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DEVELOPING A BEST MANAGEMENT PRACTICE FOR *CATHARANTHUS ROSEUS* (L.)

By

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ABSTRACT

DEVELOPING A BEST MANAGEMENT PRACTICE FOR *CATHARANTHUS ROSEUS* (L.)

By

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Iron chlorosis and low temperatures are major problems when growing *Catharanthus roseus* (L.). The cultural parameters that cause chlorosis were studied with 'Grape Cooler' vinca plants. Overwatering and low temperatures created conditions conducive to chlorosis. The effects of five day settings (15 to 35C), five night settings (15 to 35C), and three light levels (50% shade and ambient and supplemental light) were determined for vinca. Average daily temperature (ADT) was calculated for the 25 DT/NT combinations. Curves for flower development rate and leaf unfolding rate were derived from regression analysis of the data and compared to develop a prediction model. The effect of DIF on internode elongation was studied. Plants responded to the DIF treatments. Flower size was measured and determined to be greatest at a day settings of 25C and under supplemental light.

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INTRODUCTION

The bedding-plant industry in America was valued at $3.12 billion in 1992 (Agricultural Statistics Board, 1993). The most popular crops at that time included petunias, geraniums, marigolds, impatiens, and pansies; however, many other crops are becoming more popular as newer varieties and more cultural information are developed. One of these crops, vinca, is increasing in popularity because of its heat and drought resistance and new cultivars, which are more resistant to cooler temperatures (the Cooler series), have larger flowers (the Tropicana series), and are winning awards in America and Europe (the Pretty in ... series and Parasol). Because of the increased interest in this plant, there is a need for cultural information to help growers avoid some of vinca's major problems: chlorosis, root rots, and slow growth. Some of these problems are easier to solve than others, and many of them are linked.

Different environmental factors - light, temperature, and moisture - affect how a plant will grow and mature. There is an optimum range under which normal growth will occur. A maximum and minimum value exist for each factor and can be determined by experimentation. Thus, crops can be grown to determine the optimal ranges for each factor. Once the optimum range is determined, many of the cultural problems can be eliminated and higher-quality plants can be produced.

LITERATURE REVIEW

Catharanthus roseus L., or Madagascar vinca, is a perennial in its native habitat, but is cultivated as an annual in cooler climates. Vinca is a member of the Apocynaceae, or dogbane, family, which is characterized by milky sap. Until recently, *Catharanthus roseus* was classified as *Vinca rosea*. It has often been confused with *Vinca major* (grave myrtle) and *Vinca minor* (periwinkle), which are members of the same family. Both of these vines are used extensively in landscaping.

Although vinca is thought to have originated in tropical America, it was first discovered on the island of Madagascar. The southwestern part of Madagascar where vinca grows wild receives 20 to 59 inches of precipitation yearly (Preston-Mafham, 1991). The area has an annual average of 25 to 26C, although temperatures sometimes reach as high as 40C during the summer months. Vinca thrives under these conditions, which makes it an excellent plant for use in hot, dry climates.

Madagascar vinca can be recognized by its upright habit and simple, opposite leaves, which are 1 to 2 inches long, entire, oblong, and glossy. The flowers are quinquemerous salverform, 1 to 1 1/2 inches across, and found singly or in pairs in the leaf axil. Flower color ranges from light purple to pink to white, with or without a red "eye" (Bailey, 1976; Smith, 1977).

Bedding plants compose 35% of floriculture crops grown in the U.S.A. (Agricultural Statistics Board, 1993), and vinca accounts for up to 4% of the flatted bedding-plant market, a number that is quickly increasing. It is ranked number three in the southern states, popular there because of its heat and drought tolerance (Colgrave, 1992). It is also very pollution tolerant, making it a good crop for larger, warmer cities.

With increased production of vinca, production problems are perceived as being more prevalent. Growers are having difficulty with the plants from germination onward. Germination is divided into four stages, as defined by Koranski (1988). Stage one is the most critical of the four and lasts from sowing until radicle emergence, a period of one to seven days; however, the same stage for vinca lasts three to five days. Germination can be slowed or stopped when temperatures are kept too low. Carpenter and Boucher (1991) found that optimum germination settings for three vinca cultivars were 25 to 30 or 35C. Carlson (1992) and Koranski and Laffe (1988) suggested germinating vinca at 32 to 35C for three days and then dropping the setting to 25 to 30C. Both temperature recommendations are much higher than those for bedding plants such as geraniums (20 to 25C), marigolds (24 to 27C), impatiens (21 to 27C), petunias (21 to 27C), or begonias (23 to 28C) (Karlovich and Sanford, 1992; Koranski and Laffe, 1988).

Many growers are having trouble once vinca reaches stage three - growth and development of true leaves (Koranski and Laffe, 1988) - because plants grow very slowly and often become diseased. Slow growth is frequently caused by low temperatures in the greenhouse (Thomas and Gilbertz, 1992). When it is caused by a combination of low temperatures and high moisture levels, conditions are optimum for many diseases such as *Rhizoctonia* root rots, to which vinca is very susceptible (Bethke, unpublished 1990; Harris and Davies, 1978; Powell, 1989; Thomas and Gilbertz, 1992; Carlson, 1992). The fungus is spread by splashing water; therefore, it thrives when plants are kept too wet (Gildersleeve and Ocumpaugh, 1989). Since vinca's native climate is dry, high moisture levels in the soil may be detrimental.

In other plants, high moisture also affects the overall growth (de Graaf-van der Zande, 1990). Petunias grown at three constant pF, or , values of 1.7 (wet), 2.5 (humid), and 4.0 (dry) showed increased height, fresh and dry weight, total leaf area, number of buds and open flowers, and side shoots with buds as moisture levels increased. Verbena grown at a constant pF value of 4.0 were shorter and took longer to reach saleable stage than those grown under a variable watering strategy of saturation and then dryness before resaturating. In both cases, plants grown at lower moisture levels were not as tall or well branched as those grown at higher moisture levels.

This type of watering strategy can be used as a growth regulator to keep plants shorter. The same watering strategy can be used for vinca. If plants are still too tall, chemical growth regulators can be used. A-rest, B-nine, and Bonzi are registered for use on vinca plugs, although leaf injury may occur with Bonzi. These three growth regulators may also be used on vinca bedding-plant flats, as can Sumagic (Bailey, 1991). Sumagic applied at low concentrations (0.5 to 3.0 ppm) before bud initiation may decrease time to flower (Bridgen and Smith, 1988).

Another problem associated with vinca is chlorosis caused by iron deficiency. Because iron is immobile in the plant, deficiency symptoms appear in new growth, while older growth remains green. The first signs are interveinal chlorosis of younger leaves. If the deficiency is not corrected, new leaves will be completely white, containing little or no chlorophyll. As much as 80% of the total iron found in plants is in the chloroplast and is utilized in heme pigments such as chlorophyll and Fe-S clusters or ferredoxins (Mengel and Kirkby, 1987). Metabolic processes are severely limited when iron is deficient. Without ferredoxins, which are an important component of the electron transport chain as well as many other biological processes, and heme pigments, which are the building blocks of chlorophyll, photosynthesis would not occur. Iron is classified as a micronutrient because it is required by the plant in small quantities. Often iron deficiency is correlated to high manganese content in the plant. These two elements compete for uptake, and if Mn^{2+} is more available in the medium than Fe^{2+}, more Mn will be incorporated. When pH is above 7, iron becomes insoluble and thus unavailable to the plant. Acidic soils contain higher levels of soluble iron than do calcareous soils (Mengel and Kirkby, 1987). Many field soils and potting media are mixed with lime to raise the pH, which can induce chlorosis in susceptible plants.

Gildersleeve and Ocumpaugh (1989) used field soils with high $CaCO_3$ content to quantify iron chlorosis in subterranean clover. Clover was transplanted into modified field soils and put under saturated conditions for two weeks. It was then rated for chlorosis using a scale of 0 (no chlorosis) to 4 (dead). The field soils were analyzed to determine their chemical composition; soils with clay content and high Ca and P appeared to influence the expression of chlorosis, a conclusion corroborated by work done on soybeans. Morris, Loeppert, and Moore (1990) showed a positive correlation between soil clay content and chlorophyll concentration. In both cases, chlorophyll concentration is highly correlated to iron chlorosis. While the experimental work on iron was conducted on other crops, it is assumed that the same dynamics of iron activity occur in vinca.

Temperature

Temperature influences the growth and maturation rates of plants. A general growth-response curve shows that there are several important temperature set points that determine how the plant will grow. The low temperature extreme at which plants do not grow is called the base temperature. Plant growth increases until it reaches an optimum temperature, beyond which it decreases rapidly until the plant dies at a maximum temperature. Plant growth rate is linear as temperature increases from the base temperature to the optimum temperature (Heins, 1990). The point at which each of these temperatures occurs is different for each plant. The base temperature is defined as the lowest temperature at which plants are not killed or damaged, but at which no growth can be recorded. This temperature is being used more frequently to store plug trays until needed. Recent work at Michigan State University has shown that crops such as geraniums, petunias, pansies (Lange, Heins, and Carlson, 1991), and alyssum (Heins and Wallace, 1992) can be stored for up to four weeks at temperatures as low as 0C with or without light. Other crops such as impatiens (Lange, Heins, and Carlson, 1991), marigolds (Heins and Lange, 1991), New Guinea impatiens, and vinca (Heins and Wallace, 1992) need temperatures above 7.5C to be stored without injury. The latter plants were susceptible to chilling injury at cooler temperatures, whereas the former could withstand much colder temperatures.

Heat delay occurs when plants are grown at temperatures above the optimum, but below the maximum. Optima for chrysanthemums and Easter lilies are 18C (Karlsson et al., 1989) and 24C (Heins,1990), respectively. Above these temperatures, flowering is delayed and plants do not mature as quickly. Bedding plants often have a higher optimum temperature, although it varies as much as base temperature. The maximum setting for geraniums is about 32C (Armitage, Carlson, Flore, 1981), while impatiens do well at 30 and 35C (Lee, Barrett, and Nell, 1990).

Temperature affects plants in different ways. Average daily temperature (ADT) influences leaf-unfolding rate, flower development rate, and plant growth or development rate (Heins and Erwin, 1990; Hendricks, 1990; Moe and Heins, 1990). DIF, or the difference between day (DT) and night temperature (NT), influences internode length, or plant height (Heins and Erwin, 1990; Moe and Heins, 1990). The response to DIF is quantitative, varying from plant to plant, and is most effective during rapid growth stages (Moe and Heins, 1990). DIF is quantified by DT - NT. When DT is higher than NT, DIF is positive; when NT is higher than DT, DIF is negative. Internode length increases as DIF moves from negative to positive, which causes plant height to increase. Most DIF work has been done on poinsettias, chrysanthemums, and Easter lilies. A predictive curve for poinsettia internode elongation rate has been determined and allows growers to adjust crop growth based on the rate of internode elongation. By adjusting DIF, the final length of each internode can be predicted (Berghage and Heins, 1991).

Growers are able to monitor the rate of plant growth by using a technique called graphical tracking (Heins and Carlson, 1990). The plants' height is tracked from a specified point in time, such as pinch date or transplant date, until they reach a marketable stage. Minimum and maximum curves are graphed to show target minimum and maximum heights over time. Graphical tracking is currently being used extensively for poinsettias, mums, and lilies.

Plants grown at the same DIF will have similar heights at flower because of similar internode elongation (Erwin, Heins, and Karlsson, 1989; Heins and Erwin, 1990; Hendricks, 1990), although they will mature at different rates because of different ADT. Plants grow faster as ADT increases until the optimum temperature is achieved.

ADT affects time to flower; a higher ADT decreases the time, as demonstrated in such diverse crops as *Oxypetalum caeruleum*, a cut flower (Armitage et al., 1990), *Impatiens wallerana*, a bedding plant (Lee, Barrett, and Nell, 1990), and *Lilium longiflorum*, a pot plant (Erwin, Heins, and Karlsson, 1989). Armitage, Carlson, and Flore (1981) found that as temperature increased from 15 to 32C, days to flower for geranium decreased almost linearly. For chrysanthemums, a DT/NT combination of 18/17C was the optimum for flower development (Karlsson et al., 1989). As temperatures increased or decreased, time to flower increased. At low light levels, combinations of 30C and 10 or 30C inhibited flowering even under short days. Optimum temperature can be used to force a crop to flower in the shortest time.

