A STUDY OF LIGHT INTENSITY-TEMPERATURE RELATIONSHIP WITH SELECTED INDOOR PLANTS

Thesis for the Degree of M. S.
MICHIGAN STATE UNIVERSITY
GEORGE STABY
1967

ABSTRACT

A STUDY OF LIGHT INTENSITY-TEMPERATURE RELATIONSHIP WITH SELECTED INDOOR PLANTS

By George Staby

The environmental factors of light intensity and temperature, under home conditions, are usually not satisfactory for indoor plant growth. The purpose of this study was to provide more information on the growth responses of indoor plants grown under different combinations of light intensities and temperatures.

Eight species of commonly grown indoor plants were tested in three separate experiments. The first experiment was a preliminary one using three light intensity ranges of 200, 400, and 750 foot-candles. Results under these conditions were different for each species. Variations of temperature, soil fertility, humidity, and possibly others, were thought to have masked the effects due to light intensity alone. To overcome these variable factors, two more experiments were run in growth chambers, with more precise control of temperature, relative humidity, and light intensity.

Results of the growth chamber experiments indicated that growth mainly increased due to the effects of high night temperatures at all light intensity. Light intensity also influenced growth but not as much as the temperature factor.

The fact that lower night temperatures did not increase growth as was expected, has many possible explanations. Some of these explanations can be related to the plants age, species, size, and previous environmental conditions.

A STUDY OF LIGHT INTENSITY-TEMPERATURE RELATIONSHIP WITH SELECTED INDOOR PLANTS

By

George Staby

A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Horticulture

1967

ACKNOWLEDGMENTS

I would like to take this opportunity to thank Dr. Richard F. Stinson, Department of Horticulture, for his guidance and inspiration during this crucial time of my life. The time and effort expended on my behalf is greatly appreciated.

I would also like to express my appreciation to Dr. David R. Dilley, Department of Horticulture, and to Dr. Irving W. Knobloch, Department of Botany and Plant Pathology, for their guidance and teachings.

Finally, I would like to thank the Michigan Division of the Womens National Farm and Garden Association. Without their Fellowship, my studies at Michigan State University would not have been possible.

George Staby
Spring, 1967

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

There are three main considerations that one should be aware of when cultivating plants indoors: (1) these indoor plants are expected to grow in home environments that are probably far removed from their natural habitat; (2) they are grown at times of the year when they may not normally grow; (3) they are expected to produce more and better foliage and flowers than they would naturally. The achievement of these three considerations is difficult under home environments. However, with proper awareness and understanding of the factors influencing indoor plant growth, much success can be realized.

Some of the factors that influence indoor plant growth are: soil type, light intensity, light quality, soil moisture, temperature, soil reaction (pH), nutrient status, and humidity. Light intensity and temperature are thought to be two of the more important environmental factors influencing indoor plant growth.

The purpose of this study was to investigate the relationship of light intensity and temperature on the growth of selected indoor plants.

LITERATURE REVIEW

Light Measurement

An understanding of light measurement and its relation to plant growth is a necessity for today's plant scientist.

Some years ago, electric lamps were rated in terms of luminous intensity, that is, in terms of candles. As time went on, they were rated in terms of power, or watts. Today, the fluorescent lamps and other types are rated in terms of total "radiant flux," that is, lumens. Lumens, lux, foot-candles, luminous flux, radiant flux, and watts are some of the terms used today when referring to light measurements.

The behavior of energy is described by the Laws of Thermodynamics (29). Radiant energy in particular, is the energy of the electromagnetic waves, and is also explained by these laws. Each source of radiation consumes a certain quantity of energy per unit time (power), and releases it in the equivalent amount of energy. The power consumed is released into:

1. A quantity of heat per unit time; heat lost by conduction and by convection.
2. A quantity of radiation per unit time emitted in all direction called a "radiant flux."

Radiant flux is characterized qualitatively (spectral distribution of energy), and quantitatively (intensity).

The spectral energy distribution is denoted by the quantity of radiation as a function of its wave length. The wave length used here is in terms of Ångstrom units. One Ångstrom unit equals 0.1 millimicron, or 10^{-10} meter. The radiant energy intensity per unit time can be expressed in terms of watts. Other units for expressing the intensity of radiant energy are the calorie and the erg. One watt equals 0.239 calories per second, or 10^{7} ergs per second. Table 1 lists these as well as many of the terms associated with light measurement, and their meanings.

Many biological functions are influenced mostly by the electromagnetic waves in the range from 4000 Ångstroms to 7500 Ångstroms, the so-called "visible spectrum" (35). This also happens to be the range in which visual purple, the light absorbing pigment in the human eye, is stimulated. Figure 1 shows the electromagnetic field from cosmic rays to radio waves. Figure 2, however, shows the relative visual sensitivity of visual purple to different wave lengths. It is from this curve that much information is derived. The understanding of the visual purple curve will facilitate the understanding of the light measurement picture.

The quantitative value of radiant flux for illumination purposes is determined by its "luminous flux." The luminous flux is a measure of the overall stimulation of the visual purple that actually takes place. Referring to Figure 2, a certain quantity of radiant energy in the red and blue

Table 1.--Photometric Units and Definitions. (32)

Luminous flux	The total "visible energy" emitted by a source per unit time.
Lumen	Flux emitted per unit solid angle by a point source of 1 candela. Therefore, 1 candela emits 4π "lumens" in all directions.
Luminous intensity (of a source)	Property of a source of emitting luminous flux.
Candela	One-sixtieth of the intensity of 1 cm^2 of a blackbody radiator at a temperature of solidification of platinum (2042°K).
Illumination (of a surface)	Luminous flux incident of unit area of a surface.
Foot-candle	1 lumen/ft^2.
Lux	1 lumen/m^2.
Phot	1 lumen/cm^2 = 929 foot-candles.
Luminous efficiency	Ratio of total luminous flux to the total power consumed. Lumens/watt.
Radiant flux	Rate of flow of energy from a source of light.
Watt	1 watt = 0.239 calories/sec. = 10^7 ergs/sec.
Ångstrom	Measurement of wave length. 1 Ångstrom = 0.1 millimicron = 10^{-10} meter.

Figure 1.--The Electromagnetic Spectrum (7).

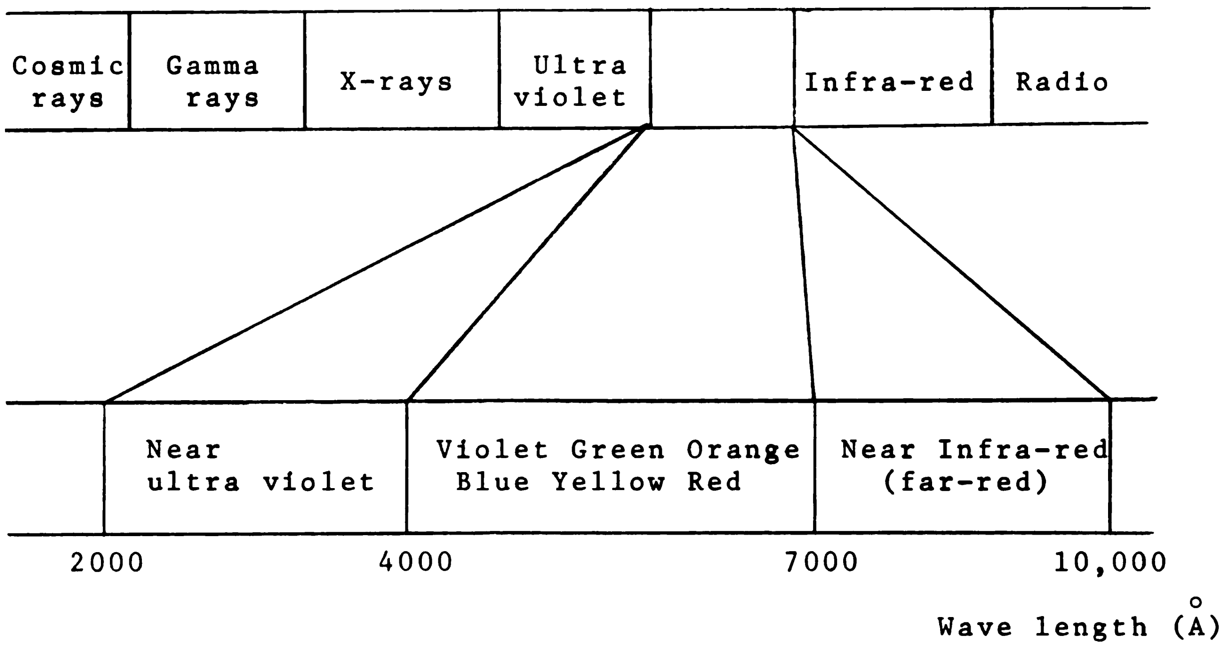
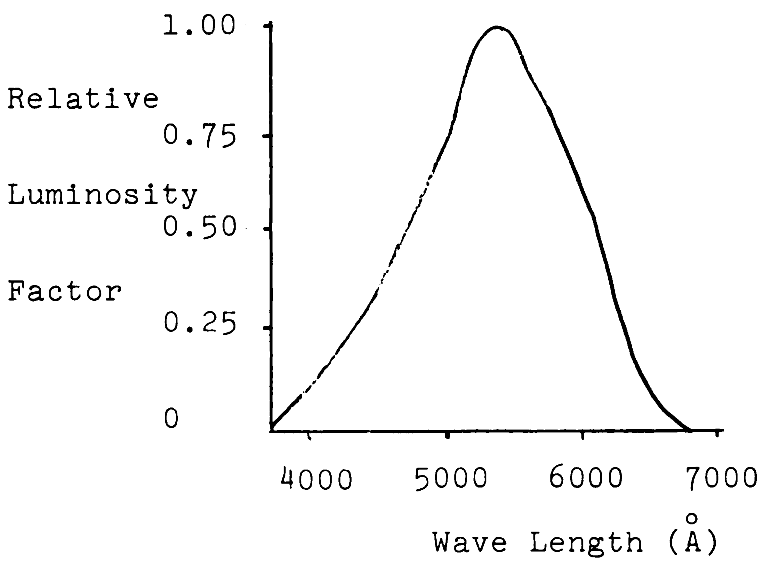


