.3	9.4	3.8	180	193	15	0.19
		16	100	40.2	3.7	4.2	112	135	23	0.38
	5-6	8	1	-	-	-	235	240	-	-0.01
		12	95	43.9	8.9	3.9	175	191	16	0.21
		16	99	43.6	4.9	4.1	143	160	18	0.30
	8-9	8	1	48.0	7.0	5.0	182	198	16	0.00
		12	94	45.5	7.9	3.7	181	198	18	0.19
		16	100	40.8	7.0	4.0	160	178	18	0.26
16	2-3	8	64	25.7	4.9	3.0	127	148	21	0.15
		12	94	27.8	4.7	3.8	117	132	22	0.27
		16	100	29.8	3.5	3.8	101	125	24	0.30
	5-6	8	90	26.7	3.3	2.9	118	140	22	0.24
		12	97	25.9	3.0	3.4	108	130	22	0.28
		16	100	31.2	2.7	2.8	115	138	23	0.27
	8-9	8	100	27.2	4.2	3.0	126	149	24	0.24
		12	100	26.9	2.8	3.2	112	134	22	0.28

	16	100	30.3	3.0	3.1	115	138	23	0.27
Initial Photoperiod(I)		0.0001	0.0001	0.0001	0.0006	0.000 1	0.0001	0.0001	0.0001
Transplant (T)									
Linear (L)		0.0087	NS	NS	NS	0.0001	0.0001	NS	0.0001
Quadratic (Q)		NS	NS	0.0004	NS	NS	NS	NS	0.0001
Final Photoperiod (F)									
L		0.0001	0.0001	NS	0.0027	NS	NS	NS	0.0001
Q		NS	0.0006	0.0001	0.0186	0.0007	0.0002	0.0007	0.0001
I*TL		NS	NS	0.0002	NS	0.0002	0.0017	NS	0.0001
I*TQ		NS	NS	0.0126	NS	NS	NS	NS	0.0001
I*FL		0.0001	0.0265	0.0002	NS	0.0001	0.0001	NS	NS
I*FQ		NS	NS	NS	NS	NS	NS	NS	0.0001
TL*FL		NS	NS	0.0026	NS	0.0008	0.0117	NS	0.0001
TQ*FQ		NS	NS	NS	NS	NS	NS	NS	0.0001
TL*FQ		NS	NS	0.0001	NS	0.0006	0.0110	NS	0.0001
TQ*FL		NS	NS	NS	NS	0.0006	0.0045	NS	0.0001
I*TL*FL		NS	NS	0.0002	NS	0.0014	0.0069	NS	0.0001
I*TQ*FL		NS	NS	NS	NS	NS	NS	NS	0.0001
I*TL*FQ		NS	NS	NS	NS	NS	NS	NS	0.0001
I*TQ*FQ		NS	NS	NS	NS	NS	NS	NS	0.0001

[z] Number of true leaves

[y] 1-5 rating with 5 being best being highest quality

[x] Campanula seed were sown on 12 September 1997

[w] production cost – sales = profit or loss

[v] inflorescences did not reach anthesis prior to termination of experiment

Table 2.2. Effect of initial photoperiod and 8 h supplemental light intensity on flower quality and crop time for *Campanula medium* 'Champion Blue'. Plants were transplanted at the appearance of 5-6 true leaves and placed in 16 h final photoperiod. Means are an average of data from 64 to 72 plants per treatment. Year two 8 h HID duration.

Initial photoperiod	Supplemental lighting[z]	Plants flowered (%)	Stem length (cm)	Stem diameter (mm)	Quality rating[y]	Sowing to visible bud[x] (days)	Sowing to anthesis (days)	Visible bud to anthesis (days)	Profit per flower harvested[w] ($)
8	Yes	97	63.3	6.8	4.5	111	127	16	0.39
	No	100	62.9	6.5	4.4	114	129	15	0.39
16	Yes	97	39.8	4.8	2.9	91	108	16	0.44
	No	100	42.7	5.4	3.2	107	122	14	0.41
Initial Photoperiod (I)		NS	0.0001	0.0001	NS	0.0001	0.0001	NS	0.0001
Light intensity (H)		NS	NS	NS	0.0001	0.0001	0.0001	0.0010	0.0001
I*H		NS	0.0001	0.0004	0.0014	0.0001	0.0001	NS	0.0001

[z] Presence or absence of HID supplemental lighting

[y] 1-5 rating with 5 being best being highest quality

[x] Campanula seed were sown on 2 December 1998

[w] production cost – sales = profit or loss

Table 2.3. Effect of 8 and 16 h initial photoperiods, 8 or 16 h supplemental light intensity and transplant stages[y] on flower quality and crop time for *Campanula medium* 'Champion Blue'. After transplanting, plants were placed in 16 h photoperiod. Means are an average of data from 53 to 60 plants per treatment. Year two.

Initial photoperiod	Supplemental lighting[z]	Transplant stage[y]	Plants flowered (%)	Stem length (cm)	Stem diameter (mm)	Quality rating[x]	Sowing to visible bud[w] (days)	Sowing to anthesis[x] (days)	Visible bud to anthesis (days)	Profit per flower harvested[v] ($)
8	Yes	2-3	100	47.4	4.8	3.7	101	118	16	0.42
		5-6	100	49.2	5.6	3.7	114	131	16	0.39
		8-9	100	73.3	7.5	4.4	122	145	23	0.35
	No	2-3	98	45.1	5.0	3.5	107	122	15	0.40
		5-6	100	59.2	6.1	4.0	116	135	18	0.38
		8-9	98	69.3	7.5	4.2	126	148	23	0.33
16	Yes	2-3	97	47.2	5.1	3.8	98	112	15	0.43
		5-6	100	45.5	5.5	3.9	88	105	17	0.46
		8-9	100	47.9	5.4	4.0	95	112	17	0.44
	No	2-3	100	53.4	4.8	3.6	104	118	14	0.42
		5-6	98	49.8	4.6	3.2	111	127	16	0.39
		8-9	100	46.2	4.1	3.3	107	123	15	0.41
Initial Photoperiod(I)			NS	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Transplant (T)										
Linear (L)			NS	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Quadratic (Q)			NS	0.0128	NS	NS	NS	NS	NS	0.0001

Light intensity (H)	NS	NS	0.0101	0.0001	0.0001	0.0001	NS	0.0001
I*TL	NS	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
I*TQ	NS	NS	0.0165	NS	NS	NS	0.0054	0.0001
I*H	NS	NS	0.0003	0.0004	0.0002	0.0009	NS	0.0001
H*TL	NS	0.0456	0.0216	NS	NS	NS	NS	0.0001
H*TQ	NS	0.0006	NS	NS	0.0169	0.0026	NS	0.0001
H*I*TL	NS	NS	NS	NS	NS	NS	NS	0.0001
H*I*TQ	NS	0.0074	NS	0.0178	0.0011	0.0038	NS	0.0001

[z] Presence or absence of HID supplemental lighting

[y] Number of true leaves

[x] 1-5 rating with 5 being best being highest quality

[w] Campanula seed were sown on 27 August 1998

[v] production cost – sales = profit or loss

Table 2.4. Effect of 8, 12 and 16 h photoperiods and transplant stages[z] on flower quality and crop time for *Campanula medium* 'Champion Pink'. Plants were moved from initial to final photoperiod at the time of transplanting. Means are an average of data from 71 to 72 plants per treatment. Year one.

Initial photoperiod	Transplant stage[z]	Final photoperiod	Plants flowered (%)	Stem length (cm)	Stem diameter (mm)	Quality rating[y]	Sowing to visible bud[x] (days)	Sowing to anthesis (days)	Visible bud to anthesis (days)	Profit per flower harvested[w] ($)
8	2-3	8	17	46.0	12.4	3.4	202	229	27	0.02
		12	88	40.4	9.5	3.7	187	198	16	0.18
		16	100	37.1	3.9	4.0	123	144	21	0.25
	5-6	8	19	53.6	11.4	4.4	219	229	20	0.02
		12	81	39.2	9.2	3.8	185	198	16	0.16
		16	100	39.2	4.9	3.5	149	165	16	0.29
	8-9	8	11	51.5	10.3	4.0	225	241	26	0.01
		12	96	40.8	8.3	3.5	190	204	17	0.18
		16	100	47.5	7.5	4.1	167	188	20	0.23
16	2-3	8	63	37.9	8.8	3.6	183	198	19	0.06
		12	94	37.3	8.1	3.9	173	191	18	0.11
		16	100	31.9	4.0	3.5	121	141	20	0.26
	5-6	8	82	24.7	3.8	3.0	122	144	23	0.21
		12	89	22.8	3.2	3.3	116	139	23	0.24
		16	100	19.9	3.3	3.0	125	145	20	0.25
	8-9	8	100	24.5	3.1	2.5	125	150	25	0.23
		12	97	20.6	3.1	2.9	122	143	21	0.25

	16	100	24.4	3.1	2.8	124	148	24	0.24
Initial Photoperiod (I)		0.0369	0.0053	0.0004	0.0126	0.0001	0.0002	0.0107	0.0001
Transplant (T)									
Linear (L)		NS	0.0249	0.0012	0.0099	0.0039	0.0256	0.0466	0.0001
Quadratic (Q)		NS	NS	0.0130	NS	0.0006	0.0001	NS	0.0001
Final Photoperiod (F)									
L		0.0003	NS	0.0156	NS	0.0045	0.0171	NS	0.0001
Q		NS	NS	0.0131	NS	0.0167	0.0357	0.0077	0.0001
I*TL		NS	0.0010	0.0001	0.0315	0.0001	0.0001	0.0446	0.0001
I*TQ		NS	NS	0.0398	NS	0.0002	0.0006	NS	0.0001
I*FL		NS	NS	0.0037	NS	0.0006	0.0025	NS	NS
I*FQ		NS	NS	NS	NS	NS	NS	0.0482	0.0001
TL*FL		NS	0.0201	0.0002	NS	0.0001	0.0001	NS	0.0001
TL*FQ		NS	NS	0.0135	NS	0.0003	0.0001	NS	0.0001
TQ*FL		NS	NS	NS	NS	0.0003	0.0001	NS	0.0001
TQ*FQ		NS	NS	NS	NS	0.0075	NS	NS	0.0001
I*TL*FL		NS	NS	NS	NS	0.0079	0.0060	NS	0.0001
I*TQ*FL		NS	NS	0.0433	NS	0.0009	0.0036	NS	0.0001
I*TL*FQ		NS	NS	NS	NS	NS	NS	NS	0.0001
I*TQ*FQ		NS	NS	NS	NS	NS	0.0264	NS	0.0001

[z] Number of true leaves

[y] 1-5 rating with 5 being best being highest quality

[x] Campanula seed were sown on 12 September 1997

[w] production cost – sales = profit or loss

Table 2.5. Effect of initial photoperiod and 8 h supplemental light intensity on flower quality and crop time for *Campanula medium* 'Champion Pink'. Plants were transplanted at the appearance of 5-6 true leaves and placed in 16 h final photoperiod. Means are an average of data from 68 to 72 plants per treatment. Year two 8 h HID duration.

Initial photoperiod	Supplemental Lighting[z]	Plants flowered (%)	Stem length (cm)	Stem diameter (mm)	Quality rating[y]	Sowing to visible bud[x] (days)	Sowing to anthesis (days)	Visible bud to anthesis (days)	Profit per flowered harvested[w] ($)
8	Yes	100	58.0	6.9	4.1	118	132	14	0.38
	No	100	56.8	7.3	4.1	116	132	16	0.38
16	Yes	97	46.5	6.5	3.3	107	122	15	0.40
	No	100	55.0	6.4	3.8	114	129	15	0.39
Initial Photoperiod (I)		NS	0.0001	0.0011	0.0001	0.0001	0.0001	NS	0.0001
Light intensity (H)		NS	0.0098	NS	0.0121	NS	0.0057	0.0019	0.0001
I*H		NS	0.0004	NS	NS	0.0001	0.0039	0.0141	0.0001

[z] Presence or absence of HID supplemental lighting

[y] 1-5 rating with 5 being best being highest quality

[x] Campanula seed were sown on 2 December 1998

[w] production cost – sales = profit or loss

Table 2.6. Effect of 8 and 16 h initial photoperiods, 8 or 16 h supplemental light intensity and transplant stages[y] on flower quality and crop time for *Campanula medium* 'Champion Pink'. After transplanting, plants were placed in 16 h photoperiod. Means are an average from 51 to 60 plants per treatment. Year two 8 and 16 h light intensity.

