

THESIS
AIR AND MEDIUM TEMPERATURES FOR
ALSTROEMERIA 'ATLAS' AND 'MONIKA'

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER
OUR SUPERVISION BY LINDA SUE KEIL ENTITLED AIR AND
MEDIUM TEMPERATURES FOR ALSTROEMERIA 'ATLAS' AND
'MONIKA' BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS
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ABSTRACT OF THESIS
AIR AND MEDIUM TEMPERATURES FOR ALSTROEMERIA
'ATLAS' AND 'MONIKA'

Alstroemeria cultivars 'Atlas' and 'Monika' were grown in four 25.4 m² fiberglass-covered greenhouse compartments at the W.D. Holley Plant Environmental Research Center, Colorado State University. Each compartment contained two raised redwood benches subdivided into four 75 x 105 cm plots with buffer zones at either end of the bench. Individual benches had replicated plots of cooled and non-cooled substrate treatments. The cooled plots contained seven loops of .625 cm OD Biotherm tubing buried 15 cm beneath the pea gravel surface. A thermostatically-controlled cooling system supplied cold water, upon demand, in an attempt to maintain a medium temperature of 11°C.

Compartments were heated to 10° to 11°C during night periods, and the following daytime temperature regimes were established: Compartment A, 14° to 20°C; Compartment B, 20° to 26°C; Compartment C, 23° to 28°C; and Compartment D, 17° to 23°C. A night break was provided with incandescent lamps when natural daylengths were less than 12 hours.

Developing cultivar rhizomes were transferred from 10 cm pots to the bench plots on November 18, 1985. The first flower data were taken on February 10, 1986, then collected every other day and summarized weekly during the next 52 weeks. Parameters measured

included: stem length, flower grade, and total production. Data were analyzed as a split-split plot design with media treatments randomized within each pair of plots.

Total flower production of 'Atlas' in all compartments was 1.6 times as great as 'Monika'. Significantly larger numbers of flower stems were produced in the cooled substrate of compartments A and D. The results provided evidence that the greatest production of 'Atlas' and 'Monika' occurred with average daytime temperatures of 20°C combined with an average medium temperature of 12°C to 14°C. Consequently, the cooled medium treatment coupled with cooler air temperatures allowed production to continue virtually year-round.

The warmer daytime temperatures of compartments B and C increased the flower quality. However, the higher production in compartments A and D far outweighed the advantage that warmer temperatures contributed to quality. The flower quality of 'Monika' was considerably less than that of 'Atlas' in all temperature treatments. Warmer daytime temperatures also contributed to longer stems. 'Atlas' and 'Monika' stems from compartment C averaged a maximum of 13 cm longer than those from the remaining compartments. 'Atlas' stems were significantly longer than those of 'Monika' in all compartments.

A five week sub-trial was conducted to determine air temperature effects on *Alstroemeria* inflorescence characteristics. Parameters measured included: number of cymes per stem, cyme length, stem thickness, and number of buds per cyme. Data were analyzed as a split plot design. No significant differences were observed for number of cymes per stem and stem thickness between compartments, although

'Atlas' had thicker stems than 'Monika'. A significant trend toward increasing cyme length with increasing daytime temperature was evident in both cultivars. Significantly more buds were produced on stems of both cultivars in compartment D (i.e., 20°C average day air temperature) compared to all other compartments.

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CHAPTER I
LITERATURE REVIEW

A. HISTORY

Alstroemeria spp. have been referred to as Alstroemer's Lily, Lily of Lima (47), Lily-of-the-Incas, the Peruvian Lily (18), or Inca Lily (6). The plants are native to the South American countries of Chile, Brazil, Peru, Ecuador, Paraguay, Bolivia, and Argentina (50). The indigenous Alstroemeria species grow in a wide variety of habitats ranging from coastal dunes, desert sites, and semi-woodlands to the snowlines of the Andes and as far south as 40°S latitude (27). In the early 1700's, Father Louis Feuillet travelled through South America documenting his observations of the native flora. Upon discovery of Alstroemeria, he unknowingly identified them as a new species of Hemerocallis (47). The misnomer remained until 1754, when Don Claudius Alstroemer, the Swedish Consul in Spain, discovered several relocated plants in the present-day city of Cadiz. By 1762, Alstroemer had presented sketches, seeds, and dried flowers to his former instructor of Natural Sciences, Carl von Linnaeus. After investigation, Linnaeus realized the plant had been mistakenly named and classified. Since there were no available synonyms, Linnaeus (47) declared, "What prohibits us then from naming this plant, ALSTROEMERIA?" thereby giving the flower a permanent name and taxonomy.

In the 1960's, an English and a Dutch company began intensive research to create commercially productive cultivars through interspecific hybridization and radiation induced mutations (19). In 1980, Verboom (51) noted that all commercially grown varieties, both male and female, were sterile. Six main breeding lines have been described (28) as follows:

- 'Orchid' flowering type- tall, vigorous stems that produce a high percentage of 'select' grade.
- 'Butterfly' type- stems <1.5 m tall, later blooming, grown warmer, predominantly pink and purple.
- 'Carmen' type- medium tall, need frequent thinning, lower percent 'select', many colors available.
- 'Year-round' cultivars- more even fall production, only darker colors available currently.
- 'Ayr' varieties (13)- do not need supplementary lighting for winter flowering.
- 'Outdoor hybrids'- frost hardy cultivars for outdoor cultivation.

Modern cultivars are available from several sources, including: Parigo Horticultural Company (England), Van Staaveren (Holland), A. Wulfinghoff (Holland), Cor Van Duyn (Holland), Van Zanten (Holland), Konst Alstroemeria (28) (Holland), Sun Valley Farms (Myrtle Point, Ore.), and the Canadian Ornamental Plant Foundation (31) (Durham, Ontario). The plants are patented and leased to growers who must sign a contract which allows them to use only the cut flowers and forbids propagation. At the present time, the cost includes the plant price plus a royalty charge, depending on the source. Because of their unique characteristics, Alstroemerias are predicted to become a major "new" cut flower throughout the world (21, 29, 36, 50, 51).

B. MORPHOLOGY

Alstroemeria is a monocotyledonous, herbaceous perennial with both fibrous and storage roots arising from a system of fleshy

rhizomes. Starch granules, similar to those in potato tubers, have been isolated from the *Alstroemeria* roots (10). New shoots arise sympodially from a white "growing point" at the tip of each rhizome. As a shoot is harvested, a new rhizome branches off from the second axillary bud of that shoot. Storage roots arise from the third axillary bud (18), and all other nodes on the aerial stem lack axillary buds (27). Both vegetative and reproductive shoots vary in length and have been reported to reach as tall as 2.2 m (51). Normally, shoots with more than thirty leaves unfolded are considered vegetative and are periodically removed (19). The leaves on a vegetative stem will usually form a visible rosette when viewed from overhead (W.E. Healy, personal communication). A reproductive shoot will have fewer nodes spaced farther apart. Leaves of all shoots ascend in a counter-clockwise spiral up the stem (41). An expanding leaf rotates 180° causing the adaxial surface to become the abaxial one (41). Noordergraaf (39) described the inflorescence as an umbel, whereas others (52) have referred to it as a whorl of simple or compound cymes with each cyme bearing one to five sympodially arranged buds. These buds open in an acropetal direction as the flower below reaches anthesis (19). Under a $3/8$ phyllotaxis rule, the flowers will most commonly have three, five, or eight cymes per inflorescence (38). A leaf blade subtends each flower which has six stamens and six petals. These petals have distinctive speckled markings. The flower colors range from shades of red, orange, and yellow to white, purple, and pink. The inferior ovary can develop into a seed capsule, and Linnaeus (33) described the seeds as: ". . . most numerous, globular, covered with elevated dots, and rather naveled at the top."

C. PROPAGATION

Thompson and Newman (48) developed a technique for germinating high percentages of viable *Alstroemeria* seeds, however, commercial cultivars are commonly propagated asexually. Powell and Bunt (40) identified cyclic *Alstroemeria* production patterns which appeared to be related to seasonal changes rather than date of propagation. Thus, the plants are lifted and divided when production begins to decrease in the fall of the second and/or third year. One to two weeks before lifting, the plants should be pruned back 15 to 20 cm above the growing medium (19). A division consists of 5 to 7.5 cm of new rhizome with four to five young shoots and as many storage roots as possible. Older rhizome parts can not be used for successful divisions because they contain no active "growing points" (W.E. Healy, personal communication). Asexual propagation of cultivars grown in ground beds may be difficult because "growing points" have been noted at depths of 35 cm at propagating time (19).

Planting density in a Colorado experiment (16) was reportedly optimized at .186 m² per plant, or .163 m² for less vigorous cultivars. A study in Belgium (6) revealed that a density as high as ten plants per square meter had no influence on flower quality, however, the increased returns were not greater than the increased production costs. Experimenters (6, 16) noted that selling price would affect the economic feasibility at various densities.

European ground beds are approximately one meter in width, and it is common to space the plants 40 to 60 cm apart in two rows which are 50 cm apart (1). When transplanting, "growing points" should be placed toward the center of the bench or pot so the rhizome has room

to expand. Stubs from the initial division should be removed after four weeks when new shoots begin emerging (W.E. Healy, personal communication). Four to eight weeks of 16° to 18°C air temperatures have been shown to be beneficial for establishment of the divisions after transplant (19). Healy and Wilkins (19) indicated that failure to replant immediately after division sometimes results in delayed re-establishment or death. Transplant losses in most cases are predicted to be 5% to 25%, however, fungicidal drenches have helped reduce these losses (21). If bare root plants must be stored, rhizomes should be placed in moist peat moss and kept at 2°C (52).

D. GENERAL CULTURAL PRACTICES

Lisiecka (34) conducted an analysis of eight media combinations and determined 'Regina' produced best in a 1:1 to 1:2 medium ratio consisting of a muck soil combined with either peat moss or bark compost. Other media with ratios of 1:1:1 (7, 22, 23, 26, 27) and 2:2:1 (36) soil, peat, perlite have been utilized. Several authors (6, 11, 34, 51) listed desirable media characteristics as: light, airy, well-drained, and well-aerated, with high amounts of organic matter. Healy (15) has shown many commercial cultivars produced better in a soil versus gravel medium, possibly due to better temperature control.

Alstroemerias are "heavy feeders" (26), and some researchers (20) have fed vigorous plants up to 10 meq-liter⁻¹ (600 ppm) nitrate biweekly without any adverse effects. Bik and Van den Berg (3) studied 'Orchid' and 'Carmen' and reported that; ". . . N and K₂O should be supplied in a ratio ranging from 1:1 to 1:1.4." The recommendation failed to refer to the elements in their available form. Blomme and Dambre (6) found that four annual applications of 20.75

$\text{g}\cdot\text{m}^{-2}$ potassium ($25 \text{ g}\cdot\text{m}^{-2}$ KCl) optimized the production of 'Orchid' plants already receiving lesser amounts of nitrogen and phosphorus. It should be noted, however, that ammonium nitrate was used as the sole nitrogen source for both of these studies. According to Wilkins (52), ammonium should be avoided as it is not readily converted to nitrate at 13°C temperatures. Verboom (51) suggested a liquid feed consisting of an 18-6-18 fertilizer supplied at about one gram per liter. Slow release fertilizers have also been proven effective on *Alstroemeria* (6). Healy (15) observed interveinal chlorosis during peak production in July and August. However, the deficiency symptoms disappeared without additional fertilizer when the flowers began to show color. Many researchers (1, 2, 6, 11, 19, 30, 36, 51, 53) have reported a pH of 6.5 to be best for *Alstroemeria* production.

Watering is required more frequently in gravel than in soil, whereas excess soil watering can rot rhizomes. Luxurious watering of 'Regina' in gravel (one twelve hour application) has been shown to cause dramatic elongation of shoots (15). Studies conducted on 'Pink Panter' and 'Rosario' (44) indicated that salinity threshold values for salt content of nutrient irrigation water should be kept below $.8 \text{ mmhos}\cdot\text{cm}^{-1}$ at 25°C . Insufficient irrigation practices can result in shorter shoots (15), bud abortion, and blindness (53).

Very few CO_2 enrichment studies have been conducted involving *Alstroemeria*. In one investigation, Verboom (51) found that a CO_2 atmosphere of $1200 \mu\text{l}\cdot\text{liter}^{-1}$ applied to 'Canaria' and 'Orchid' resulted in a 10% increase in yield and an acceleration in production time. The same study indicated an apparent, but unverified, interaction between CO_2 and temperature. Humidities of 80% to 85% are recommended for

most cultivars (11), except the triploid cultivar 'Rosario' which reportedly grows best in a RH of 75% to 80% (2).

In 1975, Molnar (36) reported a disorder which stunted vegetative stems and produced rusty lesions on the foliage. A floricultural research station in the Netherlands erroneously diagnosed the symptoms as physiological aging. Since that time, several viruses have been identified as the causal agents (8). The diseases can be spread by pests in the Trichodorus family (6). Cultivars appear to vary in their resistance to these viruses, and Healy (19) observed the symptoms disappeared between air temperatures of 13° and 21°C.

Alstroemerias have very few insect and disease problems. Reported pests include: Rhizoctonia and Botrytis, slugs, caterpillars, thrips, spider mites, and aphids (1, 6, 19, 36, 51, 53). Pesticide spraying should be done in the early morning or on a cloudy day to prevent leaf burn (19). Some people have developed skin rashes after working with this crop for extended periods of time. Researchers (43) have identified the source of the rash as an ester of glucose called tuliposide. The rash is more commonly called "Tulip Fingers" since it first developed on the skin of tulip harvesters.

