SUPPLEMENTAL LIGHTING

Debra Schwarze
University of Minnesota

Light can be the most limiting environmental factor in high quality plant production.

Light can be the most limiting environmental factor in high quality plant production. Light controls a number of different plant responses, but, for practical purposes, the most important effects are on plant shape and the nature of plant growth (i.e. vegetative or reproductive) (Canham, 1966). Manipulating light can involve increasing, or decreasing, the amount of light that a plant receives (irradiance), increasing or decreasing the duration of lighting (photoperiod) or changing the quality of light that is available to plant (color).

In many cases growers are lighting to increase the total amount of light available to plants. Total daily irradiance can be increased by day extension lighting via supplemental lighting. Total daily lighting is intended to increase the total amount of photosynthesis which a plant can carry out during a day. In seed geraniums (*Pelargonium* x *hortorum* L.H. Bailey), flower initiation occurs earlier as the amount of light which seedlings receive each day increases. Plants receiving 1900 fc of light bloomed a full 25 days earlier than plants receiving 300 fc of light and one week earlier than plants receiving 500 fc of light (Armitage et al., 1984). Seed geraniums receiving higher light intensity also produce a more compact plant. Plants grown under 1900 fc had internode lengths of 1.75 cm while plants grown under 300 fc had internode lengths of 3.75 cm (Hopper, 1986). Since plants grown under similar temperature conditions will have the same number of internodes, the total plant height difference is quite evident.

Photosynthesis is the process by which plants use light energy to convert carbon dioxide and water into carbohydrates or sugars.

Photosynthesis is the process by which plants use light energy to convert carbon dioxide and water into carbohydrates or sugars (Canham, 1966).

$$CO_2 + H_2O \rightarrow CH_2O + O_2$$

Sugars are used as energy to increase plant size and mass. By increasing the irradiance or the length of time a plant is lit, total daily photosynthesis increases and, therefore, the plant size or mass may increase. In general, with seed geranium, increased irradiance levels will increase plant dry weight (an indicator or plant size) (Pytlinski and Krug, 1988). In the case of snapdragons (*Antirrhinum majus* L.), Peterson (1955) showed that dry weight of the plants was markedly increased if the young plants were lit all night using fluorescent lamps with about 10 lamp watts per square foot and the lamps placed 8 to 10 inches above the plants.

Plant photosynthesis has a saturation point, beyond which additional light does not increase the rate of photosynthesis (Aldrich and Bartok, 1989). This level can vary from a few hundred foot candles (about 60 μmol m^{-2}s^{-1}) for some foliage plants to several thousand foot candles (about 800 μmol m^{-2}s^{-1}) for some ornamental and vegetable crops (Aldrich and Bartok, 1989). Plants respond differently to different wavelengths of light. Maximum plant sensitivity for photosynthesis occurs at 675 μmol m^{-2}s^{-1} (Whealy, 1991).

The intensity of light where P_R is saturated can also vary depending on plant age and other environmental conditions such as, plant temperature or watering regime. As a rule, plant growth will increase if supplemented lighting is delivered at a lower irradiance for a longer period of time rather than at a high irradiance for a short period of time (Whealy, 1989).

Photoperiod can affect plant growth, especially the type of growth (i.e. vegetative vs. reproductive).

Photoperiod can affect plant growth, especially the type of growth (i.e. vegetative vs. reproductive) (Canham, 1966). Some plants require a specific photoperiod to initiate flowering or tuber or bulb formation. For example, pot mums (*Dendranthemum grandiflora* Tzlev.) require a critical night length of 9.5 hours to initiate flowering and a critical night length of 10.5 for flowers to develop (Schwabe, 1952; Cathey and Borthwick, 1970; Langton, 1977). The critical photoperiod for poinsettias (*Euphorbia pulcherrima* Willd. ex. Klotzch.) to initiate flowers is 12.5 hours (Grueber, 1985). Tuberous begonias (*Begonia* x *tuberhybrida* Voss) require less than 10 hour nights as soon as they germinate or plants will form tubers instead of flowering (Canham, 1966; Kaczperski et al., 1989). Carnations (*Dianthus caryophyllus* L.) are considered a quantitative long-day plant, where long days promote and short days delay flower initiation (Blake, 1957). Once the carnation flowers are initiated, photoperiod does not affect flower development.