Initial photoperiod	Supplemental lighting[z]	Transplant stage[y]	Plants flowered (%)	Stem length (cm)	Stem diameter (mm)	Quality rating[x]	Sowing to visible bud[w] (days)	Sowing to anthesis (days)	Visible bud to anthesis (days)	Profit per flower harvested[v] ($)
8	YES	2-3	100	51.6	5.3	3.8	110	127	17	0.40
		5-6	100	54.8	7.0	4.2	119	138	19	0.37
		8-9	100	67.7	8.5	4.4	128	153	25	0.33
	NO	2-3	100	46.9	5.3	3.6	112	129	18	0.39
		5-6	100	52.7	6.4	3.9	120	140	19	0.36
		8-9	100	74.3	7.4	4.1	125	149	24	0.34
16	YES	2-3	94	44.4	5.7	3.5	111	127	16	0.37
		5-6	98	46.7	5.6	3.8	108	124	16	0.40
		8-9	100	52.4	6.2	3.9	104	122	17	0.41
	NO	2-3	98	46.3	5.2	3.5	109	125	16	0.39
		5-6	98	49.7	5.7	3.3	124	144	20	0.34
		8-9	97	53.6	5.7	3.8	118	136	18	0.36
Initial Photoperiod(I)			NS	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Transplant (T)										
Linear (L)			NS	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Quadratic (Q)			NS	0.0227	NS	NS	0.0290	NS	NS	0.0001

Light intensity (H)	NS	NS	0.0120	0.0005	0.0017	0.0012	NS	0.0001
I*TL	NS	0.0004	0.0001	NS	0.0002	0.0001	0.0002	0.0001
I*TQ	NS	NS	NS	NS	NS	0.0130	0.0266	0.0001
I*H	NS	NS	NS	NS	0.0020	0.0016	NS	0.0001
H*TL	NS	NS	NS	NS	NS	NS	NS	0.0001
H*TQ	NS	NS	NS	NS	0.0402	0.0223	NS	0.0001
H*I*TL	NS	NS	NS	NS	0.0032	0.0032	NS	0.0001
H*I*TQ	NS	NS	NS	NS	NS	NS	NS	0.0001

[z] Presence or absence of HID supplemental lighting

[y] Number of true leaves

[x] 1-5 rating with 5 being best being highest quality

[w] Campanula seed were sown on 27 August 1998

[v] production cost – sales = profit or loss

Table 2.7. Effect of 8, 12 and 16 h photoperiods, and transplant stages[z] on flower quality and crop time for *Lupinus hartwegii* 'Bright Gems'. Plants were moved from initial to final photoperiod at the time of transplanting. Means are an average of data from 51 to 59 plants per treatment. Year one.

Initial photoperiod	Transplant stage[z]	Final photoperiod	Plants flowered (%)	Stem length (cm)	Stem diameter (mm)	Quality rating[y]	Sowing to visible bud[x] (days)	Sowing to anthesis (days)	Visible bud to anthesis (days)	Profit per flower harvested[w] ($)
8	2-3	8	98	46.4	7.9	3.3	151	170	18	0.27
		12	100	56.5	6.8	3.2	72	188	17	0.23
		16	100	59.5	7.9	3.5	144	160	17	0.31
	5-6	8	100	48.0	8.2	3.5	160	178	17	0.26
		12	100	59.3	7.5	3.5	170	185	15	0.24
		16	100	59.6	7.5	3.6	152	169	17	0.28
	8-9	8	100	44.3	8.1	3.3	172	187	15	0.23
		12	100	50.2	6.9	3.3	161	175	15	0.26
		16	100	56.6	6.7	3.3	154	170	16	0.28
16	2-3	8	100	50.9	8.9	4.1	158	177	18	0.26
		12	100	56.9	7.5	3.2	177	193	17	0.21
		16	96	57.4	7.5	3.5	137	154	16	0.31
	5-6	8	100	54.1	8.9	4.0	172	188	16	0.23
		12	98	60.2	8.2	3.4	160	175	14	0.26
		16	100	62.7	7.8	3.6	151	167	16	0.29
	8-9	8	100	45.7	8.1	3.6	157	175	17	0.26
		12	100	54.6	7.7	3.4	160	176	15	0.26

	16	100	60.3	7.0	3.4	161	177	16	0.26
Initial Photoperiod(I)		NS	NS	0.0233	0.0006	NS	NS	NS	0.0001
Transplant (T)									
Linear (L)		NS	0.0369	NS	NS	0.0414	NS	0.0234	0.0001
Quadratic (Q)		NS	NS	NS	0.0291	NS	NS	NS	0.0001
Final Photoperiod (F)									
L		NS	0.0001	0.0002	NS	0.0005	0.0002	NS	0.0001
Q		NS	0.0188	0.0152	0.0063	0.0006	0.0013	0.0041	0.0001
I*TL		NS	NS	NS	NS	NS	NS	NS	0.0001
I*TQ		NS	NS	NS	NS	NS	NS	NS	0.0001
I*FL		NS	NS	NS	0.0005	NS	NS	NS	0.0001
I*FQ		NS	NS	NS	0.0071	NS	NS	NS	0.0001
TL*FL		NS	NS	NS	NS	NS	NS	NS	0.0001
TL*FQ		NS	NS	NS	NS	0.0001	0.0001	NS	0.0001
TQ*FL		NS	NS	NS	NS	NS	NS	NS	0.0001
TQ*FQ		NS	NS	NS	NS	NS	NS	NS	0.0001
I*TL*FL		NS	NS	NS	NS	0.0092	0.0121	NS	0.0001
I*TQ*FL		NS	NS	NS	NS	NS	NS	NS	0.0001
I*TL*FQ		NS	NS	NS	NS	NS	NS	NS	0.0001
I*TQ*FQ		NS	NS	NS	NS	NS	NS	NS	0.0001

[z] Number of true leaves

[y] 1-5 rating with 5 being best being highest quality

[x] Lupinus seed were sown on 12 September 1997

[w] production cost – sales = profit or loss

Table 2.8. Effect of 8, 12 and 16 h final photoperiods, supplemental light intensity and transplant stages on flower quality and crop time for *Lupinus hartwegii* 'Bright Gems'. Plants were transferred from a 16 h initial photoperiod to final photoperiod at the time of transplanting. Means are an average of data from 62 to 72 plants per treatment. Year two.

Transplant stage[z]	Final photoperiod	Supplemental lighting[y]	Plants flowered (%)	Stem length (cm)	Stem diameter (mm)	Quality rating[x]	Sowing to visible bud[w] (days)	Sowing to anthesis (days)	Visible bud to anthesis (days)	Profit per flower harvested[v] ($)
2-3	8	Yes	99	64.0	9.7	3.9	141	156	15	0.31
2-3	12		100	78.9	8.6	4.1	133	148	15	0.34
2-3	16		100	79.2	8.0	3.8	137	152	15	0.33
2-3	8	No	100	61.1	9.2	3.9	146	160	14	0.31
2-3	12		100	77.5	8.9	3.9	139	153	14	0.33
2-3	16		100	84.7	7.9	3.7	131	146	15	0.34
5-6	8	Yes	100	61.1	9.3	4.0	135	149	14	0.34
5-6	12		100	77.1	8.5	3.9	131	147	16	0.34
5-6	16		100	79.6	8.5	4.0	128	144	15	0.35
5-6	8	No	100	54.9	8.6	3.6	151	165	13	0.29
5-6	12		100	75.5	7.6	3.5	144	156	13	0.32
5-6	16		100	78.7	7.3	3.4	141	157	15	0.31
8-9	8	Yes	100	63.7	9.2	4.0	138	153	15	0.33
8-9	12		100	78.9	8.8	4.3	119	135	16	0.38
8-9	16		100	81.6	8.5	4.2	128	142	15	0.36
8-9	8	No	100	57.1	7.8	3.5	142	155	13	0.32
8-9	12		100	73.4	7.8	3.7	140	156	16	0.32

8-9	16	100	76.3	7.8	3.7	133	147	14	0.34
Transplant (T)									
Linear (L)		NS	0.0260	NS	NS	0.0209	0.0197	NS	0.0001
Quadratic (Q)		NS	0.0158	NS	0.0072	NS	NS	NS	0.0001
Final Photoperiod (F)									
L		NS	0.0001	0.0003	NS	0.0001	0.0009	NS	0.0001
Q		NS	0.0001	NS	NS	NS	NS	NS	0.0001
Light intensity		NS	0.0166	0.0006	0.0001	0.0002	0.0003	0.0339	0.0001
TL*FL		NS	NS	0.0104	0.0252	NS	NS	NS	NS
TL*FQ		NS	NS	NS	NS	NS	NS	NS	NS
TL*H		NS	0.0032	0.0181	0.0023	NS	NS	NS	0.0001
TQ*FL		NS	NS	NS	NS	NS	NS	NS	0.0001
TQ*FQ		NS	NS	NS	0.0267	NS	NS	NS	0.0001
TQ*H		NS	NS	NS	NS	0.0150	0.0202	NS	0.0001
FL*H		NS	NS	NS	NS	NS	NS	NS	0.0001
FQ*H		NS	NS	NS	NS	NS	NS	NS	0.0001
TL*FL*H		NS	0.0424	NS	NS	NS	0.0121	NS	0.0001
TL*FQ*H		NS	NS	NS	NS	NS	NS	NS	0.0001
TQ*FL*H		NS	NS	NS	NS	NS	NS	NS	0.0001
TQ*FQ*H		NS	NS	NS	NS	NS	0.0321	0.0113	0.0001

[z] Number of true leaves

[y] Presence or absence of HID supplemental lighting

[x] 1-5 rating with 5 being best being highest quality

[w] Lupinus were sown 14 October 1998

[v] production cost – sales = profit or loss

CHAPTER III

COLD PRETREATMENT, PLANTING DEPTH AND SHADING AFFECT FLOWERING RESPONSE AND PERENNIALIZATION OF FIELD GROWN DUTCH BULBS

Todd J. Cavins and John M. Dole. Department of Horticulture and Landscape Architecture, Oklahoma State University, Stillwater, OK 74078-6027.

Additional Index Words. *Hyacinthoides hispanica*, *Hyacinthus* 'Gypsy Queen', *Narcissus* 'Music Hall', *Narcissus* 'Tahiti', *Tulipa* 'Couleur Cardinal', *Tulipa* 'White Emperor'

Abstract. *Hyacinthoides hispanica*, *Hyacinthus* 'Gypsy Queen', *Narcissus* 'Music Hall', *Narcissus* 'Tahiti', *Tulipa* 'Couleur Cardinal' and *Tulipa* 'White Emperor' bulbs were given 0 or 6 weeks of preplant 5°C cold treatment and planted into raised ground beds at 15, 30 or 45 cm depths under 0, 30 or 60 % shade. Greatest percentage of bulbs flowered when planted 15 cm deep. The 45 cm planting depth reduced bulb flowering percentage or did not allow plant emergence. Preplant 5°C cold pretreatment reduced percentage of bulbs flowering for *Narcissus* 'Tahiti', *Tulipa* 'Couleur Cardinal' and *Tulipa* 'White Emperor' but did not affect *Hyacinthoides*, *Hyacinthus* 'Gypsy Queen' and *Narcissus* 'Music Hall' percentage of bulbs flowering. Cold pretreatment also delayed anthesis and

produced shorter stem lengths for all cultivars except *Hyacinthoides hispanica* and *Narcissus* 'Music Hall'. Increasing shade increased stem lengths but did not encourage perennialization.

Introduction

Many flowers produced by Dutch bulbs are favorites in the cut flower industry. Numerous bulb species can be grown in Oklahoma and surrounding states, but are often treated as annuals due to inconsistent perennialization. High bulb cost limits profitable annual production. Bulb perennialization and yield of flowers for two or more years would allow cost effective production. Possible reasons for lack of perennialization include: inadequate duration of cold, improper planting depth, and excessive summer heating (Armitage, 1993; A. De Hertogh, personal communication).

Proper temperatures are the most important factor for bulb flowering and production (Buschman and Roozen, 1980; De Hertogh, 1996; Hartsema, 1961; Rees, 1972a). Cool storage temperatures promote rapid growth after planting and faster plant elongation. *Tulipa* bulbs stored at 10°C for 20 weeks flowered faster and produced longer stems than those stored for 5 weeks at 10°C (Le Nard and De Hertogh, 1993). Low temperature storage before planting improves root development at growing temperatures as high as 30°C compared to the optimum rooting temperature of 13-17°C (Jennings and De Hertogh, 1977; Le Nard and De Hertogh, 1993).

Proper daughter bulb formation is crucial for perennialization in that the daughter bulb replaces the mother bulb at the end of the growing season. Extended foliage life allows leaves to contribute to the photosynthate storage of bulbs. Stored photosynthates are responsible for daughter bulb formation. Aung et al. (1973) reported that 83% of the starch in the matured bulblets was derived from photosynthesis. Early senescence of roots from warm temperatures also deprive daughter bulbs of essential nutrients for development (Le Nard and De Hertogh, 1993). Plants senesce early during early hot dry summers which reduces bulb yields (Rees, 1972a)

Deep planting depths may improve perennialization. Shallow planting causes poor rooting and increased probability of disease due to the higher soil temperatures (Le Nard and De Hertogh, 1993). Soil temperatures stay cool for longer periods of time at deep depths. If the bulbs are planted at deep depths, the bulb will remain cool longer which may simulate a longer spring season than shallow planting depths. However, planting bulbs too deep delays emergence, flowering and decreases yield (Allen, 1938; Le Nard and De Hertogh, 1993; Wallis, 1964).