Much of the labor required for Alstroemeria production involves caging, thinning, and harvesting. Two to four layers of supports are usually necessary, with the mesh spacing at approximately 20 x 18 cm (53). Actively flowering shoots can develop at a rate of 15 to 20 cm a day (W.E. Healy, personal communication); thus, the plants should be confined within the caging at least twice a week (28). Excessive shoot densities tend to produce tall, etiolated growth; therefore, vegetative shoots must be thinned every three to four weeks.

Researchers (27) believe thinning enhances photosynthesis by increasing light penetration through the canopy. It may also promote lateral rhizome branching (52) and increase aerial shoot formation due to decreased apical dominance (27). Growers are cautioned to remove no more than 25% of the vegetative shoots at one time (19). Excessive thinning can initiate the "short shoot" phenomenon (15), where reproductive shoots fail to elongate during the next flowering cycle. "When the problem is severe, the only apparent way to break the cycle is to remove the flower buds without removing the shoots" (15).

Healy (15) recommended harvesting in the late morning or early afternoon when the turgor pressure is lower and the stems are less prone to breakage. Flowers are harvested when at least one flower has begun to dehisce pollen (19). Stems may be cut at the soil line or pulled from the rhizome with a quick jerking motion. When the cutting method is used, the remaining stubs should be removed at a later date (51). From August through the end of the flowering period, stem cutting may be preferred over pulling since the lateral rhizome can break away from the main rhizome (15).

Shoots are reportedly marketed with ten to twelve stems in a bunch (52). Although no standard grading system exists, Wilkins (52) recommended bunches be made from the following categories:

- Grade 1- 90+ cm stem with five or more cymes
- Grade 2- 60+ cm stem with three to four cymes
- Grade 3- 30+ cm stem with less than three cymes

Stemlength is measured from the bottom of the stem to the base of the cymes, and they are downgraded for poor foliage and/or crooked, damaged stems (52). Following harvest, the white segment at the base of the stem should be removed since it has been shown to inhibit

water uptake (W.E. Healy, personal communication). It is recommended that harvested flowers be kept in a cooler at 2°C for at least 24 hours (19). Alstroemeria can be dry stored at 2°C for at least five days, although quality may be seriously reduced (19).

Postharvest studies conducted by Molnar (36) on 'Regina' and 'Orchid' indicated that recently harvested flowers kept at room temperature lasted twelve to fourteen days in preservative versus seven to eight days in water. He also noted smaller buds opened in the preservative solution, but did not open in the water treatment. Another Alstroemeria study involving 'Regina' (26) showed commercial preservatives did not significantly increase vase life at 21°C with ten hours of fluorescent lighting. However, the author acknowledged the preservatives may have decreased individual flower shattering.

E. FLOWER INDUCTION AND INITIATION

Cyclic production is one of the greatest problems facing Alstroemeria producers because prices tend to drop when supplies are high (49). Consequently, researchers have sought to discover the mechanisms which control Alstroemeria flowering to obtain continuous high quality yields. Experimental evidence (6, 22, 23, 25, 26, 27, 30, 32, 34, 36, 38, 39, 40, 42, 51) now points to two primary factors which influence Alstroemeria flowering: temperature and long-day photoperiod. Healy and Wilkins (22) referred to it as a multiphasic requirement which involves an obligatory thermophase followed by a photophase. In simpler terms, photoperiod will not induce flowering unless the plants have first received a vernalization.

E1. Temperature

Noordegraaf (38, 39) conducted two of the first studies which examined temperature effects on 'Orchid' (also known as 'Walter Fleming') shoot formation and flowering. When he (38) compared growth at 17°, 21°, and 25°C, shoot formation was found to increase with increasing temperatures. In contrast, low temperatures (9° to 13°C) promoted flowering with a twelve hour photoperiod. Above 25°C, both flowering and growth were inhibited. Lower temperatures caused more rhizome branching and root thickening; higher temperatures caused more lateral shoots to develop. These results suggested a competition between shoot development and flower initiation, where only one of the two occurred under specific temperature conditions.

Several authors (23, 27, 29) have studied the relationships between air and soil temperature. Heins and Wilkins (27) found constant 15°C soil temperatures with night interruption lighting produced the greatest percentage of flowering 'Regina' shoots compared to a 15°/21°C alternating treatment. Healy and Wilkins (23) concluded that ". . . floral induction was controlled primarily by the temperatures to which the rhizome was subjected, regardless of air temperature or photoperiod." They (23) also suggested: ". . . 'induction' is not a singular event, but rather is a continuous process for each shoot as a rhizome elongates." Therefore, low soil temperatures must be maintained for production to persist year-round. This was confirmed by Langhans and Price (29) who reported a minimum of twelve weeks at 13°C soil temperatures caused an unnamed cultivar to bloom continuously. Healy and Wilkins (22) further stated:

". . . once the *Alstroemeria* has been adequately programmed to flower, the rate of flower shoot development is governed by the forcing temperature." In other words, once a vernalization has been perceived, low air temperatures delay flowering. Consequently, soil temperature was proven to be critical for flower induction, and air temperature was found to be crucial for initiation.

Blom and Piott (5) studied the effects of controlled soil temperatures on production of cultivars 'Red Sunset', 'Rosita', 'Rosario', and 'Rio' grown in ground beds. Production in a control greenhouse (with only a surface mulch) was compared to a test greenhouse with subsoil piping spaced 45 cm apart. The test greenhouse soil was heated or cooled as necessary to maintain an average temperature of 16°C. Results indicated an 11.6% depression in yield with controlled soil temperatures compared to the control. These results appear to contradict the findings of other researchers (23, 27, 29), however, the authors acknowledged the need for additional cooling lines because the soil temperatures rose to above 18°C during one 12 week period. In addition, the 11.6% yield depression was not analyzed for statistical significance, thus it could possibly be a result of experimental variation.

Healy and Wilkins (17, 22, 23, 24) have conducted numerous *Alstroemeria* temperature studies. In one 'Regina' study (17), four weeks of a 5°C vernalizing pretreatment followed by 18°C (night) air temperatures produced the most rapid flowering. However, higher production was maintained when the treatment involved six weeks of 5°C followed by 13°C (night) forcing temperatures. Days-to-Flower (DTF) were found to be inversely related to the number of weeks the

plants were kept in the 5°C pretreatment (24). The authors (22) suggested that vernalized rhizomes could be forced faster at higher air temperatures, whereas nonvernalized could receive the equivalent through lower forcing temperatures (13°C continuously). They (22) concluded; ". . . the flower inducing cold treatment may be an accumulated response acquired over a long time at 13°C or rapidly at 5°C."

E2. Photoperiod

Once the temperature requirement has been fulfilled, photoperiod has been shown to enhance flower development (22, 25, 26, 27, 30, 32, 34, 35, 36, 38, 39, 42, 51).

Verboom (51) listed five *Alstroemeria* responses to photoperiod:

1. 14+ hours with greater than 18°C temperatures caused a decrease in growth and number of shoots per plant.
2. greater than 14 hours caused a decrease in the number of cymes per umbel.
3. lengthening daylight hours in winter stimulated bud formation in the shoot; stems became shorter and flowering started earlier.
4. for nearly all varieties, 13 hours appeared to be the best in winter and spring.
5. lighting up to 13 hours in a 24 hour period in winter and spring had a favorable influence on renewed growth of the plants in summer after the first crop in June was over.

Verboom (51) recommended long days be given from January to April at 50° to 54°N latitude, and possibly from September to January. He cautioned, however, that spring flowering could be delayed if fall photoperiodic treatments are applied to plants which will remain in the soil for the next year. Noordegraaf (38) studied the cultivar 'Orchid' and found generative shoot percentage was the highest with daily treatments of eight hours natural (ND) irradiation followed by eight hours supplemental incandescent irradiation. Long days (LD) (i.e., >12 hours) promoted flowering, but limited shoot formation.

Heins and Wilkins (27) reported 'Regina' plants receiving night interruption (NI) incandescent irradiation flowered six weeks earlier than in normal winter/spring daylength and produced 30% more flowering stems. The NI treatment was given as a supplement to natural daylength so that a total of twelve hours of light was supplied. Short days (SD) (i.e., <12 hours) inhibited flowering regardless of soil temperature. Long day photoperiods increased the number of flowering stems per plant, decreased the average number of flowers per stem, and caused earlier flowering (27).

Healy, et al. (25) discovered supplemental irradiation applied to 'Regina' had no effect on flowering when natural daylengths were greater than twelve hours. When daylight was less than twelve hours and air temperatures were kept at 13°C, supplemental irradiation caused plants to flower earlier. Flowering was hastened with twenty hours of High-Intensity Discharge (HID) irradiation compared to twenty hours of incandescent. Plants given incandescent or red light NI flowered earlier than far-red NI, ND, or SD. Once again, short days inhibited flowering at all air temperatures.

Lin and Molnar (32) found eight hours of natural irradiation extended with eight more hours of high-pressure sodium (HPS) irradiation caused a dramatic increase in production of 'Orchid' and 'Regina' flowering stems. Molnar (36) reported plants were 20% taller when supplied with a sixteen hour photoperiod during the winter. Robinson and Kanterovitz (42) reinforced the theory that long day treated 'Orchid' plants flowered earlier, although the treatment resulted in shorter stems, thinner shoots, and less flower cymes per stem.

In addition to duration, radiant intensity is equally important to flower production. Low intensities have been shown to decrease the number and percentage of generative shoots (38). Furthermore, bud blasting can be a detrimental consequence of inadequate radiant energy (51). Under sixteen hours of HPS irradiation during November to February, the number of flower stems increased 49% for 'Orchid' and 26% for 'Regina' during the first year of a Canadian study (32). Researchers (27) have recommended that Alstroemeria growers at latitudes with low winter solar insolation apply supplementary irradiation with HID lamps from December through January. Three methods have been used for photoperiod and/or radiant intensity applications:

Cyclic lighting- 20 min·hr⁻¹ to conserve energy (36)

Day extension- applied at dusk or dawn (26)

Night interruption- 2200 hr to 0200 hr (22)

F. SUMMARY

Based on the literature reviewed, research indicates that air and media temperature interact with photoperiod for optimum growth and yield of specified Alstroemeria cultivars. Most of the studies to-date were conducted in areas with naturally low solar insolation. In contrast, the Colorado climate has high light intensities and a large percentage of sunny days. Thus, the results of this research are applicable only to geographic environments similar to Colorado. With this limitation in mind, the objective of this research was to determine the "general" daytime air temperature requirements of the two cultivars, 'Atlas' and 'Monika'. The study was also designed to define the extent to which medium cooling can keep the two cultivars

CHAPTER II MATERIALS AND METHODS

A. FACILITIES AND GENERAL EQUIPMENT

Alstroemeria cultivars 'Atlas' and 'Monika' were grown in a compartmentalized 4.8 x 21.2 m (101.8 m²) greenhouse covered with corrugated fiberglass (PVF-coated Lascolite) at the W.D. Holley Plant Environmental Research Center, Colorado State University. The building was oriented in an east/west direction. Interior walls and doors separated the facility into four 4.8 x 5.3 m (25.4 m²) compartments which were designated "A" to "D" from west to east (Fig. 2.1).

Within each compartment, there were two 3.6 x 1.1 x .2 m raised redwood benches oriented east/west (Fig. 2.1). Each bench was subdivided into four 75 x 105 cm plots with a 30 x 105 cm buffer zone at either end. Cedar boards, 2.5 cm thick, were used to separate plots.

Each compartment was equipped with a cooling system and overhead/peripheral steam heating pipe. The cooling system consisted of an automated vent and aspen pads incorporated into the north wall of each compartment and a two-speed, 1/3-1/9 horsepower exhaust fan on the south wall (Fig. 2.1). Plastic baffles were hung from the ventilators during the summer to increase the horizontal air flow.