The optimum temperature for days to flower may be different than that for flower size. The optimum DT/NT combination for flower size in chrysanthemums was 20/15 to 16C (Karlsson et al., 1989). The average temperature was the same as that for flowering, but the day and night combination was different. Impatiens grown at a DT/NT regime of 24/18C had larger flowers than those grown at 30/24C or 35/30C (Lee, Barrett, and Nell, 1990). Days to flower were not reported; therefore, a comparison between days to flower and flower size cannot be made. Geraniums, however, had the largest flowers at 15C, whereas time to flower was optimum between 24 and 28C (Armitage, Carlson, and Flore, 1981; White and Warrington, 1988).

If the number of nodes needed for flowering is known, it can be used to determine the time to flower, a concept that has been extensively studied. When plants are placed under favorable flowering conditions, there is still vegetative growth before they became reproductive (Holdsworth, 1956). Holdsworth tried to reduce leaf number on *Xanthium* and *Eupatorium adenophorum* using nutrition levels and daylength. Starvation of the seedlings reduced leaf number significantly. Holdsworth concluded, however, that the concept of minimum leaf number may not be viable. Collins and Wilson (1974) examined the relationship between leaf stage and total number of nodes present. Using the period from flower initiation to flower, they developed an equation to define it: time = (number of leaves to be expanded)(rate of leaf expansion). Armitage (1984) found that the critical leaf number for flowering in geraniums was six to eight; the minimum node number for flowering was fifteen. The arrangement of the six to eight leaves was critical. Leaving six leaves within the first eight nodes caused no delay in flowering.

Leaf-unfolding rate (LUR) is a function of ADT and is defined as the time it takes for one leaf to reach a predefined size at a given temperature. Karlsson, Heins, and Erwin (1988) determined LUR for 'Nellie White' Easter lily to be linear as temperature increased from 14 to 30C. A prediction curve could be developed to determine temperature set points and to time crops. *Hibiscus rosa-sinensis* had a linear LUR between 10 and 30C, which was accurate until the appearance of flower buds (Karlsson et al., 1991). Poinsettias experienced a delay during which LUR was slower after plants were pinched. After three leaves had unfolded, LUR could be predicted based upon a prediction equation (Berghage, Heins, and Erwin, 1990). LUR decreased in all cases as temperature increased in the defined ranges.

The effect of temperature on vinca has been studied recently because of the slow growth observed at lower temperatures. Vinca grows best when temperature set-points are higher than those for other plants. Carpenter and Boucher (1991) demonstrate this with higher temperature set points for germination. Higher temperature set points for growing vinca are gaining more publicity as more is learned about the plant. Set-point recommendations for stage four of germination in 1991 were reported as 18 to 20C (Scullin, 1991), whereas by the end of 1992, the recommendation for stage four was to keep settings above 20C (Thomas and Gilbertz), although lower temperatures are still reported (Dill, 1993). The literature has focused on temperatures needed for growing the crop. These studies have not looked at the effects of ADT on flowering, LUR, or flower diameter, or the effects of DIF on plant height.

Irradiance

Light is the most important factor in plant growth. Many plant functions, such as photosynthesis, phototropism, and photoperiodism, are controlled by the quantity and quality of light the plant receives. These functions are grouped and described by the term photomorphogenesis (Vince, 1960). Plant growth can be optimized in a greenhouse situation if the effects of photomorphogenesis on greenhouse crops are known.

Supplemental lighting is one way of increasing the amount of light a plant receives. As photosynthetic photon flux (PPF) increased, time to flower for chrysanthemums decreased and flower diameter increased (Karlsson et al., 1989). Gagnon and Dansereau (1990) reported 4.3 times as many flowers on gerbera plants grown under 16 hours of 90 $\mu mol \cdot m^{-2} \cdot s^{-1}$ than on those grown under ambient light in the fall. The light level also significantly increased height, width, and top dry weight of gerberas grown in the fall.

Supplemental high-pressure sodium (HPS) lighting reduced time to flower and increased fresh weight and stem length for snapdragons grown during the winter (Stefanis and Langhans, 1982). Another cut-flower crop, *Oxypetalum caeruleum*, showed a decrease in stem length as PPF increased, although stem diameter and number increased (Armitage et al., 1990). These differences in stem elongation under supplemental lights may be due to species variations or lighting application.

Bedding plants show different responses to supplemental lights. Impatiens, marigolds, petunias, and zinnias were affected differently when grown under one to four weeks of supplemental lighting (Carpenter and Beck, 1973). Impatiens showed no significant differences in fresh weight between lighted and unlighted plants regardless of the treatment length. Marigolds, petunias, and zinnias, however, showed significant differences in fresh weight when exposed to three or four weeks of continuous supplemental lighting. Days to flower greatly decreased when all four bedding plants were exposed to continuous supplemental lighting. Petunias flowered much faster when exposed to 16 hours of supplemental lighting. In another study, petunias benefitted from up to 10 days of continuous lighting at 83 $\mu mol \cdot m^{-2} \cdot s^{-1}$ when it was applied to seedlings at least five days after emergence (Graper, Healy, and Lang, 1990). Days to flower were significantly decreased after transplant. When the irradiance level was increased to 120 $\mu mol \cdot m^{-2} \cdot s^{-1}$, petunia seedlings showed the greatest response.

Begonias responded like petunias when given supplemental light. Using a procedure similar to that used for petunias, Graper and Healy (1990) found that 10 days of continuous supplemental lighting applied up to 25 days after emergence significantly decreased days to transplant in begonia seedlings. Higher light intensities also decreased time to transplant. Kessler, Armitage, and Koranski (1990, 1991) achieved similar results. They found that applications of 16 hours of light at 125 $\mu mol \cdot m^{-2} \cdot s^{-1}$ for two weeks had the greatest effect on time to flower. Exposing plants to longer periods of supplemental lighting or higher or lower light levels was not as effective. Treatments in this experiment were begun two weeks after seedling emergence, and seedlings were lighted for 0, 2, 4, 6, or 8 weeks.

Geraniums have been studied for a different reason. Flower initiation is directly related to light; therefore, much work has been done to determine the quantity and type of light needed. Erickson et al. (1980) suggested that the relationship between days to flower and photosynthetically active radiation (PAR) may be linear at low light levels until a threshold level between 6.89 and 9.01 $\mu E \cdot m^{-2} \cdot day^{-1}$ is reached. White and Warrington (1988) determined that 975 $mol \cdot m^{-2}$ of light is needed from emergence to macrobud for earliest initiation and development of 'Red Elite' geraniums. Light did not greatly affect geranium plants after the macrobud stage, a conclusion that is supported by work done by Armitage, Carlson, and Flore (1981). They showed that bud development was not significantly affected by light level. Development from seedling to visible bud, however, was highly correlated to light level. Light levels below 30 $\mu E \cdot m^{-2} \cdot s^{-1}$ were not great enough to initiate visible bud.

The light source can be important in determining what kind of PAR the crops will receive. Armitage and Tsujita (1979) studied the differences between high-pressure and low-pressure sodium (HPS and LPS, respectively) lights and their effects on flower initiation in geraniums. They found that LPS lamps did not promote flowering at any intensity or duration, whereas HPS produced many of the results mentioned above. They concluded that LPS lamps are not useful in producing geranium seedlings.

Plant Modelling

In this review, each factor has been considered as an individual occurrence, but this is not the case. Light and temperature interact to create optimum environments for plant growth. Many of the experiments noted have used both temperature and light to determine the effects on plant growth. In the case of geraniums, light is important for flower initiation, while temperature influences the speed of subsequent flower initiation (Heins, 1979; White and Warrington, 1988). Flowering is delayed by extreme temperatures, low light levels, or both. In chrysanthemums, high day or night temperatures in combination with low light levels (less than 1.8 $mol \cdot day^{-1} \cdot m^{-2}$) prevented flower initiation under short-day conditions (Karlsson et al., 1989). By raising the light level, flower initiation did occur, but plants took much longer to flower than at lower temperatures. By looking at how temperature and light interact to affect plant growth and flowering, models can be developed to predict a plant's growth. These models can then be used by growers to determine environmental parameters to best fit their production practices. Because of the growth of computer technology and accessibility, computers can be used to monitor and adjust the environmental conditions set by the grower (Karlsson, Heins, and Carlson, 1983).

Graphical tracking is the simplest approach to plant modelling. It is already being used to monitor plant growth and determine cultural practices such as applying growth retardants or changing temperatures on crops like poinsettia, mums, and lilies (Heins and Carlson, 1990). This type of modelling gives growers a window in which to keep crops on schedule, assuming the timing of the crop is known. Graphical tracking does not show the effects of different temperatures or light levels on the plants. It merely tells a grower if the plants are on schedule or not.

A model for determining the window for a specific crop needs to be developed before graphical tracking can be used for it. Different ways of approaching these models can be found. Larson (1990) investigated a mechanistic approach to modelling. He examined the use of integrated temperature, light, and daylength models in which each component could be modeled separately or combined into one equation, which became more complex as each component was included. This complex equation should be better able to predict growth of a plant over time; however, as the model becomes more complex, it is more likely to contain errors. Therefore, Larson suggested keeping the model simple.

Karlsson, Heins, and Carlson (1983) looked at two different approaches to plant modelling: photosynthetic maximization and whole-plant modelling. The photosynthetic maximization model contrasts standard conditions with optimum ones for plant growth. To determine optimum photosynthetic conditions, plants were grown at various temperatures and CO_2 set points, and photosynthesis was measured. A regression equation was calculated from the data and used to determine optimum temperature and CO_2 concentration. This type of modelling takes advantage of the amount of light a plant receives and optimizes temperatures and CO_2 concentrations to maximize photosynthesis in the plant. Temperature and CO_2 concentration are adjusted to compensate for light levels. Whole-plant modelling looks at how plants grow under various day and night temperature combinations and light regimes.

Determining which type of modelling to use depends on what will be done with the information. Mechanistic models are good as computer models. The information for mechanistic models can be developed or tested using either of the other two models. Photosynthetic maximization models can be used if optimum photosynthetic conditions can be maintained. This modelling technique is useful if only one crop is being grown.

Whole-plant modelling gives information on crop growth under optimal and suboptimal conditions. When many crops are grown together, it can be used to determine the best conditions to satisfy most of the plant requirements. Scheduling can be timed by the parameters that best fit all crops that will be grown together. This same technology could be used on the production of vinca.

Objectives

Much has been accomplished in determining the best ways to produce crops like petunias and geraniums; but new crops are appearing all the time and also need defined production optimums. Studies must be conducted to determine the best way to grow these crops. At the same time, many problems can be avoided or overcome by finding the causes and correcting them before the damage is irreversible. The research in the following papers was designed and executed with the following objectives:

1. to determine the environmental factors that induce iron chlorosis in vinca,

2. to determine the effects of ADT on vinca flowering, LUR, and flower diameter and use the data to develop a predictive model for vinca flowering,

3. to determine the effects of DIF on internode elongation and plant height of vinca, and

4. to determine the effects of different light regimes on flowering and plant growth of vinca.

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A Study of Iron Chlorosis in *Catharanthus roseus* (L.) 'Grape Cooler'

A study of Iron Chlorosis in *Catharanthus roseus* (L.) 'Grape Cooler'

Introduction

Catharanthus roseus L., or Madagascar vinca, has grown in popularity as a bedding plant because of its heat and drought tolerance. With increased production, vinca susceptibility to iron chlorosis caused by cultural parameters such as medium pH, water content, and temperature is a common grower concern (Scullin, 1991; Thomas and Gilbertz, 1992).

Iron is taken up by the plant in the reduced, or Fe^{2+}, form. As pH increases from 4 to 7, iron is oxidized to the Fe^{3+} state. Above a pH of 7.4, iron reacts with hydroxyl groups and forms insoluble precipitates (Mengel and Kirkby, 1987). A peat-based medium pH of 5.5 to 6.5 is usually recommended to ensure that all elements, including iron, are available to the plant.

The amount of water in the medium influences air space, which influences the oxygen concentration. As oxygen concentration decreases, favoring anaerobic conditions, iron will be in a reduced state (Fe^{2+}) and more available to the plant (Mengel and Kirkby, 1987). Moisture content also affects vinca growth. Vinca is more susceptible to chlorosis and root rot disease when overwatered (Thomas and Gilbertz, 1992).