Plants are generally categorized in one of three photoperiodic groups, short day, long day or day neutral (Canham, 1966). This is generally a term used in regard to the flowering response of a plant to day length (Canham, 1966) (Table 1). Short day plants require a night length over a critical time for the plant to respond, i.e. chrysanthemum or poinsettia. Long day plants require a night period shorter than a critical length, i.e. fuchsia. Day neutral plants can flower regardless of day or nigh length, i.e. cyclamen or tomato (Canham, 1966).

Night interruption lighting is commercially practiced on mums and poinsettias to keep plants vegetative. Traditionally, lights are turned on for five hours each night in the winter months in the northern latitudes when day length is less than 10-12 hours (Kofranek, 1992). This allows the plant to 'perceive' long days and prevent flower initiation from occurring. Some plants will respond to flowering with the use of cyclical lighting (Cathey and Borthwick, 1961). In many cases this can be an energy saving tactic. The economic effectiveness of this treatment, as well as a range of plants that this treatment is effective on still needs to be studied. Light flashing of four seconds per minute saves over 80% of energy and is as effective as traditional night interruption lighting on chrysanthemums (Aldrich and Bartok, 1989).

Night interruption lighting is commercially practiced on mums and poinsettias to keep plants vegetative.

Not only is the total daily light and photoperiod critical for plant growth, but also the quality or color of light is important for many processes in plant growth. Light quality, in particular the ratio of red to far-red light, can have an impact on seed germination, rooting of cuttings, growth habit of the plant, internode elongation and flower initiation (Aldrich and Bartok, 1989). Sunlight generally provides the full spectrum light needed by the plant (Figure 1). When considering supplemental lighting, the spectrum provided by each type of light needs to be reviewed. Far-red light, just beyond the visible light spectrum, but available to plants in many light sources, increases stem elongation, increases leaf size, decreases branching and reduces the color intensity of leaves and flowers (Bickford and Dunn, 1972). Red light is important in photosynthesis, and chlorophyll synthesis, as well as promoting seedling germination, flowering, stem elongation and anthocyanin formation (Whealy, 1991).

Not only is the total daily light and photoperiod critical for plant growth, but also the quality or color of light is important for many processes in plant growth.

Table 1. *Photoperiodic classification of plants (no temperature effects). (Bickford and Dunn, 1972.)*

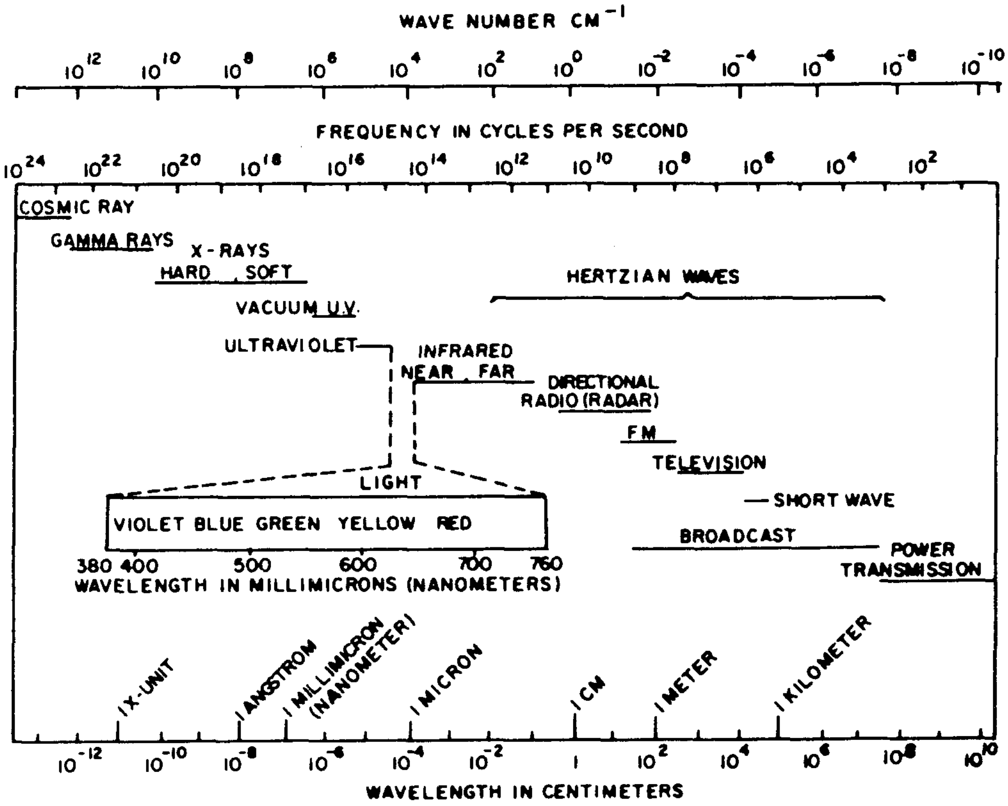
Day-Neutral Plants	
Gardenia jasminoides	Cape jasmine
Gomphrena globosa	Globe amaranth
Impatiens balsamina	Balsam
Rhododendron sp.	Azalea
Quantitative short-day plants	
Chrysanthemum sp.	Chrysanthemum
Cosmos bipinnatus	Cosmos
Senecio cruentus	Cineraria
Zinnia sp.	Zinnia
Quantitative long-day plants	
Fragaria chiloensis	Strawberry
Nigella arvensis	Fennel flower
Oenothera rosea	Evening primrose
Short-day plants	
Cattleya trianae	Orchid
Ipomoea hederacea	Morning Glory
Kalanchoe blossfeldiana	Kalanchoe
Long-day plants	
Antheum graveolens	Dill
Dianthus superbus	Carnation
Oenothera suaveolens	Evening primrose
Oenothera longiflora	Evening primrose
Oenothera stricta	Evening primrose