An aspirated thermostat and a CO₂ injection tube were centrally-located in each compartment. The air temperature thermostats were

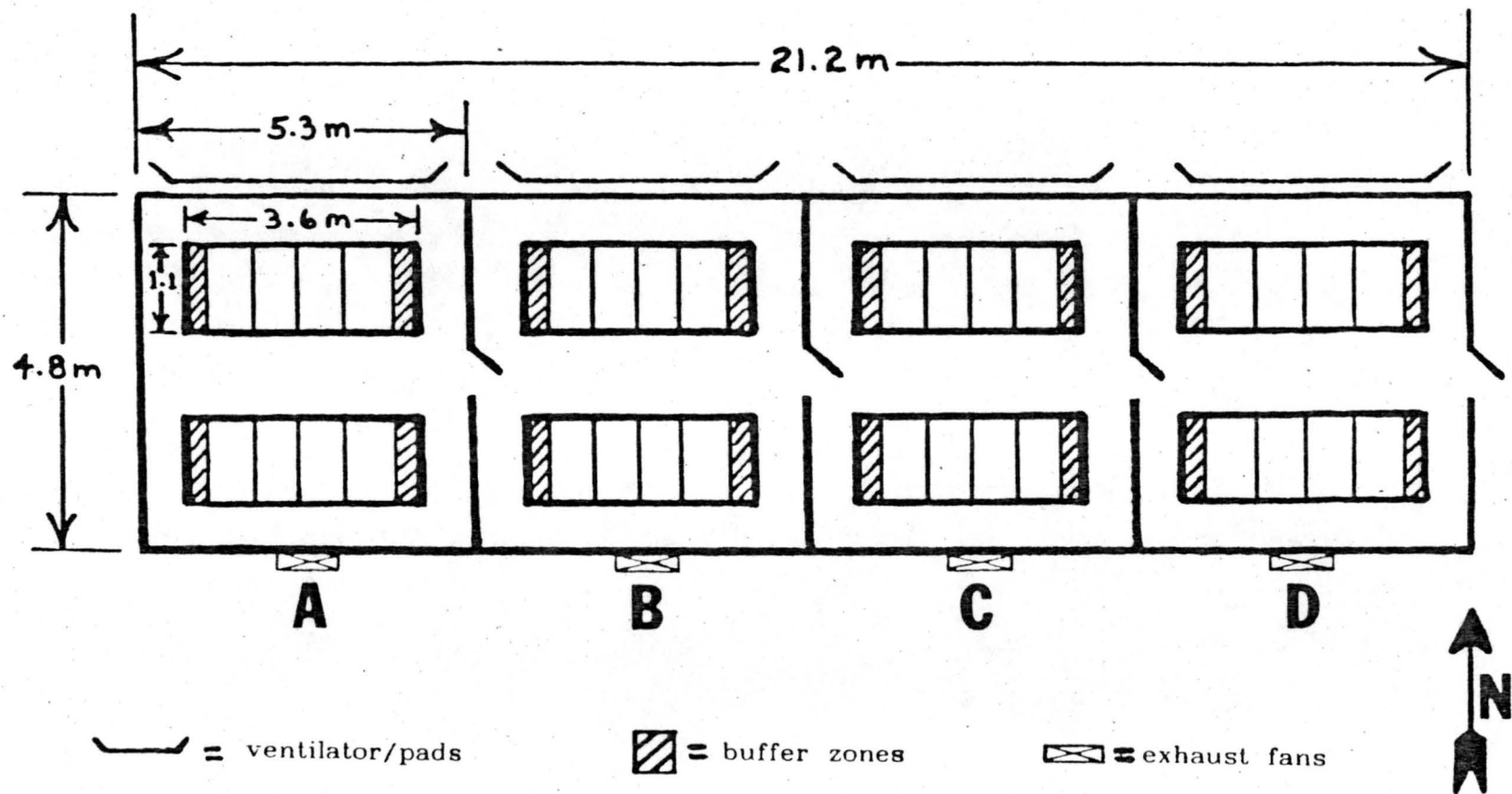


Fig. 2.1. Top view of the temperature facility used to study the flowering response of *Alstroemeria* cultivars 'Atlas' and 'Monika' to air and medium temperatures. Not to scale.

placed in shelters .75 m above ground and were aspirated at 120 $\text{cm}\cdot\text{sec}^{-1}$. A flow meter in each compartment controlled the rate of CO_2 injection which began January 1, 1986 and continued through to the end of the trial. Approximately 1000 $\mu\text{l}\cdot\text{liter}^{-1}$ CO_2 per compartment were supplied during daylight hours. An Oglevee gas analyzer was used to monitor the actual levels maintained by rotating the sampling tube between compartments.

Three incandescent 40 watt lamps were strung over each bench to supply a radiant flux density of approximately 0.1 to 0.5 $\text{W}\cdot\text{m}^{-2}$. During the trial, low intensity irradiation was applied when natural daylengths were less than 12 hours: December 4, 1985, to April 1, 1986, and September 15, 1986, to the end of the experiment. Time clocks turned the lights on at 2200 hr and off at 0200 hr.

Each bench had six Chapin drip irrigation tubes installed lengthwise on the bench and across the plots. Pressure regulators controlled the flow rate through the irrigation system. Plants were automatically watered daily at 0800, 1100, 1400, and 1700 hr using the standard CSU carnation mix (14). Solubridge readings were taken intermittently and benches were leached if soluble salt levels became greater than .8 $\text{mmhos}\cdot\text{cm}^{-1}$. Compartments were intermittently fogged with Vapona or Dibrom to control aphids. Metaldehyde bait was spread on the medium to control slugs.

A total of five layers of plant caging supports, spaced 20 cm apart, were added to each bench. Plants were thinned on a monthly basis, with no greater than 25% of the stems removed at one time.

B. TEMPERATURE TREATMENTS AND RELATED EQUIPMENT

Compartments were heated to 10 to 11°C during night periods, and the following daylight temperature regimes were established:

	<u>HEAT TO</u>	<u>COOL AT</u>
COMPARTMENT A	14°C (58°F)	20°C (68°F)
COMPARTMENT B	20°C (68°F)	26°C (78°F)
COMPARTMENT C	23°C (73°F)	28°C (83°F)
COMPARTMENT D	17°C (63°F)	23°C (73°F)

The system was switched from day to night temperatures by a time clock which was changed to correspond to seasonal daylengths. Steam valves opened when temperatures fell below the "heat to" point. Two stages of cooling were utilized: first stage, low fan speed only; second stage, high fan speed and gradual ventilator opening. To prevent uneven heating patterns, each compartment contained a central circulating fan positioned below the ridge to direct the air vertically.

Low temperature substrate treatments were maintained with a cold water cooling system (Fig. 2.2). A 192 liter (50 gallon) barrel was placed in compartment "A" on a 65 x 65 x 50 cm raised table with a freon compressor underneath. The tank was insulated with a wall of 5 cm thick styrofoam. A double wall polycarbonate material was placed around the compressor to prevent heat exchange with the surrounding air. During the warmer months, exhaust from the compressor was vented out a hole in the west wall of compartment "A".

Freon was pumped from the compressor through 1.25 cm (1/2 inch o.d.) copper tubing which was coiled within the barrel to cool the surrounding water to 4°C. A 1/12 horsepower pump circulated cold water from the barrel to the bench areas and back via 1.9 cm (3/4 inch i.d.) polyvinyl chloride (PVC) piping (Fig. 2.3). Thermostatically controlled valves provided the cold water to each bench upon demand.

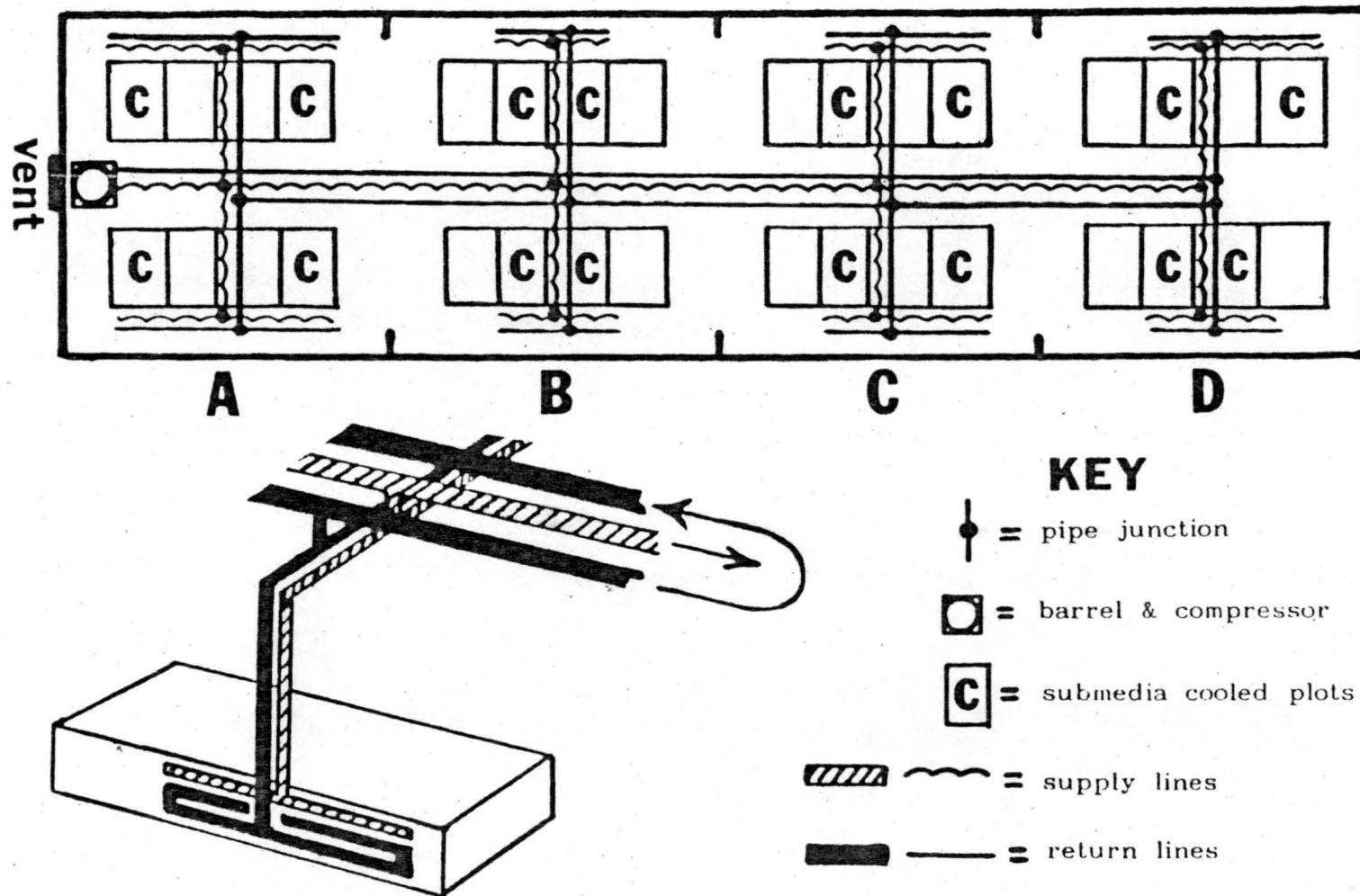


Fig. 2.2. Schematic of the randomized plot design and the submedium cooling system used to determine flowering responses of 'Atlas' and 'Monika' compared to non-cooled plots.



Fig. 2.3. PVC supply and return lines attached to a bench.

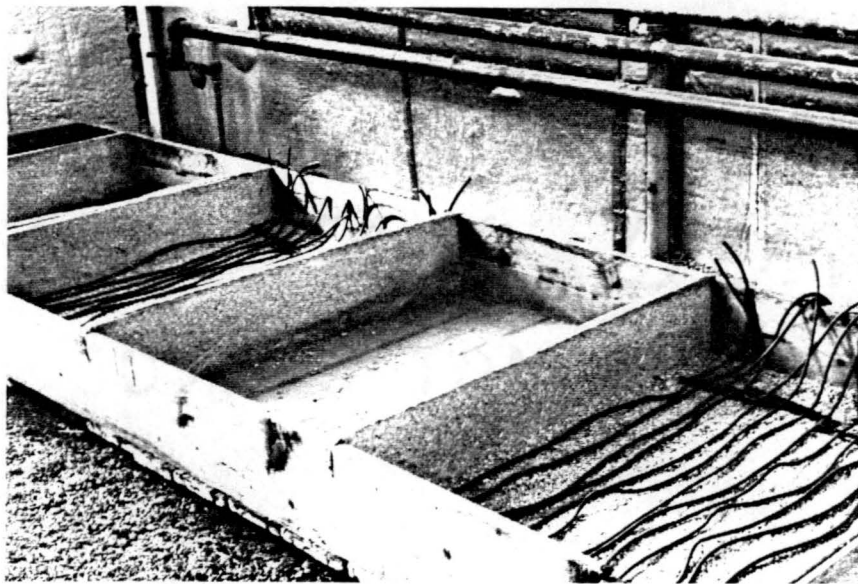


Fig. 2.4. Seven loops of Biotherm tubing laid on a 5 cm base of pea gravel in each of the cooled plots in a bench.

Individual benches in each compartment had replicated cooled and non-cooled medium treatments. The cooled plots contained seven loops of .625 cm (1/4 inch o.d.) Biotherm tubing laid on a 5 cm foundation of pea gravel (Fig. 2.4). The remaining plot was then filled with gravel. Each bench had a thermostatically-controlled brass zone valve which would allow cold water through the Biotherm tubing when the medium temperature rose above the 11°C (52°F) set point. Eight brass balancing valves (i.e., one per bench) were positioned along the supply lines so the water to each bench could be manually shut off if necessary.

C. PLANT DATA COLLECTION

Two cultivars, 'Atlas' (Carmen-type) and 'Monika' (Butterfly-type) (28) were leased from the Van Staaveren Company, Aalsmeer, Holland. Prior to planting, all benches were steam pasteurized at 82°C for 30 minutes. Potted rhizomes of both cultivars arrived October 22, 1985, from Henry's Plant Farm, Snohomish, Washington. To insure equal cultivar sizes at planting, 'Atlas' pots were held in a 2°C cooler while the smaller 'Monika' divisions were allowed to grow in a 15°C greenhouse. Ninety-six divisions of each cultivar were randomly planted in the benches on November 18, 1985. The buffer zones were filled with 'Regina' and 'Red Sunset' cultivars. Every plot contained six plants, three 'Atlas' and three 'Monika' (plant density of 7.6 plants per square meter).