The rate of nutrient uptake is regulated by metabolic processes and, therefore, decreases as plant growth decreases. Thus, the degree of chlorosis exhibited is more severe if the temperature is below the optimum range. Vinca growth is slowed and stunted below 20C. The objective of this research was to determine how each of these factors (medium pH, moisture content, and temperature) influences the degree of chlorosis expressed.

Materials and Methods

'Grape Cooler' vinca seeds were sown in 288 plug trays filled with Metro Mix 360 (Grace Sierra Co.,Allentown, Pa.) and covered with vermiculite 11 Jan. 1993. Trays were covered with clear plastic and placed at 25C in a greenhouse and allowed to germinate.

A 7:3 peat:perlite (Fisons Canadian Sphagnum Moss Peat) medium was mixed and divided into thirds. To provide three different pH ranges, one-third received 3.0 kg/m^3 dolomitic lime and 1.8 kg/m^3 gypsum, one-third received 5.2 kg/m^3 dolomitic lime and 1.2 kg/m^3 gypsum, and one-third received 5.2 kg/m^3 dolomitic lime, 1.2 kg/m^3 hydrated lime, and 0.6 kg/m^3 gypsum. All other nutrients were added to each medium at rates of 0.6 kg/m^3 $Ca(NO_3)_2$, 0.6 kg/m^3 KNO_3, 0.3 kg/m^3 $MgSO_4$, and 1.2 kg/m^3 superphosphate with trace elements provided by Micromax (Grace Sierra Co., Allentown, Pa.) at 0.7 kg/m^3. These lime levels were chosen to bring the media pH into ranges of 4.0 to 5.0, 5.5 to 6.5, and 7.0 to 8.0, respectively. The initial pH of the three media were 4.2, 4.35, and 4.9, respectively. To monitor changes in media pH and EC, media samples for pH and electrical conductivity (EC) readings were collected from plants under the same water treatments, but not from plants used for determining the degree of chlorosis or other determinations. Each medium was within 0.4 pH units of the target ranges by the second week of the experiment.

Water treatments were based on the percentage of available water. Several cell packs with rooted seedlings were watered to container capacity, weighed, allowed to dry to the wilting point, and reweighed. The difference between these weights was the amount of water available to the plants; it was multiplied by 50%, 75%, and 100% and then added to the weight at the wilting point to determine the final weights for each treatment. Water (28 to 80 ml) was added to the cell packs every 24 hours to keep them at the specified weights.

Growth chambers were set at 15, 20, and 25C, and lighting was provided by cool-white florescent lamps for 12 hours per day at 100 $\mu mol \cdot s^{-1} \cdot m^{-2}$ (4.3 $mol \cdot day^{-1} \cdot m^{-2}$). Each chamber held up to four 1.2- x 0.8-meter movable benches.

Seedlings were sorted and transplanted into 32-cell flats filled with one of the three premixed media on 25 Feb. 1993. Treatments were randomly assigned to each group of four cell packs, and plants were moved to the appropriate growth chamber. Treatments were replicated three times with a block represented by the plants placed on one bench. The experimental design used was a split-split plot with the main plot split for temperature; the second, for water treatment. Plants were watered every 24 hours with either tap or distilled water to maintain the pH of the media based on the pH tests of the extra plants. Each cell in all treatments was fertilized after four weeks with 7 ml of KNO_3 and NH_4NO_3 at 300 ppm N and K.

Plants were evaluated weekly, and the number of chlorotic leaves was counted. A leaf was considered chlorotic if 50% or more of the leaf was chlorotic. One cell pack per treatment was removed after five weeks. Medium pH and EC were tested for each cell, and the condition of individual plant roots and shoots was evaluated to correlate with the degree of chlorosis. Analysis of variance was performed on the data for degree of chlorosis in the shoot. Tissue samples were collected and dried, and two samples were sent to a lab for spectrum analysis. These samples were chosen to correspond with the plants that exhibited either the most or the least chlorosis.

Results

Plants began to show signs of chlorosis within the first two weeks and became more chlorotic as growth continued through the sixth week (Table 1). There were no differences between the pH treatments (Table 2). Plants at the low pH range showed the same number of chlorotic leaves as those kept at the medium and high pH levels. Media pH had no effect regardless of water or temperature treatment. Therefore, pH was combined across water and temperature treatments.

The degree of chlorosis was affected primarily by the amount of water applied, which was most apparent at 25C (Fig. 1). There was more chlorosis when plants were kept at 100% available water than at 50%. As temperatures decreased, the differences in degree of chlorosis between water treatments were not as great, but the treatment with

100% available water still showed the most chlorosis; plants became very chlorotic and died, presumably because of root-rot pathogens. Fungus gnats and algae were present mainly on the high moisture content media. Plants at 50% available water had the least degree of chlorosis. Chlorosis on plants at 75% available water varied, affecting 0% to 100% of the leaves. Cell moisture fluctuated significantly because of air currents in the growth chambers, causing some cells to dry more than others.

Plants held at 15C grew slower, and the bottom leaves turned yellow. Chlorosis was most severe at this temperature. As the air setting increased from 15 to 25C, chlorosis decreased. At 25C, chlorosis became a function of water treatment. Leaf size and number were greater at 25C than at 20 or 15C, with the largest plants at 50% available water.

Since pH treatments were not significantly different, tissue samples were combined across media pH for water and temperature treatments. Tissue samples from plants with either the least or most chlorosis were anayzed for elemental concentration. The chlorotic tissue had much lower concentrations of all elements tested (Table 3); zinc, manganese, iron, and aluminum concentrations were more than 50% lower in the chlorotic tissue.

Discussion

Medium pH is important in determining nutrient availability. The recommended pH range is 5.5 to 6.5 for peat-based media. The media pH treatments in this study were designed to be above, at, or below this range. High pH in the medium has been cited as a cause of chlorosis in vinca (Scullin, 1991; Thomas and Gilbertz, 1992). The source of iron in the media affects iron availability to the plant. Mattis and Hershey (1992) demonstrated that vinca develops abnormal roots when grown in nutrient solutions containing iron-EDTA or iron-DTPA fertilizers. In this experiment, micronutrients were provided in a nonchelated form. The lack of pH effect could be due to the initial pH being below the desired levels. Media pH levels did not reach desired levels until after the second week of the experiment, but when samples were collected after the fifth week, pH levels were already at desired levels, and still there were no differences in leaf chlorosis.

The amount of water in the container was the prime factor that determined the degree of chlorosis, which was exacerbated by cool temperatures. Vinca was most chlorotic in media kept at container capacity and low temperatures. Under situations in which the medium approaches anaerobic conditions, such as when the plants are at container capacity, iron is in the reduced state and should be more readily available (Mengel and Kirkby, 1987).

If iron is available to the plant but is not being taken up, something other than availability must induce chlorosis. If chlorosis cannot be explained by availability factors, something may be inhibiting root uptake. Factors that influence ion uptake include nutrient availability, competitive inhibition, efficiency of roots in taking up nutrients, and physiology of roots (Moore, 1977).

Ions that compete with iron for uptake include Mn, Cu, Zn, and other divalent heavy metals. If any of these competes with iron for uptake, it's concentration increase should be revealed by tissue analysis. Zn and Mn show significant decreases in tissue concentrations, and Cu shows some decrease (Table 3). Therefore, iron uptake is not competitively inhibited by uptake of the elements listed.

Using iron and other nutrients, efficiency of uptake has been studied (Hershey, 1991). Plants are considered efficient if they are able to lower the pH of the surrounding medium to take up the nutrient in question. In this experiment, the cultural methods that influence chlorosis were studied, not the mechanisms by which nutrients are taken up; therefore, there are no data showing whether the plants are efficient in iron uptake. The lower amounts of other nutrients in chlorotic tissue could mean that uptake of more than just iron is limited and may indicate that the problem is not caused by inefficiency of the roots.

Deformed roots that cannot take up nutrients could possibly cause chlorosis. Plants grown at high water concentrations had little or no root growth after five weeks; whereas those grown at low water concentrations showed normal root growth (Table 4). The patterns of root growth seem to follow closely the degree of chlorosis, which could be an indication that the physiological state of the roots may be the main factor that causes inhibition of nutrient uptake. The lower concentrations of all elements in the chlorotic plants support this conclusion. Root physiology and it's effect on ion uptake in vinca needs to be studied further.

Conclusion

Chlorosis in vinca has been attributed to iron deficiency. In this experiment, the concentration of all elements in chlorotic plants was lower than that in green plants. The chlorosis may not be just an iron deficiency, but could be due to the physiological state of the roots under adverse conditions, which include low temperatures and high moisture levels in the medium. Avoiding these conditions by raising greenhouse temperatures and allowing0 the plants to dry between waterings will help prevent vinca chlorosis.

Table 1. Weekly chlorotic ratings - average number of chlorotic leaves out of eight to ten per plant. Weeks 3, 4, and 5 are averaged over 144 plants. Weeks 6 and 7 are averaged over 108 plants. Week 8 is averaged over 72 plants.

Temp	Percent water	Weeks of treatments 3	4	5	6	7	8
25	100	3.0	4.6	3.9	3.2	1.9	2.1
	75	1.2	1.5	1.1	0.8	0.6	0.9
	50	0.1	0.1	0.1	0.8	0.0	0.0
20	100	2.8	4.4	4.4	4.6	3.8	3.6
	75	2.2	2.6	2.5	2.2	1.6	1.3
	50	1.0	0.4	0.2	0.1	0.0	0.0
15	100	2.6	4.0	4.2	4.3	3.9	3.8
	75	3.0	3.7	3.2	3.3	2.7	2.9
	50	2.2	2.3	1.6	1.2	0.7	0.7

Table 2. Analysis of varience for degree of chlorosis after five weeks.

Source	DF	MS	F	
Water	2	406.86	150.598	***[a]
Water x temp	4	15.23	5.363	**
Error A	12	2.70		
Media pH	2	2.14	0.070	ns
pH x water	4	3.92	0.127	ns
pH x temp	4	5.10	0.166	ns
pH x water x temp	8	3.88	0.126	ns
Error B	36	30.74		

[a]ns, **, *** Nonsignificant or significant at P=0.01 and 0.005, respectively.

Table 3. Tissue analysis of plant material from 36 plants after five weeks of treatments.

Nutrient (%)	Chlorotic tissue	Green tissue	Percent decrease
Phosphorus	0.47	0.57	17.5%
Potassium	2.25	3.41	34.0%
Magnesium	0.44	0.69	36.2%
Calcium	0.73	1.25	41.6%
Nutrient (ppm)			
Zinc	47	95	50.5%
Manganese	105	471	77.7%
Copper	8	11	27.3%
Iron	49	119	58.8%
Boron	94	104	9.6%
Aluminum	48	101	52.5%

Table 4. Condition of the roots after five weeks of treatments. Numbers are means of 36 plants.

	Percent available water		
Temperature	100	75	50
15C	2.1 ± 0.8	2.9 ± 1.5	4.8 ± 0.6
20C	2.4 ± 1.2	3.5 ± 1.3	4.9 ± 0.4
25C	3.2 ± 1.5	4.6 ± 1.0	4.9 ± 0.7

1 = no roots present, 5 = roots in excellent condition

Figure 1. Average number of chlorotic leaves out of eight to ten total after five weeks of treatments.