Figure 2.--The Standard Luminosity Function (32).



regions contributed less to the visual impression than the same quantity of energy in the green. For example, a neon lamp, a mercury lamp and an incandescent lamp can have the same luminous flux as related to the visual purple curve. However, the spectral distribution of each lamp is very different. The incandescent lamp's spectral distribution is high in the near infra-red region, while a mercury lamp has its peak at the green-yellow region (7). The differences in their spectral distribution probably have marked effects on photosynthesis and other light requiring physiological processes. Thus, the manner in which luminous flux is determined is not a satisfactory measurement of light for plants.

In the visual purple graph in Figure 2, the abscissa is a wave length scale, and the ordinate is the relative luminosity factor os the standard light-adapted eye (35). The plot is a relationship between the two, with the maximum luminosity for the human eye at 5550 Ångstroms, corresponding to 1.0 on the relative luminosity ordinate.

A luminous flux is measured in "lumens." A lumen is the luminous flux emitted in a solid angle of one "steradium" by a uniform point of light having an intensity of one "candela." The equation for a solid angle is:

$$\text{Solid Angle} = \Omega = \frac{A}{r^2}$$

where A is the area of the surface of the sphere in question divided by its radius squared. Therefore, to obtain one steradium, the ratio of the sphere surface-area to the square of its radius must be equal. Thus, a uniform point source of one candela intensity will emit 4π lumens.

At a wave length of 5550 Ångstroms, a radiant flux of one watt equals a luminous flux of 680 lumens. To determine the luminous flux of an unknown source of light, corresponding to a radiant flux of one watt, one can multiply 680 by the relative luminosity factor derived from the visual purple graph in Figure 2, at the wave length under consideration. If a radiant flux (source of light) has more than one quality of light, multiply the radiant flux (in watts) of each wave length by the correct factor (680 x luminosity factor) and add the products. The sum is the total luminous flux for that particular light source in terms of lumens.

The term "illumination" has already been mentioned. The illumination of a certain area is the amount of luminous flux falling on a unit area of that surface. The unit of illumination is the "lux" which is the illumination of one lumen per square meter. Illumination varies inversely with the square of the distance between the source of light and the surface. It also varies with the angle between the source and surface. The following two formulae can be used:

1. $\frac{I}{d^2}$ lumens per square foot.

2. $\frac{I}{d^2}$ COS Θ lumens per square foot.

I equals the appropriate intensity; d equals the distance; Θ equals the angle between the source and surface.

From the preceeding paragraphs, it may be seen that the "lumen" and the "lux" are based upon the luminosity factor. Therefore, when a lamp is described in lumens, the basis for the description is related to its effect on visual purple. This type of classification is fine for human beings. However, chlorophyll-containing plants have many light absorbing pigments, each with their spectral distribution curves that are unlike the visual purple curve.

Therefore, a much more complex picture is seen. T. W. Engelman, 1883 (35), determined that photosynthesis was effected most by blue and red light with very little stimulation in the green region, which happens to be the region most effected by visual purple, thus the luminosity factor.

Ideally, two main pieces of information should be known. First, a measure of the radiant flux (quality and intensity) should be known and plotted for a certain type of lamp. Secondly, the "action spectrum" (7) for the physiological response of the plant in question should also be known. This information is important for better understanding of light and plant growth.

In 1951, the Committee for Plant Irradiation in the Netherlands (35) proposed specific bands of wave lengths of light expressed in milliwatts per meter squared, or in any equivalent unit, to which specific plant responses could be assigned. These first proposals were later amended by the International Horticultural Congress at Scheveningen in 1955 (28). Table 2 illustrates the bands adopted at the Scheveningen Congress and their meanings. However, these bands also have use limitations. For example, Figure 3 shows the action spectrum for chlorophyll synthesis. Note that band number 5 does not distinguish between the line of (1) and (2) of a mercury lamp spectrum since they are in the same band. However, it may be seen that (2) is much more effective for chlorophyll synthesis.

Figure 3.--Action Spectrum for Chlorophyll Synthesis, with Superimposed Mercury Resonance Lines (slashes) (7).

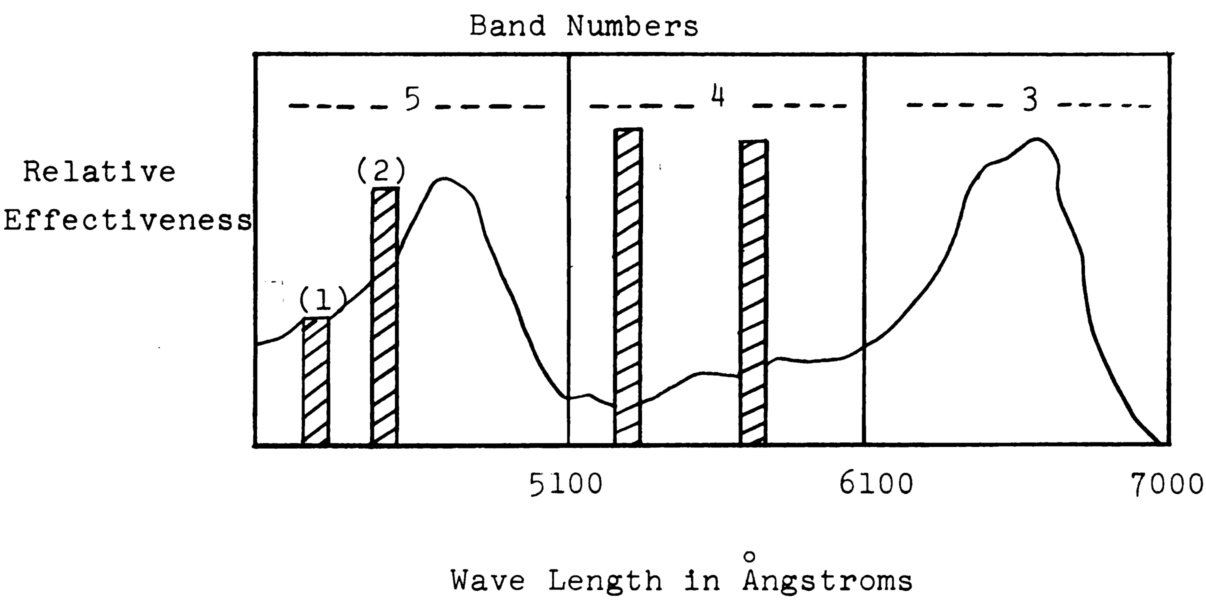


Table 2.--Wavebands of Light According to the Physiological Activity Associated with Each. (28)

Band 1.	Wave lengths longer than 10,000 Å (heating effect only).
Band 2.	10,000 - 7,000 Å (elongating effect).
Band 3.	7,000 - 6,100 Å (region of maximum photosynthetic effect, maximum chlorophyll synthesis and maximum effect of nightbreak light).
Band 4.	6,100 - 5,100 Å (minimal physiological effect).
Band 5.	5,100 - 4,000 Å (absorption by yellow pigments, secondary peak of chlorophyll absorption, possible peak of photosynthesis, strong formative effects).
Band 6.	4,000 - 3,150 Å (limited formative effect).
Band 7.	3,150 - 2,800 Å (detrimental to most plants).
Band 8.	Less than 2,800 Å (lethal to plant life).