Plant data were collected every other day and summarized weekly during a 52 week period beginning February 10, 1986. Flowering stems were harvested by pulling them when a minimum of one anther began to dehisce pollen. For the first few months of the trial, 'Monika'

stems had to be cut to prevent uprooting. Stubs were removed later to promote lateral rhizome branching. Each harvested stem was measured from the base of the stem to the base of the cyme. The stems were then graded according to the following criteria:

<u>GRADE</u>	<u>CATEGORY</u>	<u>CRITERIA</u>
1		90+ cm stem with five or more cymes
2		60+ cm stem with three to four cymes
3		30+ cm stem with two cymes
4		<30 cm stem with one cyme

Both the length and cyme number requirements had to be fulfilled for a stem to be considered in a specific grade category. If only one of the two criteria was met, the stem was downgraded. Lower grades were also assigned to stems with poor foliage.

To gain insight into air temperature effects on inflorescence characteristics, specific flower data were collected for five weeks beginning July 14 through August 17, 1986. Once a week, eight 'Atlas' and eight 'Monika' stems were randomly selected from each plot for the following measurements: number of cymes, cyme length, stem thickness, and the number of buds per cyme.

D. ENVIRONMENTAL DATA COLLECTION

Air temperature and radiation values were collected from the fifth to the 52nd week of the trial. A Hewlett-Packard (HP) computer system recorded daily air and substrate temperature and radiation data for each compartment (Fig. 2.5). A HP-41CV hand programmable calculator was connected in series to a HP3421A data acquisition unit and a HP82162A thermal printer.

T-type (copper/constantan) thermocouples were placed in aspirated shelters in the center of each compartment for air temperature sensing. Substrate temperature data were collected during



Fig. 2.5. Hewlett-Packard (HP) computer system used to collect environmental data. Left to right: HP41CV programmable calculator, HP3421A data acquisition unit, and a HP82162A thermal printer.

the following weeks of the study: 9, 13, 16, 23, 28, 31, 34, and 39. T-type thermocouples were placed in copper sheaths and inserted into the medium (15 cm deep) at the center of a plot. Due to limited channel space on the HP3421, only two soil probes were available per compartment. During a soil data collection week, probes were randomly moved to a different pair of plots every other day.

Daily radiation was measured with four Mark I-G Sol-A-Meter silicon cell pyranometers (.35 to 1.15 micron spectral response range) placed in each compartment. For the first 18 weeks of the study, the pyranometers were placed on platforms 1.5 m above ground. Thereafter, the sensors were strung from wires 10 cm below the fiberglass covering to prevent shading by steam pipes.

All sensing devices were connected to channels on the HP3421A interfacing unit which converted electrical signals into temperature ($^{\circ}\text{C}$) and radiation values ($\text{W}\cdot\text{m}^{-2}$). The 41CV calculator was programmed to take channel readings every 10 minutes. Each time a channel was read, the value was used in further calculations and the results stored. The pyranometer in compartment C was used to sense when the system should switch from day to night, and vice versa. When the reading from that channel became less than $10 \text{ W}\cdot\text{m}^{-2}$, the system printed a day summary for each channel; if the value exceeded $70 \text{ W}\cdot\text{m}^{-2}$, a night summary was printed. After completion of a printout, all storage registers were re-initialized.

Each 10 minute temperature reading was tested by the program to see if it qualified as a maximum or minimum value. Any changes were then saved in the "maximum"/"minimum" storage registers, and the value was added to the "total temperature" register. Prior to printing

of a summary, the program calculated the average temperature for each channel ("total temperature" divided by the number of 10 minute executions that occurred in that period).

Every 10 minute radiation value was added to the "total radiation" register. Before the radiation values were used in statistical analyses, the units were converted from $W \cdot m^{-2}$ to $kJ \cdot m^{-2}$. Relative humidity was monitored with a Vaisala portable capacitance probe. A daily or nightly summary (Appendix A) consisted of: the time and date of printing; the number of 10 minute executions; the minimum, maximum, and average temperatures ($^{\circ}C$) for each air and substrate channel; and the total radiation ($W \cdot m^{-2}$) for each radiation channel. The data from these printouts were entered on a weekly basis in files on the CYBER mainframe computer at Colorado State University.

E. STATISTICAL PROCEDURES

The experimental design for the 52 week trial consisted of a split-split plot with media treatments randomized within each pair. Compartments were the main effect with media treatments and cultivars as the subunits. In the whole plot design, pairs within compartments could not be randomized due to the fixed position of each pair. Data from three plants had to be discarded because the supplier inadvertently sent divisions of the wrong cultivars. Because only three of the 192 plants were missing, equally weighted means were assumed. Yield data for the three plots with a missing plant were balanced by adding the mean of the existing two plants to the total number of stems produced by that plot. The average grade and height values from those plots were left as means of data from the two remaining plants.

Computer files were aggregated and analysis of variance tables were generated using the "Statistical Package for the Social Sciences (SPSS*)" (45). Standard errors for the split plot design with two subdivisions were calculated as described by Cochran and Cox (9). Treatment averages were compared using Tukey's mean separation test for Honestly Significant Differences (HSD) (46). Rough drafts of all graphs were created with "LOTUS" on a personal computer.

The five week sub-trial on inflorescence characteristics was analyzed as a split plot design with compartments as the main effect and cultivars as the subunit. Substrate treatments were omitted from these analyses so as to focus solely on air temperature influences. HSD's were calculated as described by Steel and Torrie (46).

CHAPTER III RESULTS

A. RADIATION, HUMIDITY, AND CO₂

Total irradiance received in the two easterly compartments (C and D) was approximately 20% less than that recorded in the westerly compartments (A and B) during the 48 week period (Table 3.1). Relative humidity varied less than 15% between compartments when periodic measurements were taken, and averaged almost 15% less than the recommended 80% to 85% (11) (Table 3.1). The lower humidities in the cooler compartments (A and D) were attributed to the continual ventilation required to maintain lower air temperatures. Average CO₂ concentrations in all compartments were more than 900 ppm when 20 random observations were made (Table 3.1).

B. AIR AND SUBSTRATE TEMPERATURE EFFECTS ON YIELD, QUALITY, AND STEM LENGTH

The average substrate temperatures in the cooled plots of each compartment ranged from 1° to 4°C (2° to 6°F) lower than the non-cooled plots (Table 3.2 & Fig. 3.1). Even though specific heating and cooling temperatures were established, the weekly daytime air temperatures of the four compartments (Fig. 3.2) fluctuated considerably throughout the 48 weeks environmental data were recorded.

During weeks five to 33 (March 10 to September 28) the average air temperature in compartments A and D could not be kept low enough to make them differ from each other. After week 33, the air temperature differences became more evident. Although the pre-set

Table 3.1. Average relative humidity, average CO₂ concentration, and yearly total irradiance in four 25.4m² fiberglass-covered greenhouse compartments.

Compt	Total irradiance (GJ·m ⁻²)	Avg RH ^z (%)	Avg CO ₂ concn ^z (μl·liter ⁻¹)
A	4.1	57.2	990.0
B	4.1	68.6	986.7
C	3.2	72.1	920.0
D	3.3	64.8	920.3
Overall avg	3.7	65.7	954.3

^z Each CO₂ value is the mean of 20 random daily observations.

^v Each relative humidity value is the mean of 20 random daily measurements taken at a standard atmospheric pressure of 847 mb and average air temperatures of 22°, 23°, 24°, and 25° (compartments A to D, respectively).

Table 3.2. Average day/night air temperatures and cooled or non-cooled medium temperatures recorded from March 10, 1986, to February 8, 1987, in four 25.4 m² greenhouse compartments.

Compt	Avg air temp (°C)		Avg medium temp ² (°C)	
	Day	Night	Cooled	Non-cooled
A	20	14	14	16
D	20	13	12	16
B	22	13	16	17
C	24	14	15	18

²Each value is the mean of 40 random daily observations.

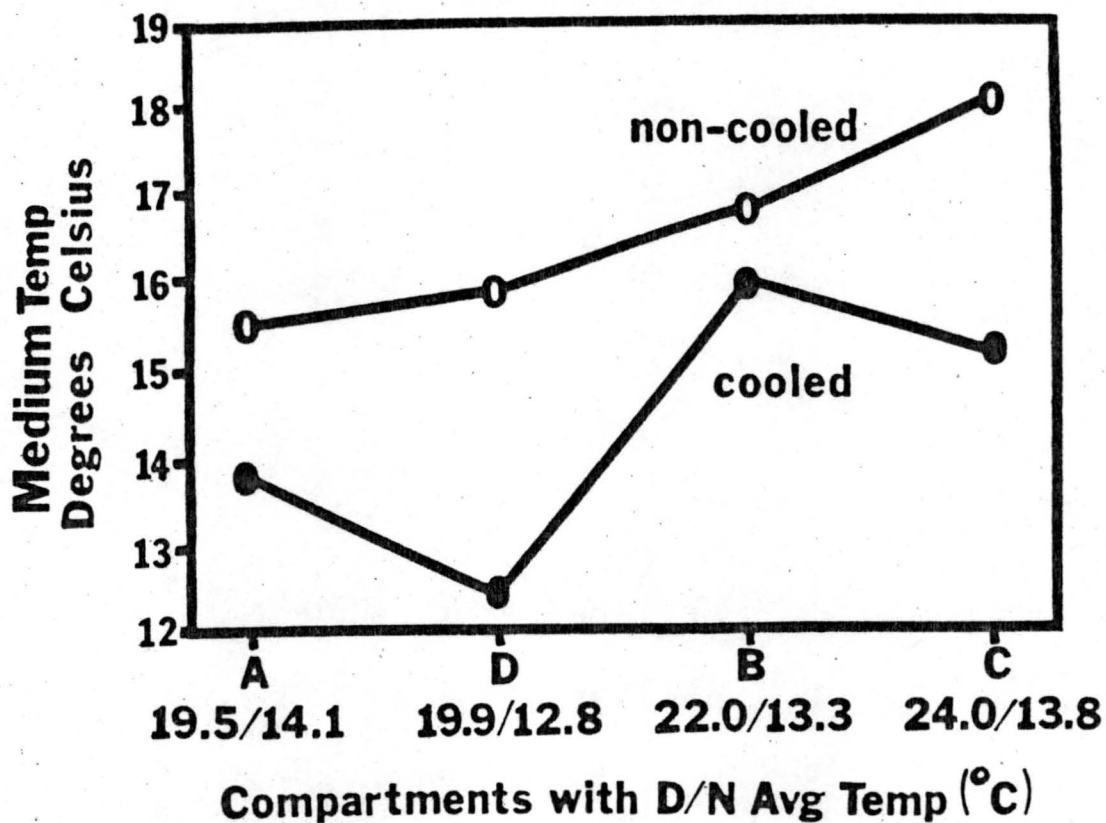


Fig. 3.1. Random daily average temperatures of cooled and non-cooled medium treatments used for Alstroemeria production in four compartments with various average day/night (D/N) air temperatures (recorded from March 10, 1986, to February 8, 1987).

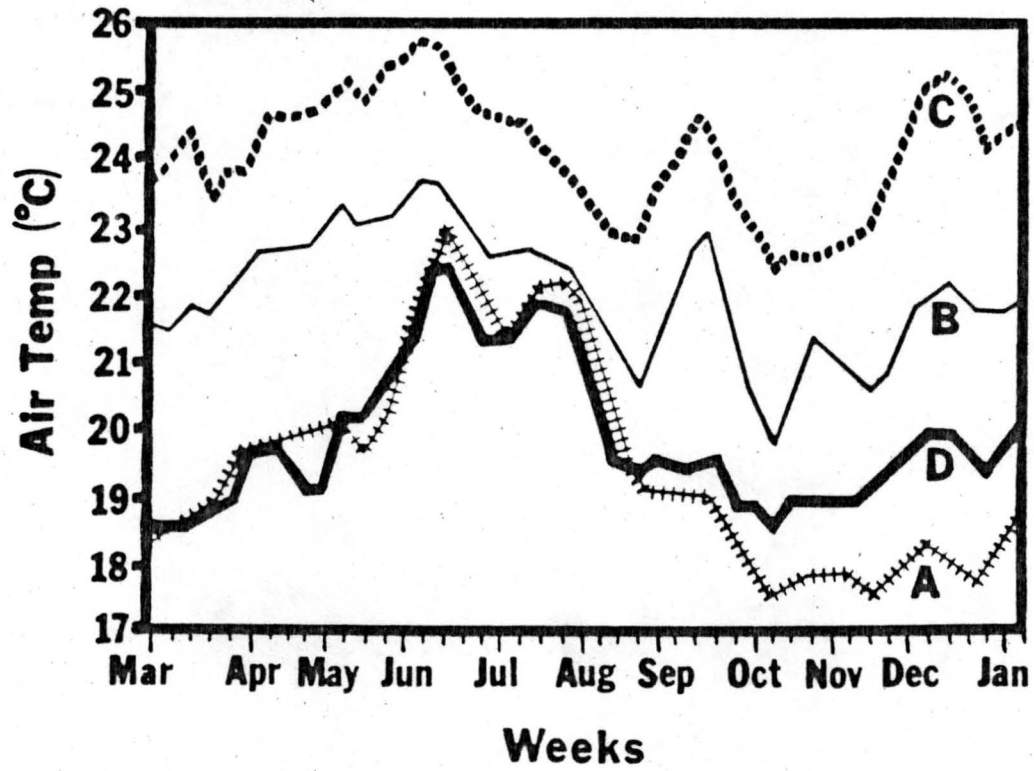


Fig. 3.2. Smoothed weekly averages of daytime air temperatures in four 25.4 m² greenhouse compartments (designated A to D from west to east) used for *Alstroemeria* production experiments.

temperatures were not achieved for compartments A and D, the conclusions drawn regarding plant responses are valid since temperature differences still existed between the remaining compartments. Furthermore, the observed loss of summer temperature control is a common occurrence in commercial greenhouses. Thus, the results of this study may be more pragmatic from a grower's point of view because the temperature regimes actually maintained are feasible in a commercial setting.