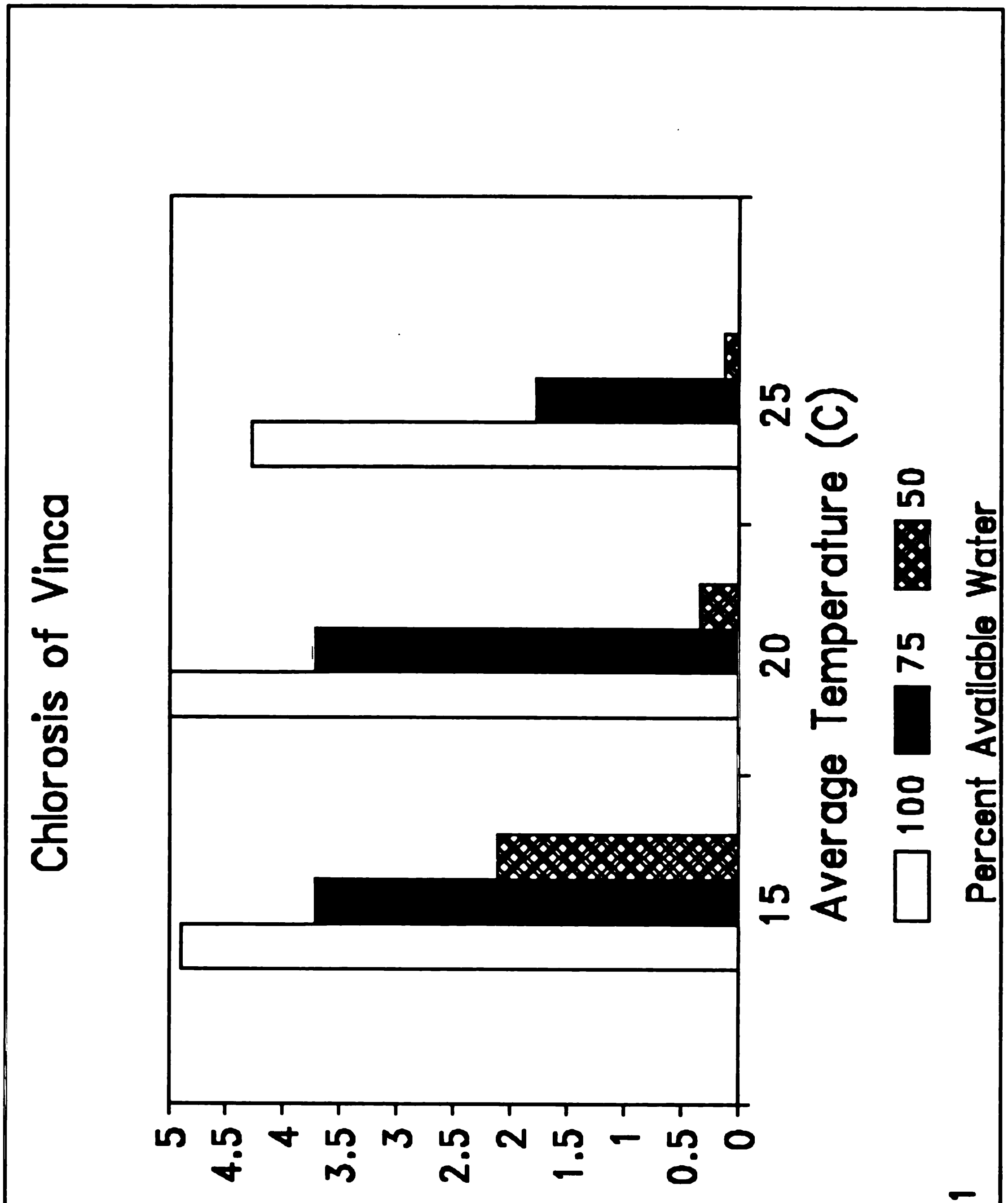
Chlorosis of Vinca
Number of Leaves Chlorotic
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
15
20
25
Average Temperature (C)
100
75
50
Percent Available Water

Figure 1

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The Effect of Day and Night Temperature and Light Level on *Catharanthus roseus* (L.) 'Grape Cooler'

The Effect of Day and Night Temperature and Light Level on *Catharanthus roseus* (L.) 'Grape Cooler'

Introduction

The bedding-plant industry produces over 1.5 billion plugs each year to supply consumers with a variety of annuals (Dill, 1993). Geraniums, petunias, impatiens, and begonias have dominated the market for many years, but with 4% of the total sales for 1991, *Catharanthus roseus* L., or Madagascar vinca, is becoming an important crop (Agriculture Statistics Board, 1993). Therefore, environmental information such as growing temperatures and light levels needs to be studied to determine optimum conditions for growing vinca.

Air temperature affects plant growth two ways; average daily temperature (ADT) influences the growth or developmental rate, while the difference between day and night temperature (DIF) affects the height or internode length of the plant (Heins and Erwin, 1990). These effects were demonstrated on species like poinsettia (Berghage, Heins, and Erwin, 1990; Berghage and Heins, 1991), Easter lily (Erwin, Heins, and Karlsson, 1989), chrysanthemum (Karlsson et al., 1989), and hibiscus (Karlsson et al., 1991), and on such bedding plants as geranium (Heins, 1979; Armitage, Carlson, and Flore, 1981; White and Warrington, 1988) and impatiens (Lee, Barrett, and Nell, 1990).

Crops can be produced for a specific market date under commercial conditions. Many species of bedding plants are grown together, and if the cultural requirements for each crop are known, species with similar growing conditions can be placed together. In commercial production, vinca is often placed with crops grown at cooler temperatures, which may slow or stunt growth. (Thomas and Gilbertz, 1992).

The amount of light the plant receives influences flowering time and size. Karlsson et al. (1989) showed that as photosynthetic photon flux (PPF) increased, time to flower decreased and flower diameter increased in chrysanthemums. Carpenter and Beck (1973) studied the effects of light on four bedding-plant species: impatiens, marigolds, petunias, and zinnias. They found that four weeks of supplemental lighting caused shorter, more compact plants that flowered earlier. Graper, Healy, and Lang (1990) determined that the application of 5 to 10 days of supplemental HPS on ten-day-old petunia seedlings decreased time to flower. The effects of supplemental light on vinca have not been studied, but it would be useful to know how light affects time to flower and flower size.

This experiment had three main objectives: (1) to develop a prediction model for days to flower in vinca, (2) to determine the effect of various DIF regimes on vinca internode length, and (3) to determine the effects of temperature and light on flower diameter.

Materials and Methods

Experiment 1. Five 4.0- x 4.7-meter greenhouse sections were maintained at constant 15, 20, 25, 30, and 35C. Each 0.9- x 2.7-meter bench was given a different PPF level. One bench was covered with 50% mesh shadecloth, one was equipped with 2 HPS lamps that provided 12 hours of supplemental light at 250 to 300 $\mu mol \cdot m^{-2} \cdot s^{-1}$ (10.8 to 13.0 $mol \cdot m^{-2} \cdot day^{-1}$), and the third bench provided ambient light levels. Extraneous light was minimized by aluminum foil hung from the HPS lamps.

Plug trays of eight-week-old *Catharanthus roseus* L. 'Grape Cooler' were received and transplanted into 32-cell (eight 4-pack) flats filled with Baccto potting medium (Michigan Peat Co., Houston TX) on 5 March 1992. There were three replications, each consisting of one flat. Each flat was assigned a day and night temperature, a light level, and a replication number. Two different sowing dates were recorded for the plugs, so replications were first sorted by sowing date and then by plant height. Flats were moved every 12 hours to provide 25 DT/NT environments. Movement of plants took an average of 30 minutes. Plants were kept under the same light treatments.

Flowering dates for first flower, 50% flower per flat, and 100% flower per flat were recorded daily. Height, node number, fresh weight of roots and shoots, and dry weight of roots and shoots were recorded weekly.

Experiment 2. Plugs were received and transplanted 15 March 1993, and were used as a verification of the 1992 experiment. Plants were treated like those used the previous year, with a few modifications. Plants under constant temperature were rearranged each time the other plants were moved to simulate stress effects on plants moved between chambers. Soluble salts and pH were checked weekly and subirrigation water was adjusted to keep salt levels stable. Supplemental light intensities were 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ ($8.6\ mol \cdot m^{-2} \cdot day^{-1}$).

As each flat came into full flower, it was marked and removed after data from the week were collected. Dry weights were not recorded, but all other measurements, including flower size, number of leaf nodes at first flower, and internode length, was recorded weekly. The uppermost leaf pair on transplants that received constant temperature treatments were marked and leaf-pair numbers were counted every other day.

Data analysis. Flowering data for both years were converted to rates, and regression lines were plotted through the data. Lines were compared statistically using the procedure by Snedecor and Cochran (1967). Similarities between ambient and 50% shade regression lines were observed and compared statistically using the same procedure. The inverse of each regression line was calculated and plotted.

Linear regression analysis was performed on leaf-pair numbers collected until half the flat was in flower to determine leaf-pair unfolding rates (LUR) at specific temperatures. These data were then combined for treatments that had flowered, and linear regression analysis was performed to create a curve over temperature. The slope and y-intercept of each line were used to calculate base temperature and degree-day per leaf pair. The inverse of each LUR curve was calculated and plotted.

The leaf node of first flower was determined by averaging the data collected. The number of leaf pairs on the plant at flower was determined by averaging the total number of leaf nodes when the plants first flowered. The number of leaf pairs at transplant was counted and averaged to determine the initial leaf pairs.

Results

As ADT increased, days to flower decreased at all light levels (Figures 2b, 3b, and 4b). Plants with an ADT of 15 or 17.5C had not flowered under ambient or 50% shade conditions when the experiment was terminated eight weeks after transplant. Plants under supplemental light flowered earlier than those at the other two light levels, but did not flower under an ADT of 15C.

No statistical differences were found between regression lines for flower development rate for plants grown under 50% shade, but there was a difference in the y-intercept for those grown under ambient light (Table 5). This difference was not large enough to be horticulturally significant, so the data for shade and ambient light were combined for both years. However, data for supplemental light could not be combined because of the differences between the two years.

Curves and their inverses for flower development rate were plotted for each of the light treatments (Figs. 2, 3, and 4). These curves showed that as air temperature increased from 15 to 35C, flower development rate increased and days to flower decreased. Comparisons of regression lines for 50% shade and ambient light showed that there were some differences (Table 6), but when the data were examined at set points most often seen horticulturally (17.5 to 22.5C), these differences were not large enough to be important. Therefore, data were combined for these treatments, and regression lines for flower development rate and days to flower were plotted (Fig. 5).

LUR regression lines for ambient and supplemental light treatments were parallel (Fig. 6). The slope for 50% shade was different than that of the other two treatments; therefore, the data for ambient and 50% shade could not be combined. The degree days required to unfold one leaf pair were calculated using the slopes of the regression lines. They showed that as light level increased, the degree days per leaf pair decreased (Table 7). Base temperature was calculated and determined to be between 10 and 12C.

Plotting the inverse of the LUR regression lines gives the time required to unfold one leaf pair (Table 8.). By determining the number of leaf pairs on the plant at time to flower and subtracting the number at transplant, the number of leaves to unfold before the plant flowers can be determined. There was an average of 9.3 leaves on the plant when flowering occurred, and the average number of leaves unfolded at the time the plugs were transplanted was 4.9; therefore, approximately 4.4 more leaves had to unfold after transplant before the plants would flower. Plotting the curve for 4.4 leaves to unfold with the prediction curve for days to flower showed that the curves were similar (Fig. 7). Therefore, the curve for days to unfold one leaf pair could be used to predict days to flower. Figure 8 shows the curves for plants with three (top line) to eight (bottom line) leaves under each light treatment. By determining the number of leaves on a plant, the days to flower can be predicted using these curves.

DIF affects internode elongation of a plant. Figure 9 shows the effect of day, night, and constant temperature and DIF on the elongation of vinca stems. Day and night effects were obtained by averaging day settings across all night temperatures or night temperatures across all day settings. As day temperature increased from 15 to 35C, internode length increased, which corresponded to a greater increase in internode length with a positive DIF.

Observations of flower size during the first experiment led to measuring of flower diameter in the second. Flower diameter was greatly influenced by both day temperature and light level (Fig. 10). Flowers were largest at a day setting of 25C under supplemental light.

Discussion

The rate of growth from transplant to flower in vinca was influenced by temperature and was slowed considerably when the air setting was below 20C at all light levels, which was expected because vinca is tolerant to high temperatures (Thomas and Gilbertz, 1992; Scullin, 1991). The 50% shade treatment and ambient light yielded similar growth rates, while the rate under supplemental light was slightly faster. Comparison of the 1993 supplemental-light rate curve with the other two treatments showed that the slopes were similar, but the y-intercept was different, which suggested that the supplemental lights generated heat and raised the temperature of plants that were under them. For petunia seedlings, Graper and Healy (1991) showed that plant temperature under HPS lights was four to five degrees above that of plants under ambient light. Vinca shoot-tip temperatures under HPS lights were generally two to three degrees above shadecloth and ambient light at 35C. Further studies by Faust (unpublished data) indicated that as air setting decreased from 35 to 15C, vinca shoot-tip temperature under supplemental light remained one to two degrees above that of plants under ambient light. The greatest differences in flowering rates were seen at the lower temperatures, and the rise in temperature under supplemental lights may have caused the earlier flowering times.

