THE USE OF LIGHT TO CONTROL PLANT GROWTH, HEIGHT AND BRANCHING

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I. Introduction: Photosynthesis and Plant Growth

The growth of a plant is mainly controlled by two fundamental metabolic processes: photosynthesis and respiration (Treshow 1970). Photosynthesis is the conversion of radiant energy to chemical energy which can then be stored as carbohydrates throughout the plant cells. The utilization of this energy resource occurs through respiration which converts stored carbohydrates into the various proteins, fats and organic compounds necessary for plant processes.

Photosynthesis and respiration are carried out by an extremely complex system of specialized structures and multiple individual chemical reactions. Each of these reactions controls a step of total plant metabolism, and as such regulates total plant growth. The activity or rate of such chemical reactions will then determine the rate of growth. When conditions are optimal for the greatest number of reactions, maximum growth will result (Treshow 1970). There are several contributing factors including temperature, soil moisture, and nutrient levels, but the most important role is played by light, the key ingredient of the essential process of photosynthesis.

Through photosynthesis, the energy of light (radiant energy) is transferred to the plant's cellular compounds. Photosynthesis is initiated when chlorophyll, the green pigment contained in the chloroplasts of every leaf, receives sufficient radiant energy to activate the first photosynthetic reactions. The necessary amount of light varies in reports from 3-12 light quanta. Overall, the photosynthetic reaction (respiration is the reverse) can be written as follows:

$$CO_2 + H_2O + \text{light energy} \dashrightarrow CH_2O + O_2$$

The reaction involves the reduction of carbon to form photosynthates from which the plant can synthesize further organic substances (Veen 1959). 75% of this total photosynthate is incorporated in polysaccharides, which serve mainly as structural components for cell walls. Respiration consumes another 15-20% and the remainder is utilized as a substrate for carbohydrate, fat and protein metabolism (Treshow 1970). Plant growth, therefore depends on photosynthesis to increase the amount of photosynthates. This increase is observed on the macro level as an increase in dry weight which can be used as a measure for the increase in growth (Nelson 1991).

II. Light: Definitions and Categories

Light, then, can be viewed as the fundamental source of energy for plant growth. The electromagnetic spectrum of radiant energy can be divided into three subsets based on wavelength which define light quality:

QUALITY	WAVELENGTH (nm)
ultraviolet	100-380
visible	380-780
infrared	780-2500

Ultraviolet (UV) light is harmful in large quantities, infrared (IR) and far red (700-780 nm) are not utilized in photosynthesis, but do have an effect on stem elongation, as we will see later (Nelson 1991). "Light" is usually defined as the specific portion of the electromagnetic spectrum between 380-700 nm to which the human eye responds; or visible light. This "white light" is categorized into color based on wavelength as follows:

COLOR	WAVELENGTH (nm)
violet	400
blue	460
green	510
yellow	570
orange	610
red	650

III. Effects of Light Color on Plant Process

Plant photosynthetic response is highest for blue and red wavelengths. The effect of light color on stem elongation is somewhat more complicated. It has long been recognized that the elongation that occurs when plants are held in darkness under adequate nutritional conditions in inhibited by light. Studies show that in general, blue light will produce shorter plants than red, which tends to cause elongation (Veen 1959). For tomato seedlings irradiated with different parts of the spectrum, those grown under blue light were shorter than the average height and those grown under red light displayed taller than average height. The addition of a small amount of infrared radiation to blue light caused the greatest elongation but the addition of IR to red light had no effect. In the same study, tests were done involving a succession of color treatments. Results showed that exposure to red light predisposes the plant to elongate when subsequently exposed to IR radiation. However if IR radiation follows exposure to blue light there is no effect and plants remain short. This indicates that small amounts of blue light received previous to IR radiation will render plants insensitive to its elongating properties while simultaneous exposure to blue and IR radiations will continue to stimulate stem elongation (Veen 1959).

IV. Controlling the Color of Light

Different light colors can be provided through use and manipulation of artificial light sources. The results discussed above indicate the benefits of providing a blue light source. Recommendations for doing so and a comparison of available light sources will be given later. Red and IR radiation should be avoided due to their elongating properties.