Based on the characteristics of the light source, and the response of plants to these light energies, practical application could be provided in several ways. One suggested idea is to use an intensity of x mW/m^2 for a certain type of lamp (7). This formula could be predetermined by the manufacturer. Or one could use a reading of "x" on a certain type of photocell for a particular lamp. Finally, one could have a particular lamp "x" inches away from the surface of the subject to be lighted.

Light and Plant Growth

Winthrow (44) referred to five photochemical reactions occurring in plants: (1) photosynthesis; (2) chlorophyll synthesis; (3) phototropism; (4) photomorphogenic induction; (5) photomorphogenic reversal. It is not the purpose of this paper to expound on each of these and other photochemical reactions which may occur in plants. However, one must keep in mind all aspects of light and its relationships to plant growth before studying any one of them or groups of them.

Light may be produced by two sources, natural and artificial. Since in some respects, natural and artificial light create different within plant responses, an understanding of the characteristics of each type is necessary.

Natural Light

There are two different types of natural light; (1) sunlight, and (2) skylight, and each has a different wave length (quality) distribution.

Sunlight is the light received directly from the point in space where the sun is located. The sun occupies only a very small portion of the total sky, and its rays are highly directional, hence easily blocked by opaque objects, resulting in sharply defined shadows. The spectral distribution of the sunlight incident on the Earth's atmosphere is shown in Table 3. It may be seen that only 36% is within the visible range, while 52% is in the infra-red (heat) range.

Table 3.--Spectral Distribution of Sunlight Incident on the Earth's Atmosphere. (32)

Wave Length Region (Å ngstroms)	Percent of Incident Energy
Below 2000	0.1
2000 - 2500	0.8
2500 - 3000	2.2
3000 - 3500	3.5
3500 - 4000	5.4
4000 - 7000	36.0
7000 - 10,000	24.0
Above 10,000	28.0

Skylight is the light coming from the rest of the sky. Of course, the original souce of light is the sun, but skylight has a different spectral distribution in the range of 3000 Å to 7000 Å, the region with which we are mostly concerned. Skylight has a higher percentage of blue-violet light than direct sunlight. This is due to the different index of refraction of skylight with reference to sunlight. Shirley (34) has shown this has a profound influence upon the growth of species of plants under any type of shade. Shaded plants receive a higher percentage of blue-violet light and a lesser percentage of red light. This difference in light was found to cause significant differences in growth of certain species in the Rain Forests of Africa, as shown by Carter in 1933 (8).

Blue-violet differences between skylight and sunlight are not the only light quality differences associated with natural light. Upper leaves of a plant are thought to affect the quality of light reaching lower leaves of the same or other plants. If photosynthesis requires mainly the red and blue parts of the spectrum, then the upper-most leaves will filter out these wave lengths and change the quality of the light as it passes through them. The light filtering through their leaves will be of a different quality, and thus may effect the lower leaves. Shirley (34) and Coombe (12) think that this quality difference has no significance, while Seybold and Egle (33) (1937) think the opposite.

Although there are differences of opinion over light quality changes due to the shading effects of other leaves, there is no doubt that the light intensity is decreased by upper leaves on plants. Popp (31), Went (39), Mitchell (26) and others have shown that a plant can be shaded up to 50% of its maximum light tolerance and still maintain maximum growth. This information partly explains why so many species of plants can do well in so many diverse light intensity locations. However, when the value of this arbitrary figure of 50% light intensity is diminished, assuming no other biotic or abiotic limitations, Blackmann and Matthaei (3) and others have shown that the rate of photosynthesis is directly related to light intensity. The higher the light intensity under the 50% of maximum level, the more the photosynthesis, and vice versa. The phenomenon was also correlated with the amount of chlorophyll in the leaves. Chlorophyll content is inversely proportional to light intensity at the lower intensity levels (34). However, at very low light intensities, chlorophyll synthesis ceases.

There are many other factors, abiotic as well as biotic, that interrelate with light intensity to affect photochemical reactions and thus, plant growth. An interesting relationship was determined by Combes (11) in 1910 when he correlated light intensity optima with plant age. He found that the optimum light intensity for dry weight production increased as the plant got older. Thus, the older a plant (to a certain level), the more light intensity it needs for maximum dry weight production.

Shirley (34) correlated light intensity with root/ shoot ratio. The higher the light intensity, the more the root growth; the lower the intensity, the greater the shoot growth.

Artificial Light

Unlike temperature, humidity, barometric pressure, oxygen content and others that vary only in quantitative terms, light varies in qualitative and quantitative terms. It wasn't until the development of the electric light, especially the fluorescent lamp, that plant scientists were better able to control the quality and quantity of light in the plant environment. With artificial light they were better able to hold light intensities constant, so they could better measure the optimum light needed for certain plant responses. The development of fluorescent lamps which omit lower radiation in the infra-red region permitted better temperature control of the plant.

It is difficult to determine the optimum light intensity and optimum quality of light for a particular plant response. Two researchers working with the same lamps and crops may obtain different results. These differences in results may be explained in several ways. One researcher may have used a pyrometer for light measurements, while another may have used an illuminometer, with results that are difficult to compare. These instruments easily go out of adjustment, and maintaining standardization is often difficult. Other factors such as age and condition of plant material, environmental factors other than light, and abiotic systems, have often not been considered as variable factors.

There are two main types of electrical lamps, the incandescent bulb and the fluorescent lamp. Table 4 gives the energy spectrum in percentages, of a 40 watt fluorescent lamp, and a 500 watt incandescent bulb, as described by Withrow (43).

Table 4.--Energy Spectrum of the Two Major Types of Artificial Lamps as a Percentage of Total Spectrum.

Wave Lengths (Ångstroms)	Lamp Type* Fluorescent (%)	Incandescent (%)
Less than 4000	0.8	
4000 - 7000	20.5	12.0
7000 - 10,000	26.5	70.0
10,000 plus	53.0	18.0

*There are three main types of incandescent lamps and many fluorescent lamps; thus, the percentage are a rough average of groups of lamps.

Comparing the major differences, the fluorescent has less of its energy in the infra-red range of 7000 - 10,000 Å than the incandescent. This means less heating of the plant, and more heat loss due to convection and conduction (10,000 Å plus). The specific spectral distribution of each fluorescent lamp is different. These spectral distribution graphs can be obtained from the manufacturers (16, 17, 36). The main point concerning quality is that the incandescent is very high in the red-infra-red portion of the spectrum.

Many people have worked on the quality of artificial light as related to plant growth (15, 20, 23). This research has consistently shown that regardless of the type of fluorescent lamp used, the addition of incandescent at the rate of around 5% watts incandescent, increases growth significantly. The reason for this response is unknown. Dunn and Went (15) suggest that the incandescent light increases the efficiency with which all other light can be utilized. Others have observed that the incandescent light increases the internodal length and suggest that this allows higher light intensity to reach the lower leaves, increasing the photosynthesis rate per unit area.

The main conclusion that one can draw from the literature on artificial light quality is that a combination of 85% warm, white fluorescent light, plus 15% incandescent light appears to be the best for plant growth in general. As new lamps are produced by the lighting companies, other combinations having similar characteristics may be equally satisfactory.

The work in the field of aritificial light as a sole source of radiant energy, or as a supplement light source for vegetative growth, photoperiodic response, seed germination, and other responses, is still at a young stage. Mpelkes (27) states that there have been few studies on the effects of varying light intensities and qualities on the reproductive stages of mature plants. This is only one of many areas that need to be investigated.

Temperature and Plant Growth

Galileo Galilei conceived the idea of measuring temperature with the invention of the barothermoscope (thermometer) in 1592. From that time on, people have been studying the roles and effects of temperature as related to many different phenomenon. The relationship of temperature to plant growth is one of these studies.

The rates of most physiological processes of plants are greatly influenced by temperature. The majority of these physiological processes proceed in a limited temperature range from 0° to 50°C. Considering the entire range of temperatures, from absolute zero to the point at which atoms disintegrate (approximately 10,000°K.), this biologically significant range of 0° to 50°C. is relatively small.

Disregarding the small number of plants grown in artificial environments for their entire life span, all plant temperatures are dominated by the duirnal flow of light energy from the sun. This diurnal flow creates climates that normally have warmer day temperatures and cooler night temperatures throughout the entire world (41). Plant adaptation to this diurnal temperature variation is considered to be a prime explanation for the fact that most plants require a warmer day and cooler night temperatures for optimum growth (2, 39, 41). Saintpaulia spp. is the only plant known that requires the opposite temperature effect of cooler day and warmer night temperatures (41).