The flower development-rate lines for supplemental light between the two years could not be combined. The intensity of the HPS lamps was different between the two years because different lamps were used. The amount of ambient light changed the effectiveness of the supplemental light. Plants were lighted during the day, which means that ambient light levels were supplemented. On a cloudy day, when ambient light levels were below 10 to 15 $mol \cdot m^{-2} \cdot day^{-1}$, HPS lights increased the total amount of light the plants received. On a sunny day, when the ambient light levels were greater than 15 to 20 $mol \cdot m^{-2} \cdot day^{-1}$, HPS lights did not have as great an effect. During the two years in which these experiments were conducted, plants received different amounts of radiation; therefore, the capacity for supplemental lighting to affect the plants differed. This type of experimental error had to be considered when the data were analyzed. Other factors that could have contributed to the differences between the rates included temperature controls, time to move plants, and judgmental error in determining days to flower, etc.

Leaf-pair unfolding-rate (LUR) data were collected to determine plant growth rate. Plants grown under supplemental light (Fig. 6) had a faster LUR, which could have been caused by the elevation of temperatures under the lights. However, the slope of the curve for the plants under 50% shade is different from that of the other two treatments. The slower growth rate at the higher air temperatures may be due to the lower light levels. The lines for 50% shade and ambient light intersect at 20C, suggesting that the low air temperature is slowing growth enough to delay flowering regardless of light levels. The predicted number of days to unfold one leaf pair shows a large difference between 20 and 25C at all light levels (Table 8), which suggests that air settings of 20C or below are too low for vinca. By increasing the air temperature 5 degrees, the number of days to unfold one leaf pair will decrease by three to four days, meaning that flowering will be decreased 15 to 20 days if five leaf pairs must be unfolded.

The difference between day and night temperature (DIF) influences internode elongation. According to Heins and Erwin (1990), internode length is affected more when DIF is positive than when it is negative (Fig. 9d). Figures 9a and b show the effect of increasing the day and night temperatures. Day temperature had a greater effect on the elongation of internodes, which explained the greater response of plants to a positive DIF. Figure 9c shows the effect of constant temperature on internode length. As temperature increased, internode elongation increased, which accounts for some of the variation in internode length under DIF. In most cases, internodes were measured when the entire flat had come into flower, but at the lower temperatures, not all plants flowered. Thus, plants were not as mature, and internodes may not have been fully expanded.

The amount of light and the day temperature affected flower diameter. Flowers were largest when they received supplemental light at 25C (day). Flowers were over 0.5 cm larger under supplemental light than under 50% shade. A day setting in the range of 25 to 30C was optimum for flower size. The difference between ambient and supplemental light levels was not as great. At higher light levels, plants were able to accumulate more photosynthates, which they could incorporate into the flowers. An increase in fresh and dry weight has been reported under higher light levels in bedding plants such as impatiens, petunias, marigolds, and zinnias (Carpenter and Beck, 1973) and is due to the increased accumulation of photosynthates.

Conclusion

Time to flower for vinca is influenced by temperature; it decreases as temperature increases. The prediction curves developed can be used by growers to determine temperatures for growing vinca and predict the time it will take the plants to flower. Air settings below 20C slowed growth and delayed flowering. Vinca grew best and flowered faster when given an average setting between 25 and 30C.

Supplemental light decreased time to flower, but the decrease may actually have been a result of the heat generated by the lamps. Supplemental light also increased flower size and had the greatest effect on cloudy days. There may have been some benefit to lighting the plants on cloudy days or extending the photoperiod.

Vinca plants responded as expected to DIF, and the temperature treatments could be used for height control. By keeping plants around 25C rather than at a lower setting, flower size was maximized, plants grew normally, and flowering was earlier.

Table 5. Regression analysis for flower development rate between years. $Y = b_0 + b_1$ (ADT)

Year	Variable	50% shade	Ambient	Supplemental
1992	b_0	-0.0155	-0.0206	-0.0094
	b_1	0.0017	0.0020	0.0017
1993	b_0	-0.0152	-0.0191	-0.0178
	b_1	-0.0017	0.0019	0.0020
Comparison of slopes		F = 0.0245 n.s.	F = 5.1235 *	F = 8.5223 **
Comparison of intercepts		F = 2.4157 n.s.	F = 3.0977 n.s.	F = 3.1543 *

ns, *, ** Nonsignificant or significant at P=0.05 and 0.01, respectively.

Table 6. Regression analysis for flower development rate between 50% shade and ambient light levels. $Y = b_0 + b_1$ (ADT)

	50% shade	Ambient	Comparisons	
b_0	-0.0151	-0.0196	20.2347	**
b_1	0.0017	0.0019	4.7449	*

*,** Significant to P=.05 and .01, respectively

Table 7. Calculated values for degree days/leaf-pair and base temperature using LUR regression lines.

Light level	Degree days/leaf	Base temperature
50% shade	126.6	10.0
Ambient	94.3	11.9
Supplemental	82.0	11.1

Table 8. Calculated days to unfold one leaf-pair based on LUR regression lines.

	Light level		
Temperature	50% shade	Ambient	Supplemental
15	22	27	19
20	12	11	9
25	8	7	6
30	6	5	5
35	5	4	4

Figure 2. Curves of flower development rate and predicted days to flower for 50% shade.

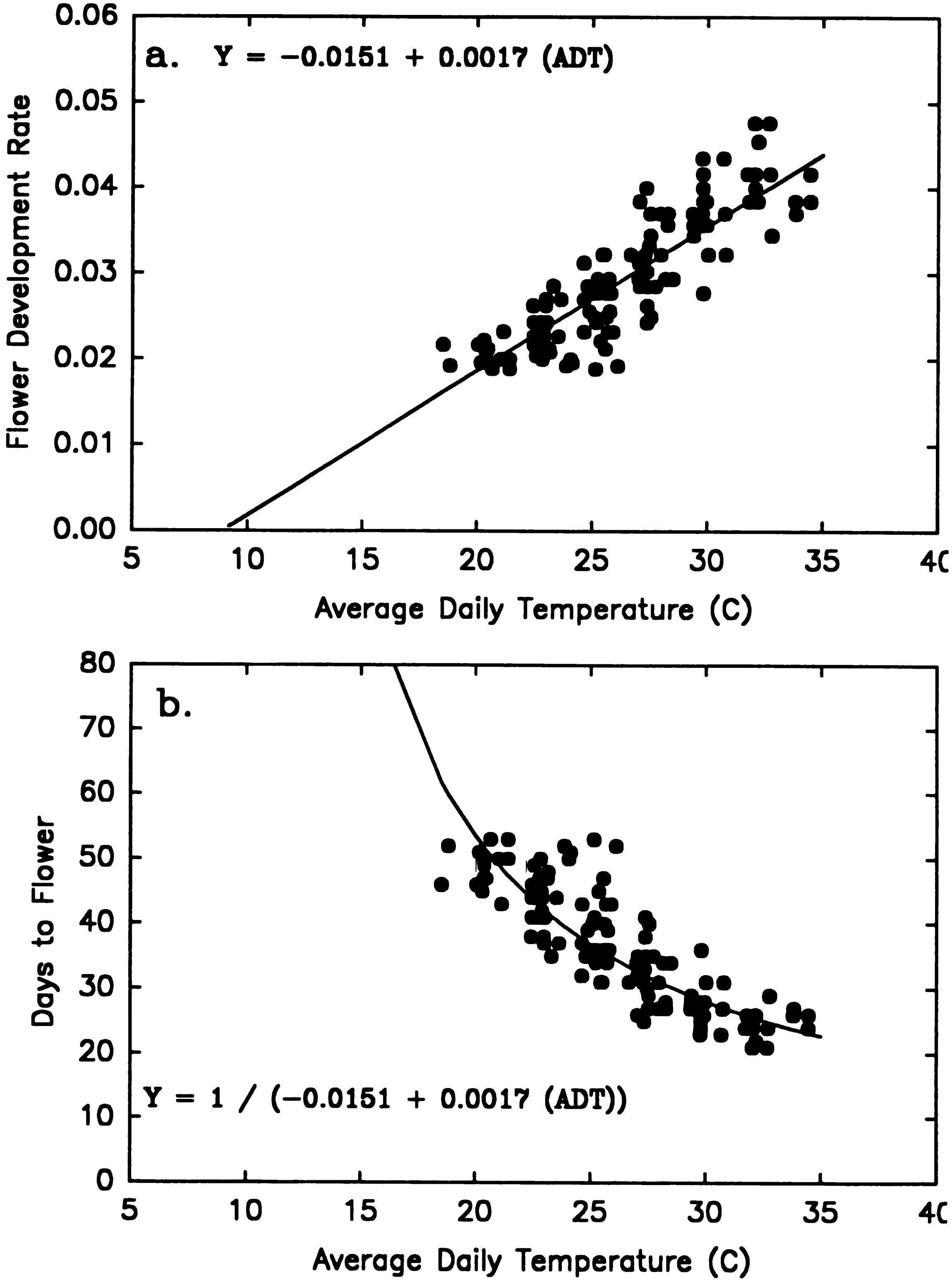

a. Y = −0.0151 + 0.0017 (ADT)
Flower Development Rate
0.06
0.05
0.04
0.03
0.02
0.01
0.00
5
10
15
20
25
30
35
40
Average Daily Temperature (C)
b.
Y = 1 / (−0.0151 + 0.0017 (ADT))
Days to Flower
80
70
60
50
40
30
20
10
0
5
10
15
20
25
30
35
40
Average Daily Temperature (C)

Figure 2

Figure 3. Curves of flower development rate and predicted days to flower for ambient light.

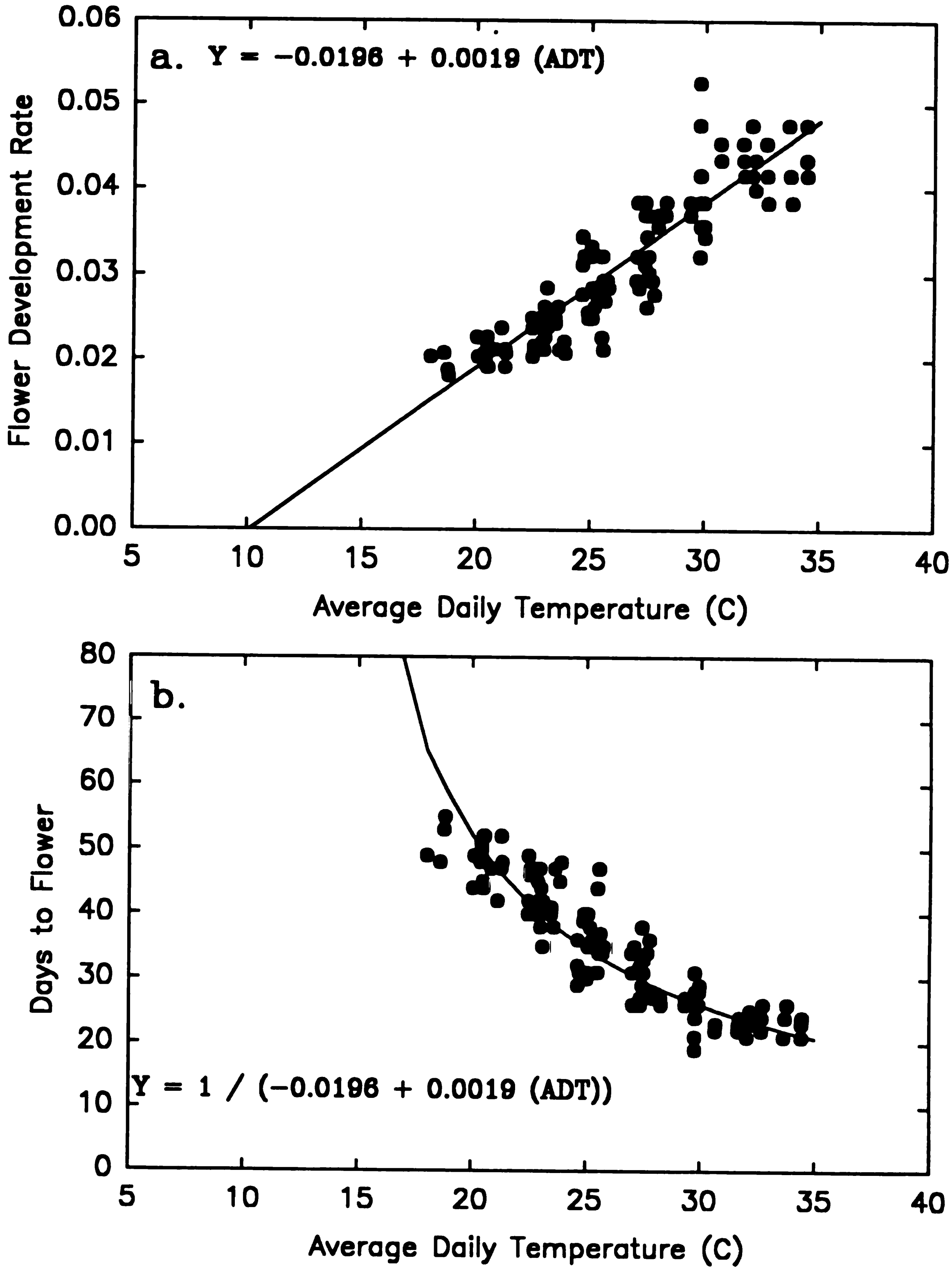

a. Y = −0.0196 + 0.0019 (ADT)
Flower Development Rate
0.06
0.05
0.04
0.03
0.02
0.01
0.00
5
10
15
20
25
30
35
40
Average Daily Temperature (C)
b.
Y = 1 / (−0.0196 + 0.0019 (ADT))
Days to Flower
80
70
60
50
40
30
20
10
0
5
10
15
20
25
30
35
40
Average Daily Temperature (C)

Figure 3

Figure 4. Curves of flower development rate and predicted days to flower for supplemental light.