Finally, reducing light intensity through shading may help the soil to remain cool while protecting the foliage from excessive heat. Thus, the foliage may live longer and continue to produce photosynthates for daughter bulb growth. However, while excessive shading decreases flower quality in many species, hyacinths have been shown to flower in darkness (Armitage, 1991; Nowak and Rudnicki, 1993). Flowering in darkness would indicate a very low light saturation point. Wassink (1965) also showed that tulips were able to flower, elongate (grow), and produce bulblets in the absence of light. Bulbs are able to continue development by using mother bulb photosynthate reserves (Le Nard and De Hertogh, 1993).

Shading also increases stem length (Armitage, 1991; Armitage et al., 1990; Gude et al., n.d.). Most plant species produce fewer flowers, but longer stems when subjected to shade. However, flower number per plant of *Anemone coronaria*, a bulbous species, did not decrease when given 67% shade and produced a longer stem at reduced light levels (Armitage, 1991).

The following bulb species have similar growing requirements and show potential as cut flowers. *Hyacinthoides hispanica* (Mill.) Roth. and *Hyacinthus* L. 'Gypsy Queen' have been favorites for many years in the floral industry due to their fragrance and unique shape. The campanulate flowers are born along racemes (Griffiths, 1995). Gude et al., (n.d.) showed that reduced light intensity increased stem length but decreased flower pigmentation. Hyacinths require sufficient light for photosynthesis but are day neutral plants (Nowak and Rudnicki, 1993). No published information exists on the field production of hyacinths in Oklahoma or surrounding states.

Narcissus L. 'Music Hall' and *Narcissus* L. 'Tahiti' are popular garden plants. The perianth of 'Music Hall' is cream colored with a yellow corona. 'Tahiti' is a yellow double petaled flower with a red center (De Hertogh, 1996). Although no specific information for successful perennialization in Oklahoma or surrounding states is available, *Narcissus* generally naturalize well in Oklahoma (P. Mitchell, personal communication)

Tulipa L. 'Couleur Cardinal' and *Tulipa* L. 'Emperor White' were chosen because tulips have long been the most popular of the bulbous species for cut flowers. The solitary flowers are bell or cup shaped (Griffiths, 1995). Temperature is the most important factor for flower initiation in tulips (Rees, 1972a). Increased light intensity reduces stem length and stem toppling (Gude et al., n.d.). It has been suggested that when using tulips as cut flowers that they should be treated as annuals due to inconsistent perennialization (Armitage, 1993).

The objective of this study was to determine which cold pretreatments, planting depths and shade amounts promote perennialization, therefore increasing grower profit, of *Hyacinthoides, Hyacinthus, Narcissus* and *Tulipa* cut flowers in the southern plains region of the United States.

Materials and Methods

Bulbs were divided into two groups, one half receiving six weeks preplant cooling at 5°C and one half receiving no preplant cooling. The preplant cold treatment began at the same time that the uncooled bulbs are planted in the ground. Bulbs were stored at 18°C prior to planting or cold treatment.

Bulbs were planted at 15, 30 or 45 cm. Depths were measured from the bottom of the bulb to the surface of the soil. Three levels of shade were provided, 0, 30 and 60% providing average light intensities of 1480, 831 and 331 $\mu mol \cdot m^{-2} \cdot s^{-1}$ respectively. The shade was supplied by woven polypropylene cloth covering the top and south side of the raised beds.

Location of plots was Stillwater, Oklahoma with USDA climatic zone of 6b-7a. The bulbs were grown in raised field beds of Norge Loam (fine-silty, mixed, thermic Udic Paleustolls) with a soil pH adjusted to 6.4. Based on soil fertility analysis, amendments included 4 $g \cdot m^{-2}$ NH_3NO_3 for nitrogen, 25 $g \cdot m^{-2}$ $CaCO_3$ to adjust soil pH and 74 $g \cdot m^{-2}$ bone meal as a slow release source of nitrogen and phosphorus. Data collected included: percent bulbs flowering, stem length (*Hyacinthoides*, *Hyacinthus* and

Narcissus: from soil line to upper-most tip; *Tulipa*: from node of wrapper leaf to upper-most tip) and daily soil temperatures at 15, 30 and 45 cm depth (Table 3.1). The experiment was a split plot design with shade treatments representing the main plot with four repetitions. Depth and cold pretreatment represented the subplots. Data were collected for two growing seasons and analyzed by the general linear model procedure (SAS Insitute, Cary, NC.).

Results

HYACINTHOIDES HISPANICA

Percent bulbs flowered. Increasing planting depths linearly reduced bulb flowering percentages (Table 3.2).

Days to anthesis. Bulbs planted at the 30 cm planting depth increased days to anthesis compared to bulbs planted at the 15 cm planting depth. Flowering did not occur for bulbs planted at the 45 cm depth.

Stem lengths. Increasing planting depths and increasing shade generally decreased stem lengths.

Quality rating. Quality rating was unaffected by treatments.

Days to foliage senescence. In year one, shade and shallow planting depths delayed foliage senescence.

In year two, no treatments were significant for the parameters tested as bulbs from only two treatments survived into the second year.

HYACINTHUS 'GYPSY QUEEN'

Percent bulbs flowered. Increasing planting depth linearly reduced bulb flowering in both years (Table 3.3).

Days to anthesis. Cold pretreatment and planting depth interacted such that bulbs receiving the cold pretreatment and deeper planting depths required more days to reach anthesis compared to bulbs not receiving the cold pretreatment and planted at the 15 cm depths. Increasing shade delayed days to anthesis. In year two, bulbs exposed to cold pretreatment before planting in year one took more days to reach anthesis than bulbs not previously receiving the cold treatment. Increasing planting depth also delayed anthesis.

Stem length. Stem length was unaffected by shade treatments in year one, but in year two bulbs grown under shade resulted in longer stems

Quality rating. Quality rating was unaffected by treatments in both years.

Days to foliage senescence. Days to foliage senescence was unaffected by treatments.

NARCISUS 'MUSIC HALL'

Percent bulbs flowered. In year one, shade decreased percentage of bulbs flowering (Table 3.4). Increasing planting depth reduced bulb flowering percentage in both years.

Days to anthesis. In year one, flowering was delayed under 60% shade when given cold pretreatment. Increasing planting depth increased days to anthesis in both years.

Stem length. Stem length increased with increasing shade in both years.

Quality rating. Cut stem quality increased with increasing shade in both years. In year two, quality ratings for the 45 cm planting depth decreased compared to shallower planting depths.

Days to foliage senescence. In year one days to foliage senescence was unaffected by treatments. In year two, deep planting depths delayed foliage senescence.

NARCISUS 'TAHITI'

Percent bulbs flowered. In year one, planting depth interacted with cold pretreatment such that 30 and 45 cm planting depths and cold pretreatment reduced bulb flowering percentage compared to bulbs planted at 15 cm not receiving the cold pretreatment (Table 3.5). In year two, increasing planting depth decreased percentage of bulbs flowering.

Days to anthesis. Increasing planting depth delayed anthesis in both years. In year two, cold pretreatment increased days to anthesis for bulbs planted at 15 and 30 cm. However, the cold pretreatment hastened flowering for bulbs planted at 45 cm. Increasing shade also delayed anthesis.

Stem length In year one, bulbs planted at the 15 cm depth and not receiving the cold pretreatment produced the longest stems, while cold pretreated bulbs planted at the 45 cm planting depth produced the shortest stems. In year two, shading increased stem lengths.

Quality rating. In year one, planting depth interacted with cold pretreatment affecting quality rating such that bulbs receiving cold treatments and 30 and 45 cm planting depths produced the lowest quality ratings. While in year two, bulbs grown under shade increased quality ratings compared to bulbs grown in full light. Quality ratings also increased when plants were planted at the shallow planting depths.

Days to foliage senescence. In year one, days to foliage senescence were unaffected by treatments. In year two, a three way interaction of cold pretreatment, planting depth and shade affected foliage senescence such that bulbs not receiving cold pretreatment when planted at deep planting depths with shade increased days to senescence.

TULIPA 'COULUER CARDINAL'

Percent bulbs flowered. Planting depth interacted with cold pretreatment affecting percentage of bulbs flowering such that deeper planting depth and cold pretreatment reduced bulb flowering percentage compared to bulbs planted at shallow planting depths that did not receive the cold pretreatment (Table 3.6). In year two, deeper planting depths generally decreased the number of bulbs flowering compared to shallower planting depths.

Days to anthesis. In year one, interactions of shading and planting depth occurred. Anthesis was delayed with shading and deep planting depths. Planting depth and cold pretreatment also interacted such that increasing planting depth with cold pretreatment delayed flowering compared to shallow planting depths and no cold pretreatment.

Stem length. In year one, a three way interaction of shading, planting depth and cold pretreatment affected cut stem length such that bulbs planted under 60% shade at 30 cm deep and receiving no cold treatment produced the longest stems. In year two, increasing shade, cold pretreatment and increasing planting depths increased stem length.

Quality rating. In year one, a three way interaction of shading, planting depth, and cold pretreatment affected cut stem quality such that bulbs planted under 60% shade at 30 cm depth and not receiving a cold treatment produced the highest quality rating. In year two, increasing shade and planting depths increased quality rating.

Days to anthesis. Cold pretreatment and planting depth interacted such that plants receiving the cold pretreatment and deeper planting depths delayed flowering compared to plants which did not receive the cold pretreatment and planted at the shallower depths. Shading also increased days to anthesis.

Days to foliage senescence. In year one, cold pretreatment and shade generally delayed foliage senescence. In year two, foliage senescence was unaffected by treatments.

TULIPA 'WHITE EMPEROR'

Percent bulbs flowered. In year one, depth interacted with cold pretreatment such that deeper planting depths and cold pretreatment reduced bulb flowering percentage compared to bulbs planted at shallow planting depths that did not receive the cold pretreatment (Table 3.7). In year two, deeper planting depths decreased the number of bulbs flowering compared to shallower planting depths. Cold pretreatment also decreased the number of bulbs flowering.

Days to anthesis. In year one, an interaction of shading percentage and cold pretreatment increased days to anthesis for bulbs receiving shade and cold pretreatment.

Planting depth also interacted with cold pretreatment. Cold pretreatment increased days to anthesis for bulbs planted at the 15 and 30 cm depths. However, the cold pretreatment hastened flowering for bulbs planted at the 45 cm depth. In year two, bulbs receiving cold pretreatment and deep planting depths increased days to anthesis. Planting depth also interacted with shading such that deep planting depths and shade increased days to anthesis.

Stem length. In year one, a three way interaction of shading, planting depth and cold pretreatment affected stem length. Increasing shade and deep planting depths produced short stems. Cold pretreatment decreased stem length except for bulbs planted under 60 % shade. In year two, shading increased stem length.

Quality rating. In year one, a three way interaction of shading, planting depth and cold pretreatment affected cut stem quality. Shading and deep planting depths generally decreased cut stem quality. The cold pretreatment reduced quality except for bulbs planted at 30 and 45 cm planting depths under 60% shade. In year two, planting depth and shade interacted to affect quality rating such that deep planting depths with shade increased quality rating

Days to foliage senescence. In year one, shade and depth interacted such that shade and deep planting depths delayed foliage senescence. Shade and cold pretreatment interacted such that bulbs given cold pretreatment and grown under shade delayed days to foliage senescence.

Discussion

Planting depth was instrumental in determining the number of bulbs flowering for all species (Tables 3.2, 3.3, 3.4, 3.5, 3.6 and 3.7). Increased planting depth decreased percent bulbs flowering which was noted also by Fodor (1974), Van der Knaap (1969), Van Ouwerkerk (1969) and Wallis (1964). Bulbs planted at 45 cm produced few or no flowers. Bulbs at the 15 cm planting depth generally produced more flowers than at the 30 cm planting depth. *Hyacinthoides hispanica* perennialized only when planted 15 cm deep (Table 3.2).

Planting depth affected days to anthesis such that bulbs planted 30 and 45 cm deep required more days to reach anthesis compared to the 15 cm planting depth (Tables 3.2, 3.3, 3.4, 3.5, 3.6 and 3.7) which was also noted by Allen (1938), Le Nard and De Hertogh (1993), and Wallis (1964). Excessive planting depths delay plant emergence which results in delayed anthesis.

Stem length was affected by planting depth. Results were species specific such that *Hyacinthoides hispanica* (year one), *Narcissus* 'Tahiti' (year two) and *Tulipa* 'White Emperor' (year one) produced shorter stems when planted at 30 and 45 cm compared to the 15 cm planting depth (Tables 3.2, 3.6 and 3.7). At deeper planting depths, more of the stem was submerged under the soil compared to the shallower planting depths. However, *Tulipa* 'Couleur Cardinal' stem lengths were longest when planted at 30 cm (year one) (Table 3.6) and at 45 cm (year two) which is similar to *Narcissus* as noted by Wallis (1964). *Hyacinthus* 'Gypsy Queen' and *Narcissus* 'Music Hall' stem lengths were unaffected by planting depth (Tables 3.3 and 3.4).