There is much support for the idea that plants have different temperature optima for light and dark periods of growth, a phenomenon that Went termed "thermoperiodicity" (41). One explanation for thermoperiodicity is that the solubility of oxygen and carbon dioxide increases as the temperature is lowered (24). This causes an increase in the availability of sugars and certain acids which are important raw materials of growth. Since growth takes place mainly in the dark period, the advantage of more sugars and acids due to lower temperatures in this dark period is notable. The sugar is not only made more available, but the translocation of sugar at lower temperatures is greatly enhanced (41). With higher night temperatures, the opposite effect of decreased translocation is noted, especially in mature plants where the distance from the "sinks" of food to the utilization points is often great. In younger plants, the translocation of sugar is accomplished more easily, even at higher temperatures. The reason for this is that with younger plants, the distance between sinks and utilization points is often shorter than in mature plants (6). This difference in optima temperatures between young and mature plants is in full accordance with the ecologists' statement that the temperature optima may shift as the plant develops from one stage to another (29).

There are, however, some exceptions to the generalization that plants normally require cooler night temperatures and warmer day temperatures for optimum growth. Parker and Borthwick (30), working with *Glycine Max*, found no advantage in having cooler night temperatures over continuously warm temperatures. Dale (13), working with *Phaseolus spp.*, had the greatest increase in dry weights under constantly warm temperatures. Whittle (42) also achieved similar results. The reasons for their different responses have been explained in many ways.

For example, Whittle (42) showed that there was a diurnal fluctuation in the rate of mass transfer of sugars even when the plants were held at constant temperature--more so than plants given a cooler dark temperature. Jensen and Taylor (22) showed that the higher the temperature, the less viscosity, the more the water movement. Dale (13) demonstrated that a high leaf area-plant ratio (in dry weight) was more important than having a cooler night temperature, so far as plant growth was concerned. He showed that the higher the night temperature, the higher the leaf area-plant ratio, and the more plant growth.

The difference between day and night temperatures can be too large for optimum growth (41). Such wide changes in temperature can result in a breakdown of certain metabolic activities within the plant (39).

The kind of plant being considered is a very important factor when measuring temperature-plant interactions. Went (41) found that with *Lycopersicom esculentum*, under the warmest night temperatures, only 20% of the food produced in the preceeding day is lost due to respiration. With some other species such as *Fragaria spp.*, almost all food produced in the day is respired under warm night conditions (19).

Another plant response to temperature is related to mitochondrial activity. Geronimo and Beevers (18) state that high night temperatures do *not* directly regulate respiration in *older* leaves. They showed that high night temperatures actually slowed down respiration in older leaves by influencing the metabolic activity of mitochondria. The high temperatures caused the mitochondria to become inactive, thus slowing down respiration. Lower temperatures actually prolonged the life of the mitochondria, thus increasing respiration.

What an organism becomes during its development, and how its development may respond to environmental stimuli, are determined in the last analysis, by its genetic material--the DNA in the nuclei of its cells. Brown (5) has shown that temperatures could possibly be a major factor in the control of RNA. Using epicotyl tissue of *Mimosa*, he showed that the quantities of sRNA per unit dry weight varied between samples, but were not correlated with growth rates. However, base components of sRNA were correlated with growth rates, especially guanine and uracil. Their growth rates were determined by temperature differences--the higher the temperature, the more the growth, the more base components. Two possible explanations result from his work:

1. Changes in temperature stimulated the synthesis of different enzymes.

2. Changes in temperature resulted in the synthesis of different proportions of the same inducing and inhibiting enzymes.

Light Intensity--Temperature Relationship

There is considerable evidence to show that individual features of a plant's vegetative growth, as well as the

proportional relationship between various organs, can be varied by changes in environmental conditions. Mitchell(26), Black (2), Gist (19), and others have shown that changes in leaf shape, leaf numbers, relative growth rate, leaf-stem ratio, and other physiological and morphological changes, can be induced by differences in light and temperature conditions.

The importance of light intensity and temperature to plant growth has been known for many years. In 1928, Davis and Hoagland (14) concluded that the temperature required for optimum dry weight production increased with increasing light intensities within certain low limits. Went (40) concluded in 1945 that Lycopersicon esculentum required cooler night temperatures as the light intensity decreased for maximum dry weight production. Miller (25) also found this true with Antirrhinum majus. Went (39) also stated that a low light intensity with a low temperature during the light cycle limits carbohydrate accumulation, and if this is followed by a warm dark cycle, the rate of respiration is high and the available food supply is rapidly exhausted.

The light and temperature requirements for optimum growth were found to vary with the stage of development of the plant. Brandes and Lauritsen (4), working with Saccharum officinarum under three temperatures and three light intensities in all combinations, found that early growth (first 5 - 6 weeks) was best promoted by high temperature at all light intensities. However, when the plants were more mature, only those at the higher light intensity treatments at all temperatures continued to show increased growth rates, and the lower intensity plants started to show decreased growth rates. Thus, temperature was the main growth-determining factor in the early stages, but light intensity was more important as the plant matured. Went (39), working with _Lycopersicon esculentum_, showed this same general relationship. He concluded that light intensity (to a minimum of 450 ft-c) had little effect on the growth rate of young tomato plants for a short period of time, even when comparing 450 ft-c to full sunlight. The growth rate in these young plants was influenced more by temperature than by light intensity. When the plants were more mature, the light intensity (as with the _Saccharum officinarum_) became the main influencing factor and not temperature.

Cline (10) in 1964, working with _Scrophularia marilandica_ L., concluded the following: the length of the vegetative phase was sharply decreased at higher light intensities. Temperature effects were more pronounced than were light effects on the production of dry weight. Stem elongation was completely inhibited at temperatures below 63°F. at night and 73°F. during the day. Consequently, the shoot developed a rosette form and flowering was inhibited. This rosette effect was _not_ induced by changes in light intensities. At higher temperatures, the number of flowers produced was directly correlated with increases in light intensities.

Beinhart (1), working with Trifolium repens, concluded that the day temperature greatly influenced the number of leaves produced. Total leaf production rose sharply as the day temperature increased from 10° to 17°C., but decreased as the temperature increased from 23° to 30°C. Leaf production was also stimulated by each increase in light intensity. The greatest difference was between 600 and 900 ft-c. At 600 ft-c, leaf production increased with each rise in night temperature; between 900 and 2000 ft-c, leaf production was maximal at 17°C. night temperature, and minimal at 30°C. night temperature. However, increasing light intensity from 600 to 900 ft-c offset the night 30°C. temperature effect. He also concluded that neither photosynthesis nor respiration was adversely affected by temperature within the 10° to 30°C. ranges. The poor growth of the Trifolium repens under low light intensity and high temperature, therefore, does not imply partial inhibition of either of these fundamental processes.

Many plants, even when exposed to different light intensity and temperature combinations, do not notably change morphologically or physiologically. Mitchell (26) and Black (2) stated a possible reason for this in that growth is predetermined to a large extent, and only very broad changes in light intensities and temperatures produce notable plant changes. Yet, Went (39) stated that very small changes in temperatures (5°F.) resulted in large changes in growth, flower and fruit production with Lycopersicon esculentum.

The light intensity-temperature interactions are so closely interrelated that one must be cautious in ascribing a specific plant response to either factor (39). The phenomena of growth, respiration, photosynthesis and other physiological processes not only vary with light and temperature, but also with species, variety, age, year, season and other environmental factors (10).

PRELIMINARY EXPERIMENT

The purpose of this preliminary experiment was to investigate a number of different combinations in order to more clearly define the areas for later investigation.

Materials and Methods

Five species of plants were selected for this experiment. Their technical and common names appear in Table 5.

Table 5.--Species of Plants Grown in Preliminary Experiment.

Technical Name	Common Name
Begonia semperflorens var. *"Scarletta"*	Wax Begonia
Coleus blumei var. *"Max Levering"*	Coleus
Pilea cadierei	Aluminum Plant
Philodendron oxycardium	Trailing Philodendron
Saintpaulia spp. var. *"Giant Blue Cress"*	African Violet

There were two main reasons why these five particular species were chosen; first, they are all common indoor plants, and second, they all respond quickly to environmental stresses.

Three light intensities with ranges of 180-220, 375-415 and 690-800 ft-c were used. These intensities are referred to as 200, 400 and 750 ft-c respectively in the experimental results. These three light intensities were chosen because of their practicability for the homeowner. All three light intensities can be easily obtained in the home with no special fixtures (e.g. cooling devices) other than the light fixture itself. The light intensity measurements were determined by a Weston illumination meter, model 756. This instrument indicates the illumination in candelas on the surface of the light target, or lumens per square foot evenly distributed. These light intensities were obtained by varying the distances between the light source and plants.

The quality of light used could be determined by the spectral distribution of equal proportions (40 watts per lamp) of cool-white and day-light fluorescent lamps. The lamps were mounted in portable, three-tray growth carts (37). No incandescent bulbs were used due to the high amount of infra-red heat given off. The photo-period was 16 consecutive hours per day.