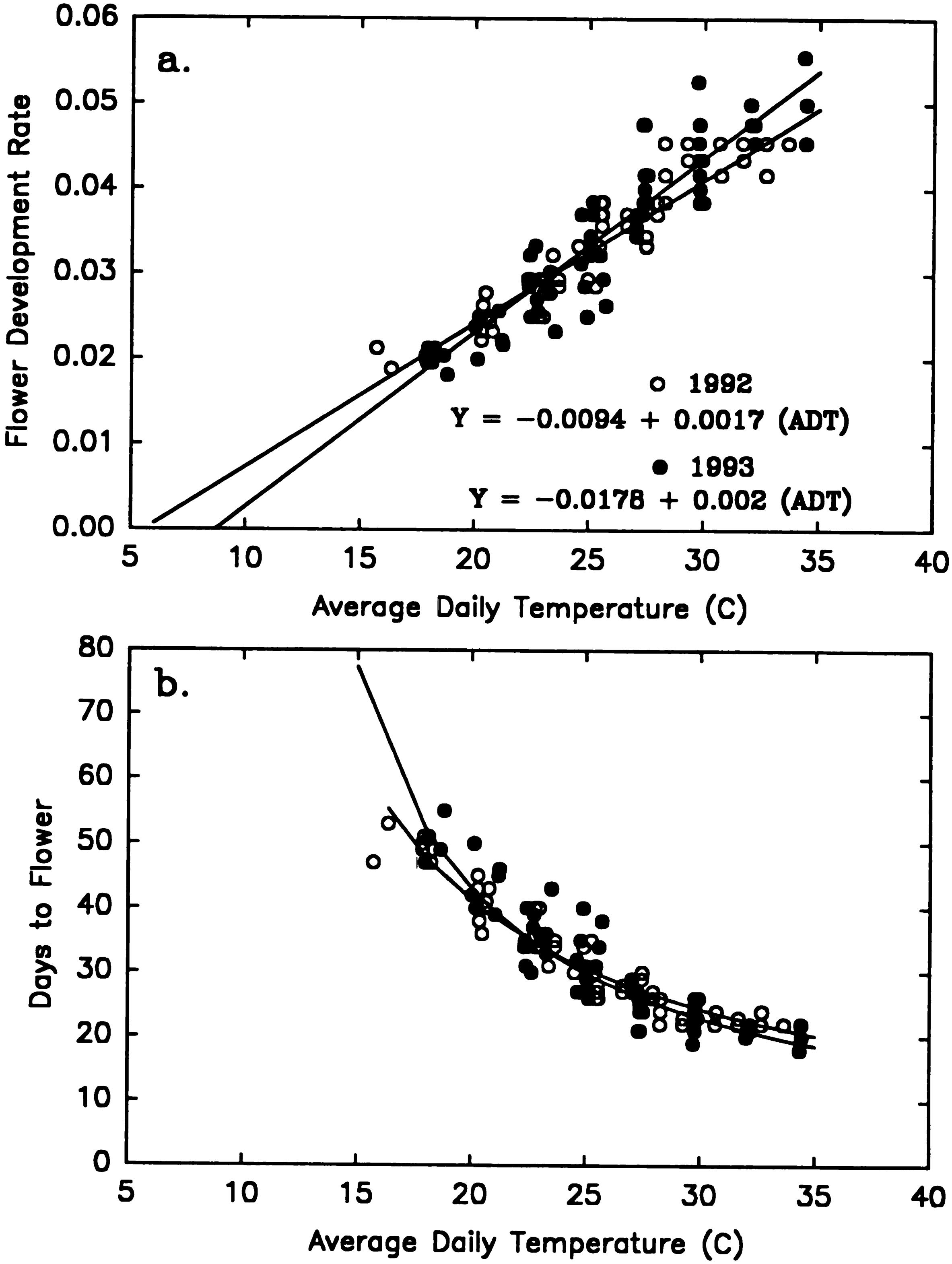

a.
0.06
0.05
0.04
0.03
0.02
0.01
0.00
Flower Development Rate
o 1992
Y = −0.0094 + 0.0017 (ADT)
● 1993
Y = −0.0178 + 0.002 (ADT)
5
10
15
20
25
30
35
40
Average Daily Temperature (C)
b.
80
70
60
50
40
30
20
10
0
Days to Flower
5
10
15
20
25
30
35
40
Average Daily Temperature (C)

Figure 4

Figure 5. Curves of flower development rate and predicted days to flower for combined shade and ambient treatments.

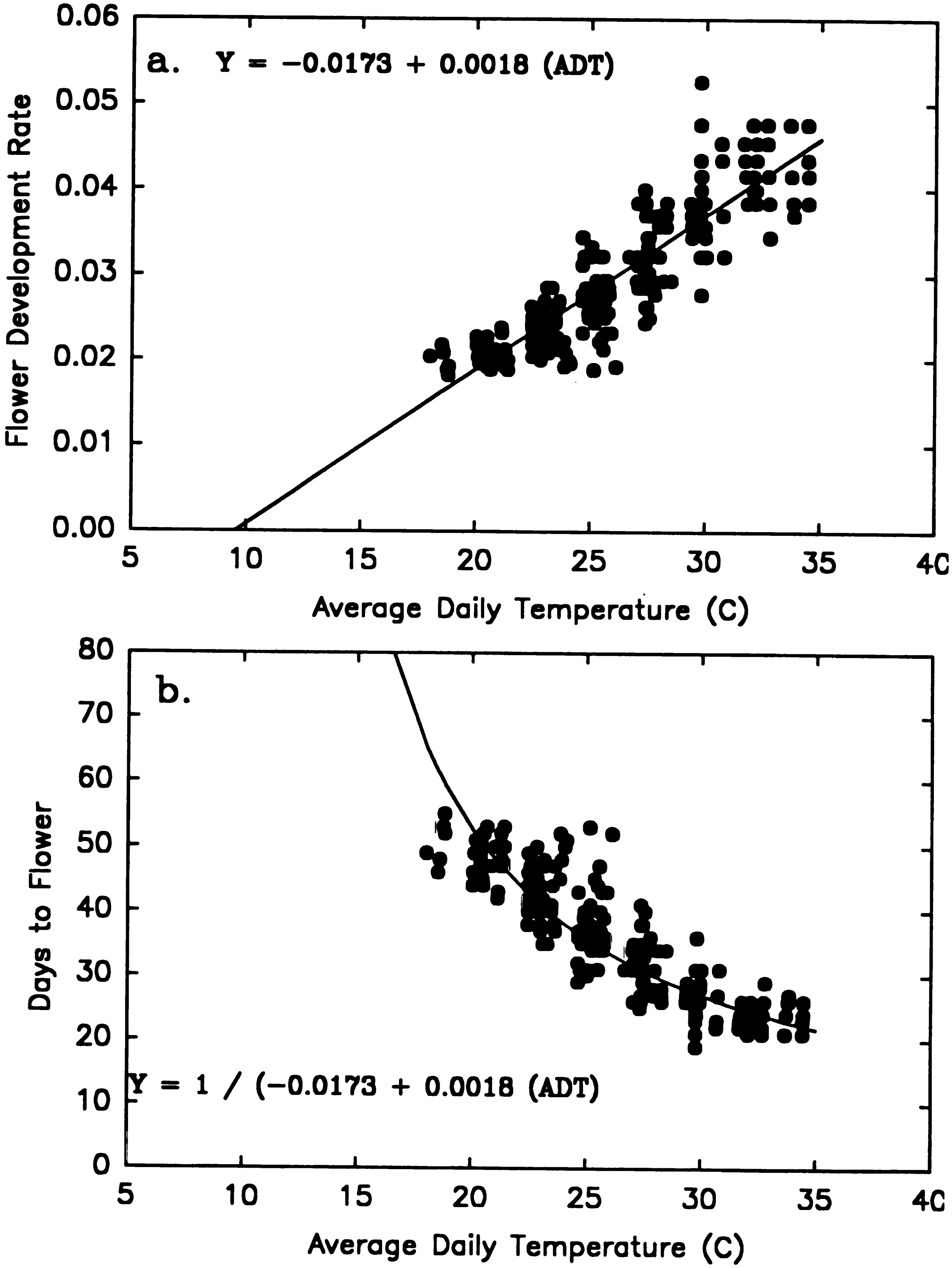

a. Y = −0.0173 + 0.0018 (ADT)
Flower Development Rate
0.06
0.05
0.04
0.03
0.02
0.01
0.00
5
10
15
20
25
30
35
40
Average Daily Temperature (C)
b.
Days to Flower
80
70
60
50
40
30
20
10
0
Y = 1 / (−0.0173 + 0.0018 (ADT))
5
10
15
20
25
30
35
40
Average Daily Temperature (C)

Figure 5

Figure 6. Curves of leaf-pair unfolding rate for 50% shade and ambient and supplemental light.