Increasing planting depth reduced quality ratings compared to shallower planting depths for *Narcissus* 'Music Hall', *Narcissus* 'Tahiti' and *Tulipa* 'White Emperor' (Tables 3.4, 3.5 and 3.7). The deep planting depths delayed emergence; therefore, flower buds and stems suffered from exposures to sunlight and winds that decreased cut stem quality. However, *Tulipa* 'Couleur Cardinal' (year two) quality ratings were highest when planted at deep depths (Table 3.6). *Hyacinthoides hipspanica* and *Hyacinthus* 'Gypsy Queen' quality ratings were unaffected by planting depth (Tables 3.2 and 3.3).

Deep planting depths delayed foliage senescence for *Hyacinthoides hipspanica, Narcissus* 'Music Hall', *Narcissus* 'Tahiti' and *Tulipa* 'White Emperor'. The deep planting depths delayed the increase of soil temperatures and improved rooting which allowed for extended foliage life (Le Nard and De Hertogh, 1993). *Tulipa* 'Couleur Cardinal' and *Hyacinthus* 'Gypsy Queen' days to foliage senescence was not affected by planting depth (Tables 3.2, 3.3, 3.4, 3.5,3.6 and 3.7).

Providing bulbs with the cold pretreatment affected percentage of bulbs flowering. Percentage of *Narcissus* 'Tahiti', *Tulipa* 'Couleur Cardinal' and *Tulipa* 'White Emperor' bulbs flowering decreased when given the cold pretreatment (Tables 3.5, 3.6 and 3.7). *Hyacinthoides*, *Hyacinthus* 'Gypsy Queen' and *Narcissus* 'Music Hall' flowering percentage was unaffected by cold pretreatment (Tables 3.2, 3.3 and 3.4).

Le Nard and De Hertogh (1993) noted that days to anthesis were generally reduced when bulbs were cold pretreated. However, in our study days to anthesis was delayed by cold pretreatment for all species except *Hyacinthoides hispanica* (year one and two) and *Narcissus* 'Music Hall' (year two) (Tables 3.2, 3.3, 3.4, 3.5, 3.6 and 3.7). Bulbs not given cold pretreatment were planted six weeks prior to bulbs receiving the cold pretreatment which may have allowed the bulbs in ground to produce roots and elongate shoots while cold pretreatment bulbs were still in a cooler. Results were similar to Van Staden (1978) who showed *Narcissus* root well without cold pretreatment and Le Nard and Cohat (1968) noted that tulips grow well at optimum planting temperatures without cold pretreatment.

Stem lengths were shortened when *Narcissus* 'Tahiti' (year one), *Tulipa* 'Couleur Cardinal' (year one and two) and *Tulipa* 'White Emperor' (year one) were given cold pretreatment (Tables 3.5, 3.6 and 3.7). Generally, cold pretreatments produce longer stem lengths (Le Nard and De Hertogh, 1993). However, the bulbs not receiving the cold pretreatment were provided sufficient cooling from ground temperatures (Table 3.1). The same three cultivars also produced lower quality ratings when given the cold pretreatment. However, *Tulipa* 'White Emperor' only decreased quality rating at the 15 cm planting depth (Tables 3.5, 3.6 and 3.7).

Cold pretreatment delayed foliage senescence for *Tulipa* 'Couleur Cardinal' and 'White Emporer'. The cold pretreatment may have improved root development and prolonged foliage life (Jennings and De Hertogh, 1977; Le Nard and De Hertogh, 1993). However, days to foliage senescence were reduced for *Narcissus* 'Tahiti'. Days to foliage senescence was unaffected by cold pretreatment for *Hyacinthoides hispanica*, *Hyacinthus* 'Gypsy Queen', and *Narcissus* 'Music Hall' (Tables 3.2, 3.3, 3.4, 3.5,3.6 and 3.7).

Increasing shade decreased number of bulbs flowering for *Narcissus* 'Music Hall' (Table 3.4). However, all other species were unaffected by shading for number of bulbs flowering (Tables 3.2, 3.5, 3.6, and 3.7).

Shading delayed flowering for *Hyacinthus* 'Gypsy Queen' (year one), *Narcissus* 'Music Hall' (year one), *Narcissus* 'Tahiti' (year one), *Tulipa* 'Couleur Cardinal' (year one and two) and *Tulipa* 'White Emperor' (year one and two) (Tables 3.3, 3.4, 3.5, 3.6, and 3.7). Shading reduced soil temperatures which may have slowed plant growth and delayed days to anthesis (Table 3.1).

While *Hyacinthoides hispanica* stem lengths were shortened under shade, stem lengths of all other species increased with shade which was most evident in year two (3.2, 3.3, 3.4, 3.5, 3.6 and 3.7). Shading increased stem length for *Tulipa* 'White Emperor' (year one) only at the 15 cm planting depth (Table 3.7). Shading reduced light intensity which often increases stem length such as with *Anemone, Centaurea, Echinops, Eryngium, Oxypetalum, Tulipa* and *Zantedeschia*

(Armitage, 1991; Armitage et al., 1990; Gude et al., n.d.).

The quality ratings for *Narcissus* 'Music Hall' (year one and two), *Tulipa* 'Couleur Cardinal' (year one and two) and *Tulipa* 'White Emperor' (year two) increased under shading (Tables 3.4, 3.6 and 3.7). Shading affected quality ratings such that plants grown under shade produced high quality ratings. Shading reduced light intensities which helped reduce heat stress and increased cut stem quality.

Shade delayed foliage senescence for *Hyacinthoides hispanica*, *Narcissus* 'Tahiti', *Tulipa* 'Couleur Cardinal', and *Tulipa* 'White Emperor'. Shading reduced excessive heat and allowed the foliage to live longer. Days to foliage senescence was unaffected by shade for *Hyacinthus* 'Gypsy Queen' and *Narcissus* 'Music Hall' (Tables 3.2, 3.3, 3.4, 3.5,3.6 and 3.7).

Conclusions

Cold pretreatment, deep planting depths and shading were not sufficient to encourage perennialization. The 45 cm planting depth greatly reduced or did not allow plant emergence. The 30 cm planting depth was not as successful as the 15 cm planting depth in encouraging perennialization which increases grower profit. Although shade increased stem lengths and delayed foliage senescence, shade did not encourage perennialization. Cold pretreatment results were species specific but do not appear to be commercially usable.

Literature Cited

Allen, R.C. 1938. Factors affecting the growth of tulips and narcissi in relation to garden practice. Proc Amer. Soc. .Hort. Sci. 35:825-829.

Armitage, A.M. 1991. Shade effects yield and stem length of field-grown cut-flower species. HortScience 26:1174-1176.

Armitage, A.M. 1993. *Tulipa*, pp. 311-315. In: Specialty Cut Flowers. Varsity Press, Portland, Ore.

Armitage, A.M. and J.M. Laushman. 1990. Planting date, in-ground time affect cut flowers of *Acidanthera*, *Anemone*, *Allium*, *Brodiaea* and *Crocosmia*. HortScience 25:1236-1238.

Armitage, A.M., N.G. Seager, I.J. Warrington and D.H. Greer. 1990. Response of *Oxypetalum caeruleum* to irradiance, temperature and photoperiod. J. Amer. Soc. Hort. Sci. 115:910-914.

Aung, L.H., F. Tognoni, and A.A. De Hertogh. 1973. Changes in the carbohydrates of tulip bulbs during development. HortScience 8:207-208.

Buschman, J.C.M. and F.M. Roozen. 1980. Introduction. pp.3. In: Forcing Flowerbulbs. International Flower-bulb Centre, Hillegom, The Netherlands.

De Hertogh, A. 1973. Changes in the carbohydrates of tulip bulbs during development. HortScience 8:207-208.

De Hertogh, A.A. 1996. *Allium giganteum*, pp. D13-14. In: Holland Bulb Forcer's Guide, 5th ed. International Flower Bulb Center, Hillegom, The Netherlands.

Fodor, B., 1974. Bulb yield of tulip in connection with row-distance and planting depth. Kerteszeti Egyetem Kozlemenyei, 38:241-247.

Griffiths, M. 1995. Royal Horticultural Society Index of Garden Plants. Timber Press. Portland, Ore.

Gude, H., K. de Jong, and P. Vreeburg, n.d. The forcing of tulip and hyacinth under artificial light. Laboratory voor Bloembollenonderzock, Bulb Research Center, Lisse, The Netherlands.

Hartsema, A.H., 1961. Influence of temperatures on flower formation and flowering of bulbous and tuberous plants. In: Hanbuch der Pflanzenphysiologie, W. Ruhland ed., Springer - Verlag, Berlin, 16:123-167.

Jennings, N.T., and A.A. De Hertogh, 1977. The influence of preplanting dips and postplanting temperatures on root growth and development of nonprecooled tulips, daffodils and hyacinths. Scientia Horticulturae, 6:157-166.

Le Nard, M. and Cohat, J. 1968. Influence des temperatures de conservation des bulbes sur l'elongation, la floraison et la bulbification de la tulip (*Tulipa gesneria* L.). Anales de l'Amelioration des Plantes, 18:181-215.

Le Nard, M. and A.A. De Hertogh.1993. *Tulipa*, pp.617-682. In: The physiology of flower bulbs: A comprehensive treatise on the physiology and utilization of ornamental flowering bulbous and tuberous plants. Elsevier, N.Y.

Nowak, J. and R.M. Rudnicki. 1993. *Hyacinthus*, pp.335-347. In: The physiology of flower bulbs: A comprehensive treatise on the physiology and utilization of ornamental flowering bulbous and tuberous plants. Elsevier, N.Y.

Rees, A.R., 1972a. Flower initiation and differentiation, pp. 98-115. In: The Growth of Bulbs, vol I. J.F. Sutcliffe, ed. Academic Press, London.

Rees, A.R., 1972b. Structure morphology development and periodicity, pp. 17-44. In: The Growth of Bulbs, vol I. J.F. Sutcliffe, ed. Academic Press, London.

Wallis, L.W. 1964. Bulbs. Rosewarne Experimiental Horticulture Station Annual Report 1963:14-31.

Van der Knaap, W., 1969. Opbrengstderving bij tulpen door planten op ongelijke en te grote depte. Weekblad voor Bloembollencultuur, 80:367-368.

Van Ouwerkerk, C., 1969. Invloed van de relatieve boldiepte op de opbengst van tulpen. Tuinbouw Mededeelingen, 32: 398-403.

Van Staden, J. 1978. The levels of endogenous cytokinins in daffodil bulbs stored under different environmental conditions. Zeitschrift fur Pflansenphysiologie 86:323-330.

Wassink, E.C., 1965. Light intensity effects in growth and development of tulips in camparison with those in Gladioulus. Mededeelingen van de Landbouwhoogesdchool Wageningen, 65:1-21.

Table 3.1. Average daily soil temperatures (^{o}C) at 15, 30 and 45 cm depths and 0, 30 and 60 % shade. Standard deviations of temperatures are in parentheses.

Planting depth (cm)	% shade		
	0	30	60
		Year one	
15	15 (±5)	13 (±4)	13 (±1)
30	11 (±2)	11 (±2)	11 (±2)
45	10 (±1)	10 (±1)	10 (±1)
		Year two	
15	14 (±3)	14 (±3)	14 (±3)
30	14 (±3)	14 (±3)	14 (±3)
45	13 (±2)	13 (±2)	13 (±2)

Table 3.2. Effect of cold treatment, planting depth and shade on cut stem quality and perennialization of *Hyacinthoides hispanica*. Means are an average of data from 8 bulbs per treatment.

Shade (%)	Cold pretreatment[z]	Planting depth (cm)	Bulbs flowering (%)	Days to anthesis[y]	Stem length (cm)	Quality rating[x]	Days to foliage senescence[y]
				Year one			
0	N	15	88	72	28.1	2.8	128
		30	0	.	.	.	.
		45	0	.	.	.	.
	Y	15	63	73	27.6	2.8	118
		30	25	73	22.0	2.3	114
		45	0	.	.	.	.
30	N	15	100	71	22.8	2.5	128
		30	13	76	27.0	2.5	128
		45	0	.	.	.	.
	Y	15	75	75	26.7	2.4	128

		30	25	76	23.0	1.8	118
		45	0	.	.	.	.
60	N	15	63	77	27.4	2.7	128
		30	25	80	22.0	2.0	128
		45	0	.	.	.	.
	Y	15	50	76	25.4	2.0	128
		30	50	72	24.4	2.3	122
		45	0	.	.	.	.
Shade (S)							
Linear (L)			NS	NS	NS	NS	0.0039
Quadratic (Q)			NS	NS	NS	NS	NS
Cold (C)			NS	NS	NS	NS	NS
Depth (D)							
L			0.0001	NS	0.0341	NS	0.0006
Q			NS	0.0310	NS	NS	NS
Significant (P=0.05) interactions			None	None	SQ*DL	None	None

Year two

0	N	15	38	49	23.7	2.2	108
		30	0	.	.	.	.
		45	0	.	.	.	.
	Y	15	0	.	.	.	.
		30	0	.	.	.	.
		45	0	.	.	.	.
30	N	15	25	47	16.5	1.3	118
		30	0	.	.	.	.
		45	0	.	.	.	.
	Y	15	0	.	.	.	.
		30	0	.	.	.	.
		45	0	.	.	.	.
60	N	15	0	.	.	.	.
		30	0	.	.	.	.

