14-PART • **SPECIAL** EDUCATION SERIES

LIGHTING UP

In the ninth article of our 14-part series, researchers focus on the supplemental lighting of potted plants.

by ***HELMA VERBERKT, ROYAL HEINS*** *and* ***THEO BLOM***

LIGHT is often the limiting factor for plant growth in greenhouses during the winter. Supplemental lighting increases plant growth and, depending on the crop, can also affect plant development (time to flower). For most crops, supplemental lighting improves crop quality during the winter, although in rare cases, it can lead to a decrease in crop quality.

In this article, we define plant quality as those factors a consumer views as desirable in a flowering pot plant, including flower number, flower size, stem strength, leaf number, color, plant height and number of lateral shoots. Most of these factors increase/improve with increasing DLI. In this article, we provide information about the effects of supplemental lighting on foliage and flowering potted plants.

Light Requirements

Although many light recommendations are based on footcandles, this is not a good way to describe the light requirements for quality potted plants. While a maximum number of footcandles is often useful to avoid high light stress on a plant, overall plant quality is related to the light integral received during the entire day, often referred to as the daily light integral (DLI). The unit describing DLI is moles of photons (mol) per square meter (m^2) per day (d), or $mol{\bullet}m^{-2}{\bullet}d^{-1}$. In Europe, the unit used is usually Joules per square centimeter (cm^2) per day (d) or $J{\bullet}cm^{-2}{\bullet}d^{-1}$. Both