Blue light is also important in photosynthesis and chlorophyll synthesis and also helps reduce plant stem length and increases branching along with improving leaf and flower color, stomatal opening, phototropism and spore formation (Whealy, 1991). This is one of the reasons that a balanced light source is important for quality plant growth.

Blue light is also important in photosynthesis and chlorophyll synthesis and also helps reduce plant stem length and increases branching along with improving leaf and flower color, stomatal opening, phototropism and spore formation.

Visible light is in the light spectrum with 380 to 760 nanometer wavelengths. (Figure 1). The wavelength in the lower end of this range constitutes blue light that helps plants to reduce stem elongation, remain compact and increase branching. The upper end of the visible light

Figure 1. *Radiant energy of the electromagnetic spectrum (adapted from IES Lighting Handbook, 1959).*



Generally incandescent lights are used for photoperiod control.

spectrum is red light (600-700 nm) which helps produce strong plant growth and increase stem elongation. While both light sources sound good, either one alone would not produce a quality plant. Cholorphyll, the green pigment in plants that utilizes a light receptor to carry out photosynthesis is thought to have a greater response to blue light than to red light, but researchers differ in their opinions of this (Canham, 1966).

Types of Supplemental Light

Incandescent Lights. Generally incandescent lights are used for photoperiod control. Much of the light emitted is in the far-red range (700-760 nm). This type of light can cause increased stem elongation (Bickford and Dunn, 1972). It is economical to put up incandescent light, however, the bulbs are short lived (approximately 1000 hours) (Canham, 1966). When using incandescent lights be sure that you use either reflector bulbs or provide a reflector at the fixture to increase the area that the light is available to the plants. These lamps are available in a wide range of sizes from 15 to 1500 watts (more generally 40 to 200 watts) and in clear, pearl or "inside silica-coated" styles (Canham, 1966). Incandescent lights give off a lot of heat for the wattage that is provided due to the resistance in the bulb of the tungsten filament, especially in contrast to fluorescent bulbs (Bickford and Dunn, 1972). Be sure that the lights aren't placed too close to the plants or scorching could occur on leaves of sensitive plants, generally three to five feet above the canopy is recommended for photoperiod control. The light quality emitted by incandescent bulbs can change over the life of the bulb, however, this is generally not a concern for night interruption lighting. For night interruption lighting, a minimum of 7 to 10 fc (2-5 μmol m^{-2}s^{-1}) of light is required to prevent flower initiation in poinsettia or chrysanthemum (Sachs and Kofranek, 1979). The spectra of incandescent bulbs generally in the far-red range, but if using lamps with dichroic reflectors in the bulb the spectra can be increased to 380 to 760 nm (Bickford and Dunn, 1972).