The room in which the growth carts were placed had no source of light other than the light from the growth carts. The temperature in the room was maintained between 70° and 76°F., with a mean of 74°F. day and night. This temperature range approximates temperature conditions found in the average home.

The _Coleus blumei_ and _Begonia semperflorens_ were started from cuttings. The _Philodendron oxycardium_, _Pilea cadierei_ and _Saintpaulia spp_. were purchased in 2 1/4 inch pots. All of the plants were grown in the same oil medium of:

2 parts soil

2 parts peatmoss

2 parts turface

plus $CaCO_3$, 10-20-20 ratio fertilizer, and trace elements, all in appropriate amounts.

At two week intervals, all plants received additional nitrogen and potassium as 25-0-25 ratio soluble fertilizer. Watering was done when needed.

A total of 15 plants per treatment were used; and a total of 15 treatments analyzed as a randomized block design.

Weekly observations were taken of leaf numbers, plant height, and number of flowers produced where applicable. Fresh and dry weights, not including roots, were obtained at the termination of the experiment. The total length of the experiment was 85 days, from September 24th to December 17th, 1966.

Results

Saintpaulia spp., *Begonia semperflorens*, *Coleus blumei*, and *Philodendron oxycardium* responded rapidly in terms of growth, to the three light intensities. However, *Pilea cadierei*'s response to the different light intensities was much slower. Table 6 summarizes the increases in growth of the five species.

Table 6.--The Increase in Growth of the Five Species Grown Under Different Light Intensities.*

Light Intensities (ft-c)	Height (mm)	Leaf (no)	Flowers (no)	Fresh Wt. (g)	Dry Wt. (g)
		Philodendron oxycardium			
200	244 a	6.6 a		20.7 a	4.3 a
400	433 b	11.0 b		28.9 b	7.0 b
750	454 b	11.9 b		30.7 b	5.2 c
		Coleus blumei var. "Max Levering"			
200	44 a	24.9 a		6.8 a	1.6 a
400	81 b	33.2 b		15.2 b	1.8 b
750	99 c	39.1 c		26.0 c	1.9 b
		Begonia semperflorens var. "Scarletta"			
200	89 a	4.9 a	59.5 a	8.1 a	0.7 a
400	105 b	6.5 b	74.4 b	10.4 b	1.1 b
750	111 b	7.5 c	98.5 c	11.8 b	1.4 c
		Pilea cadierei			
200	38 a			6.3 a	1.2 a
400	47 a			8.5 b	1.5 b
750	40 a			12.5 c	2.1 c
		Saintpaulia spp. var. "Giant Blue Cress"			
200		8.7 a	2.0 a	32.8 a	4.4 a
400		5.9 b	2.3 a	30.4 a	2.9 b
750		8.3 a	5.4 b	30.5 a	3.1 b

*Means followed by unlike letters are significantly different at the 1% level.

Philodendron oxycardium

The 400 and 750 ft-c levels of light intensity promoted more growth than the 200 ft-c level. Comparing the 400 and 750 ft-c levels, increases in height, leaf number and final fresh weight were similar. The 400 ft-c level produced more dry weight than the 750 ft-c level.

Rating this plant strictly on its growth response to the three light intensities, the 400 ft-c could be the best light level of the three tested. However, as with all species used in this experiment, other growth responses should be considered. One of these growth responses was intensity of foliage color. By visual observation, certain light intensities produced colored foliage for certain species. Philodendron oxycardium developed the greenest color at 200 ft-c intensity.

Coleus blumei var. "Max Levering"

In all cases, except for the amount of dry weight produced, the 750 ft-c level produced more growth. Figure 4 shows the size relationship among the three light intensities.

One of the main reasons for selecting this particular variety of Coleus was because of its four colored leaf. It was thought that color differences could be better detected if a four colored leaf variety was used instead of a monochromatic one. This idea proved to be useful because at the 750 ft-c level, all four colors were present, while at the

Figure 4.--Size of Coleus blumei var. "Max Levering" Grown Under Three Light Intensities.

400 and 200 ft-c levels, only three and two colors developed respectively.

<u>Begonia semperflorens var. "Scarletta"</u>

As the light intensity increased, growth increased with respect to leaf number, flower number and dry weight. Height and fresh weight increases were different only between the lowest light intensity and the other two intensities. Necrotic upper leaves appeared on the plants nearest the lamps. It is not known whether these necrotic leaves were a results of light intensity, nutrient imbalance, or the higher temperatures since these plants were closer to the fluorescent lamps.

<u>Pilea cadierei</u>

There was no difference in the height of the plants at all levels of light intensities. The amounts of fresh and dry weight increased as the light intensity increased. The high light intensity plants produced chlorotic upper leaves. As with <u>Begonia semperflorens</u> var. "Scarletta," this effect could be caused by the temperature, light intensity, nutrient imbalance, or some other unknown factor.

<u>Saintpaulia spp. var. "Giant Blue Cress"</u>

The number of leaves produced was equal at the 200 and 750 ft-c levels, but the 400 ft-c level produced significantly fewer leaves. Leaf color was better at the 200 ft-c level. The 200 ft-c level also produced the highest amount of dry weight. The lowest light intensity produced more and greener foliage, but the highest intensity produced the most flowers.

Discussion

Theoretically, light intensity was the only variable factor within each species. However, the assumption that all other biotic and abiotic variables were fixed must be considered. It has already been noted that higher temperatures were associated with higher light intensities. This higher temperature amounted to 3 $\pm$ 1°F. Temperature must, therefore, be considered as a possible variable factor, confounding with light intensity, possibly effecting the physiological and morphological development of the plants. Other possible variables are fertility levels, within-species differences, and within-light intensity differences.

The higher temperatures associated with higher light intensities could be the reason why *Philodendron oxycardium*, *Pilea cadierei* and *Saintpaulia spp*. exhibited poor leaf color. Shirley (34) states that chlorophyll content is inversely proportional to light intensity at lower intensity levels. The fact that temperature was also higher at high light intensity could have increased the rate with which chlorophyll levels decreased.

The fertility level of the soil medium was found to be inconsistent. Five soil analyses indicated five different fertility levels. The fluctuations between the soil tests show the possibility of plant to plant differences as to fertility levels. For example a potassium reading of 84 ppm. in one week was followed by a reading of 5.3 ppm. seven days later.

Within-species differences were kept to a minimum by careful selection for uniform plant material at the beginning of the experiment. Statistical analyses performed at the start of the experiment to compart within-species differences showed no differences within all plants tested. Cline (10) reported that cuttings taken from a single mother plant exhibited marked morphological differences when given the same environmental conditions. Since morphological differences are evident, physiological differences are likely to be present. Even if a plant does not show visible growth differences, the chances of differences still remain (24).

The light intensity varied at each intensity level. For example, at the 750 ft-c level, readings were noted from 690 to 800 ft-c. It is difficult to arrange the apparatus so that all plants under one treatment receive equal intensities. Another problem is the shading effect of upper leaves which reduces light intensities for lower leaves (26, 21, 39). The The possibility of differences in light quality must also be considered. It is possible that with the Coleus plants at higher light intensities, the leaf color differences on the same plant could be due to quality and quantity differences in light.

Summary

It was the purpose of this preliminary experiment to investigate a number of different light intensity treatments in order to obtain leads for future work. Five species of plants grown under three light intensities were tested. The temperature was maintained at the approximate level found in the average home. Results showed that each species responded differently under the range of light intensities tested. It was noted that other variables besides light intensities had to be considered when interpreting the results.

GROWTH CHAMBER EXPERIMENTS

The results of the preliminary experiment not only indicated plant responses, but also demonstrated the need for more control over environmental conditions. It was thought that the use of growth chambers would eliminate many of these environmental variables.

Materials and Methods

Two experiments were run in growth chambers. The materials and methods for each experiment are different, and thus will be described separately.

The first experiment involved *Philodendron oxycardium.* This species was chosen because its growth can be measured efficiently, and theoretically, its light saturation point can be reached at low light intensity levels (45).

Two Sherer model #257-HL growth chambers were used. One chamber had the recommended temperatures for *Philodendron oxycardium* of 75°F. day and 65°F. night (45). The second chamber had constantly war temperatures of 75°F. to simulate temperature environments found in many homes. The relative humidity in both chambers was maintained at 30%.

Two light intensities with ranges of 380-415 and 730-770 ft-c were used in each chamber. These light intensities were obtained by varying the distance between the plants and lights. Two 40 watt cool-white lamps and two 25 watt incandescent lamps were used in each chamber. The intensities were measured by a Weston #756 illumination meter.

The P. oxycardium plants at the 400 ft-c range and cool night treatment were the control plants. From recommendations made to date, this combination of light intensity and temperature should result in maximum growth (9, 45).