The daytime temperature difference between compartments in the winter approached the pre-set levels. In contrast, summer temperatures in compartment A could not be kept at the desired level because the cooling capacity of the ventilation system was exceeded (Fig. 3.2). The average night air temperatures were: compartment A=14°C, compartment D=13°C, compartment B=13°C, and compartment C=14°C. Even though the environmental parameters were defined, the production cycles in each compartment varied with cultivar.

The total production of 'Atlas' (10,018 stems) in all compartments was 1.6 times as great as 'Monika' (6,376 stems). 'Atlas' plants in compartment D produced the greatest number of stems when production in all compartments was compared during the 52 week period (Fig. 3.3). The 'Atlas' cultivar reached its highest production peak from approximately June 23 to July 6, 1986. After July 6, production declined steadily in all compartments. In the 18 week period from September 1 through January 11, both cultivars grown in compartments B and C virtually ceased to produce, despite substrate treatment. Furthermore, it was noted the 'Regina' and 'Red Sunset' cultivars in the buffers (no medium cooling) did not produce flowers from September

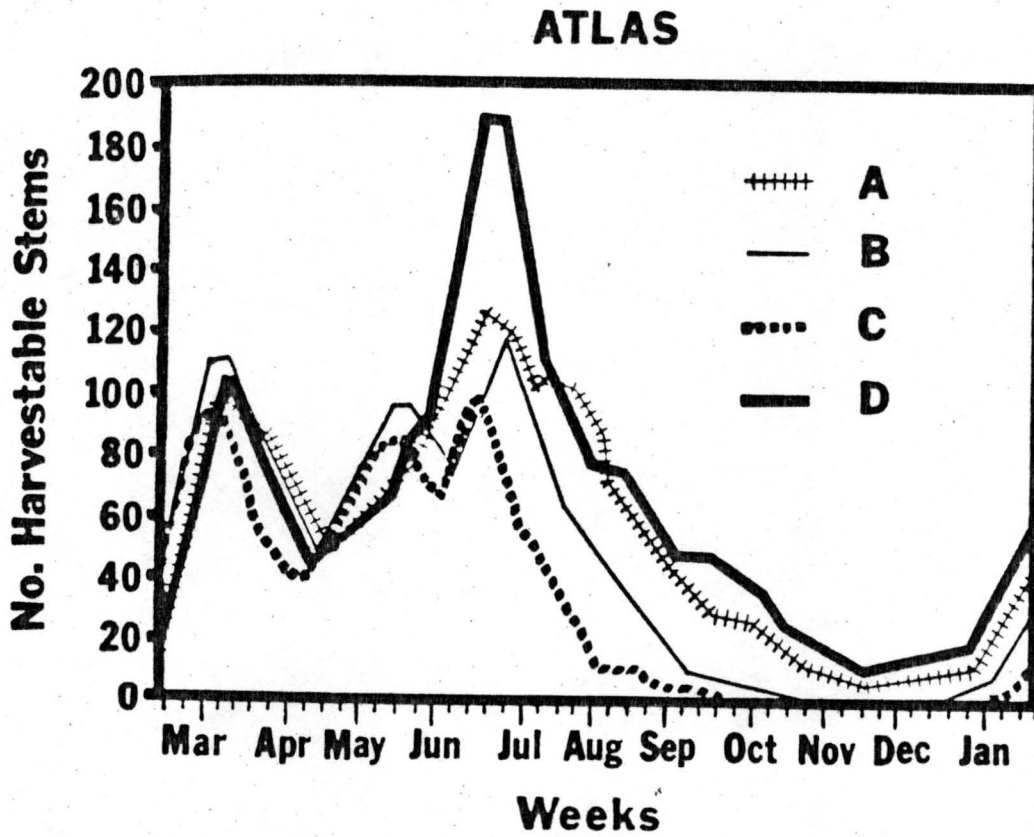


Fig. 3.3. Smoothed weekly yield of *Alstroemeria* 'Atlas' stems from four compartments with different average day/night (D/N) air temperatures.

through January, regardless of air temperature. During that same period, the coolest compartments yielded: 303 stems from the cooled substrate versus 25 from the non-cooled substrate in compartment A; and 430 cooled versus 64 non-cooled in compartment D. Consequently, the cooled substrate treatment coupled with cooler air temperatures allowed production to continue virtually year-round.

'Monika' production peaked at approximately the same time as 'Atlas', however, the yield of harvestable stems was much less than 'Atlas' (Fig. 3.4). Compartment C produced the greatest yield of 'Monika' during the peak period, and the decline in production thereafter was similar to that seen in 'Atlas'. From September through January, the production trend by compartment was similar to 'Atlas': 111 stems from the cooled versus 10 from the non-cooled substrate in compartment A; and 192 cooled versus 26 non-cooled in compartment D.

Each plot contained three plants of a cultivar, therefore, the average production was calculated on the basis of three plants grown in a particular medium treatment. The average flower yield from three plants of a cultivar was influenced (Appendix B) by the temperatures of the growing medium and compartment air temperature (Fig. 3.5). It was evident the flower production in either root temperature treatment was influenced ($P=.021$) by the compartment air temperature. Plant yield data from the substrate treatments were statistically (Appendix C) similar in compartments B and C (warmer air temperatures) but different in compartments A and D (cooler temperatures). Plants in compartments A and D produced significantly more flowering stems in the cooled root treatment, however, no

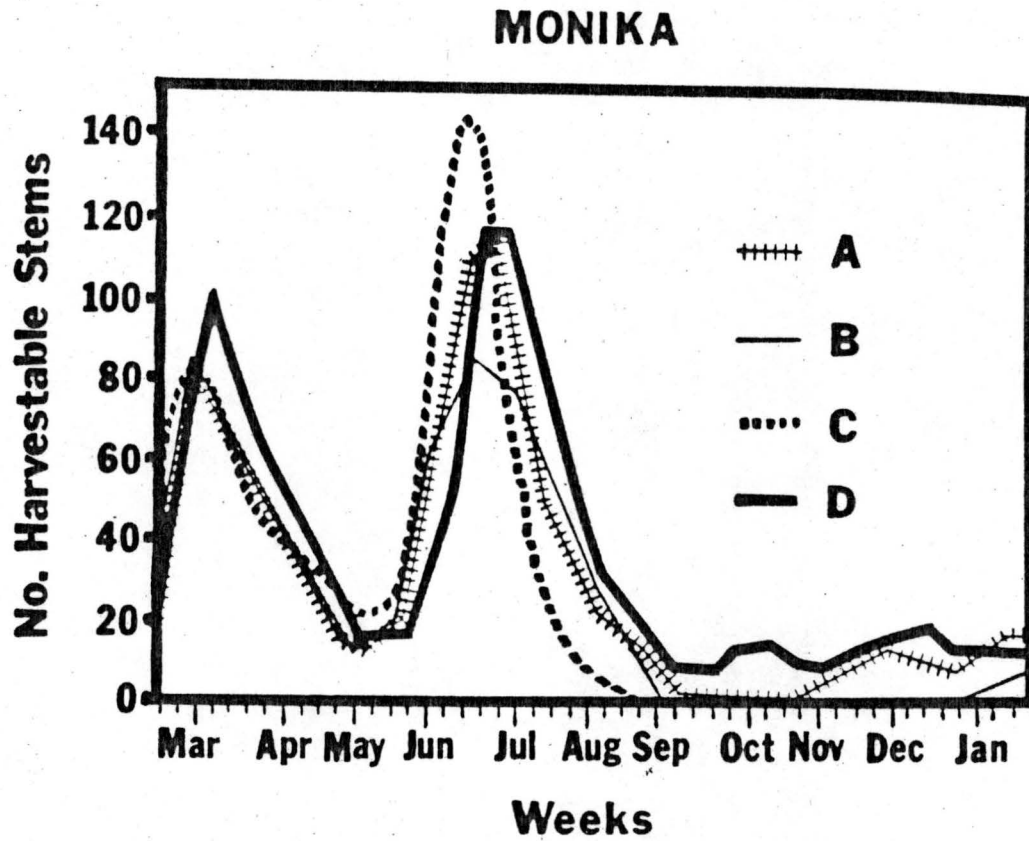


Fig. 3.4. Smoothed weekly yield of Alstroemeria 'Monika' stems from four compartments with different average day/night (D/N) air temperatures.

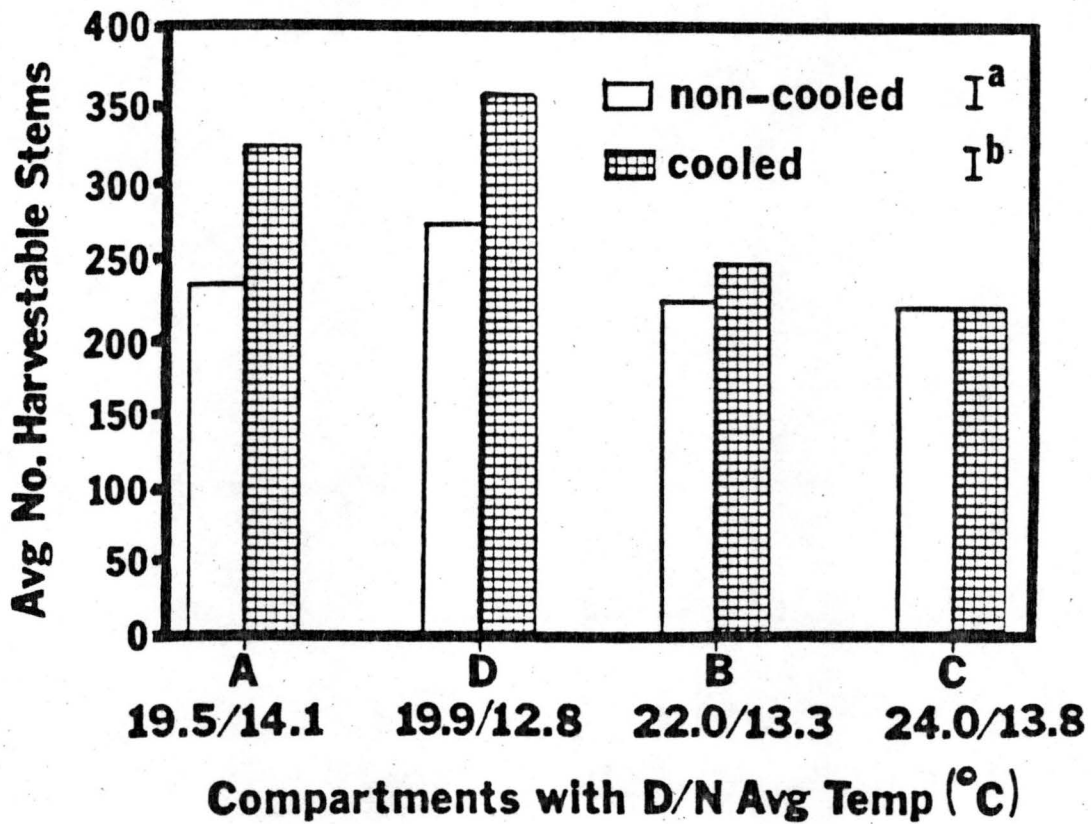


Fig. 3.5. Average annual yield of stems from three plants of a cultivar grown in cooled and non-cooled substrate treatments (4 replicates) in four compartments with different average day/night (D/N) air temperatures (recorded March 10, 1986, to February 8, 1987). (a) SE of a difference between medium treatments in the same compartment=20 stems. (b) SE of a difference between compartment means for the same medium treatment=18.1 stems.

statistical differences in production were observed between compartments when the medium was not cooled (Appendix C). These results support the supposition the greatest production of 'Atlas' and 'Monika' occurred with average daytime temperatures of 20°C combined with an average medium temperature of 12° to 14°C.

Cultivar flower production differed significantly (Appendix B) with and between compartments (Fig. 3.6). 'Atlas' plants grown in compartments A and D (20°C) produced the greatest number of harvestable stems (Appendix D), but average daytime temperatures ranging from 22° to 24°C (compartments B and C) reduced production. There were no statistical differences (Appendix D) in the production of 'Monika' due to daytime air temperature. 'Atlas' dramatically out-produced 'Monika' under all air temperature conditions, which was confirmed by the interaction ($P < .001$) between cultivar and compartment.

Medium temperature had no significant (Appendix E) effect on the quality of stems produced in this study. However, quality was influenced ($P = .001$) by the compartment air temperature, and the cultivars were significantly different in their average grade (Fig. 3.7). 'Atlas' plants produced higher quality ($P < .001$) flowers than 'Monika' in all air temperature regimes (Table 3.3).