Basically the same as incandescent bulbs and used in similar situations, tungsten-iodine bulbs will maintain the same light output throughout the life of the bulb due to a small amount of iodine vapor that has been introduced into the atmosphere around the filament.

Tungsten-Iodine Lights. Also known as tungsten-halogen lights. Basically the same as incandescent bulbs and used in similar situations, tungsten-iodine bulbs will maintain the same light output throughout the life of the bulb due to a small amount of iodine vapor that has been introduced into the atmosphere around the filament (Canham, 1966). Generally the bulbs are available with a reflector in the bulb, eliminating the need for an outside reflector on the fixture. These lamps are available in sizes of 500, 750, 1000, 1500 and 2000 watts (Canham, 1966). As with incandescent bulbs, the efficiency of the bulbs is relatively low compared with other types of lighting (converting only 6-12% of the input electrical energy into light energy) (Bickford and Dunn, 1972; Whealy, 1991). Tungsten lamps are often used for flood lighting. Their spectra is similar to that of incandescent bulbs.

Fluorescent Lights. Cooler than incandescent lights, fluorescent bulbs also provide a wider spectrum and are more efficient in converting input energy into light energy. Fluorescent lamps have a tungsten filament in a cathode at each end of the tube. These cathodes produce electrons that are passed through the mercury and inert gas that is maintained under pressure in the phosphor coated tubes the make up the bulbs. The electrons passing through the pressurized gas create the light. While providing more efficient lighting, fluorescent lights are more expensive and provide more shading due to the large ballasts required for their use compared to other lamp types in the greenhouse (Whealy, 1991). Because of this shading, fluorescent lights are often used in specialty situations such as growth chambers where shading of sunlight will not occur (Whealy, 1991). In growth chambers fixtures can be mounted on a side wall and provide very even, well distributed light. For plants that will be grown for their entire life in a growth chamber, it is recommended to also have some incandescent lights in addition to complete the light spectrum and give a more "natural" light effect to provide for better plant growth (Whealy, 1991). Fluorescent lamps are available in various colors and in eight or more shade of "white" (Bickford and Dunn, 1972). Research done by Cathey et al. (1978) examined seven different types of fluorescent lamps (cool white, warm white, Gro-lux, Gro-lux wide spectrum, Agrolite, Vitalite and an experimental lamp) on 11 kinds of foliage and flowering plants. While some differences were seen with the dry weight of the plants under various light sources, the greatest differences were seen when incandescent light was added to bring red and far-red light into the spectrum. None of the bulbs tested provided enough UV light either, no levels even approached that provided by the sun. The authors concluded that the efficiency, or ability to convert power into visible radiation, of the lamps used is of primary importance, with the light quality or spectral distribution being of second order

Cooler than incandescent lights, fluorescent bulbs also provide a wider spectrum and are more efficient in converting input energy into light energy.

HID Lights. HID, or high intensity discharge, is a generic term used to include mercury, metal halide (MH), low pressure sodium (LPS) and high pressure sodium (HPS) lights (Whealy, 1991). They are all considered highly efficient in terms of converting power to light energy, with uniform light distribution and lower levels of shading from fixtures. Some of these lamps provide remote ballasting, or ballasts that are distant from the light source, to reduce shade levels over the plants even more (Aldrich and Bartok, 1989). They generally provide very long lived bulbs, 10,000 to 24,000+ hours compared to 750 to 2000 hours for incandescent and tungsten lamps, although the initial investment is more expensive.

HID, or high intensity discharge, is a generic term used to include mercury, metal halide (MH), low pressure sodium (LPS) and high pressure sodium (HPS) lights.