		45	0	.	.	.	.
	Y	15	0	.	.	.	.
		30	0	.	.	.	.
		45	0	.	.	.	.
Shade (S)							
Linear (L)			NS	NS	NS	NS	NS
Quadratic (Q)			NS	NS	NS	NS	NS
Cold (C)			NS	NS	NS	NS	NS
Depth (D)							
L			NS	NS	NS	NS	NS
Q			NS	NS	NS	NS	NS
Significant (P=0.05) interactions			None	None	None	None	None

[z] Bulbs received 0 or 6 weeks of 5°C preplant cold treatment

[y] Days from 50% emergence on 20 February 1998 in year one and on 20 February 1999 in year two

[x] 1-5 rating with 5 being highest

Table 3.3. Effect of cold treatment, planting depth and shade on cut stem quality and perennialization of *Hyacinthus* 'Gypsy Queen'. Means are an average of data from 8 bulbs per treatment.

Shade (%)	Cold pretreatment[z]	Planting depth (cm)	Bulbs flowering (%)	Days to anthesis[y]	Stem length (cm)	Quality rating[x]	Days to foliage senescence[y]
				Year one			
0	N	15	100	43	13.6	1.5	128
		30	38	51	18.7	2.3	128
		45	25	49	11.0	1.5	114
	Y	15	75	45	15.1	1.6	123
		30	50	50	18.5	2.0	122
		45	13	61	26.0	2.5	128
30	N	15	100	48	17.9	2.1	128
		30	75	53	18.5	2.2	128
		45	0	61	21.0	2.5	128
	Y	15	100	49	18.4	2.1	124

		30	25	51	17.3	2.0	121
		45	0	.	.	.	.
60	N	15	63	49	17.2	1.8	128
		30	63	54	16.6	1.8	128
		45	0	.	.	.	.
	Y	15	88	51	20.9	2.4	124
		30	75	53	17.2	1.8	123
		45	0	.	.	.	.
Shade (S)							
Linear (L)			NS	0.0016	NS	NS	NS
Quadratic (Q)			NS	NS	NS	NS	NS
Cold (C)			NS	NS	NS	NS	NS
Depth (D)							
L			0.0001	0.0001	NS	NS	NS
Q			NS	0.0364	NS	NS	NS
Significant (P=0.05) interactions			None	DL*C	None	None	None

Year two

0	N	15	8	25	15.3	1.4	109
		30	4	26	17.3	1.5	111
		45	2	39	13.0	1.0	115
	Y	15	7	32	14.8	1.6	109
		30	5	34	15.9	1.6	109
		45	3	35	16.7	1.3	111
30	N	15	8	29	16.5	1.5	113
		30	5	30	17.3	1.3	110
		45	1	42	18.0	1.0	111
	Y	15	7	35	16.6	1.7	112
		30	4	33	14.6	1.3	111
		45	2	39	21.0	1.5	111
60	N	15	7	27	15.6	1.4	111
		30	6	29	18.2	2.1	112
		45	0	.	.	.	.

	Y	15	6	36	16.5	1.7	112
		30	6	36	20.9	2.0	111
		45	3	38	17.8	1.5	111
Shade (S)							
Linear (L)			NS	NS	0.0032	NS	NS
Quadratic (Q)			NS	NS	NS	NS	NS
Cold (C)			NS	0.0001	NS	NS	NS
Depth (D)							
L			0.0099	0.0014	NS	NS	NS
Q			NS	NS	NS	NS	NS
Significant (P=0.05) interactions			None	None	None	None	None

[z] Bulbs received 0 or 6 weeks of 5°C preplant cold treatment

[y] Days from 50% emergence on 20 February 1998 in year one and on 20 February 1999 in year two

[x] 1-5 rating with 5 being highest

Table 3.4. Effect of cold treatment, planting depth and shade on cut stem quality and perennialization of *Narcissus* 'Music Hall'. Means are an average of data from 24 bulbs per treatment.

Shade (%)	Cold pretreatment[z]	Planting depth (cm)	Bulbs flowering (%)	Days to anthesis[y]	Stem length (cm)	Quality rating[x]	Days to foliage senescence[y]
				Year one			
0	N	15	79	44	29.4	2.9	128
		30	67	50	27.9	2.8	125
		45	46	61	30.5	3.1	125
	Y	15	88	46	29.1	2.9	125
		30	67	50	27.9	2.6	127
		45	58	55	26.2	2.5	123
30	N	15	83	44	30.0	2.9	125
		30	88	49	29.0	3.1	128
		45	4	52	28.0	2.5	128
	Y	15	83	49	30.0	3.1	128

		30	58	53	34.2	3.5	122
		45	67	54	26.9	2.7	125
60	N	15	58	47	29.4	3.1	128
		30	63	52	30.8	3.2	128
		45	13	56	32.6	3.7	125
	Y	15	75	47	30.3	3.0	128
		30	54	54	30.6	3.1	128
		45	46	57	27.0	2.6	128
Shade (S)							
Linear (L)			0.0427	0.0197	0.0055	0.0123	NS
Quadratic (Q)			NS	NS	NS	NS	NS
Cold (C)			NS	0.0064	NS	NS	NS
Depth (D)							
L			0.0001	0.0001	NS	NS	NS
Q			NS	NS	NS	NS	NS
Significant (P=0.05) interactions			None	None	None	None	None

Year two

0	N	15	8	15	30.4	3.3	109
		30	6	14	30.9	3.4	118
		45	1	24	33.0	2.5	109
	Y	15	9	17	30.1	3.5	111
		30	6	19	29.3	3.3	111
		45	3	19	28.7	2.7	118
30	N	15	17	15	30.9	3.4	110
		30	13	20	31.4	3.4	120
		45	0	.	.	.	.
	Y	15	16	17	30.3	3.5	112
		30	9	22	29.0	3.0	117
		45	5	23	31.0	3.0	120
60	N	15	13	15	33.8	3.8	116
		30	11	20	32.1	3.7	119

Year two

0	N	15	8	15	30.4	3.3	109
		30	6	14	30.9	3.4	118
		45	1	24	33.0	2.5	109
	Y	15	9	17	30.1	3.5	111
		30	6	19	29.3	3.3	111
		45	3	19	28.7	2.7	118
30	N	15	17	15	30.9	3.4	110
		30	13	20	31.4	3.4	120
		45	0	.	.	.	.
	Y	15	16	17	30.3	3.5	112
		30	9	22	29.0	3.0	117
		45	5	23	31.0	3.0	120
60	N	15	13	15	33.8	3.8	116
		30	11	20	32.1	3.7	119

		45	0	.	.	.	.
	Y	15	11	13	31.5	3.7	112
		30	12	20	31.7	3.6	119
		45	1	28	31.5	2.8	128
Shade (S)							
Linear (L)			NS	NS	0.0007	0.0027	NS
Quadratic (Q)			NS	NS	NS	NS	NS
Cold (C)			NS	NS	NS	NS	NS
Depth (D)							
L			0.0072	0.0001	NS	0.0279	0.0348
Q			NS	NS	NS	0.0318	NS
Significant (P=0.05) interactions			None	None	None	None	None

[z] Bulbs received 0 or 6 weeks of $5^{o}C$ preplant cold treatment

[y] Days from 50% emergence on 20 February 1998 in year one and on 20 February 1999 in year two

[x] 1-5 rating with 5 being highest

Table 3.5. Effect of cold treatment, planting depth and shade on cut stem quality and perennialization of *Narcissus* 'Tahiti'. Means are an average of data from 32 bulbs per treatment.

Shade (%)	Cold pretreatment[z]	Planting depth (cm)	Bulbs flowering (%)	Days to anthesis[y]	Stem length (cm)	Quality rating[x]	Days to foliage senescence[y]
				Year one			
0	N	15	97	50	38.1	4.0	128
		30	94	53	33.3	3.4	128
		45	13	68	33.5	3.4	127
	Y	15	84	53	32.3	3.4	127
		30	84	55	27.1	2.6	128
		45	44	60	26.1	2.4	126
30	N	15	100	52	39.3	4.2	128
		30	91	56	32.4	3.1	128
		45	6	65	35.5	3.8	127
	Y	15	97	53	32.3	3.3	125

		30	88	57	31.2	3.2	126
		45	28	62	27.7	2.6	128
60	N	15	88	52	37.2	3.8	130
		30	84	55	33.6	3.1	128
		45	9	73	43.3	4.5	127
	Y	15	94	54	31.3	3.1	128
		30	78	58	30.6	3.1	128
		45	31	67	27.6	2.9	128
Shade (S)							
Linear (L)			NS	0.0074	NS	NS	NS
Quadratic (Q)			NS	NS	NS	NS	NS
Cold (C)			NS	0.0024	0.0001	0.0001	NS
Depth (D)							
L			0.0001	0.0001	0.0001	0.0001	NS
Q			NS	0.0001	NS	NS	NS
Significant (P=0.05) interactions			DL*C	DQ*C	DQ*C	SL*DL	None

						DQ*C	
				Year two			
0	N	15	22	38	34.5	3.7	118
		30	21	41	35.5	3.6	124
		45	0	.	.	.	.
	Y	15	22	43	34.4	3.8	113
		30	16	43	35.6	3.8	119
		45	6	44	30.0	3.1	124
30	N	15	20	39	40.2	4.0	113
		30	22	41	38.2	3.8	124
		45	1	43	41.0	4	109
	Y	15	30	42	38.2	4.0	112
		30	20	43	38.2	3.8	122
		45	10	45	33.9	3.5	128
60	N	15	24	38	40.8	4.1	125
		30	22	42	40.8	4.0	126

		45	0	.	.	.	.
	Y	15	24	42	39.1	4.0	120
		30	20	42	37.7	3.7	123
		45	4	45	37.5	4.0	128
Shade (S)							
Linear (L)			NS	NS	0.0001	0.0124	NS
Quadratic (Q)			NS	NS	0.0261	NS	NS
Cold (C)			NS	0.0006	NS	NS	NS
Depth (D)							
L			0.0001	0.0002	NS	0.0185	0.0347
Q			NS	NS	NS	NS	NS
Significant (P=0.05) interactions			None	DL*C	None	None	DQ*C SL*DL*C

[z] bulbs received 0 or 6 weeks of 5°C preplant cold treatment

[y] Days from 50% emergence on 20 February 1998 in year one and on 20 February 1999 in year two

[x] 1-5 rating with 5 being highest

Table 3.6. Effect of cold treatment, planting depth and shade on cut stem quality and perennialization of *Tulipa* 'Couleur Cardinal'. Means are an average of data from 44 bulbs per treatment.

Shade (%)	Cold pretreatment[z]	Planting depth (cm)	Bulbs flowering (%)	Days to anthesis[y]	Stem length (cm)	Quality rating[x]	Days to foliage senescence[y]
			Year one				
0	N	15	82	44	13.8	1.6	95
		30	70	49	15.0	1.9	91
		45	0	.	.	.	.
	Y	15	70	55	10.3	0.9	97
		30	56	56	15.0	1.6	99
		45	23	59	11.7	1.6	99
30	N	15	84	46	15.4	1.6	98
		30	86	49	17.1	2.3	100
		45	0	.	.	.	.
	Y	15	86	58	12.6	1.2	103

		30	77	60	12.0	1.2	106
		45	30	66	11.9	1.3	102
60	N	15	89	45	16.4	1.9	98
		30	73	51	18.2	2.4	101
		45	9	59	12.3	1.5	99
	Y	15	84	58	13.0	1.4	104
		30	50	63	11.1	1.0	105
		45	25	65	12.5	1.4	102
Shade (S)							
Linear (L)			NS	0.0118	NS	NS	0.0127
Quadratic (Q)			NS	NS	NS	NS	NS
Cold (C)			NS	0.0001	0.0001	0.0001	0.0001
Depth (D)							
L			0.0001	0.0001	NS	NS	NS
Q			NS	0.0026	0.0002	0.0013	NS
Significant (P=0.05) interactions			DL*C	SL*DL	SL*C	SL*DL*C	None

				DL*C	SL*DL*C		
				Year two			
0	N	15	22	44	16.4	1.3	94
		30	7	46	19.8	2.1	94
		45	0	.	.	.	.
	Y	15	5	47	17.8	1.5	99
		30	6	48	20.4	2.3	100
		45	3	48	21.8	2.4	102
30	N	15	20	46	19.0	1.8	99
		30	6	49	22.6	2.6	104
		45	0	.	.	.	.
	Y	15	5	47	22.8	2.7	97
		30	8	48	24.3	3.1	99
		45	0	.	.	.	.
60	N	15	22	46	19.1	1.8	99
		30	3	49	24.0	2.8	96

		45	0	.	.	.	.
	Y	15	6	48	21.9	2.6	97
		30	3	48	20.3	2.7	102
		45	2	50	26.0	3.3	83
Shade (S)							
Linear (L)			NS	0.0006	0.0003	0.0019	NS
Quadratic (Q)			NS	NS	0.0193	NS	NS
Cold (C)			NS	0.0103	0.0015	NS	NS
Depth (D)							
L			0.0007	0.0001	0.0013	0.0037	NS
Q			NS	NS	NS	NS	NS
Significant (P=0.05) interactions			None	DL*C	None	None	NS

[z] Bulbs received 0 or 6 weeks of 5°C preplant cold treatment

[y] Days from 50% emergence on 20 February 1998 in year one and on 20 February 1999 in year two

[x] 1-5 rating with 5 being highest

Table 3.7. Effect of cold treatment, planting depth and shading on cut stem quality and perennialization of *Tulipa* 'White Emperor'. Means are an average of data from 44 bulbs per treatment.