A completely randomized design was used for this experiment. There was a total of five plants per four treatments for a total of twenty plants. Table 7 lists the treatments.

Table 7.--Treatment Combinations for the Philodendron oxycardium Growth Chamber Experiment.

Treatment	Temperature (F.°)		Light Intensity
	Day	Night	(ft-c)
A. (control)	75	65	400
B.	75	75	400
C.	75	65	750
D.	75	75	750

The photoperiod was an 18 hour day starting at 4 A. M.

All plants were randomly selected from an homogenous lot of 1000. They were grown in a medium of 100% vermiculite. One pint plastic coated freezer containers were used for the plant containers. No drainage was provided in these containers to prevent rapid drying of the medium. To reduce salt accumulation, a one-half Hoagland solution (21) with both nitrate and ammonia forms of nitrogen was used. The iron was supplied by a 10% metalic chelated $FeSO_4 \cdot 7H_2O$. Total nitrogen was 128 ppm. The pH of the solution was 5.8. All watering was done using this solution.

A second group of twenty P. oxycardium were randomly selected and height, number of leaves, fresh and dry weights were determined. Analysis of variance showed no significant differences among all plants. Although no direct comparison to the twenty experimental plants can be made, this information shows the homogeneity of the plant material. Number of leaves and height of the twenty experimental plants also showed no significant differences when measured at the start of the experiment.

The length of the P. oxycardium experiment was 38 days from February 14th to March 24th, 1967.

Results

The results of the P. oxycardium experiment are listed in Table 8.

Table 8.--Growth Results of Philodendron oxycardium Growth Chamber Experiment.*

Treatment	Temp. (F°) Day	Temp. (F°) Night	Light Intensity (ft-c)	Leaf (no)	Height (mm)	Fresh Wt. (g)	Dry Wt. (g)
A. (control)	75	65	400	13.8 b	512 d	20.3 a	2.1 a
B.	75	75	400	17.6 a	632 ac	25.1 a	2.7 a
C.	75	65	750	14.0 b	556 b	21.8 a	2.6 a
D.	75	75	750	16.4 ab	667 a	26.3 a	2.9 a

*Means followed by unlike letters are significantly different at the 1% level.

Leaf number and height increased with increasing temperature. However, the fresh and dry weights did not increase with increasing temperatures. Changes in light intensities only influenced the height of the plants at low night temperatures. The interaction between light intensity and temperature was not significant. There was no visible color difference among plants from all treatments.

The second growth chamber experiment involved two species of plants: Coleus blumei var. "Goldbond," and Impatiens sultanii variegata. The same two growth chambers were used, but the temperature ranges were changes. Table 9 lists the treatments for this experiment.

Table 9.--Treatment Combinations for the Coleus blumei var "Goldbond" and Impatiens sultanii variegata Experiment.

Treatment	Temperature (F°) Day	Night	Light Intensity (ft-c)
E.	76	63	400
F.	76	63	750
G.	76	76	400
H.	76	76	750

There were four plants of each species in each of the four treatments for a total of thirty-six plants. The design was completely randomized, and the light intensities and qualities were the same as the P. oxycardium growth chamber experiment.

Three inch plastic pots with drainage were used with a medium of 100% vermiculite. The 1/2 Hoagland solution (21) was applied every day.

Fifty cuttings were taken from two C. blumei var. "Goldbond" mother plants. They were rooted under mist in 100% vermiculite. At the onset of the experiment, all C. blumei plants were pinched to the second node from the bottom leaving four leaves and four axillary buds. This was done to assure more uniform plants and also to remove much of the growth that had developed under previous environmental conditions.

The I. sultanii variegata cuttings were taken from ten mother plants. They were rooted in sand under mist and were also pinched at the onset of the experiment. The experiment ran for 37 days, from March 30th to May 6th, 1967.

At the onset of the experiment, analysis of variance within both species of plants, for number of leaves and nodes, showed no difference. At the end of the experiment, due to a sudden increase in temperature in one of the growth chambers, only dry weight measurements could be made.

Results

The final dry weights for the two species are listed in Table 10.

The analysis of variance, including both species, showed the three factor interaction of species x temperature x light intensity being significant at the 5% level. The

Table 10.--Dry Weight Results of the Coleus blumei var. "Goldbond" and Impatiens sultanii variegata Growth Chamber Experiment.*

Treatment	Temperature (F°) Day	Night	Light Intensity (ft-c)	Dry Weight (g)
	Coleus blumei var. "Goldbond"			
E.	76	63	400	0.5 a
F.	76	63	750	0.6 a
G.	76	76	400	1.1 b
H.	76	76	750	1.4 c
	Impatiens sultanii variegata			
E.	76	63	400	0.7 a
F.	76	63	750	1.2 b
G.	76	76	400	1.5 c
H.	76	76	750	2.0 D

*Means followed by unlike letters are significantly different at the 1% level.

main effects of temperature, light intensity and species were all highly significant.

Coleus and Impatiens did not show the same responses to the environmental conditions. For the purpose of explanation, each species will be discussed separately.

Coleus blumei var. "Goldbond" showed no difference in dry weight at the low light intensity levels regardless of the temperature. Increasing the light intensity increased growth. At the higher light intensities, increasing temperature did increase growth. Therefore, light intensity effected dry weight production only at the high temperature level. Figure 5 graphically represents these results.

Impatiens sultanii variegata showed an increase in dry weight production over all four treatment combinations. The lowest growth was at 76-63°F day-night temperature and 400 ft-c; while the highest was at 76-76°F day-night temperature and 750 ft-c. The color of the foliage and numbers of flowers produced was the same for all treatments. Therefore, higher light intensities and higher temperatures both increased dry weight production. Figure 5 graphically represents these results.

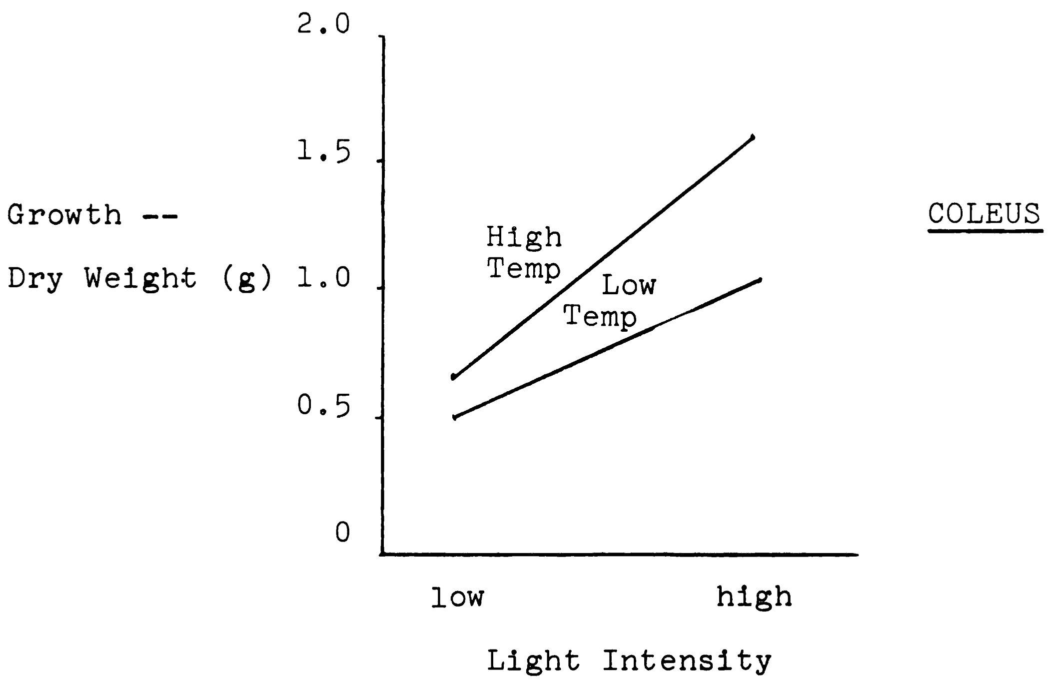
Figure 6 pictorially shows the results of both species.

Discussion

Results of the growth chamber experiments will be discussed in general terms, except for those cases where different species responded differently, and these will be discussed separately.

Before discussing the growth responses, the term "growth" has to be defined in terms of this experiment. Growth in terms of *Philodendron oxycardium* will refer to leaf number and plant height and not to dry and fresh weights, since dry and fresh differences were not different. With the *Coleus blumei* var. "Goldbond" and *Impatiens sultanii variegata*, growth will refer to dry weights only since no other measurements were possible due to the defective operation of the growth chambers.

Figure 5.--Relation of Light Intensity and Temperature to Dry Weight Production.