V. Effects of Light Intensity on Plant Processes

Light quality, intensity and duration all play vital roles in normal plant development. However, it is the intensity of light that is most critical in the photosynthetic process, and thereby it is important in determining plant growth. For each crop, there is a species-determined optimal light level. When light intensities are extremely high, rapid transpiration will occur, chlorophyll molecules will break down and stem elongation will become slowed, inhibiting further growth. As light intensity falls too low, photosynthesis, stem elongation and growth will diminish rapidly until all processes cease. Thus extremes in either direction will inhibit stem elongation, but at the cost of healthy growth.

It is important then to keep the intensity at a level that will maintain photosynthesis at a rate faster than that of respiration. At the point where photosynthesis equals respiration, CO_2 is neither absorbed nor evolved and the amount of photosynthate produced is inadequate for plant survival. This is called the compensation point and it varies among species, particularly between shade and sun plants (Treshow 1970).

In general, maintaining photosynthesis at adequate levels demands a high light intensity (Veen 1959). Stem length and size are also influenced by the total amount of light. In studies with *Pelargonium x hortorum*, a close correlation was observed between the dry weight of the plant and absorbed quanta of light. Dry weight in turn correlates directly with number of leaves and shoots per plant. In fact, net photosynthesis and the number of shoots per plant increased with increasing quantum flux density, evidencing the intrinsic relationship between photosynthesis, growth and light intensity (Welander and Hellgren 1988). Hence it can be seen that maintenance of a high light intensity will encourage increased growth, increased elongation and increased branching.

The interaction between light intensity and light color therefore becomes important. At a certain Critical Intensity (CI), the effects of red light and blue light become equal and radiation will cause the same amount of elongation. At low intensities blue light is always less active than red causing an increase in elongation which is known as stretching (Veen 1959). It is necessary therefore to maintain high light intensities in order to encourage blue light activity and prevent excessive stem elongation, but not exceedingly high such that the effect of intensity counteracts that of color and increases elongation.

VI. Determining Optimal Light Intensity

Thus in determining how to use light to affect plant height, it becomes important to accurately determine the optimum level of light intensity for photosynthesis and blue light activity. The rate of photosynthesis vs. light intensity is illustrated by the saturation curve. At low light intensities, the rate of photosynthesis is directly proportional to the intensity. As intensities increase, however, the curve will bend and level off. This is the level of saturation, and is dependent on temperature. At light saturation, no additional carbon can be fixed and photosynthesis will occur as rapidly as the most limiting factor. It becomes difficult to accurately determine the optimal intensity level for a plant because light saturation for one leaf will be quite different than that for the entire plant due to self shading among leaves (Veen 1959). For example, a single leaf may reach saturation at 1000-2000 foot candles (fc), whereas the whole plant might not reach saturation at levels greater than 10,000 fc. If every leaf were held at such high intensities, growth would surely cease completely. Since it is not possible to obtain such levels of saturation for every leaf, optimal intensities are assumed to be measured by whole plant saturation. At such levels, both photosynthesis and blue light activity will be maximized.

VII. Irradiance Levels in the Greenhouse

Throughout the year, natural irradiance levels vary. A greenhouse that has 12,000 fc total irradiance on a sunny summer day may have only 1000 fc or less on a cloudy day in winter. Neither situation is ideal for most plant growth, and steps can be taken to alter the light intensity to an appropriate level.

VIII. Controlling Irradiance Level in the Summer

Reduction of summer intensities has long been accomplished through the practice of shading. Light levels as well as temperature levels can be effectively reduce using either whitewash on the outer surface of the greenhouse, or hanging an interior shade cloth. This is necessary to ensure that healthy growth will continue. Reduction of excessive light levels, combined with an adequate cooling system and good cultural practices will permit optimum photosynthesis during the summer months. When the grower is sure that he/she is obtaining healthy accumulation of dry weight, attention can be turned to the control of height and branching.