Flower quality of both cultivars increased with increasing air temperature (Fig. 3.7). This phenomenon was due to the use of stem length as one of the criteria for grading. The shorter stems from the cooler compartments (A and D) were often downgraded because they fell below the length limitation for a particular grade category. Considering the lower plant production in the warmer compartments,

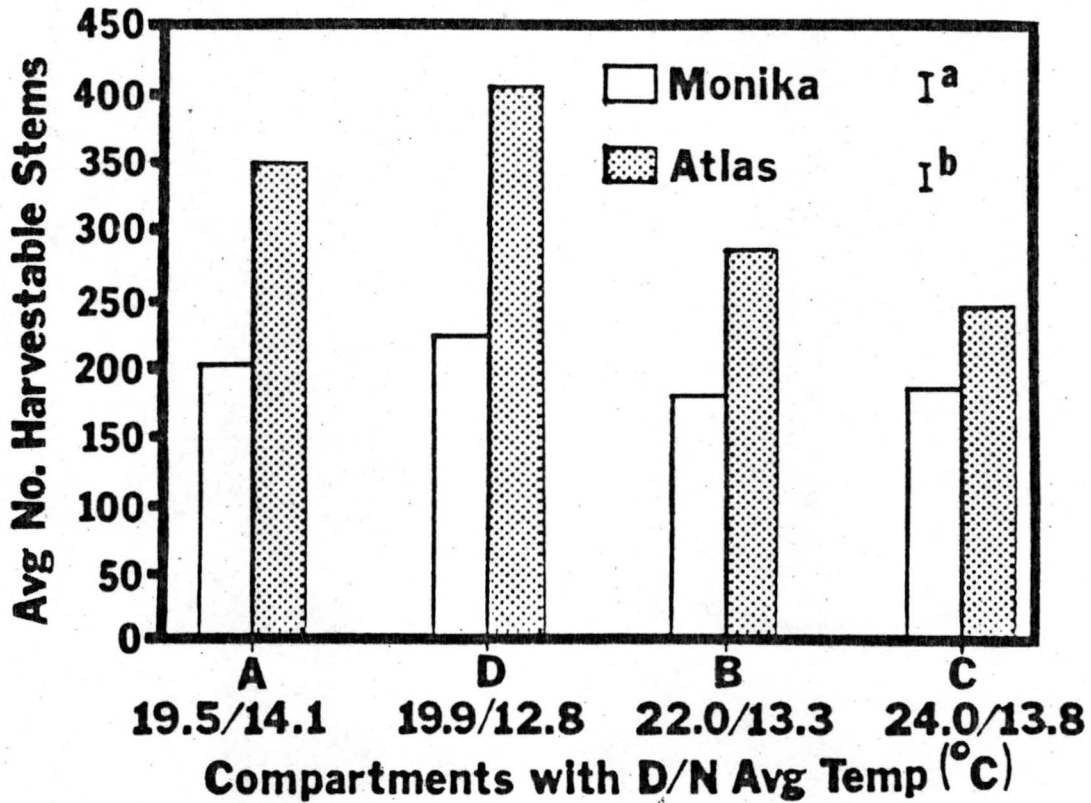


Fig. 3.6. Average yield of 'Atlas' and 'Monika' stems (8 replicates, 3 plants per cultivar per replicate) produced from February 10, 1986, to February 8, 1987, in four compartments with different average day/night (D/N) air temperatures (recorded from March 10, 1986, to February 8, 1987). (a) SE of a difference between cultivar means in the same compartment=18.2 stems. (b) SE of a difference between compartment means for the same cultivar=17.1 stems.

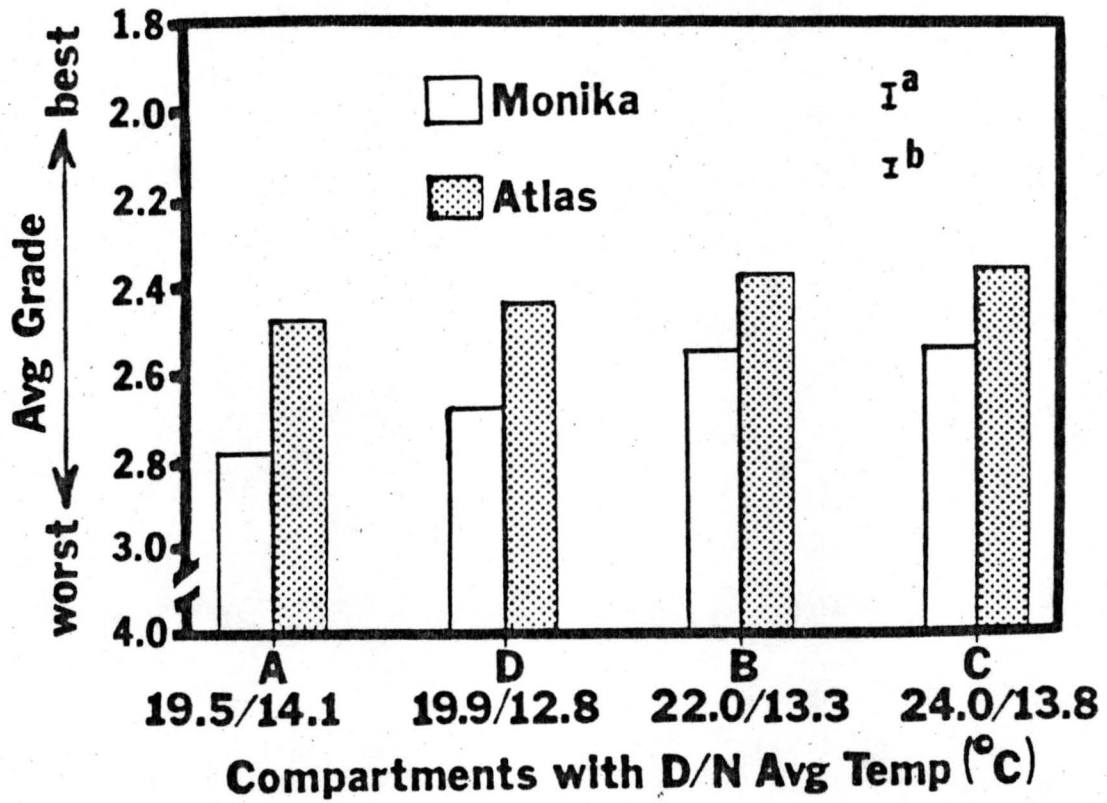


Fig. 3.7. Average quality grade of 'Atlas' and 'Monika' stems (8 replicates, 3 plants per cultivar per replicate) produced from February 10, 1986, to February 8, 1987, in four compartments with different average day/night (D/N) air temperatures (recorded from March 10, 1986, to February 8, 1987). (a) SE of a difference between cultivar means in the same compartment = .04 units. (b) SE of a difference between compartment means for the same cultivar = .04 units.

Table 3.3. Quality grade for stems of Alstroemeria cultivars 'Atlas' and 'Monika' harvested during the period February 10, 1986, to February 8, 1987. "Grade 1"= 90+ cm stem with 5+ cymes, "Grade 2"= 60+ cm stem with 3 to 4 cymes, "Grade 3"= 30+ cm with 2 cymes, and "Grade 4"=<30 cm stem with 1 cyme.

Category	Atlas		Monika	
	Number	Percent	Number	Percent
"Grade 1"	245	3	38	0.6
"Grade 2"	5543	55	2452	38.4
"Grade 3"	4004	40	3698	58.0
"Grade 4"	226	2	188	3.0

the quality advantage possessed by plants grown in warmer temperatures should be economically outweighed by a grower's desire for greater yields.

Substrate temperature did not affect (Appendix G) stem length. Air temperature was the most significant ($P < .001$) factor influencing stem lengths of both cultivars (Fig. 3.8). Longer stems of both cultivars were produced in the warmest average air temperature treatment (24°C day and 14°C night). The stem lengths of 'Atlas' were comparable in the other three temperature treatments, but were more than 6 cm shorter than the cut flowers in the warmest treatment (Appendix H). The average length of all harvested 'Monika' stems was 19% less than that of 'Atlas', which significantly (Appendix H) reduced the quality of 'Monika' stems.

Due to the nature of the experimental design used to determine plant responses, a discussion of the concept of confounding is relevant. To concentrate on air and medium temperature effects on *Alstroemeria* cultivars 'Atlas' and 'Monika', an attempt was made to keep all other environmental conditions and cultural practices consistent within and between compartments. Without complete replication, utilizing numerous greenhouses of the same size and conformity, the idiosyncrasies of each individual compartment are difficult to distinguish. Although compartment replication was impossible, sufficient media treatment replication was achieved, thereby making that part of the study more reliable.

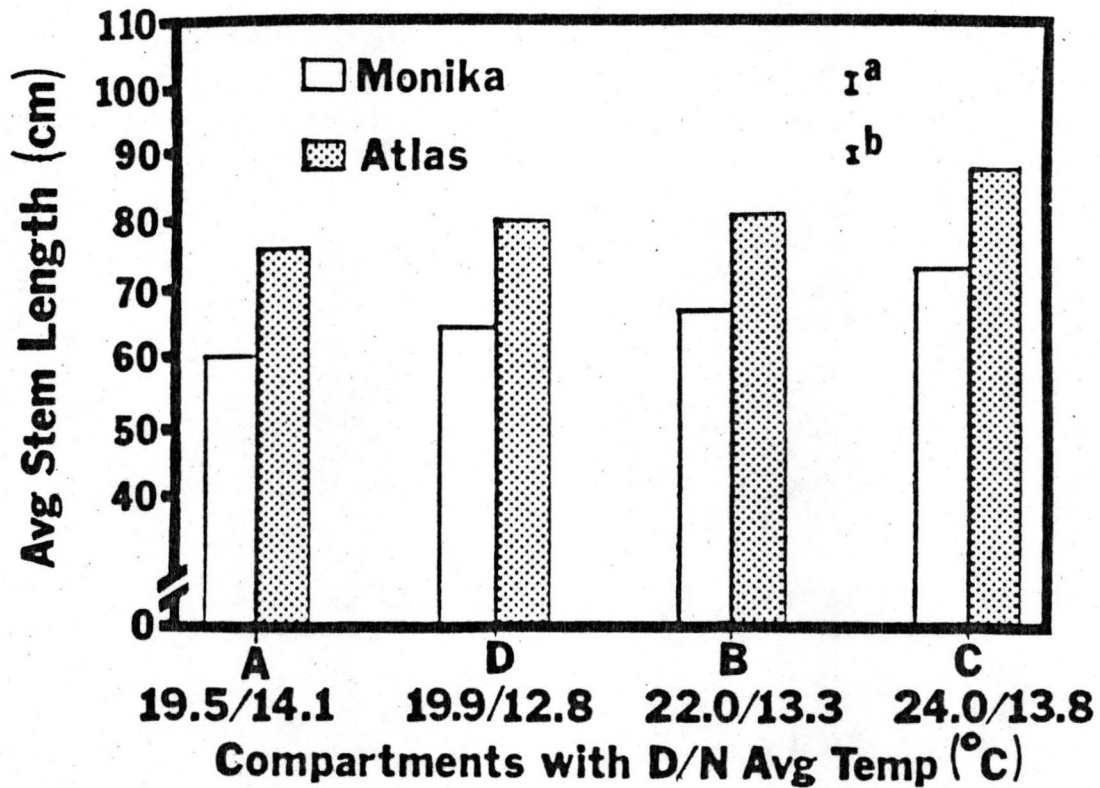


Fig. 3.8. Average length of 'Atlas' and 'Monika' stems (8 replicates, 3 plants per cultivar per replicate) produced from February 10, 1986, to February 8, 1987, in four compartments with different average day/night (D/N) air temperatures (recorded from March 10, 1986, to February 8, 1987). (a) SE of a difference between cultivar means in the same compartment=1.9 cm. (b) SE of a difference between compartment means for the same cultivar=1.7 cm.

C. AIR TEMPERATURE EFFECTS ON THE INFLORESCENCE: FIVE WEEK SUB-TRIAL, JULY 14 TO AUGUST 17, 1986

Results from the five week sub-trial indicated that air temperature influenced (Appendices I,J,K,L) cyme length and number of buds per cyme for both cultivars. Bud counts and cyme lengths of stems harvested during the sub-trial were undoubtedly influenced by air temperatures prior to that period. Thus, the mean air temperatures reported include the day/night averages from the five week sub-trial plus those from the previous six weeks (June 2 to August 17).

Warmer air temperatures increased ($P < .001$) the combined average cyme length for both cultivars (Fig. 3.9). 'Atlas' cymes were, on average, 68% (5.42 cm) longer than those of 'Monika'. Orthogonal polynomials were fit to the dependent variable, and the analyses revealed evidence of an overwhelming linear trend toward increased cyme length with increasing daytime air temperature. A small deviation from linearity was found, and the slope of the trend was dependent on cultivar.

Compartment D produced markedly (Appendix L) greater numbers of buds per cyme compared to all other compartments (Fig. 3.10). Air temperature was linearly related to the number of buds per cyme, however, the pattern was not easily described.

Total bud count of both cultivars differed statistically (Appendix K) between compartments. However, the variation observed (a range of 2.33 to 2.79 buds per cyme) would not be considered substantial. 'Monika' (Butterfly-type) had a lower ($P = .002$) bud count than 'Atlas' (Carmen-type) when subjected to the same air temperatures.