Mercury Lights. Rather than passing through tungsten wires as in an incandescent lamp, mercury lamps pass electrical current through a gas or vapor under pressure using a mercury arc (Bickford and Dunn, 1972). This is similar to a fluorescent lamp. The light produced by the mercury is typically bluish-white and there is little light output in the red part of the light spectrum (Aldrich and Bartok, 1989). The lamp requires a large ballast and a reflector to provide the light at the plant surface. The size of these lamps make it difficult to provide uniform light, and the fixtures provide a lot of shading of plants from sunlight. Early lamps were available only in 1000 watt bulbs. The newer 400-watt lamp is considered the best compromise for uniformity of illumination, economy of use, size of unit and area covered compared to other types of lamps of similar size (Aldrich and Bartok, 1989) Because of the pressure in the light bulb, if current to the light is cut, even for an instant, the bulb must cool down before it can be restarted, this may take five to ten minutes (Bickford and Dunn, 1972; Aldrich and Bartok, 1989). These lamps will also produce a great amount of heat, so care must be taken not to place them too close to sensitive plants, generally no closer than five feet. The spectra of mercury

Rather than passing through tungsten wires as in an incandescent lamp, mercury lamps pass electrical current through a gas or vapor under pressure using a mercury arc.

lamps peaks at 365.4, 404.7, 435.8, 546.1 and 578.0 nm, covering a wide area of the spectrum (Bickford and Dunn, 1972).

> **Metal halide lamps are less efficient, 120 to 125 per watt compared to an efficiency of 135 to 140 lumens per watt for HPS lamps, and shorter lived than LPS or HPS lamps.**

Metal Halide Lights. These lamps provide the best spectral distribution of all of the HID lamps with wavelengths in the blues, reds and far reds (Bickford and Dunn, 1972). Metal halide lamps are less efficient, 120 to 125 per watt compared to an efficiency of 135 to 140 lumens per watt for HPS lamps, and shorter lived than LPS or HPS lamps. They are very effective in retail areas where a more natural white light is provided giving the most natural lighting for the plants and customers (Whealy, 1991). The spectra has a peak light output in the blue to green area of 320 to 540 nm (Bickford and Dunn, 1972).

Low Pressure Sodium Lights. While the most efficient supplemental light source, LPS lights are not widely used (Aldrich and Bartok, 1989). Research from the USDA showed that low pressure sodium lamps, with the addition of light from incandescent lamps provided simultaneously, produced plants that were more compact with higher fresh weight than plants grown under low pressure sodium lights alone (Cathey et al., 1982). They produce very little heat and the light provided is in the yellow range (Aldrich and Bartok, 1989). The lamps require a rather large fixture that can cause shading problems (Whealy, 1991). The spectra for these lamps is 580 to 650 nm (Bickford and Dunn, 1972).

> **Research from the USDA showed that low pressure sodium lamps, with the addition of light from incandescent lamps provided simultaneously, produced plants that were more compact with higher fresh weight than plants grown under low pressure sodium lights alone.**

High Pressure Sodium Lights. Generally considered the best supplemental lighting source for greenhouse production, HPS lamps provide light in the upper end of the spectrum (red, orange and yellow) at 550 to 700 nm (Bickford and Dunn, 1972). They are very efficient and fewer fixtures are needed to provide as much light as with other types. These lamps provide more photosynthetically useful light per unit of electricity than other light sources and they are among the most efficient users of electricity to produce the light. They have very long lives (for example, 400- or 1,000-watt sodium lamps are rated to last 24,000 hours; metal halide, 20,000 hours; low pressure sodium, 18,000 hours; and fluorescent, 15,000) and the fixtures and reflectors are smaller than other lamps (Whealy, 1991). As with other HID lamps, interruption of electrical current will cause the lights to shut down and will require about one to two minutes for the bulbs to be relit (Aldrich and Bartok, 1989).

The cost of all supplemental lighting needs to be weighed against the benefits to the plants. In many cases the cost can be minimal compared to the benefits of improved plant growth. The cost of lighting is decreasing and the efficiency of most types of lights is increasing. The benefits of supplemental lighting will be the greatest if other growth factors aren't limiting, such as temperature, fertility and water. As with any improvement in growing conditions, it is the overall environment that must be improved so that the plant can make the most of the conditions provided.

Literature Cited

Aldrich, R.A. and J.W. Bartok, Jr. 1989. Environmental Modification, pp. 92-101. In: M. Sailus, C. Napierala and M. Sounders (eds.). Greenhouse Engineering. 2nd Edition. Northeast Regional Agricultural Engineering Service, Ithaca, NY.