IX. Controlling Irradiance Level in the Winter

The situation during the winter months requires a good deal of planning. During the months of November, December and January, light intensities are often insufficient to obtain adequate growth of many plants (Veen 1959). Artificial lighting systems can be used to augment the amount of light in the greenhouse to levels more optimal for height gain and branching. When the goal is to increase photosynthetic activity, supplemental lights should be of relatively high intensity and contain an adequate level of red wavelengths. Usually an installed power of 50-100 Watts/meter^2 (W/m^2) is recommended for an exposure of 8-12 hours per day. This intensity will work sufficiently with the existing sunlight to create an environment suited to proper growth rates and earlier flowering (Carpenter 1976). Eight hours of night lighting is more effective than an equal duration of day lighting, but 16 hour continuous lighting from morning to midnight results in even greater growth increases although it is not usually justifiable economically and may promote too much growth resulting in excessively tall plants (Cathey and Campbell 1979).

X. Comparison of Light Sources

There are several available artificial light sources, each with its own advantages and disadvantages. The following is a comparison of the three most commonly employed in greenhouses.

Incandescent lamps provide a convenient and inexpensive light source. They are a better choice for photoperiod control than growth supplementation however. Their primary wavelengths of red and far red encourage unwanted stem elongation and stretching that create a plant with leggy characteristics. Side shoot development is additionally suppressed as the plant will expand in height only (Cathey and Campbell 1980). Incandescent lamps also give off excessive heat as a result of their poor efficiency. Only 7% of the electrical energy consumed in their operation is converted to light energy, the remainder is dissipated as heat (Nelson 1991).

Fluorescent lamps are available in several spectral range distributions, but cool white and warm white are traditionally used. There is no conclusive evidence that any increase in growth results from different color sources, rather it is concluded that the cause is total lamp output (Cathey and Campbell 1980). Cool white is most commonly used. It emits predominantly the desired blue wavelengths, and though it is often effective alone, it is usually supplemented with a red source such as incandescent. This adds to the cost and may promote elongation. Fluorescent bulbs are not usually recommended for use to increase irradiance level due to the large size of the fixtures which block out the sun and the need for close proximity between the lamp and the plants, which is not feasible in all greenhouses. However, they are the best source of blue light, suggesting that it may be worthwhile to initiate their use in the greenhouse, especially when excessive elongation is a problem.

High intensity discharge lamps (HID) are available enriched with various metals, but high pressure sodium is most frequently used. HID are the typical choice for use as supplemental light sources for several reasons. First, they are less expensive to purchase and operate. The light emission spectrum peaks in the yellow wavelengths, but extends beyond the visible range into the 700-850 nm range. This range contains wavelengths that are beneficial for stem elongation, and hence may increase height (Nelson 1991). Problems are not generally reported, however. In fact, most studies report that stem elongation occurs very slowly, allowing the development of extra thick stems and multiple side shoots.

XI. Summary

Most growers in Pennsylvania grow potted plants. Their primary goal, therefore, is to produce a compact, well-branched plant with maximum dry weight.

Photosynthesis is the most basic and essential process affecting plant growth and accumulation of dry weight. Light, as the most vital ingredient of the photosynthetic reaction, is necessary for healthy plant growth. Once it is assured that plants are obtaining optimal growth, manipulation of height and branching can be considered. The characteristic of light with the greatest effect on photosynthesis in intensity. During the summer months optimal light intensity can be achieved by whitewash or shade cloth which reduce light levels with equal efficiency. In the winter it is recommended that high pressure HID lamps be used at a power of 50-100 W/m^2 for 8-12 hours a day to most effectively supplement low natural light levels and attain maximum plant growth.

To affect stem elongation, however, light color is most important. Blue light is most effective for the control and reduction of stem elongation. Since higher light intensities stimulate blue light activity at the cost of red light activity, the maintenance of optimal light intensities as prescribed above may be all that is necessary to keep elongation in check. If however these practices do not prove sufficient, a blue light source should be incorporated into the lighting scheme. Fluorescent lights provide the best blue source. Since no increase in light intensity is necessary during the summer, blue fluorescent lights could be employed for only a short period of time to keep plants compact as well as stimulate branching and side shoot development. The shading caused by the fixture size will not be a substantial problem since intensities need to be decreased anyway. In the winter, a combination of blue fluorescent and high pressure sodium HID lamps could be used if the HID lighting was not adequately controlling elongation. Problems may result due to shading from the fixture. No reports on the effects of such lighting schemes were found in the literature, but they may be worth trying.

XII. Literature Cited

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