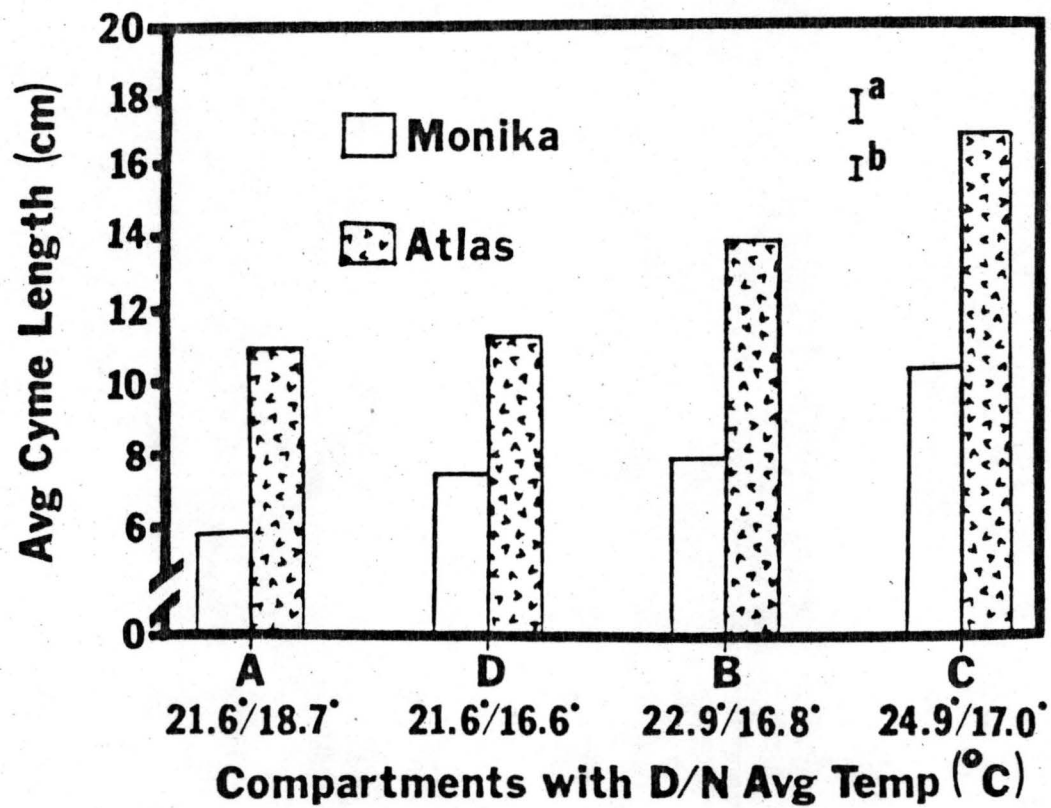


Fig. 3.9. Mean floral cyme length of *Alstroemeria* cultivars 'Atlas' and 'Monika' harvested July 14 to August 17, 1986, from four compartments with various average day/night (D/N) air temperatures. (a) SE of a difference between cultivar means in the same compartment = .72 cm. (b) SE of a difference between compartment means for the same cultivar = .61 cm.

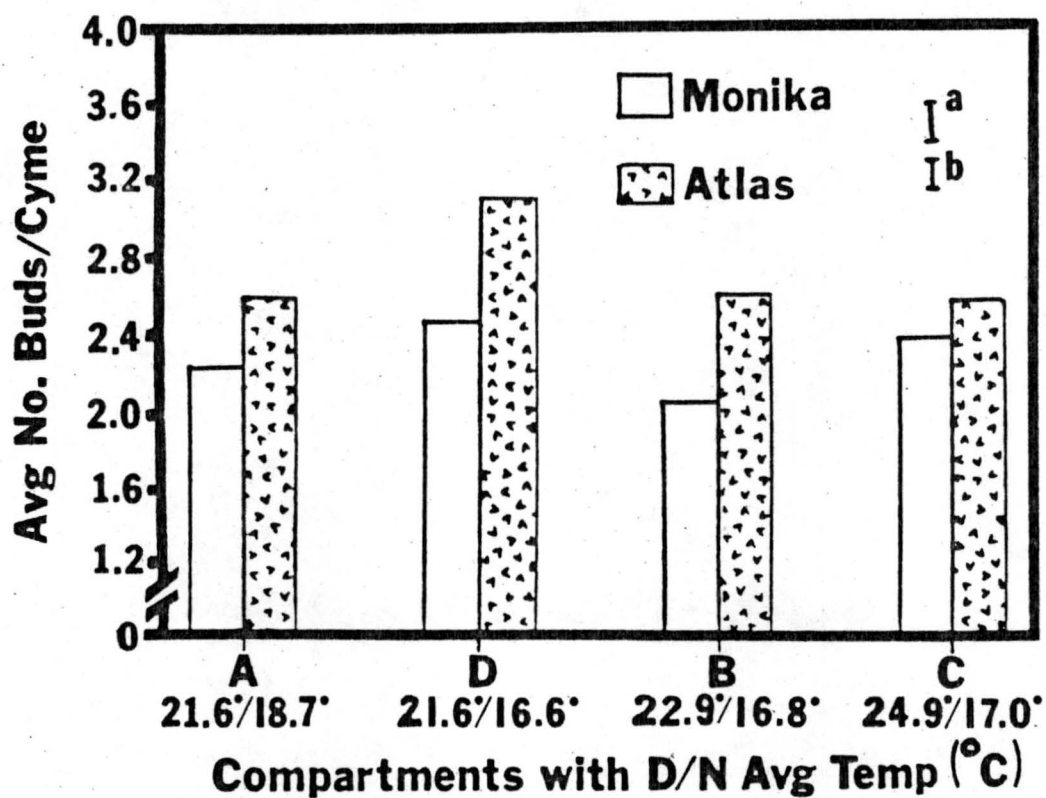


Fig. 3.10. Mean number of buds per cyme on stems of *Alstroemeria* cultivars 'Atlas' and 'Monika' harvested July 14 to August 17, 1986, from four compartments with various average day/night (D/N) air temperatures. (a) SE of a difference between cultivar means in the same compartment=.22 units. (b) SE of a difference between compartment means for the same cultivar=.17 units.

No significant differences ($P=.11$) were observed for number of cymes per stem, although there was a trend toward more cymes at higher temperatures. Stem thickness did not appear to be affected by daytime temperatures, however, 'Atlas' stems were larger ($P<.001$) in diameter (21% thicker) than those of 'Monika'.

CHAPTER IV DISCUSSION AND CONCLUSIONS

Alstroemeria producers in Colorado and the United States are currently victims of fluctuating prices (Fig. 4.1) which are directly associated with the peaks and valleys in the production cycles of the crop. There are two possible ways to reduce this problem: 1) breed for varieties that produce year-round, 2) create environmental conditions which will allow existing commercial cultivars to bloom continuously. The intent of this research was to follow the latter approach.

The two varieties studied, 'Atlas' and 'Monika', were classified as "Carmen-type" and "Butterfly-type" alstroemerias, respectively (28). Plants in these categories yield far fewer flowering stems than the highest-producing commercial "Orchid-types". As a result, the final production numbers achieved in this study could have been greatly enhanced if the supplier had permitted the use of the two "Orchid-type" cultivars which were requested.

In the event that this research is continued, an attempt should be made to obtain two "Orchid-type" varieties. If this is not possible, the 'Monika' plants should be replaced by divisions of 'Atlas'. The plant density utilized exceeded recommended levels (16), thus only two plants of each cultivar should be placed within each plot. Furthermore, the two best air temperature regimes in terms of production (compartment A, 14.4° to 20.0°C, and compartment D, 17° to 23°C)

Alstroemeria Wholesale Prices - 1986
- averages for three U.S. locations

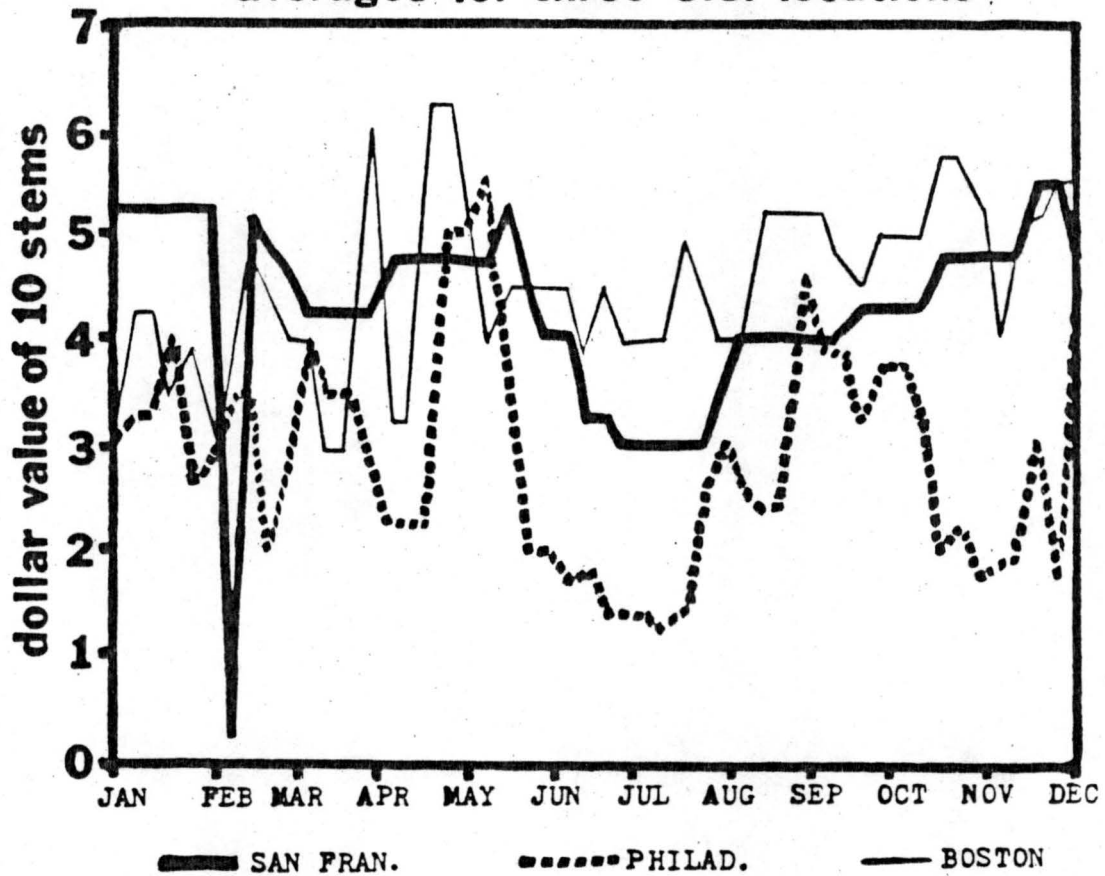


Fig. 4.1. 1986 average wholesale prices for Alstroemeria stems sold at three different U.S. locations. Data compiled from Florists' Review Grower Marketletters.

should be replicated twice in the four compartments. To decrease fluctuations in substrate temperature, a mulch should be applied to the medium surface.

Ventilation efficiency could be improved by replacing the aspen pads with Kool-Cel or Cel-Dek pads. Additional insulation should be placed around the compressor so the night temperatures in compartment A remain lower. An attempt should be made to maintain the compartment relative humidities at higher levels (11).

Lastly, it is recommended the substrate remain uncooled for at least part of the year. Assuming Noordegraaf's (38, 39) evaluation was correct, alstroemeria shoot production occurred under higher air temperatures which also inhibited flowering; fewer shoots were obtained at cooler air temperatures, but a higher percentage of these were flowering stems. Therefore, continual medium cooling may not allow maximum shoot production, even though most of the stems that are produced are reproductive. If the medium were alternately cooled and left uncooled for specific periods of time, greater yields of flowering stems could possibly be attained. In this study, the most crucial time for soil cooling appeared to be during the fall and winter.

Results of this research indicated the highest production of alstroemeria cultivars 'Atlas' and 'Monika' can be obtained with substrate temperatures of 12° to 14°C and an average air temperature of 20°C. Daytime temperatures above this level resulted in drastic yield depression, however, warmer temperatures contributed to a slight advantage in flower quality. Air temperatures in compartment D (20°C day/13°C night) produced greater numbers of buds per cyme compared to the remaining compartments. Both cyme and stem length increased

linearly as air temperature increased. Under all conditions, 'Atlas' outperformed 'Monika' in terms of yield, flower quality, and stem length.

'Monika, due to the poor yield and flower quality, is not recommended for Colorado alstroemeria growers. 'Atlas' had more acceptable yields and flower quality, however, the maximum number of cymes observed for 'Atlas' (five) was less than the eight cymes per stem commonly obtained from "Orchid-types".

A winter flowering trial (13) was conducted at Aalsmeer, Holland, to determine the alstroemeria varieties which produced the greatest winter flower yields without the aid of supplementary irradiation. From October through March, the yield of the cultivar 'Monika' (13) was reportedly 21 stems per square meter. During the same period in this research, the yield of 'Monika' stems from the cooled substrate plots in compartments A and D was 52 and 63 stems per square meter, respectively. This equates to nearly a three-fold increase in production over the Netherlands. The increase could be attributed to one of three factors: the photoperiodic irradiation utilized in this research, the beneficial influence of medium cooling on production, or the higher radiant intensities received in Colorado.

Results from this study utilizing the cultivar 'Atlas' compared favorably with that of a commercial grower in Ontario, Canada (unpublished data). During the period September through January, 'Atlas' plants grown in Canada yielded a total of 18 flowering stems per square meter. In this research, the cooled medium treatment in compartments A and D yielded 116 and 169 flowering stems per square meter, respectively. It appears that Fort Collins has a production

advantage over Ontario with regard to insolation when combined with the cooled medium treatment.