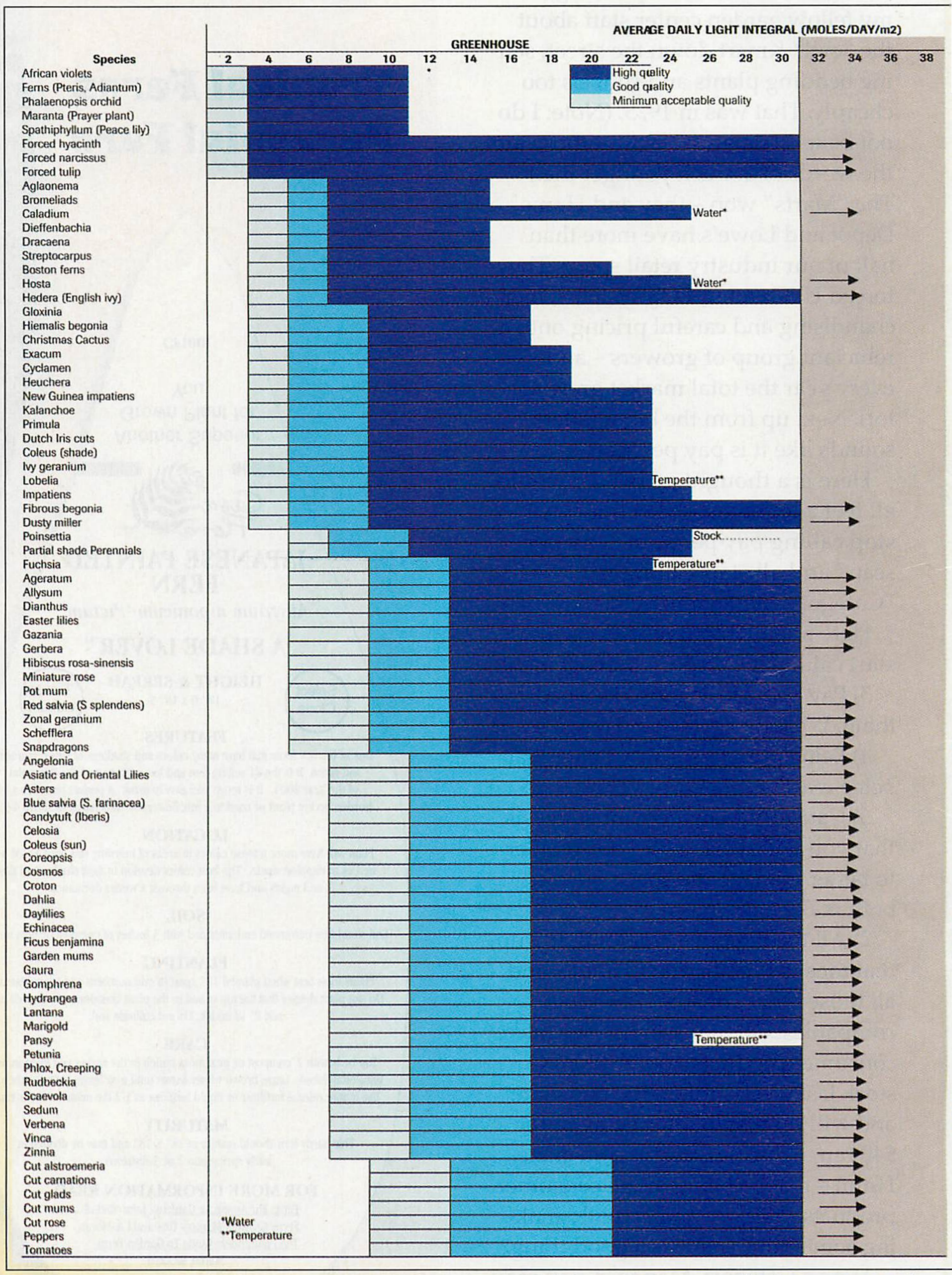

Figure 1. Relationship between daily light integral (DLI) and plant quality for a range of floricultural plant species. Table developed by Jim Faust, Clemson University. Adapted from The Ball RedBook, 17th edition, volume 2. Copyright 2003 by Ball Publishing. Used with permission.

PROFITS

units refer to photosynthetic active radiation (PAR) only.

The DLI required by a potted plant depends on the plant species and the desired plant quality. Plants can be classified according to DLI requirements (Figure 1). For example, pot roses, ficus (*Ficus benjamina*), chrysanthemum and gerbera have a high light requirement (>12 $mol \cdot m^{-2} \cdot d^{-1}$); begonia, cyclamen, kalanchoe and dieffenbachia have a moderate light requirement (>8 $mol \cdot m^{-2} \cdot d^{-1}$); and African violet and most ferns have a low light requirement (>4 $mol \cdot m^{-2} \cdot d^{-1}$). Therefore, high quality plants of species such as African violet or phalaenopsis orchid can be achieved with as little as 4 $mol \cdot m^{-2} \cdot d^{-1}$. In contrast, highest quality miniature roses only occur when plants receive more than 14 $mol \cdot m^{-2} \cdot d^{-1}$ (Figure 1).

To determine plant responses to supplemental lighting, an experiment was performed in The Netherlands to determine how an additional 2.2 $mol \cdot m^{-2} \cdot d^{-1}$ during the winter months influenced growth (such as branching and stem thickness) and development (such as time to flower). With flowering crops such as begonia, pot rose and kalanchoe, the number of flowers and buds increased, while in other crops (hydrangea and pot rose), flower bud abortion was reduced (Table 1). The variegation of the leaves of codiaeum, cordyline and schefflera increased with supplemental lighting, as did the numbers of side shoots on crops like ficus and peperomia. Extending the day length to 20 hours (with a four-hour dark period) increased the peduncle length of the flower of pot gerberas, kalanchoe and cyclamen, which may or may not be desirable.

Light And Temperature Interaction

It is important to recognize that light (radiant energy) is only one of the two sources of energy responsible for plant growth and development. Temperature (thermal energy) is the other energy source. While light drives photosynthesis, temperature controls developmental rate and determines how fast a plant will grow. High light with low temperatures produces a husky but slow-growing plant, while low light with high temperature produces a fast-growing but thin and weak plant. This is particularly true for so-called cool crops.

The relationship between DLI and plant quality, shown in Figure 1, reflects production of plants at typical greenhouse temperatures. High quality plants can be produced at lower DLIs than shown in Figure 1 if plants are also grown at lower temperatures. However, at lower temperatures, the plants will also take longer to flower (or finish).

For some greenhouse potted-plant species, there is also a DLI above which plant quality decreases due to excess light and heat stress (Figure 1 and Table 1). These plants typically fall into the category of what we call shade plants.

Is Supplemental Lighting Cost-Effective?

The answer to this question is not black and white. As a rule, however, it is profitable to add supplemental lighting in the following situations:

• When the light level is so low that low quality means that the plants are not saleable. For example, miniature potted rose has a high light requirement, and without supplemental lighting in The Netherlands during midwinter, flowers abort and plants can become unsaleable.

- When the market will pay for higher plant quality. This is more common in the Netherlands with the auction system. In America, the crop is often either good enough for sale or it is not, without awarding a greater price for higher quality.
- When more rapid growth and development with lighting means that production time is reduced sufficiently and you can produce more crop cycles. For example, supplemental lighting allows crops such as African violets to be grown at a higher temperature, and therefore grow faster in the winter months than if supplemental lighting is not provided.