Shade (%)	Cold pretreatment[z]	Planting depth (cm)	Bulbs flowering (%)	Days to anthesis[y]	Stem length (cm)	Quality rating[x]	Days to foliage senescence[y]
				Year one			
0	N	15	82	43	20.8	2.7	93
		30	84	48	21.2	2.5	96
		45	0	.	.	.	.
	Y	15	61	45	22.9	2.8	92
		30	52	49	21.3	2.4	90
		45	16	52	16.7	1.9	90
30	N	15	80	43	23.4	2.7	96
		30	82	46	22.2	2.6	96
		45	9	55	16.5	1.6	94
	Y	15	59	47	20.5	2.4	100

		30	77	60	12.0	1.2	106
		45	30	66	11.9	1.3	102
60	N	15	89	45	16.4	1.9	98
		30	73	51	18.2	2.4	101
		45	9	59	12.3	1.5	99
	Y	15	84	58	13.0	1.4	104
		30	50	63	11.1	1.0	105
		45	25	65	12.5	1.4	102
Shade (S)							
Linear (L)			NS	0.0118	NS	NS	0.0127
Quadratic (Q)			NS	NS	NS	NS	NS
Cold (C)			NS	0.0001	0.0001	0.0001	0.0001
Depth (D)							
L			0.0001	0.0001	NS	NS	NS
Q			NS	0.0026	0.0002	0.0013	NS
Significant (P=0.05) interactions			DL*C	SL*DL	SL*C	SL*DL*C	None

				DL*C	DL*C	SL*DL*C	SQ*C
				DL*C	SL*DL*C		
				Year two			
0	N	15	22	33	22.4	2.4	80
		30	12	34	20.3	1.9	81
		45	2	.		.	.
	Y	15	15	36	23.4	2.8	82
		30	11	36	23.3	2.6	84
		45	0	40	22.0	2.0	81
30	N	15	28	34	24.6	2.4	85
		30	21	37	24.1	2.5	83
		45	2	38	27.0	3.5	83
	Y	15	14	37	23.1	2.7	83
		30	17	38	23.3	2.6	84
		45	0	39	24.0	3.0	85
60	N	15	30	34	25.4	2.6	82

		30	20	37	25.2	3.0	83
		45	0	.	.	.	.
	Y	15	17	36	24.7	2.7	84
		30	11	38	27.8	3.3	88
		45	3	39	24.0	3.0	90
Shade (S)							
Linear (L)			NS	0.0018	0.0001	0.0194	NS
Quadratic (Q)			NS	0.0060	NS	NS	NS
Cold (C)			0.0019	0.0069	NS	NS	0.0208
Depth (D)							
L			0.0001	0.0001	NS	NS	0.0022
Q			NS	NS	NS	NS	NS
Significant (P=0.05) interactions			None	SL*DL DL*C	None	SL*DL	None

[z] Bulbs received 0 or 6 weeks of 5°C preplant cold treatment

[y] Days from 50% emergence on 20 February 1998 in year one and on 20 February 1999 in year two

[x] 1-5 rating with 5 being highest

CHAPTER IV

MINIMALLY-HEATED AND NON-HEATED WINTER GREENHOUSE PRODUCTION OF SPECIALTY CUT FLOWERS

Todd J. Cavins and John M. Dole. Department of Horticulture and Landscape Architecture, Oklahoma State University, Stillwater, OK 74078-6027.

Additional index words. *Antirrhinum* 'Animation Mix', *Consolida* 'Giant Imperial Mix', *Delphinium* 'Casa Blanca', *Helianthus* 'Sunrich Orange', *Lupinus* 'Bright Gems', *Matthiola* 'Cheerful White' and *Viola* 'Oregon Giant'.

Abstract. *Antirrhinum*, *Consolida*, *Delphinium*, *Helianthus*, *Lupinus*, *Matthiola* and *Viola* were grown in raised sandy loam ground beds in polyethylene-covered greenhouses with minimum night temperatures of 18°C or non-heated (ambient) in year one and 10° or 2°C in year two. Results were species specific; however, the extreme low temperatures (-6°C) in the unheated house during year one injured the *Delphinium* and limited *Lupinus* production. The warmest environments (18°C and 10°C) reduced crop time for *Anemone*, *Antirrhinum*, *Consolida*, and *Delphinium*. In year two the warmest environment also reduced crop time for *Helianthus*, *Lupinus* and *Matthiola*. The coolest environments increased stem lengths and yielded a profit or lower net loss for all species/cultivars except *Anemone* (year one), *Antirrhinum* (year two), *Delphinium* and *Lupinus* for which profits or net losses were highest in the warmest environments.

Introduction

The peak selling season of September through May for outdoor specialty cut flowers does not match the typical outdoor production season of May through September in Oklahoma. Producers could increase profits by expanding to a year-round growing season encompassing high sales holidays such as Valentines Day, Easter and Mother's Day.

Although the growing season could be extended using heated greenhouses, heating expenses might be prohibitive. However, non-heated or minimally-heated greenhouses could profitably provide season extension for specialty cut flower producers. Winter conditions in Oklahoma are typically favorable for low heating expenses due to high light intensity and warm day temperatures. During the day greenhouse soil is heated, and that heat is released at night.

A number of specialty cuts can be grown at cool temperatures. *Anemone* L. 'Jerusalem Mix' is a poppy-like flower that has been well received as a cut and potted flower. This tuberous plant produces stems up to 60 cm long with 3-8 cm diameter flowers (Griffiths, 1995). Previous work has shown that *Anemone*'s optimum production temperatures are 5-10°C night and 14-18°C day (Ohkawa, 1987). Armitage and Laushman (1990) reported that *Anemones* planted in November and December produced higher quality flowers than those planted in January and February due to cooler growing temperatures experienced during the November and December plantings versus the January and February plantings. Harvest duration from first to last harvestable flower also decreased for plantings made after November.

Antirrhinum L. 'Animation Mix' is a snapdragon cultivar used for cut flower production. The raceme inflorescence reaches lengths in excess of 2 m with numerous florets (Griffiths, 1995). Snapdragons grow best in cool temperatures of 7 to 16°C; media temperatures above 26°C increase days to anthesis (Dole and Wilkins, 1999a; Wai and Newman, 1992). Miller (1962) noted *Antirrhinum* grow slowers at 10°C compared to 25°C.

Consolida (DC.) S.F. Gray 'Giant Imperial Mix' is an annual with racemose inflorescences. *Consolida*'s common name is larkspur and is closely related to *Delphinium* (Griffiths, 1995). Cool temperatures are required for stem elongation. An optimum duration of six weeks at 2°C has been reported to be most effective for flower initiation and development (Dole and Wilkins, 1999b). Nau (1993a) noted that 10-13°C is the optimum temperature range for growing *Consolida*.

Delphinium L. 'Casa Blanca' is a perennial with a spike inflorescence which requires cool temperatures for stem elongation similar to *Consolida* (Dole and Wilkins, 1999b; Griffiths, 1995). Optimum production temperatures are 10-16°C night and 24°C day. Forcing temperature for flowering can be as low as 13°C (Dole and Wilkins, 1999b; Nau, 1993b).

Matthiola (L.) R. Br. 'Cheerful White' is commonly known as stock. Stems reach 80 cm in length with a terminal raceme (Griffiths, 1995). A great diversity in flower response occurs among cultivars. High temperatures (16°C or higher) delay flowering in most cultivars (Cockshull, 1985). Recommended night production temperatures for *Matthiola* are 10-13°C (Nau, 1993a).

Viola 'Oregon Giants' is a pansy (*V.* x *wittrockiana* Gams.) cultivar which has larger flowers and longer stems than pansies used as bedding plants. The ideal production temperatures for pansies are 4-13°C (Post, 1949). However, high temperatures promote node elongation and faster growing rates for pansies (Pearson et al, 1995). Faster growing rates affect both vegetative and reproductive growth. The high rate of development after bud initiation causes the flower to be smaller. When the pansies are grown at cooler temperatures, a slower growth rate is achieved allowing for a longer duration for flower development creating a larger flower

In addition, two popular outdoor cut flower species that prefer relatively warm production temperatures of 18-24°C may be suitable for greenhouse production. *Helianthus* (L.) 'Sunrich Orange' is commonly used as a cut flower with rich yellow-orange rays and long postharvest life (Armitage, 1993). The native sunflower has become a popular choice among florists and consumers. Optimum growth temperatures are 18-24°C and growth rates are reduced at lower temperatures (Armitage, 1993; Schuster, 1985). Under proper growing conditions sunflowers can reach anthesis as few as 8 weeks after sowing seeds (V. Stamback, personal communication).

Lupinus hartwegii Lindl. 'Bright Gems' is a relative of the famous Texas bluebonnet. 'Bright Gems' is available in a variety of colors including blue, pink and white. *Lupinus hartwegii* is a annual with pubescent raceme inflorescence reaching lengths of 90 cm with 1.5 cm diameter florets (Griffiths, 1995). No published information is available on the specific cultural requirements for *L. hartwegii*. However, optimum growing temperatures for *Lupinus polyphyllus* Lindl. are 10-13°C (Nau, 1993b)

The objective of this study was to determine if *Anemone*, *Antirrhinum*, *Consolida*, *Delphinium*, *Helianthus*, *Lupinus*, *Matthiola* and *Viola* can be economically grown in minimally heated or non-heated greenhouses and produce high quality cut flowers during the winter months.

Materials and Methods

Antirrhinum, *Consolida*, *Delphinium*, *Helianthus*, *Lupinus*, *Matthiola* and *Viola* seeds were sown in 1001 seed flats (475 cm^3 volume/cell) containing a peat-lite commercial medium (Redi Earth, Scotts-Sierra Horticultural Products Company, Marysville, Ohio). At the appearance of the first true leaves, the plants were transplanted into 1206 bedding plant flats (50 cm^3 volume/cell) using a commercial peat-based medium (BM1, Berger, Saint-Modeste, Quebec). After establishment in flats, plants were transplanted into raised sandy loam ground beds in polyethylene-covered greenhouses. *Anemone* tubers were kept at 5°C until planting of the other species, at which time the tubers were planted 15 cm deep. Plants were spaced at 7.6 cm by 12.7 cm except for *Anemone* which was spaced at 15.2 cm by 12.7 cm. In year two, *Delphinium* and *Viola* were eliminated from the study and *Helianthus* was added.

Year one. Plants were grown in two greenhouse environments: heated with average daily high, low temperatures of 29° and 15°C respectively and an average ground temperature of 17°C. The non-heated (ambient) greenhouse environment average daily high and low temperatures were 29° and 9°C respectively with a minimum temperature of –6°C and average ground temperature of 15°C.

Year two. Greenhouses were set at minimal night temperatures of 10° or 2°C. The average daily high, low temperatures for the 10°C environment were 25° and 12° C respectively with an average ground temperature of 15°C. The 2°C environment averaged daily high, low temperatures of 23° and 8° C respectively with an average ground temperature of 14°C.

Data collected included number of stems harvested, flower quality, flower value, stem length, energy, labor, supplies and other expenses. Profit or loss was calculated as sales minus labor, heating and production expenses. Results were expressed in profit or loss per treatment area, approximately 4 m^2.

Other data collected included air and soil temperatures. The design was a modified split plot. The greenhouse environments were the main plots and there were four samples of 36 plants for each cultivar except *Anemone* which had 18 plants per sample. Data were analyzed by general linear model procedure (SAS Institute, Cary, NC.).

Results

Anemone 'Jerusalem Mix'

Year one. The plants in the heated environment produced longer stems and reached anthesis seven days earlier than the plants in the unheated environment (Table 4.1). *Anemone* was not profitable when grown in either environment due to spacing requirements for the tubers. However, the unheated environment net loss was $54.03 less than the heated environment due to lack of heating expenses and increased stem yield.

Year two. As with year one, the warm environment (10°C) reduced days to anthesis (Table 4.2). However, the cool environment (2°C) produced more stems with longer stem lengths than the 10°C greenhouse. While neither environment was profitable, the cool environment (2°C) net loss was $39.89 less than the warm environment (10°C) due to reduced heating expenses. In both years, stem number was unaffected by treatments.

***Antirrhinum* 'Animation Mix'**

Year one. The unheated environment produced longer stems (60.5 cm) than the heated environment (45.0 cm) (Table 4.1). The heated environment reduced days to anthesis compared to the unheated greenhouse environment. Plants in the unheated environment netted a $91.19 profit due to increased stem number and lower heating expenses compared to the unheated environment which lost $28.65.