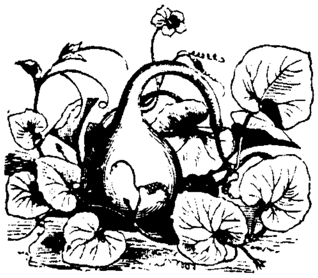
Armitage, A.M., W.H. Carlson and J.A. Flore. 1981. The effect of temperature and quantum flux density on the morphology, physiology and flowering of hybrid geraniums. J. Amer. Soc. Hort. Sci. 106:643-647.

Bickford, E.D. and S. Dunn. 1972. Lighting for Plant Growth. The Kent State University Press, Kent, OH.

Blake, J. 1957. Photoperiodism in the perpetual flowering of carnation. In: Report of the 14th International Horticulture Congress of the Netherlands. Wageningen, The Netherlands: H. Veenman and Zonen.

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

Cathey, H.M. and H.A. Borthwick. 1961. Cyclic lighting for controlling flowering of chrysanthemums. Proc. Am. Soc. Hort. Sci. 69:485-491.



Cathey, H.M. and H.A. Borthwick. 1970. Photoreactions controlling flowering of *Chrysanthemum morifolium* (Ramat. and Hemsl.) illuminated with fluorescent lamps. Plant Physiology 45:235-239.

Cathey, H.M., L.E. Campbell and R.W. Thimijan. 1978. Comparative development of 11 plants grown under various fluorescent lamps and different durations of irradiation with and without additional incandescent lighting. J. Amer. Soc. Hort. Sci. 103(6): 781-791.

Cathey, H.M., L.E. Campbell and R.W. Thimijan. 1982. The Basics of Light. USDA-SEA, Beltsville, MD 20705.

Grueber, K.L. 1985. Control of branching and reproductive development in *Euphorbia pulcherrima* Willd. ex. Klotch. Ph.D. Diss., University of Minnesota, St. Paul.

Hopper, D.A. 1986. Light and temperature effects on hybrid seed geranium development. Master's Thesis. Michigan State University, East Lansing, MI.

I.E.S. Lighting Handbook. 1959. 3rd Edition, Illuminating Engineering Society, New York.

Kaczperski, M.P., S. Derthick and W.H. Carlson. 1989. *Begonia* x *tuberhybrida*, pp. 26-38. In: Flowering and Foliage Bedding Plants. Michigan State University, East Lansing, MI.

Kofranek, A.M. 1992. Cut Chrysanthemums, pp. 3-42. In: R.A. Larson (ed.). Introduction to Floriculture. 2nd Ed. Academic Press, New York, N.Y.

Langton, F.A. 1977. The response of early-flowering chrysanthemums to daylength. Scientia Horticulturae 7:277-289.

Mastalerz, J.W. 177. The Greenhouse Environment. Wiley Press, New York, N.Y.

Petersen, H. 1955. Artificial light for seedlings and cuttings. N.Y. State Flower Grower. Bull. 122:2-3.

Pytlinski, J. and H. Krug. 1988. Modelling *Pelargonium zonale* response to various day and night temperatures. Proc. International Symposium on models for plant growth, environmental control and farm management in protected cultivation. Acta. Hort. 248:75-84.

Sachs, R.M. and A.M. Kofranek. 1979. Radiant energy required for the night break inhibition of floral initiation as a function of daytime light input in *Chrysanthemum* x *morifolium* Ramat. HortScience. 25(5):609-610.

Schwabe, W.W. 1952. Effects of temperature, daylength and light intensity in the control of flowering in the chrysanthemum. Report of the 13th International Horticultural Congress 2:952-960.

Whealy, C.A. 1991. High Intensity Discharge Lamps, pp. 259-264. In: V. Ball (ed.). The Ball Red Book. 15th Edition. Geo. J. Ball Publishing, West Chicago, IL.

Generally considered the best supplemental lighting source for greenhouse production, HPS lamps provide light in the upper end of the spectrum (red, orange and yellow) at 550 to 700 nm.

The benefits of supplemental lighting will be the greatest if other growth factors aren't limiting, such as temperature, fertility and water.