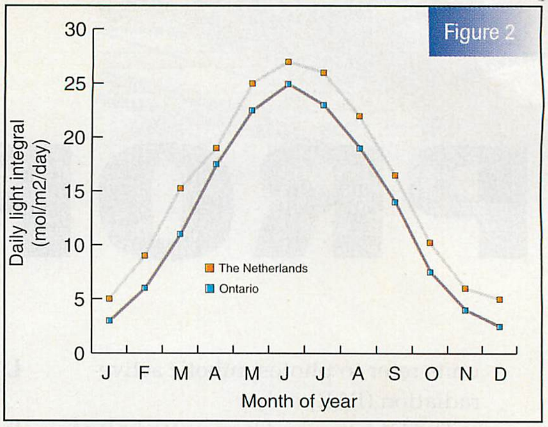

Figure 2. Daily light integral (DLI) inside a greenhouse for Naaldwijk, The Netherlands (52°N latitude), and Vineland Station, Ontario (43°N latitude) assuming 60 percent greenhouse light transmission. For conversion of natural light: 1 mol=0.48 MJ global.

Most high quality crops can be grown when the daily light integral at plant level exceeds 10 mol•m^{-2}•d^{-1} (Figure 1). So what is the DLI inside greenhouses? The DLI changes dramatically during the year, particularly in northern latitudes, such as the Midwest and Northeastern United States, Canada and The Netherlands (Figure 2). DLI in the winter is about one-fifth of the amount in the summer, due to the lower light intensities and shorter days during the winter.

The average ambient DLI in a greenhouse during midwinter is about 2.5 to 3.0 mol•m^{-2}•d^{-1} in The Netherlands and 4 to 5 mol•m^{-2}•d^{-1} in the northern United States and Ontario (Figure 2). Even with 20 hours of supplemental lighting at a light intensity of 30 µmol•m^{-2}•s^{-1} (240 foot candles), the DLI only increases by 2.2 mol•m^{-2}•d^{-1}. To obtain light conditions similar to spring (10 mol•m^{-2}•d^{-1} or more) in the winter, a grower in the northern United States and Ontario would need to provide 75 µmol•m^{-2}•s^{-1} (595 footcandles) for 20 hours per day, and a grower in The Netherlands would need to provide 120 µmol•m^{-2}•s^{-1} (950 footcandles) for 20 hours per day. In other words, a lot of supplemental lighting would be needed to create spring-like light conditions in northern locations.

Use of supplemental lighting for potted crops in North America and The Netherlands remains relatively small. In the last 15 years, the area of pot plants under supplemental lighting in The Netherlands has increased slowly to about 15 percent of greenhouse production space (1,272 hectares).

Although statistics are not available for the United States and Canada, light conditions in North America mean that most potted plants do not receive supplemental lighting because there is adequate sunlight to achieve minimum quality standards. Where quality is decreased by lack of light, growers may maximize light with high-transmission greenhouse coverings, open-roofed greenhouses or reducing the presence of overhanging baskets. Alternatively, the product mix or cultivar selection may be changed to grow crops that have adequate quality under low light.

Foliage plants are generally only illuminated with HPS lights during propagation. Cost per plant is low due to the large number of plants per unit area. In contrast, some flowering potted plants are illuminated through the end of the cultivation period to ensure proper flower development and to prevent flower bud abortion (e.g. pot rose).

Supplemental lighting installations are usually inadequate to ensure a year-round minimum DLI of 10 mol•m^{-2}•d^{-1} because of the high cost of lighting and the relative short period that it would be used. Such lower light levels compromise potted plant quality to some extent during the darkest months. Carbon dioxide supplementation and/or maintaining a lower temperature during this relative short period may increase plant quality. For most potted plants, consider enriching the greenhouse with CO_2 to a concentration of 800 ppm. Lower CO_2 levels of 600 ppm are suggested for African violets and gloxinias to prevent brittleness of the leaves.

Optimizing Supplemental Lighting

Supplemental lighting can be provided in many different ways, depending on the light level and the light duration. The relation between carbohydrate production and light intensity (light response curve) is linear at low light intensity (<125 µmol•m^{-2}•s^{-1}) but with increasing light intensity (>125 µmol•m^{-2}•s^{-1}), the response can be described by the law of diminishing return, e.g. the additional carbohydrate production per unit of light decreases. Therefore, the benefits from supplemental lighting during the daytime is less than during the night.

From a practical point, it is more economical to illuminate longer at a lower intensity than for a shorter period at a higher intensity. This is due to a smaller number of lamps required per unit area, and thus a lower power load requirement. Thus, for crops where photoperiod is not essential, one can better supplement for 20 hours at a low intensity than for 10 hours at double the intensity. For photoperiod-sensitive crops, supplemental lighting during flower initiation can only be provided during the nondark periods.

Continuous supplemental lighting (24 hours per day) of some crops can lead to unwanted abnormalities such as stunting, leaf yellowing, bleaching of the leaves, poor shelf life, curling of leaves, etc. Therefore, it is generally recommended to keep a minimum dark period of four hours.