Year two. The cool environment (2°C) produced longer stems than the warm environment (10°C). The warm environment produced the most stems and least days to anthesis (Table 4.2). Both environments were profitable with a net profit of $159.00 for the 10°C environment due to increased stem number compared to $127.34 profit of the 2°C environment.

***Consolida* 'Tall Florist Mix'**

Year one. The unheated greenhouse environment yielded longer stems (87.1 cm) compared to the heated environment (73.7cm) (Table 4.1). The unheated environment increased days to anthesis compared to the heated environment. *Consolida* was not profitable when grown in either environment. However, the unheated environments net loss was \$13.13 less than the heated environment due to no heating expenses. *Year two.* Plants in the warm environment produced longer stems and fewer days to anthesis compared to the cool environment (Table 4.2). However, plants in the cool environment produced the most stems. Both environments were profitable with a net profit of \$105.68 for the 2°C environment compared to \$92.85 profit for the 10°C environment. In both years, stem number was unaffected by treatments.

Delphinium 'Casa Blanca'

The unheated environment plants yielded longer stems (67.6 cm) compared to the heated greenhouse (62.5 cm) (Table 4.1). The plants in the heated environment reached anthesis 27 days earlier than plants in the unheated environment. Neither environment was profitable for *Delphinium*. However, the heated environments net loss was \$52.40 less than the non-heated environment due to damaging temperatures (6°C) in the non-heated environment and higher stem numbers in the heated environment. *Delphinium* was not repeated in the second year due to low production.

Matthiola ' Cheerful White'

Year one. The plants in the unheated environment yielded longer stems (52.3 cm) than the plants in the heated environment (43.1 cm) (Table 4.1). The plants in the heated greenhouse reached anthesis six days earlier than plants in the unheated environment. While *Matthiola* was not profitable when grown in either environment, the unheated environment plants net loss was $16.49 less than the heated environment plants due to heating expenses in the warm environment.

Year two. The cool environment plants produced longer stems and increased days to anthesis compared to the warmer environment (Table 4.2). Neither environment was profitable for *Matthiola*.

***Viola* 'Oregon Giant'**

Stem lengths and days to anthesis did not significantly differ between the heated and unheated greenhouses (Table 4.1). *Viola* was profitable when grown in the unheated environment, netting $25.11 due to no heating expenses and increased stem numbers compared the heated environment loss of $52.37. *Viola* was not repeated in the second year due to minimal demand.

***Helianthus* 'Sunrich Orange'**

Plants in the cool environment produced the highest stem number and longest stems (Table 4.2). The warm environment plants reached anthesis 28 days earlier than the cool environment. While neither environment was profitable, the cooler environment (2°C) net loss was $4.75 less than the warmer environment (10°C) due to greater heating expenses in the warm environment. Stem numbers were unaffected by temperature.

***Lupinus* 'Bright Gems'**

Year one. Stem length and days to anthesis were not significantly different between the plants in the heated and unheated environments (Table 4.1). Both environments were profitable with the heated environment profiting \$86.85 compared to the unheated environments profit \$21.03. The greater profits in the heated environment can be attributed to greater stem numbers than in the unheated environment.

Year two. The cool environment plants produced the longest stems (Table 4.2). The warm environment plants yielded the most stems and fewest days to anthesis. Only the warm 10°C environment was profitable for *Lupinus* yielding a \$98.34 profit due to increased stem numbers compared to a loss of \$14.44 for the cool 2°C environment.

Discussion

The extremely low temperatures (-6°C) experienced in the unheated environment greatly damaged *Delphinium* and reduced the amount of harvestable stems for *Lupinus* (Table 4.1). The low temperatures were much lower than the optimum production temperatures of 13-16°C for *Delphinium* and *Lupinus* (Dole and Wilkins, 1999b). However, *Anemone*, *Antirrhinum*, and *Viola* yielded more harvestable stems and stem length was increased for *Antirrhinum*, *Consolida*, *Delphinium* and *Matthiola* when grown in the unheated environment as compared to the 18°C greenhouse. Dole and Wilkins (1999b) noted that *Delphinium* and *Consolida* require cool temperatures for stem elongation. *Antirrhinum*, *Consolida*, *Delphinium* and *Matthiola* optimum production temperatures range from 7-16°C (Dole and Wilkins, 1999a; Dole and Wilkins, 1999b; Nau, 1993a; Nau, 1993b).

The heated environment (18°C night) reduced crop time for *Anemone*, *Antirrhinum*, *Consolida*, and *Delphinium* (Table 4.1). Pearson et al. (1995), Karlsson (1997) and Miller (1962) obtained similar results with pansies and snapdragons.

Delphinium and *Lupinus* harvestable stem numbers increased and *Anemone* produced longer stem lengths when grown in the heated environment.

The heated environment's net loss was \$216.32 compared to the unheated environment's loss of \$53.54. Greater net loss in the heated compared to the non-heated environment was due to higher heating expenses and lower stem numbers for all species except *Lupinus* and *Delphinium*. *Lupinus* was the only species that was profitable in the heated environment due to greater stem numbers which overcame heating expenses. *Antirrhinum*, *Lupinus* and *Viola* were profitable in the unheated environment.

During year two, plants were protected from the extreme low temperatures. The warm 10°C (night) greenhouse environment reduced crop time for *Anemone*, *Antirrhinum, Consolida, Helianthus, Lupinus and Matthiola* compared to the cool 2°C (night) environment (Table 4.2). High temperatures promote fast growing rates and reduce crop times in such species as *Anemone, Antirrhnum, Helianthus,* and *Viola* (Armitage, 1993; Miller, 1962; Karlsson, 1997; Ohkawa, 1987 and Pearson et al, 1995). The warm environment produced the most harvestable stems for *Antirrhinum*, *Lupinus* and *Matthiola* and longest stems for *Consolida* for which cool temperatures are required for stem elongation (Dole and Wilkins, 1999b). The warm environment (10°C) was closer to the optimum growing temperatures for those species (Nau, 1993a)

The cool 2°C environment increased stem length for all cultivars except for *Consolida* and increased harvestable stems for *Anemone*, *Consolida* and *Helianthus*. The cool temperatures also increased crop time for all cultivars. Net profit for the warmer 10°C environment was \$203.70 compared to \$117.46 for the cooler 2°C environment due to a greater number of harvestable stems and reduced crop time.

Conclusion

Result were species specific; however, the extreme low temperatures experienced in the unheated house during year one damaged the *Delphinium* and limited *Lupinus* production. The warmest environments of 18°C for year one and 10°C for year two reduced crop time, while the coolest environment increased stem lengths.

Antirrhinum, *Lupinus* and *Viola* were profitable when grown in the unheated environment. However, *Lupinus* was more profitable when grown in the warmest environments. Generally, the cool environments yielded a profit or lower net loss for all species/cultivars due to lower heating expenses except for *Antirrhinum* (year two), *Delphinium* and *Lupinus* for which profits or net losses were less in the warm environments due to reduced crop times and increased stem numbers.

Literature Cited

Armitage, A.M. 1993. *Helianthus annus*. pp.98-102. In: Specialty Cut Flowers. Varsity/Timber Press, Portland, Ore.

Armitage, A.M. and J.M. Laushman. 1990. Planting date, in-ground time affect cut flowers of *Acidanthera*, *Anemone*, *Allium*, *Brodiaea* and *Crocosmia*. HortScience 25:1236-1238.

Cockshull, K.E. 1985b. *Matthiola incana*, pp. 363-367. In: Handbook of Flowering, vol. III, A.H. Halevy, ed. CRC Press, Boca Raton, Fla.

Dole, J.M. and H.F. Wilkins. 1999a. *Antirrhinum*, In: Floriculture: Principles and Species. Prentice Hall, Upper Saddle River, N.J.

Dole, J.M. and H.F. Wilkins. 1999b. *Delphinium*, In: Floriculture: Principles and Species. Prentice Hall, Upper Saddle River, N.J.

Griffiths, M. 1995. Royal Horticultural Society Index of garden plants. Timber Press. Portland, Ore.

Karlsson, M. 1997. Flowering response of *Anemone coronaria* to photoperiod and temperature. Hortscience 32:466 (Abstract)

Miller, R.O. 1962. Variations in optimum temperature of snapdragon depending on plant size. *Proceedings of the American Society for Horticultural Science* 81:535-543.

Nau, J. 1993a. Cut flowers. In: Ball Culture Guide, The Encyclopedia of Seed Germination, 2 nd edition. Ball Publishing, Batavia, Illinois.

Nau, J. 1993b. Perennials. In: Ball Culture Guide, The Encyclopedia of Seed Germination, 2 nd edition. Ball Publishing, Batavia, Illinois.

Ohkawa, K. 1987. Growth and flowering of *Anemone coronaria* L.'de Caen'. Acta Hort. 205:159-168.

Pearson, S., A. Parker, S.R. Adams, P. Hadley, and D.R. May. 1995. The effects of temperature on the flower size of pansy (*Viola* x *wittrockiana* Gams). J. Hort. Sci. 70:183-190.

Post, K. 1949. *Viola tricolor* and *Viola cornuta*; *Viola odorata*, pp. 839-845. In: Florist Crop Production and Marketing. Orange Judd Publishing, N.Y.

Shuster, W.H., 1985. *Helianthus annuus*. In: Handbook of Flowering , Vol III, A.H. Halevy , ed. CRC Press, Boca Raton, Fla.

Wai, K.S. and S.E. Newman. 1992. Air and root-zone temperatures influence growth and flowering of snapdragons. HortScience. 27:796-798.

Table 4.1. Effect of 18°C or ambient night temperatures on stem length and crop time of *Anemone, Antirrhinum, Consolida, Delphinium, Lupinus, Matthiola* and *Viola* cut flowers. Means are an average of 18 to 36 plants per treatment.

Night temperature	Stems harvested (no.)	Stem length (cm)	Crop time[z] (days)	Net profit[y] ($)
		Anemone 'Jerusalem Mix'		
18°	36	23.9	106	-161.69
ambient	41	22.4	113	-107.66
Temperature	NS	0.0312	0.0001	0.0001
		Antirrhinum 'Animation Mix'		
18°	32	45.0	155	-28.65
ambient	74	60.5	145	91.19
Temperature	0.0096	0.0001	0.0001	0.0001

Consolida 'Giant Imperial Mix'				
18°	37	73.7	142	-15.98
ambient	35	87.1	151	- 2.85
Temperature	NS	0.0001	0.0001	0.0001
Delphinium 'Casa Blanca'				
18°	42	62.5	122	-17.66
Ambient	8	67.6	149	-70.06
Temperature	0.0008	0.0022	0.0001	0.0001
Lupinus 'Bright Gems'				
18°	79	49.3	122	86.85
Ambient	53	49.0	122	21.03
Temperature	0.0290	NS	NS	0.0001

		Matthiola 'Cheerful White'		
18°	36	38.1	111	-26.80
Ambient	35	52.3	117	-10.31
Temperature	NS	0.0001	0.0001	0.0001
		Viola 'Oregon Giant'		
18°	30	17.8	105	-52.37
Ambient	67	19.1	108	25.11
Temperature	0.0050	NS	NS	0.0001

[z] Plants were sown on 15 December 1997

[y] Cost – sales = profit for approximately 4 m^2

Table 4.2. Effect of minimal night temperatures on stem length and crop time of *Anemone, Antirrhinum, Consolida, Helianthus, Lupinus* and *Matthiola* cut flowers.

Night temperature	Stems harvested (no.)	Stem length (cm)	Crop time[z] (days)	Net profit[y] ($)
		Anemone 'Jerusalem Mix'		
10°	57	45.2	49	-93.85
2°	71	51.8	64	-53.96
Temperature	NS	0.0001	0.0001	0.0001
		Antirrhinum 'Animation Mix'		
10°	117	77.2	176	159.00
2°	102	90.9	181	127.34
Temperature	0.0206	0.0001	0.0001	0.0001

		Consolida 'Giant Imperial Mix'		
10°	83	51.6	96	92.85
2°	88	44.2	114	105.68
Temperature	NS	0.0001	0.0001	0.0001
		Helianthus 'Sunrich Orange'		
10°	33	63.0	126	-46.20
2°	35	71.6	154	-41.45
Temperature	NS	0.0053	0.0001	0.0001
		Lupinus 'Bright Gems'		
10°	89	73.7	146	98.34
2°	48	79.2	168	-14.44
Temperature	0.0226	0.0036	0.0001	0.0001

		Matthiola 'Cheerful White'		
10°	56	78.7	161	-6.43
2°	55	94.0	175	-5.69
Temperature	NS	0.0001	0.0001	0.0001

[z] Plants were sown 15 September 1998

[y] Cost – sales = profit for approximately 4 m^2

CHAPTER V

SUMMARY

To improve cost effective production of *Campanula medium* 'Champion Blue' (CB) and 'Champion Pink' (CP) and *Lupinus hartwegii* 'Bright Gems' (LH) optimum photoperiods, transplant stages and light intensities ($\pm$ HID supplemental lighting) were determined. Champion Blue and CP were long day plants that should be grown in the 8 h photoperiod until 5-6 true leaves appear to insure sufficient vegetative growth and transferred into a final 16 h photoperiod to hasten flowering. High intensity discharge supplemental lighting was not commercially useful to increase stem diameter, stem lengths or shorten crop time.