Colorado provides an excellent climate for production of alstroemeria. The W.D. Holley Plant Environmental Research Center, Fort Collins, is located 1584m above sea level at 40° 35' north latitude and 105° 8' west longitude. The average daily radiant intensities at this research facility are greater than those of locations with more northern latitudes like Vineland Station, Ontario (Table 4.1). By comparison, Fort Collins receives 20% more total radiant energy than Vineland Station. A soil cooling study, similar to this research, was conducted at Vineland Station using the cultivars 'Red Sunset', 'Rosita', 'Rosario', and 'Rio'. Their results indicated an 11.6% decrease in production when soil temperatures were controlled to 16°C (5). The higher insolation values for Fort Collins could explain the apparent conflicting results obtained between these studies.

The irradiation advantage of Colorado provides the potential for increased photosynthesis of alstroemeria. Photosynthesis could be further enhanced by research on carbon dioxide injection levels for this climate. The location of Colorado State University's Plant Environmental Research Center makes it a desirable facility for further research in the area of air and media temperature effects on alstroemeria.

Table 4.1. Comparison of radiant intensity values at Vineland Station, Ontario, and Fort Collins, Colorado.

Radiant intensity values by location (MJ·m ⁻²)				
Month	Vineland Station (4)		Ft. Collins (12)	
	Avg daily ¹	Equivalent ² Monthly Total	Avg daily ¹	Equivalent ² Monthly Total
January	4.27	132	8.69	269
February	8.04	225	11.39	319
March	12.74	395	16.64	516
April	16.17	485	19.56	587
May	20.81	645	20.98	650
June	22.50	675	25.01	750
July	21.45	665	23.30	722
August	18.23	565	20.58	638
September	13.83	415	18.04	541
October	8.85	265	13.79	427
November	5.00	150	9.12	274
December	4.03	125	7.65	237
Equivalent yearly total		4742	5930	

¹Average daily radiant intensities for each month multiplied by the number of days in that month.

²Five year averages of global radiation.

³Six year averages of global radiation.

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Appendix A. Example of a daily summary of environmental data recorded by a Hewlett-Packard computer system. Left column: heading, date, time of printing, number of 10 minute executions, air temperatures from channels 2 to 5 (compartments A to D respectively), total radiation from channels 6 to 9 (compartments A to D respectively). Right column: soil temperature from channels 12 & 13 (compartment A), channels 14 & 15 (compartment B), channels 16 & 17 (compartment C), and channels 18 & 19 (compartment D).

DAY SUMMARY			CHANNEL 12
-----			MIN T = 10.8
02/15			MAX T = 12.8
17:20			AVE T = 11.8
	58.0	***	CHANNEL 13
	58.0	***	MIN T = 9.6
CHANNEL 2			MAX T = 13.7
MIN T = 10.9			AVE T = 12.0
MAX T = 21.8			CHANNEL 14
AVE T = 18.1			MIN T = 12.9
CHANNEL 3			MAX T = 15.1
MIN T = 11.6			AVE T = 13.9
MAX T = 25.2			CHANNEL 15
AVE T = 21.2			MIN T = 12.2
CHANNEL 4			MAX T = 14.2
MIN T = 11.7			AVE T = 13.2
MAX T = 28.5			CHANNEL 16
AVE T = 24.0			MIN T = 12.6
CHANNEL 5			MAX T = 18.1
MIN T = 12.1			AVE T = 15.6
MAX T = 23.7			CHANNEL 17
AVE T = 19.3			MIN T = 11.5
CHANNEL 6			MAX T = 17.2
ACCUM RAD = 16360.3			AVE T = 15.3
CHANNEL 7			CHANNEL 18
ACCUM RAD = 15298.0			MIN T = 10.4
CHANNEL 8			MAX T = 14.1
ACCUM RAD = 11346.6			AVE T = 12.6
CHANNEL 9			CHANNEL 19
ACCUM RAD = 11663.4			MIN T = 12.3
			MAX T = 14.8
			AVE T = 13.5

Appendix B. Analysis of variance for dependent variable: annual number of flower stems produced by three plants of a cultivar.

Source of variation	SS ^z	DF ^y	MS ^x	F	Signif of F
Within + residual	31798.38	24	1324.93		
Constant	4352960.64	1	4352960.64	3285.42	
Cultivar	242433.14	1	242433.14	182.98	<.001 ^w
Compartment by cultivar	35237.30	3	11745.77	8.87	<.001 ^w
Treatment ^v by cultivar	4539.39	1	4539.39	3.43	.077
Compartment by treatment by cultivar	1154.30	3	384.77	.29	.832
Error 1 ^u	24434.06	12	2036.17		
Compartment	94044.05	3	31348.02	15.40	<.001 ^w
Error 2 ^t	19215.81	12	1601.32		
Treatment	39551.27	1	39551.27	24.70	<.001 ^w
Compartment by treatment	22774.67	3	7591.56	4.74	.021 ^w

^zSum of squares.

^yDegrees of freedom.

^xMean square.

^wLess than the 5% level of significance.

^vTreatment = medium cooled or not cooled.

^uPair within compartment.

^tTreatment by pair within compartment.

Appendix C. Average number of 'Atlas' and 'Monika' flower stems produced by three plants of each cultivar and grown in cooled or non-cooled medium in four greenhouse compartments with different day and night air temperatures (recorded March 10, 1986, to February 8, 1987).

Compt	Avg air temp (°C)		Avg no. flower stems	
	Day	Night	Non-cooled medium ^z	Cooled medium
A	19.5	14.1	233.4 a ^y	321.6 b ^y
D	19.9	12.8	272.5 a	357.1 b
B	22.0	13.3	222.4 a	247.5 a
C	24.0	13.8	215.5 a	216.4 a
Overall Avg			235.9	285.7

^zOnly compartments A and D had treatment means that differed by greater than the 5% HSD value of 43.6 stems.

^yMean separation by column using Tukey's HSD, 5% level. HSD for the difference between two compartments means for the same cultivar was 63.3 stems.

Appendix D. Average number of 'Atlas' and 'Monika' flower stems produced by three plants of each cultivar and grown in four greenhouse compartments with different day and night air temperatures (recorded March 10, 1986, to February 8, 1987).

Compt	Avg air temp (°C)		Avg no. flower stems	
	Day	Night	Atlas ^z	Monika
A	19.5	14.1	351.6 b ^y	203.4 a ^y
D	19.9	12.8	406.1 b	223.5 a
B	22.0	13.3	286.8 a	183.1 a
C	24.0	13.8	244.9 a	187.0 a
Overall avg			322.3	199.3

^zIn all cases, the difference between the 'Atlas' and the 'Monika' means for a specific compartment was greater than the 5% HSD value of 37.6 stems.

^yMean separation by column using Tukey's HSD, 5% level. HSD for the difference between two compartment means for the same cultivar was 60.9 stems.

Appendix E. Analysis of variance for dependent variable: average quality grade.

Source of variation	SS ^Z	DF ^Y	MS ^X	F	Signif of F
Within + residual	.14254	24	.00594		
Constant	407.28285	1	407.28285	68576.96001	
Cultivar	.73745	1	.73745	124.16969	<.001 ^W
Compartment by cultivar	.04505	3	.01502	2.52872	.081
Treatment ^V by cultivar	.00098	1	.00098	.16443	.689
Compartment by treatment by cultivar	.00773	3	.00258	.43383	.731
Error 1 ^U	.09882	12	.00823		
Compartment	.30515	3	.10172	12.35210	.001 ^W
Error 2 ^t	.06517	12	.00543		
Treatment	.00263	1	.00263	.48365	.500
Compartment by treatment	.00553	3	.00184	.33941	.797

^ZSum of squares.

^YDegrees of freedom.

^XMean square.

^WLess than the 5% level of significance.

^VTreatment = medium cooled or not cooled.

^UPair within compartment.

^tTreatment by pair within compartment.

Appendix F. The combined average grade of 'Atlas' or 'Monika' flower stems produced by plants grown in all medium treatments in four greenhouse compartments with different average day and night air temperatures (recorded March 10, 1986, to February 10, 1987).

Compt	Avg air temp (°C)		Avg no. flower stems	
	Day	Night	Atlas ^z	Monika
A	19.5	14.1	2.47 a ^y	2.77 a ^y
D	19.9	12.8	2.44 a	2.67 ab
B	22.0	13.3	2.39 a	2.55 bc
C	24.0	13.8	2.36 a	2.53 c
Overall avg			2.42	2.63

^zIn all cases, the difference between the 'Atlas' and the 'Monika' means for a specific compartment was greater than the 5% HSD value of .08 units.

^yMean separation by column using Tukey's HSD, 5% level. HSD for the difference between two compartment means for the same cultivar was .12 units.

Appendix G. Analysis of variance for dependent variable: average stem length.

Source of variation	SS ^z	DF ^y	MS ^x	F	Signif of F
Within + residual	342.12	24	14.26		
Constant	346776.71	1	346776.71	24326.73	
Cultivar	3675.69	1	3675.69	257.85	<.001 ^w
Compartment by cultivar	2.29	3	.76	.05	.983
Treatment ^v by cultivar	2.83	1	2.83	.20	.660
Compartment by treatment by cultivar	35.24	3	11.75	.82	.494
Error 1 ^u	224.19	12	18.68		
Compartment	1367.02	3	455.67	24.39	<.001 ^w
Error 2 ^t	94.16	12	7.85		
Treatment	24.33	1	24.33	3.10	.104
Compartment by treatment	97.56	3	32.52	4.14	.031 ^w

^zSum of squares.

^yDegrees of freedom.

^xMean square.

^wLess than the 5% level of significance.

^vTreatment = medium cooled or not cooled.

^uPair within compartment.

^tTreatment by pair within compartment.

Appendix H. Average stem length of 'Atlas' and 'Monika' flowers harvested from plants grown at different average day and night air temperatures (recorded March 10, 1986, to February 8, 1987).

Compt	Avg air temp (°C)		Avg no. flower stems	
	Day	Night	Atlas ^z	Monika
A	19.5	14.1	75.3 a ^x	59.7 a ^x
D	19.9	12.8	80.2 a	64.9 ab
B	22.0	13.3	81.2 a	66.6 b
C	24.0	13.8	88.0 b	72.9 c
Overall avg			81.2	66.0

^zStem length was measured from the base of the stem to the base of the cyme whorl.

^yIn all cases, the difference between the 'Atlas' and the 'Monika' means for a specific compartment was greater than the 5% HSD value of 3.9 cm.

^xMean separation by column using Tukey's HSD, 5% level. HSD for the difference between two compartment means for the same cultivar was 6.0 cm.

Appendix I. Analysis of variance for dependent variable: average cyme length.

Source of variation	SS ^z	DF ^y	MS ^x	F	Signif of F
Residual	12.52867	12	1.04406		
Constant	3636.16661	1	3636.16661	3482.73079	
Cultivar	234.71792	1	234.71792	224.81350	<.001 ^w
Compartment by cultivar	8.71455	3	2.90485	2.78277	.087
Error 1 ^v	10.71588	12	.89299		
Compartment	124.19810	3	41.39937	46.36041	<.001 ^w

^zSum of squares.

^yDegrees of freedom.

^xMean square.

^wLess than the 5% level of significance.

^vPair within compartment.

Appendix J. Mean cyme length of 40 flower stems of the *Alstroemeria* cultivars 'Atlas' and 'Monika' grown in four greenhouse compartments regardless of medium temperature but with different average day and night air temperatures (recorded June 1, 1986, to August 17, 1986).

Compt	Avg air temp (°C)		Avg no. flower stems	
	Day	Night	Atlas ^z	Monika
A	21.6	18.7	11.04 a ^x	5.99 a ^x
D	21.6	16.6	11.38 a	7.49 a
B	22.9	16.8	14.06 b	7.91 a
C	24.9	17.0	17.00 c	10.42 b
Overall avg			13.37	7.95

^zCyme length was measured from the base of each cyme to the base of the primary bud, and the overall average was recorded.

^yIn all cases, the difference between the 'Atlas' and 'Monika' means for a specific compartment was greater than the 5% HSD value of 1.57 cm.

^xMean separation by column using Tukey's HSD, 5% level. HSD for the differences between two compartment means for the same cultivar was 2.07 cm.

Appendix K. Analysis of variance for dependent variable: average number of buds per cyme.

Source of variation	SS ^z	DF ^y	MS ^x	F	Signif of F
Residual	1.20269	12	.10022		
Constant	199.88890	1	199.88890	1994.42621	
Cultivar	1.56056	1	1.56056	15.57071	.002 ^w
Compartment by cultivar	.26614	3	.08871	.88516	.476
Error 1 ^v	.52324	12	.04360		
Compartment	.97946	3	.32649	7.48764	.004 ^w

^zSum of squares.

^yDegrees of freedom.

^xMean square.

^wLess than the 5% level of significance.

^vPair within compartment.

Appendix L. Average number of buds per cyme for 40 stems of the Alstroemeria cultivars 'Atlas' and 'Monika' harvested from four greenhouse compartments regardless of medium temperature but with different average day and night air temperatures (recorded June 1, 1986, to August 17, 1986).

Compt	Avg air temp (°C)		Avg no. flower stems		
	Day	Night	Atlas ^z	Monika	Both cultivars
A	21.6	18.7	2.58	2.24	2.41 a ^x
D	21.6	16.6	3.13	2.45	2.79 b
B	22.9	16.8	2.60	2.05	2.33 a
C	24.9	17.0	2.58	2.38	2.48 ab
Overall avg			2.72	2.28	

^zBuds per cyme were counted for every cyme on a stem and the average for the entire stem was recorded.

^yOnly compartments B and D had cultivar means that differed by greater than the 5% HSD value of .49 units.

^xMean separation by column using Tukey's HSD, 5% level. HSD for the difference between two compartment means for the same cultivar was .31 units.