Most growers switch supplemental lighting on and off during the day when the ambient radiation level falls below and above some outside light level. Typical values are 100 and 200 Watts per square meter, respectively. These values are equivalent to about 1,000 and 2,000 footcandles (200 and 400 $\mu mol{\bullet}m^{-2}{\bullet}s^{-1}$, respectively). For high light requiring crops, higher setpoints would be more appropriate.

Other Considerations

Under ambient conditions, the temperature of the plant is usually slightly below air temperature without supplemental lighting, especially in greenhouses without an energy curtain or without overhead heating pipes. Supplemental lighting increases the plant temperature, often above the air temperature, but the increase depends on the light intensity. This increase in plant temperature reduces production time. Another benefit of supplemental lighting is the reduced incidence of foliar diseases such as Botrytis and mildew.

Supplemental lighting also forces earlier ventilation of the greenhouse due to the electrical heat input into the greenhouse. This is particularly important in areas with high outside temperatures during the winter and some considerations may be given to the placement of the ballasts.

Crop	Shortening of the Cultivation time	Plant shape	External quality
Begonia	••	More compact Shorter internodes	↑↑↑ More side shoots and flowers
Codiaeum	••••	Longer internodes, Bigger leaves	↑ More variegation of the leaves
Cordyline	••		↑ Wide red margin on the leaves, more variegation of the leaves
Cyclamen	••	Longer petioles	Good results with young plants and mother plants (seed)
Dieffenbachia	•••	More side shoots, More compact plant	↑ 'More green crop'
Epipremnum	••	Longer internodes	A little bit more variegation, but tough, stringy leaves
Exacum	••	More side shoots, More compact plant	↑↑ More flowers
Ficus	••••	More side shoots	↑ More side shoots
Fatshedera	••••••	Longer internodes	↑↑
Hedera	••••••	Longer internodes	↑↑
Hydrangea	••	Longer internodes	↑ Less abortion of flower buds, more and bigger flowers
Impatiens 'New Guinea'	••	More side shoots, More compact plant	↑↑ More flowers
Kalanchoe	•••	More side shoots, Longer flower stems	↑↑ Less abortion of flower buds
Nephrolepis	•••	More compact plant, Fuller plants	↑
Peperomia	••	More side shoots	↑
Pteris	••••	Bigger leaves with longer leaf stems, less compact	
Radermachera	••		↑
Potted rose	••••	More side shoots, Denser crop	↑↑↑ More flowers, less sensitive of powdery mildew
African Violet	••	More side shoots, More double hearts	More flowers, Tough, crispy leaves
Sinningia cardinales	•	More side shoots, More compact plant	↑
Spathiphyllum	••	More compact plant, Less elongation	↑ More side shoots, Tough, crispy leaves, Leaves are dark green
Schefflera	••••		↑ More variegation of the leaves
Syngonium	••	More side shoots, Longer internodes	↓ Small leaves, Less variegation of the leaves, Extremely long main shoot
Streptocarpus	••		↑ More flowers

• = no effect on cultivation time
•••••• = cultivation time is shortened
↓ = plant quality decreases
↑ = plant quality increases
↑↑↑ = plant quality increases dramatically

Source: Research Stations, The Netherlands

Table 1. The effect of supplemental lighting from high-pressure sodium lamps at about 30 $\mu mol{\bullet}m^{-2}{\bullet}s^{-1}$ (240 footcandles) for 20 hours per day on various potted plants in The Netherlands.

Conclusions

Supplemental lighting is used on potted plants to stimulate growth and to improve plant development. In general, supplemental lighting increases plant growth, shortens the cultivation period, and/or improves plant quality. The effect of supplemental lighting is strongly crop dependent and subject to seasonal influences. The largest benefits are obtained during the darkest periods of the year (October to February), especially at higher latitudes. The amount of supplemental lighting desired is a function of the ambient light levels from sunlight in the greenhouse, the total light (DLI) required for a desired plant response, and the number of hours one can light the crop. For most potted plants, a recommended light intensity for supplementation is 300 to 400 footcandles (38 to 51 $\mu mol{\bullet}m^{-2}{\bullet}s^{-1}$). For potted roses, the intensity may be even higher (500 to 800 footcandles). For daylength sensitive crops, it is important to keep in mind the photoperiodic requirements of the crop. **GG**

About the authors: Helma Verberkt is a researcher with DLV Facet, The Netherlands. Royal Heins is professor emeritus of horticulture, Michigan State University, East Lansing, Mich. Theo Blom is Associate Professor in Floriculture at the University of Guelph in Ontario, Canada.
Greenhouse Grower thanks "Lighting Up Profits" sponsors, Argus Controls, Signature Supply, Inc., Becker Underwood and P.L. Light Systems for their continuing support.