Lupinus hartwegii was a facultative long day plant and should be grown in a continuous 16 h photoperiod to reduce crop time. High intensity discharge lighting should be used initially to increase stem length and stem diameter and reduce crop time.

Perennialization of *Hyacinthoides*, *Hyacinthus*, *Narcissus* and *Tulipa* were most affected by deep planting depths that reduced bulb flowering (year one) and perennialization (year two). Cold pretreatment of 5°C for six weeks generally did not increase stem lengths or hasten days to anthesis compared to bulbs not receiving the cold pretreatment which benefited from the six weeks of extra rooting time. Shading generally increased stem lengths.

Increasing profits by reducing greenhouse temperatures was successful for *Anemone*, *Antirrhinum* (year one), *Consolida*, *Matthiola* and *Viola*. Cool greenhouse

temperatures reduced heating cost, increased stems harvested and increased stem length. However, *Antirrhinum* (year two), *Delphinium* and *Lupinus* were profitable when grown with warm greenhouse temperatures. The warm temperatures reduced crop time but increased production cost due to higher energy consumption.

LITERATURE CITED

Allen, R.C. 1938. Factors affecting the growth of tulips and narcissi in relation to garden practice. Proc. Amer. Soc. Hort. Sci. 35:825-829.

Armitage, A. M. and M. J. Tsujita. 1979. The effect of supplemental light source, illumination and quantum flux density on the flowering of seed propagated geranium. J. Hort. Sci. 54:195-198.

Armitage, A. M. and H. Y. Wetzstein. 1984. Influence of light intensity on flower initiation and differentiation in hybrid geranium. Hortscience 19:114-116.

Armitage, A.M. 1991. Shade effects yield and stem length of field-grown cut-flower species. HortScience 26:1174-1176.

Armitage, A.M. 1993. *Tulipa*, pp. 311-315. In: Specialty Cut Flowers. Varsity Press, Portland, Ore.

Armitage, A.M. 1993. *Helianthus annus*. pp.98-102. In: Specialty Cut Flowers. Varsity/Timber Press, Portland, Ore.

Armitage, A.M. and J.M. Laushman. 1990. Planting date, in-ground time affect cut flowers of *Acidanthera*, *Anemone*, *Allium*, *Brodiaea* and *Crocosmia*. HortScience 25:1236-1238.

Armitage, A.M., N.G. Seager, I.J. Warrington and D.H. Greer. 1990. Response of *Oxypetalum caeruleum* to irradiance, temperature and photoperiod. J. Amer. Soc. Hort. Sci. 115:910-914.

Arnosky, P. and F. Arnosky. 1997. Poppies and more will keep you on cutting edge. Growing for Market. 6(2):11-13.

Aung, L.H., F. Tognoni, and A.A. De Hertogh. 1973. Changes in the carbohydrates of tulip bulbs during development. HortScience 8:207-208.

Blom, T. J., 1998. Light Fixture Maintenance. AERGC Greenhouse Newsletter 11:1-3.

Bugbee, B., 1994. Effects of Radiation Quality, Intensity, and Duration on Photosynthesis and Growth, pp. 39-50. In: Proceedings of International Lighting in Controlled Environments workshop. NASA-CP-953309.

Buschman, J.C.M. and F.M. Roozen. 1980. Introduction. pp.3. In: Forcing Flowerbulbs. International Flower-bulb Centre, Hillegom, The Netherlands.

Cameron, A. M. Yuan, R. Heins and W. Carlson. 1996. Juvenility: your perennial crop's age affects flowering. GrowerTalks 6(8):30-32,34.

Carpenter, W. J. and R. C. Rodriguez. 1971. Earlier flowering of geranium cv. 'Carefree Scarlet' by high intensity of supplemental light treatment. Hortscience 5:183-184.

Carpenter, W.J. 1976. Photosynthetic supplementary lighting of spray pompon, *Chrysanthemum morifolium* Ramat. J. Amer. Soc. Hort. Sci. 101:155-158.

Cockshull, K.E. 1985a. *Antirrhinum majus*, pp. 476-481. In: Handbook of Flowering, vol. III, A.H. Halevy, ed. CRC Press, Boca Rotan, Fla.

Cockshull, K.E. 1985b. *Matthiola incana*, pp. 363-367. In: Handbook of Flowering, vol. III, A.H. Halevy, ed. CRC Press, Boca Rotan, Fla.

Damann, M.P. and R.E. Lyons. 1995. Juvenility and photoperiodic flowering requirements of *Chrysanthemum x superbum* 'G. Marconi' and 'Snow Lady' grown under short- and long-day conditions. J. Amer. Hort. Sci. 120:241-245.

De Hertogh, A. 1973. Changes in the carbohydrates of tulip bulbs during development. HortScience 8:207-208.

De Hertogh, A.A. 1996. *Allium giganteum*, pp. D13-14. In: Holland Bulb Forcer's Guide, 5th ed. International Flower Bulb Center, Hillegom, The Netherlands.

Dietz, C. 1976. Sowing schedules, pp.55-65. In: Bedding plants, a manual on the culture of bedding plants as a greenhouse crop, J.W. Mastalerz, ed. Pennsylvania Flower Growers Association. University Park, Pa.

Dole, J.M. and H.F. Wilkins. 1999a. *Antirrhinum*, In: Floriculture: Principles and Species. Prentice Hall, Upper Saddle River, N.J.

Dole, J.M. and H.F. Wilkins. 1999b. *Delphinium*, In: Floriculture: Principles and Species. Prentice Hall, Upper Saddle River, N.J.

Fodor, B., 1974. Bulb yield of tulip in connection with row-distance and planting depth. Kerteszeti Egyetem Kozlemenyei, 38:241-247.

Fulton, W. 1997. President's message. The Cut Flower Quarterly 9(3):4-6.

Griffiths, M. 1995. Royal Horticultural Society Index of garden plants. Timber Press. Portland, Ore.

Gude, H., K. de Jong, and P. Vreeburg, undated. The forcing of tulip and hyacinth under artificial light. Laboratory voor Bloembollenonderzoek, Bulb Research Center, Lisse, The Netherlands.

Hartsema, A.H., 1961. Influence of temperatures on flower formation and flowering of bulbous and tuberous plants. In: Hanbuch der Pflanzenphysiologie, W. Ruhland ed., , Springer - Verlag , Berlin, 16:123-167.

Jeff, A.E. and D.J. Fuller. 1961. *Anemone* spacing experiment in the southwest. Exper. Hort. 5:31-36.

Jennings, N.T., and A.A. De Hertogh, 1977. The influence of preplanting dips and postplanting temperatures on root growth and development of nonprecooled tulips, daffodils and hyacinths. Scientia Hort. 6:157-166.

Karlsson, M. 1997. Flowering response of *Anemone coronaria* to photoperiod and temperature. Hortscience 32:466 (Abstract)

Kenit, J., R. M. Sachs and G. Bernier. 1985. Control by Light, pp. 64-88. In: The Physiology of Flowering. vol. III, CRC Press, Boca Raton, Fla.

Le Nard, M. and A.A. De Hertogh.1993. *Tulipa*, pp.617-682. In: The physiology of flower bulbs: A comprehensive treatise on the physiology and utilization of ornamental flowering bulbous and tuberous plants. Elsevier, N.Y.

Le Nard, M. and Cohat, J. 1982. Influence des temperatures de conservation des bulbes sur l'elongation, la floraison et la bulbification de la tulip (Tulipa gesneria L.). Anales de l'Amelioration des Plantes, 18:181-215.

Miller, R.O. 1962. Variations in optimum temperature of snapdragon depending on plant size. Proc. Amer. Soc. . Hort. Sci. 81:535-543.

Moe, R. and R. Heins. 1990. Control of Plant Morphogenesis and Flowering by Light Quality and Temperature. Acta Hort. 272:81-89.

Nau, J. 1993a. Cut flowers. In: Ball Culture Guide, The Encyclopedia of Seed Germination, 2 nd edition. Ball Publishing, Batavia, Illinois.

Nau, J. 1993b. Perennials. In: Ball Culture Guide, The Encyclopedia of Seed Germination, 2 nd edition. Ball Publishing, Batavia, Illinois.

Nowak, J. and R.M. Rudnicki. 1993. *Hyacinthus*, pp.335-347. In: The physiology of flower bulbs: A comprehensive treatise on the physiology and utilization of ornamental flowering bulbous and tuberous plants. Elsevier, N.Y.

Ohkawa, K. 1987. Growth and flowering of *Anemone coronaria* L.'de Caen'. Acta Hort. 205:159-168.

Pearson, S., A. Parker, S.R. Adams, P. Hadley, and D.R. May. 1995. The effects of temperature on the flower size of pansy (*Viola* x *wittrockiana* Gams). J. Hort. Sci. 70:183-190.

Post, K. 1949. *Viola tricolor* and *Viola cornuta*; *Viola odorata*, pp. 839-845. In: Florist Crop Production and Marketing. Orange Judd Publishing, N.Y.

Quatchak , D. J., J. W. White and E. J. Holcomb. 1986. Temperature, supplemental lighting and chlormequat chloride effects on flowering of geranium seedlings. J. Amer. Soc. Hort. Sci. 111:376-379.

Rahman, M.S. and F.S. Gladstone. 1974. Effects of temperature and photoperiod on flowering and yield components of lupin genotypes in the field. Austral. J. Exp. Agric. Anim. Husb. 14:205-213.

Rees, A.R., 1972a. Flower initiation and differentiation, pp. 98-115. In: The Growth of Bulbs, vol I. J.F. Sutcliffe, ed. Academic Press, London.

Rees, A.R., 1972b. Structure morphology development and periodicity, pp. 17-44. In: The Growth of Bulbs, vol I. J.F. Sutcliffe, ed. Academic Press, London.

Shuster, W.H., 1985. *Helianthus annuus*. In: Handbook of Flowering , Vol III, A.H. Halevy , ed. CRC Press, Boca Raton, Fla.

Tsujita, M. J. 1987. High intensity supplementary radiation of roses, pp. 171-186. In: Roses. R. W. Langhans, ed., Roses Inc., Haslett, Michigan.

Van der Knaap, W., 1969. Opbrengstderving bij tulpen door planten op ongelijke en te grote depte. Weekblad voor Bloembollencultuur, 80:367-368.

Van Ouwerkerk, C., 1969. Invloed van de relatieve boldiepte op de opbengst van tulpen. Tuinbouw Mededeelingen, 32: 398-403.

Van Staden, J. The levels of endogenous cytokinins in daffodil bulbs stored under different environmental conditions . Zeitschrift fur Pflansenphysiologie, 86:323-330.

Wai, K.S. and S.E. Newman. 1992. Air and root-zone temperatures influence growth and flowering of snapdragons. HortScience 27:796-798.

Wallis, L.W. 1964. Bulbs. Rosewarne Experimiental Horticulture Station Annual Report 1963:14-31.

Wassink, E.C. 1965. Light intensity effects in growth and development of tulips, in camparison with those in *Gladiolus* . Medeelingen van de Landbouwhoogeschool, Wageningen, The Netherlands, 65-15, 21 pp.

Wellensiek, S.J. 1985. Campanula medium, pp.123-126. In: Handbook of Flowering, vol. II, A.H. Halevy, ed. CRC Press, Boca Raton, Fla.

Wilkins, H.F. and W. E. Healy. 1980. Influence of low light on rose branching. Roses Inc. Bulletin May p.75.

Yeh, D.M. and J.G. Atherton. 1997. Manipulation of flowering in cineraria. II. Juvenility. J. Hort. Sci. 72:55-66.

VITA

Todd Jason Cavins

Candidate for the Degree of

Master of Science

Thesis: COST EFFECTIVE PRODUCTION OF SPECIALTY CUT FLOWERS

Major Field: Horticulture

Biographical:

Personal: Born in El Reno, Oklahoma, on September 22, 1974, the son of T.J. and Judy Cavins.

Education: Graduated from El Reno High School, El Reno, Oklahoma in May 1993; received Bachelor of Science degree in Biology from Southwestern Oklahoma State University, Weatherford, Oklahoma in May 1997. Completed the requirements for the Master of Science degree in Horticulture at Oklahoma State University, Stillwater, Oklahoma, December 1999.

Professional Experience: Graduate Research Assistant, Department of Horticulture and Landscape Architecture, Oklahoma State University, August 1997 to December 1999; Teaching Assistant, Department of Horticulture and Landscape Architecture, Oklahoma State University, January 1998 to May 1998. Student Assistant, Southwestern Oklahoma State University, Weatherford, Oklahoma, January 1996 to May 1997.

Professional Memberships: American Society for Horticultural Science, Pi Alpha Xi and Beta Beta Beta