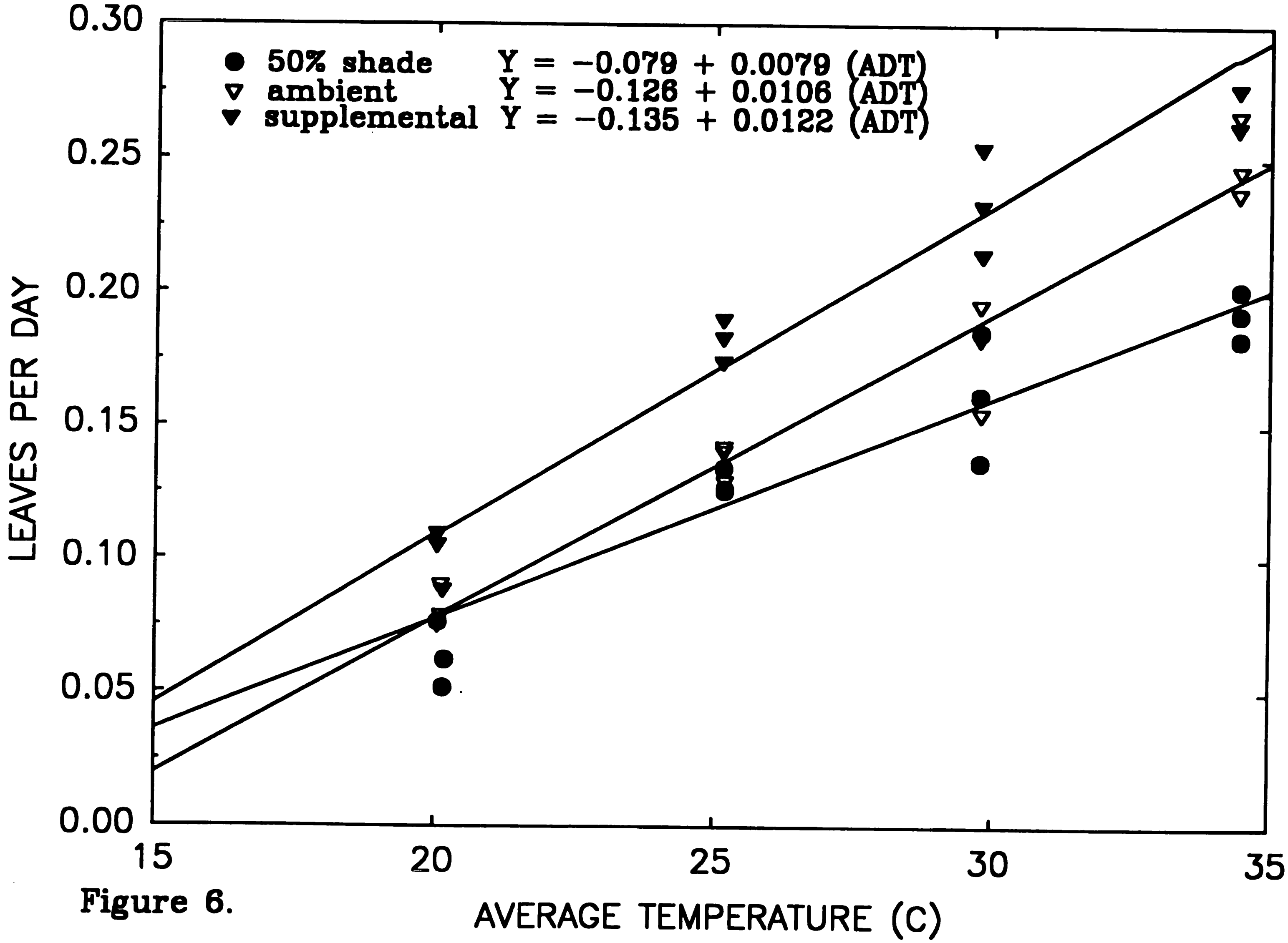
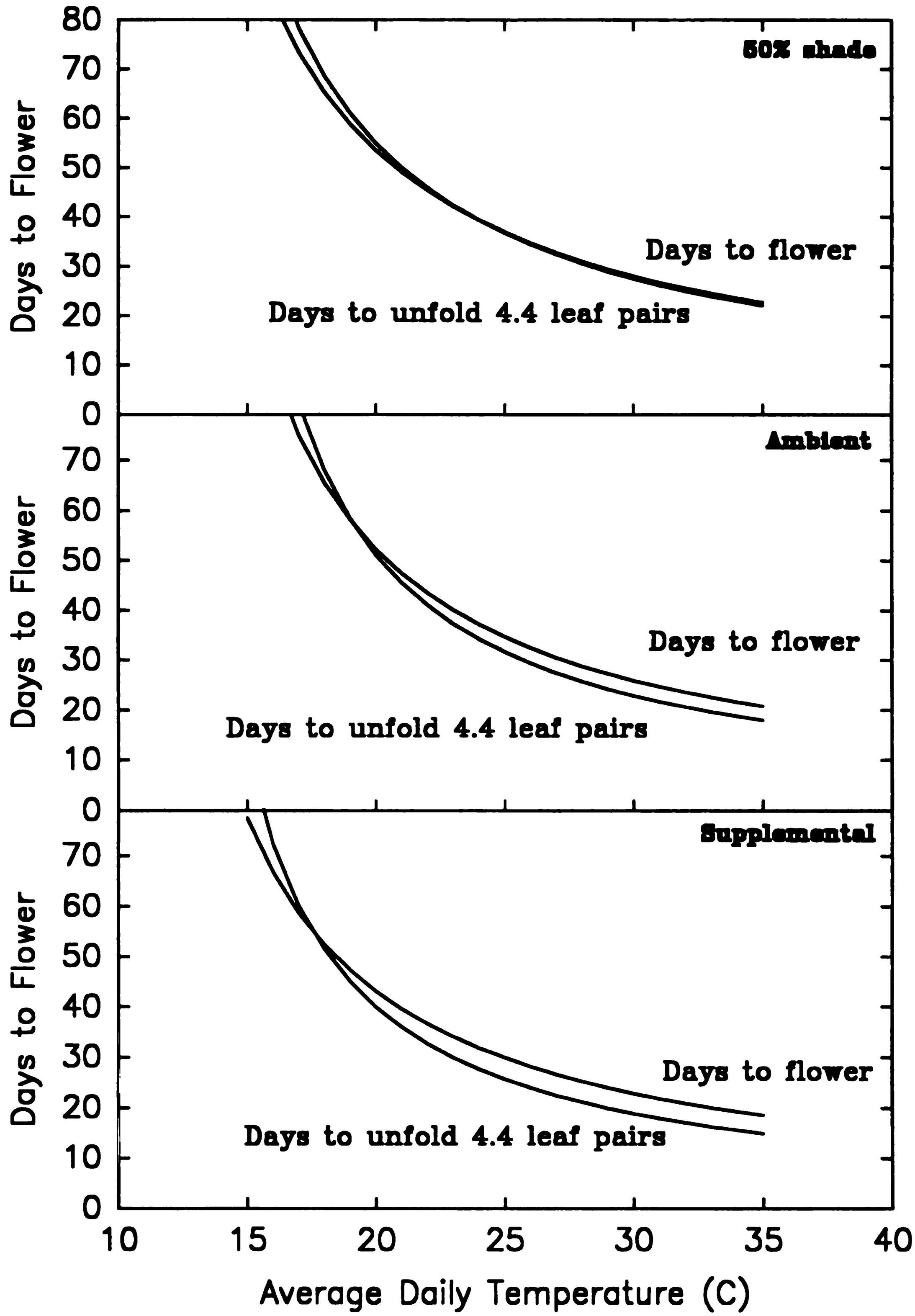

50% shade Y = −0.079 + 0.0079 (ADT)
ambient Y = −0.126 + 0.0106 (ADT)
supplemental Y = −0.135 + 0.0122 (ADT)
LEAVES PER DAY
0.00
0.05
0.10
0.15
0.20
0.25
0.30
15
20
25
30
35
AVERAGE TEMPERATURE (C)

Figure 6.

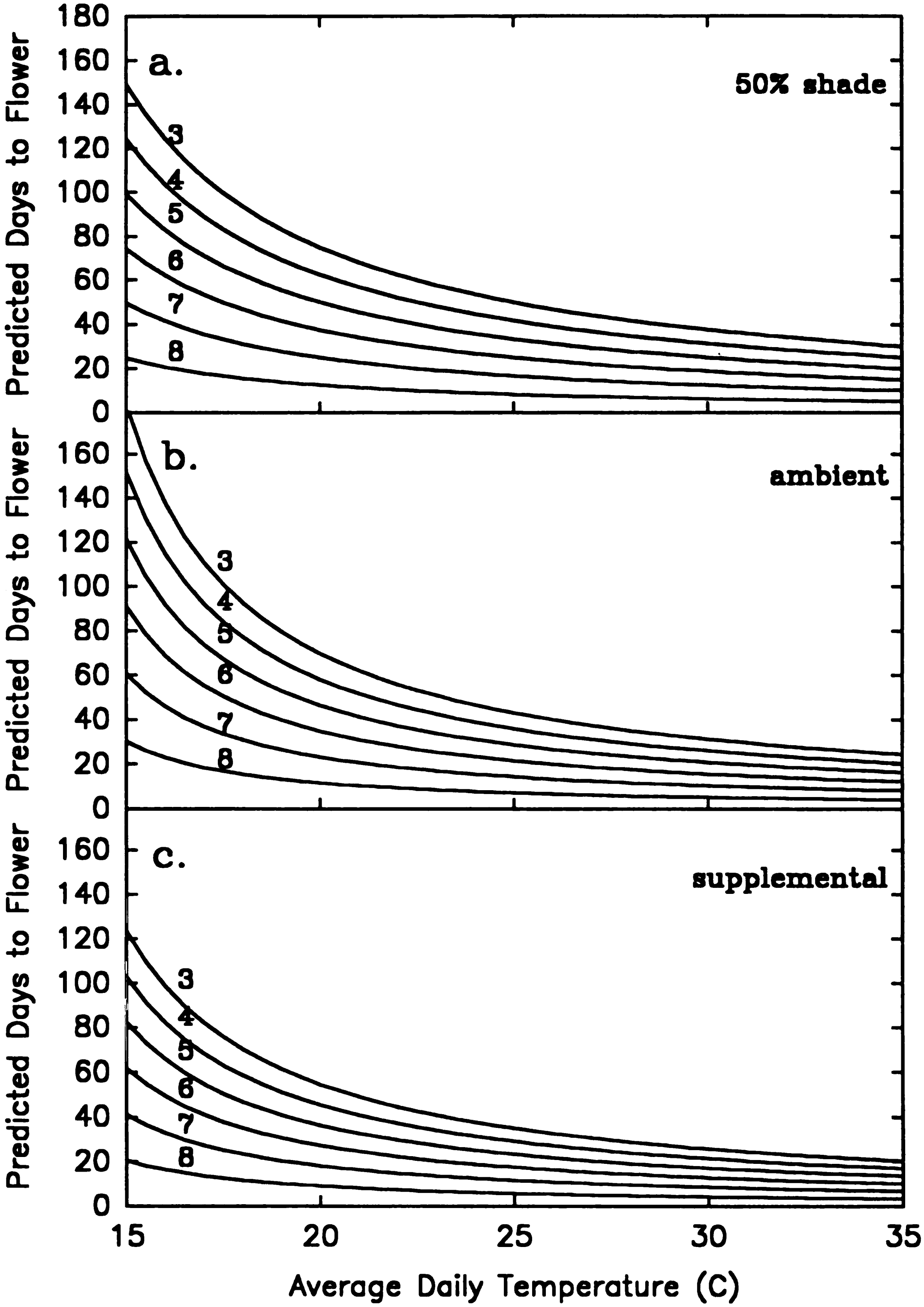
Figure 7. Comparison of curves for predicted days to unfold one leaf-pair and days to flower.



50% shade
Days to flower
Days to unfold 4.4 leaf pairs
Ambient
Days to flower
Days to unfold 4.4 leaf pairs
Supplemental
Days to flower
Days to unfold 4.4 leaf pairs
Days to Flower
Average Daily Temperature (C)

Figure 7

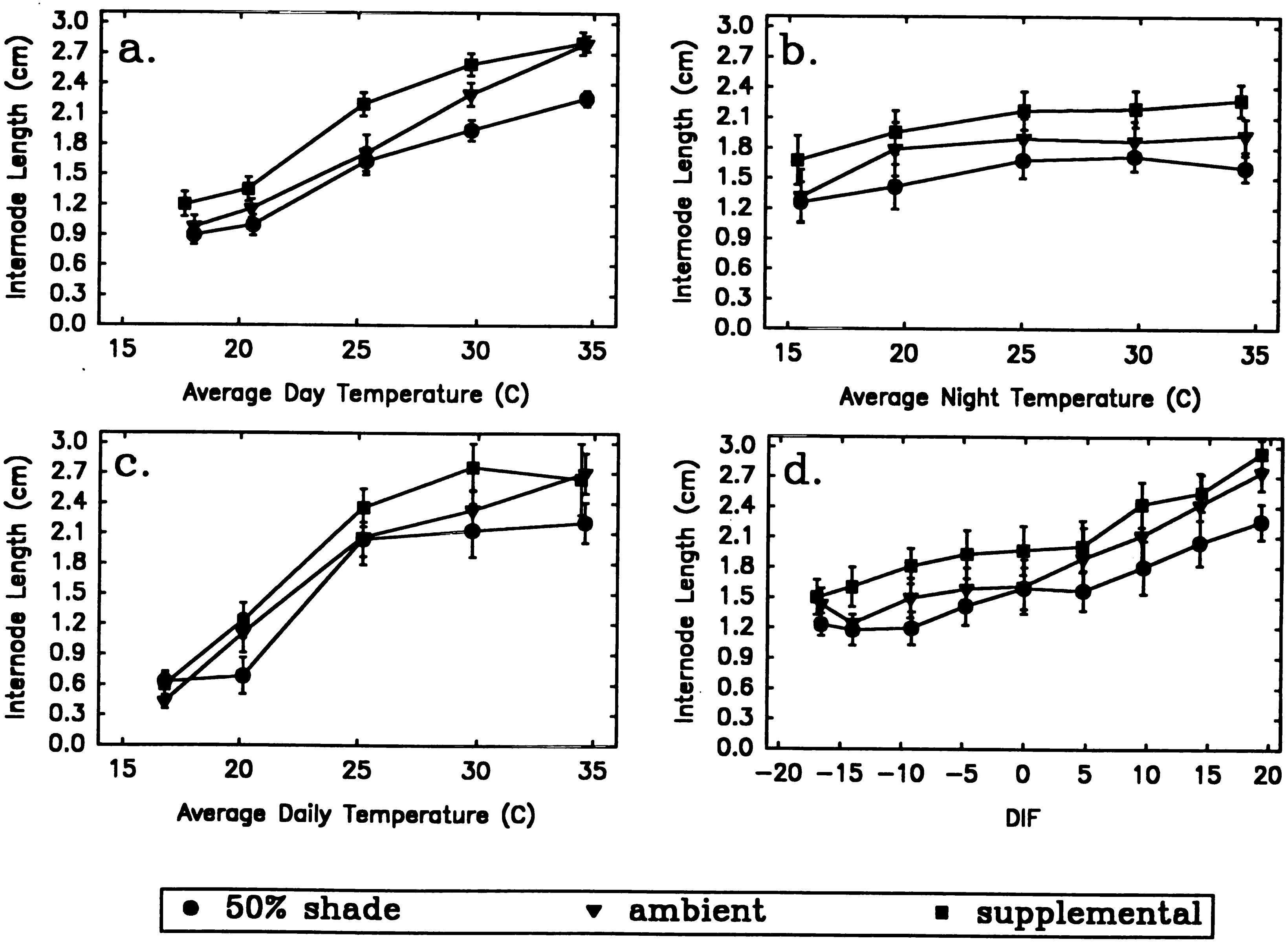
Figure 8. Curves of predicted days to flower using predicted days to unfold one leaf-pair. The numbers above each line represents the number of leaf-pairs already on the plant.