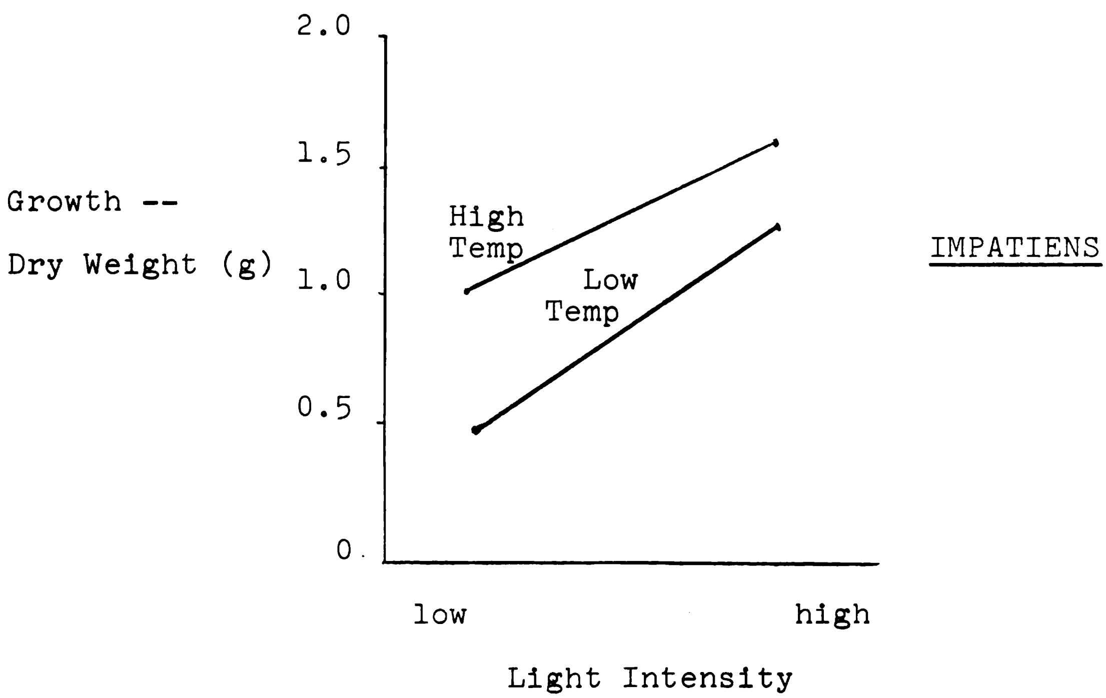
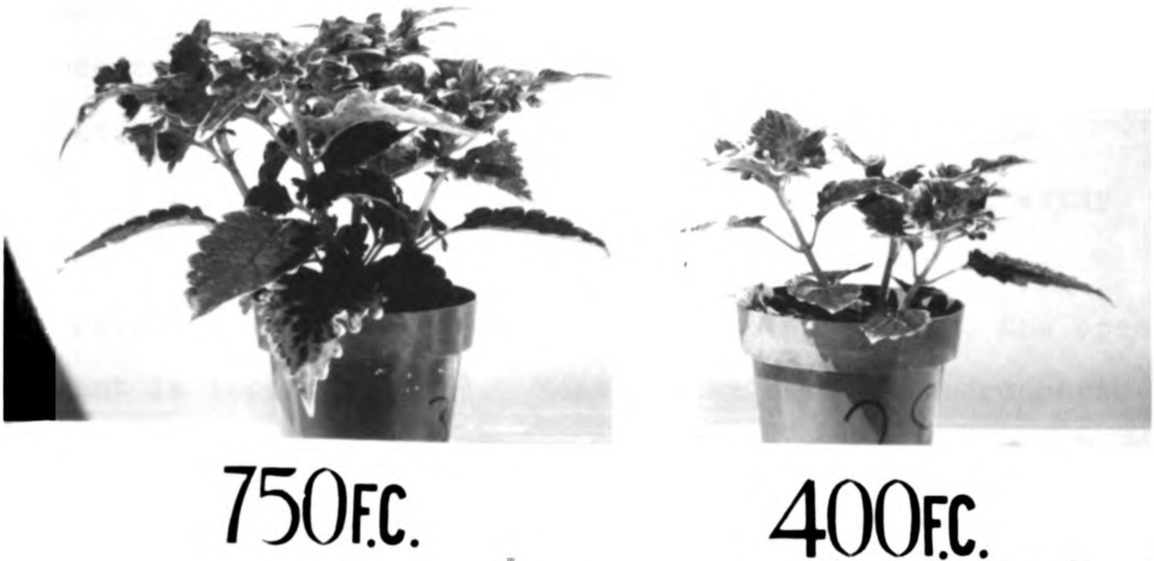
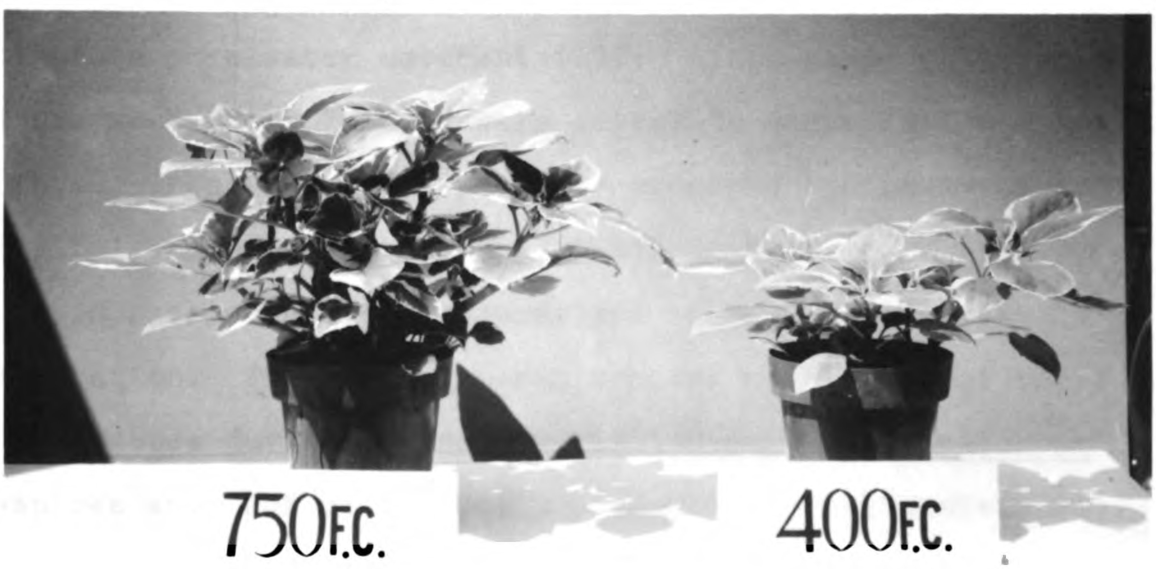


Figure 6.--Size of Coleus blumei var. "Goldbond" and Impatiens sultanii variegata Grown Under Two Light Intensities.





The most significant observation is that cooler night temperatures did not increase growth. Therefore, in the range tested, these results do not agree with the general term of "thermoperiodicity" (41). This observation can be explained in many ways. First, the age of the plants is an important factor to consider as a possible temperature regulator (4). All of the plants used were young. The younger the plant, the more temperature is related directly to growth (39). Thus, the higher the day and night temperatures tested, the more the growth. Secondly, the species of plant is important (41). Most of the work on thermoperiodicity has been done with Lycopersicon esculentum which proved to be very temperature sensitive. The three species in this experiment may not be so sensitive to temperature.

The translocation of inorganic and organic material is important for growth. The higher night temperatures can stimulate more water movement (29). Also, since only young plants were used, "sinks" were closer to assimilation points. These two facts probably enhanced the assimilation of vital compounds within the plants tested.

Higher night temperatures are thought to increase respiration. Fragaria spp. can respire nearly all of the food its produces during the day, while Lycoperscion esculentum respires only 20% of its daily production of synthates (41). However, mitochondrial activity can be decreased with higher night temperatures (18). Although respiration was not measured, in the light of previous work, one can hypothesize as to the respiration rates of the experimental plants. One hypothesis is that the plants did respire more at night, but there was a net increase in assimilation greater than the amount lost through respiration.

Coleus spp. and Impatiens spp. are generally high light requiring plants, while P. oxycardium is a low light requiring plant. P. oxycardium had a positive growth response to a light intensity higher than that which is generally recommended for growth (45). However, this higher light intensity was accompanied by higher temperatures, thus demonstrating that the light intensities required for growth can vary with temperatures (14, 29). The high light intensity level of 750 ft-c can be assumed to be less than 50% of maximum level for Coleus spp. and Impatiens spp. Therefore, growth can be directly related to light intensities (3), and increasing the light intensity increases the temperature optima under these relatively low intensity levels.