a.
50% shade
b.
ambient
c.
supplemental
3
4
5
6
7
8
Predicted Days to Flower
0
20
40
60
80
100
120
140
160
180
15
20
25
30
35
Average Daily Temperature (C)

Figure 8

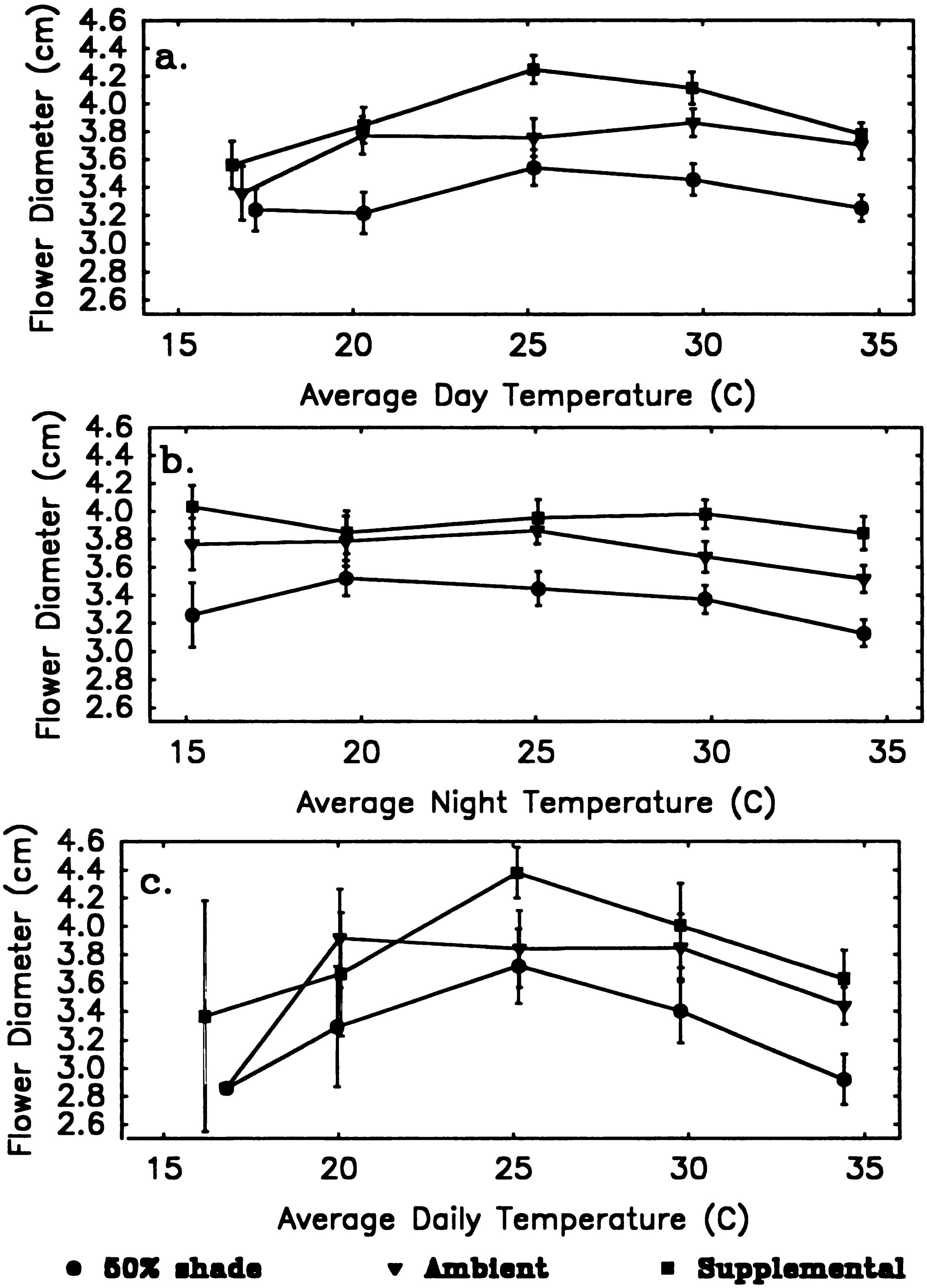
Figure 9. Comparison of internode elongation under (a)average day temperature, (b)average night temperature, (c)constant temperature, and (d)DIF.



a.
b.
c.
d.
Internode Length (cm)
3.0
2.7
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0.0
15
20
25
30
35
Average Day Temperature (C)
Average Night Temperature (C)
Average Daily Temperature (C)
−20
−15
−10
−5
0
5
10
15
20
DIF
50% shade
ambient
supplemental

Figure 9

Figure 10. Comparison of flower diameter under (a)average day temperature, (b)average night temperature, and (c)constant temperature.



Flower Diameter (cm)
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
a.
15
20
25
30
35
Average Day Temperature (C)
b.
Average Night Temperature (C)
c.
Average Daily Temperature (C)
50% shade
Ambient
Supplemental

Figure 10

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Apendix A

Table 9. Average fresh and dry weights for root and shoot at time to flower under 50% shade.

Temperature		1992				1993	
		fresh weight		dry weight		fresh weight	
day	night	root	shoot	root	shoot	root	shoot
35	35	1.44	7.00	0.33	0.76	0.93	3.29
35	30	1.30	5.18	0.32	0.60	1.10	3.17
35	25	1.89	6.63	0.36	0.74	1.15	3.61
35	20	1.56	7.97	0.35	0.92	1.65	4.22
35	15	1.44	6.69	0.33	0.78	1.20	3.45
30	35	1.23	6.73	0.29	0.69	0.88	3.62
30	30	1.91	5.44	0.24	0.59	1.21	4.10
30	25	1.83	7.67	0.33	0.82	1.29	4.54
30	20	1.34	6.89	0.29	0.80	1.15	4.07
30	15	1.85	9.10	0.28	1.09	1.12	3.52
25	35	1.21	5.06	0.31	0.57	1.00	3.52
25	30	1.41	5.43	0.35	0.62	1.05	3.74
25	25	1.60	7.03	0.32	0.81	1.05	3.69
25	20	1.56	5.57	0.35	1.03	1.05	3.50
25	15	1.88	7.42	0.39	1.01	1.07	3.75
20	35	0.98	4.45	0.25	0.54	0.95	3.15
20	30	1.07	5.09	0.27	0.64	1.12	3.27
20	25	1.80	6.24	0.33	0.77	1.25	3.13
20	20	2.17	7.30	0.31	0.90	0.56	2.08
20	15	A[1]	A	A	A	A	A
15	35	1.07	4.03	0.21	0.49	0.84	3.01
15	30	1.17	4.29	0.25	0.50	1.16	3.69
15	25	1.91	7.43	0.32	0.92	0.58	2.00
15	20	A	A	A	A	0.47	1.54
15	15	A	A	A	A	A	A

[1]Plants did not flower by the termination of the experiment.

Table 10. Average fresh and dry weights of root and shoot at time to flower under ambient light.

Temperature		1992				1993	
		fresh weight		dry weight		fresh weight	
day	night	root	shoot	root	shoot	root	shoot
35	35	1.56	8.78	0.37	1.04	1.55	6.47
35	30	1.58	7.83	0.40	0.94	1.67	6.27
35	25	2.50	9.84	0.46	1.13	1.64	6.03
35	20	2.26	10.28	0.49	1.24	1.44	6.46
35	15	1.52	8.47	0.35	1.13	2.61	6.00
30	35	1.30	7.57	0.36	0.86	1.87	6.77
30	30	1.62	8.87	0.39	1.00	2.42	6.81
30	25	2.06	10.63	0.41	1.20	1.96	6.45
30	20	1.98	9.51	0.42	1.19	1.37	5.45
30	15	2.43	11.59	0.50	1.44	1.21	6.38
25	35	1.61	8.47	0.32	0.95	1.29	5.33
25	30	1.93	9.94	0.41	1.10	0.90	4.30
25	25	1.38	7.71	0.28	1.01	0.76	3.79
25	20	2.51	11.25	0.45	1.39	0.99	3.03
25	15	1.32	10.18	0.40	1.31	0.84	3.88
20	35	1.52	7.52	0.46	0.86	1.85	4.77
20	30	1.45	6.67	0.36	0.84	1.31	4.88
20	25	2.17	9.58	0.41	1.28	1.55	5.04
20	20	3.26	11.45	0.51	1.51	2.36	5.53
20	15	A[1]	A	A	A	0.32	1.04
15	35	1.08	5.52	0.24	0.65	0.86	2.60
15	30	1.55	6.46	0.31	0.80	1.10	3.52
15	25	2.35	9.89	0.42	1.36	1.71	4.74
15	20	1.02	8.36	0.52	1.28	0.64	1.73
15	15	A	A	A	A	A	A

[1]Plants did not flower by the time the experiment was terminated.

Table 11. Average fresh and dry weight for root and shoot growth at time to flower under supplemental light.

Temperature		1992				1993	
		fresh weight		dry weight		fresh weight	
day	night	root	shoot	root	shoot	root	shoot
35	35	1.44	7.33	0.41	0.87	2.87	6.87
35	30	1.77	8.39	0.48	1.03	1.63	7.98
35	25	1.50	9.84	0.36	1.14	1.63	8.64
35	20	2.27	11.91	0.46	1.36	1.66	8.58
35	15	2.40	11.63	0.60	1.51	3.09	10.11
30	35	1.08	7.43	0.31	0.90	2.02	8.25
30	30	1.12	8.32	0.32	0.97	2.14	8.08
30	25	2.28	12.63	0.47	1.44	2.12	9.24
30	20	2.22	9.40	0.43	1.09	2.30	8.32
30	15	2.02	11.31	0.54	1.52	2.07	7.00
25	35	2.03	7.97	0.71	1.05	1.79	8.74
25	30	2.13	9.67	0.64	1.23	2.69	8.74
25	25	2.45	13.66	0.52	1.60	2.81	7.51
25	20	2.44	12.26	0.60	1.67	1.62	7.32
25	15	2.90	12.96	0.73	1.84	2.29	6.84
20	35	2.88	12.80	0.57	1.44	1.40	5.49
20	30	4.54	13.25	0.88	1.46	1.97	6.93
20	25	2.45	12.53	0.51	1.63	1.52	5.91
20	20	2.74	11.17	0.51	1.50	1.93	5.67
20	15	2.82	12.43	0.50	1.66	0.55	2.26
15	35	1.85	9.14	0.48	1.26	1.23	6.21
15	30	2.02	8.03	0.53	1.11	1.83	7.45
15	25	2.88	9.60	0.55	1.28	1.13	4.50
15	20	2.22	11.58	0.52	1.90	1.32	1.05
15	15	2.76	10.29	0.71	1.78	A	A[1]

[1]Plants did not flower by the time the experiment was terminated.