In general terms, the results of the growth chamber experiments support similar studies by Dale (13), Whittle (42), Parker and Borthwick (30) who state that there is no advantage in having cooler night temperatures over continuously warm temperatures with young plants.

The relatively short duration of the growth chamber experiments could be a possible source of error. Had the plants been able to mature, different growth responses could have resulted. This factor of age has already been mentioned.

Mitchell (26) and Black (2) stated that much growth is predetermined, and only two factors can overcome this predetermined growth: (1) very broad environmental stresses and (2) long term experiments.

How much growth may be predetermined, the environmental conditions, the species of plants, the age of the species, and many other factors must be kept in mind when formulating conclusions from any experiment.

GENERAL SUMMARY

Two main groups of experiments were run to determine the effect of different light intensities and temperatures on plant growth.

In the preliminary experiment, five species of common indoor plants were grown under three different light intensities with ranges of 180-220, 375-415 and 690-880 ft-c. All plant species responded differently. It was though that other factors, e.g. temperature, confounded the results. The information gained in this experiment was used in performing a second set of experiments in growth chambers.

The growth chambers, one at optimum temperature range for the plants in question, and the other at average home temperatures, were used. Each chamber provided for two light intensities. Three indoor plant species were grown under these conditions in two separate experiments.

The results of all the experiments demonstrated that different plants need different light intensities and temperature combinations, depending on many variable factors e.g. age of plant, temperature, light intensities. In the preliminary experiment, better growth was noted under the following light intensities: Philodendron oxycardium under 400 ft-c; Coleus blumei var. "Max Levering," Pilea cadierei, Begonia semperflorens var. "Scarletta" all under 750 ft-c;

Saintpaulia spp. produced more flowers under 750 ft-c, but more foliage under 200 ft-c. Coleus blumei var. "Max Levering" had better foliage color under 750 ft-c, while all other species produced better foliage under the 200 ft-c level. In the growth chamber experiments, Coleus blumei var. "Goldbond" and Impatiens sultanii variegata grew better under high light intensity at high night temperatures. Philodendron oxycardium produced more leaves at high light intensity and cool night temperatures, while producing greater length at high light intensity and high night temperatures.

LIST OF REFERENCES

1. Beinhart, G. "Effects of temperature and light intensity on CO_2 uptake, respiration, and growth of white clover," Plant Physiol. 37:709-721, 1962.

2. Black, J. N. "The interaction of light intensity and temperature in determining the growth rate of Subterranean Clover (*Trifolium subterraneum* L.)," Australian Journal of Biol. Sci. 8:330-343, 1965.

3. Blackmann, F. F., and Matthaei, G. L. C. "On vegetative assimilation and respiration," Proc. of the Roy. Soc. of London B76:403-460, 1905.

4. Brandes, E. W., and Lauritsen, J. I. "A required photochemical balance for survival and growth of sugar can," Sugar Bull. 18:3-5, 1940.

5. Brown, G. N. "Temperature controlled growth rates and RNA characteristics in *Mimosa* epicotyl tissue," Plant Physiol. 40:557-561, 1965.

6. Burt, R. C. "Some effects of temperature in CHO utilization and plant growth," Aust. J. of Bio. Sci. 19:711-714, 1966.

7. Canham, A. E. Artificial Light in Horticulture, Eindhoven, Centrex Publishing Company, 1966.

8. Carter, G. S. "Illumination in the rain forest at ground level," J. Linn. Soc. (Zool.) 38:579-589, 1933.

9. Cathey, H. M. Indoor Garden, U. S. Dept. of Ag., Washington, D. C., June, 1965.

10. Cline, M. G. "Effects of temperature and light intensity on the growth of *Scrophularia marilandica*," Ph.D. Thesis, University of Michigan, 1964.

11. Combers, R. "Determination of optimum light intensities," Ann. Sci. Nat. Bot. 2:75, 1910.

12. Coombe, D. E. "The composition of shade light in woodlands," J. Ecol. 45:823-829, 1957.

13. Dale, J. E. "Some effects of alternating temperatures on the growth of French bean plants," Ann of Bot. N.S. 28: 127-135, 1965.

14. Davis, A. R., and Hoagland, D. R. "Further experiments on the growth of plants in a controlled environment," Abstracts in Amer. J. of Bot. 15:624 +, 1928.

15. Dunn, S., and Went, F. W. "Influence of fluorescent light quality on growth and photosynthesis of tomatoes," Lloydia 22:(4)302-324.

16. Durotest Corporation, North Bergen, New Jersey.

17. General Electric, General Offices, Nela Park, Cleveland, Ohio.

18. Geronimo, J., and Beevers, H. "Effects of aging and temperature on respiratory metabolism of green leaves," Plant Physiol. 39:786-793, 1964.

19. Gist, G. R., and Mott, G. O. "Some effects of light intensity, temperature and soil moisture on the growth of alfalfa, red clover and birdsfoot trefoil seedlings," Purdue U. Agr. Exp. Sta. Bull. #1008, 1956.

20. Helson, U. A. "Comparison of gro-lux and cool-white fluorescent lamps with and without incandescent as light sources used in plant growth rooms for growth and development of tomato plants," Can. J. Plant Sci. 45:461-466, 1965.

21. Hoagland, D. R., and Arnon, D. I. "The water-culture method for growing plants without soil," Calif. Agr. Exp. Sta. #347, 1950.

22. Jensen, R. D., and Taylor, S. A. "Effects of temperature on water transport through plants," Plant Physiol. 36:639-642, 1961.

23. Kwack, B. H., and Dunn, S. "Effects of light quality on plant maturity II. Light intensity and quality," Advanc. Frontiers of Plant Sci. 14:143-160, 1966.

24. Leopold, A. C. Plant Growth and Development, New York, McGraw-Hill Book Company, 1964.

25. Miller, R. O. "Growth and flowering of snapdragons as affected by night temperature adjusted to light intensity," Amer. Soc. Hort. Sci. 75:761-768, 1960.

26. Mitchell, K. J. "Influence of light and temperature on the growth of ryegrass (Lolium spp.)," Physiologia Plantarum 6:21-45, 1953.

27. Mpelkas, C. C. "Radiant energy sources for plant growth," Sylvania, Salem, Mass.

28. Nieuwstraten, J. P. (ed.). Rep. 14th International Horticultural Congress, 1955, Scheveningen 22(4):246, 1957.

29. Odum, E. P. Fundamentals of Ecology, London, W. B. Saunders Co., 1959.

30. Parker, M. W., and Borthwick, H. A. "Effects of variation in temperature during photoperiodic induction upon initiation of flower primordia in Biloxi soybean," Bot. Gaz. 101:145-167, 1940.

31. Popp, H. W. "Effects of light intensity on growth of soybean and its relation to the autocatylst of growth," Bot. Gaz. 82:306-319, 1926.

32. Sieger, H. H., and McElroy, W. D. Light: physical and biological action, New York, Academic Press, 1965.

33. Seybold, A., and Engle, K. "Lichfield und Blattfar bstoffe, I.," Planta 26:491-515, 1937.

34. Shirley, H. L. "The influence of light intensity and light quality upon the growth of plants," Amer. J. Bot. 16:354-389, 1929.

35. "Specification of radiant flux and radiant flux density in irradiation of plants with artificial light," Electrotechnick 29:467-470, 1951.

36. Sylvania Corporation of General Telephone and Electronics, Salem, Mass.

37. Tube Craft, Inc., 1311 West 80th Street, Cleveland, Ohio. 44102.

38. Van Der Veen, R., and Meijer, G. Light and Plant Growth, New York, MacMillan Company, 1959.

39. Went, F. W. "Plant growth under controlled conditions II, Thermoperiodicity in growth and fruiting of the tomato," Amer. J. of Bot. 31:135-150, 1944.

40. ________. "Plant growth under controlled conditions V., The relation between age, light, variety, and thermoperiodicity of tomatoes," Amer. J. Bot. 32:469-479, 1945.

41. ________. Experimental Control of Plant Growth, Waltham, Mass., Chronica Botanica Co., 1957.

42. Whittle, C. M. "Translocation and temperature," Ann. of Bot. 28:339-343, 1964.

43. Winthrow, A. P., and Winthrow, R. B. "Plant growth with artificial sources of radiant energy," Plant Physiol. 22:494-513, 1947.

44. Wintrhow, R. B. "A kinetic analysis of photoperiodism," pp. 439-471. In R. B. Winthrow, (ed.) "Photoperiodism phenomena in plants and animals," Publ. 55, Amer. Assoc. Adv. Sci., Washington, D. C., 1959.

45. Works, D. W., and Guthrie, J. W. "Use of electric lighting for growing flowers," Farm Electrification 62, U. of Idaho, 1965.