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## Horticultural Highlights

LEDs: The Future of Greenhouse Lighting! • High Value Horticulture: Lessons from New Zealand • Revelations from *Histoire Naturelle des Indes* known as *The Drake Manuscript*: Horticulture and History • Cashew Industry in India – An Overview

## Symposia and Workshops

Medicinal, Aromatic and Nutraceutical Plants from Mountainous Areas • Mycotoxins in Nuts and Dried Fruits • Cashew Nut • Apricot Breeding and Culture • Fruit Breeding and Genetics • Sustainable Vegetable Production in South East Asia • High Tunnel Horticultural Crop Production • Organic Matter Management and Compost Use in Horticulture

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# LEDs: The Future of Greenhouse Lighting!

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Supply & Demand in the greenhouse industry dictate that product quality and delivery schedule be maintained at high market standard for intensively cultivated food and ornamental crops. Product supply and market demand determine wholesale prices that growers can expect to receive for their horticultural products. Even as growers achieve economies of scale, there continues to be increasing pressure on operating margins to compete for economic viability. Specialty (horticultural) crops represent an important sector of the economy generating approximately 50% of total crop production in the USA (USDA, 2005). Any advantage that growers can leverage to reduce production costs while maintaining product quality and schedule integrity is worthy of consideration.

## ENERGY A MAJOR QUESTION MARK

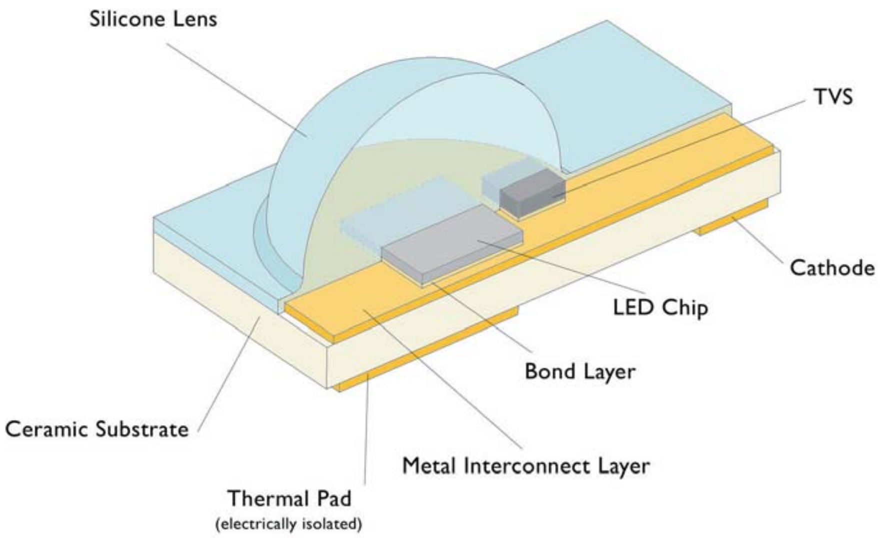
Since energy inputs range from 10 to 30% of total production costs for the greenhouse industry (Brumfield, 2007; Langton et al., 2006), energy is an important candidate for cost reduction. The two major energy inputs for greenhouse operations include temperature control and lighting. The need for both varies considerably with climate and latitude. Crop lighting is an energy-intensive necessity of the greenhouse industry, particularly with increasing latitude in either direction away from the equator resulting in significant swings in seasonal photoperiod. Cost per kilowatt-hour of electricity varies widely depending on local fuel sources for generating electrical power. Most energy used in greenhouse production today is derived from fossil fuels, which are under attack for their negative impacts on the environment. Such concerns may reduce fossil-fuel use in the long term, but drive up energy prices in the short run. Thus, any new lighting technology that significantly reduces consumption of electricity for crop lighting while maintaining or improving crop value is of great interest to growers.

## LIGHT-EMITTING DIODES

Light-emitting diodes (LEDs) represent a promising technology for the greenhouse industry that has technical advantages over traditional lighting sources, but are only recently being tested for horticultural applications. LEDs are solid-state light-emitting devices (Fig. 1), and as such, are much more robust and longer-lived than traditional light sources with fragile filaments, electrodes, or gas-filled, pressurized lamp enclosures (Bourget, 2008). LEDs can be designed to emit broad-band (white) light or narrow-spectrum (colored) wavebands specific for desired plant responses (Morrow, 2008). One of the most important features of LEDs for horticultural application is that waste heat is rejected separately from light-emitting surfaces by active heat sinking (Bourget, 2008). This is particularly important for high-intensity LEDs of 1 watt or more. Thus, emitters can be placed close to crop surfaces without risk of overheating and stressing plants (Bourget, 2008). In contrast, high-intensity discharge (HID) lamps require considerable separation between lamps and plants to ensure uniform light distribution as well as to avoid heat stress from lamps. As already is done for HIDs, the waste heat rejected from LEDs can be leveraged for greenhouse heating to offset fuel costs during cold weather. Designs of LED arrays allow waste heat to be placed within the greenhouse when and where desired during cold weather, or vented from the greenhouse during warm weather.

LEDs can be manufactured to emit photon colors that match the absorbance peaks of important plant pigments, such as the red and far-red-absorbing forms of phytochrome, or the red and blue peaks of leaf photosynthetic action spectra. Thus, energy is saved using narrow-band LEDs for specific plant responses by not providing extraneous colors of broad-band

**Figure 1. A LUXEON Rebel, surface-mount, high-voltage LED used for lighting applications in horticulture. The main components include a high-brightness LED chip array on a ceramic substrate that provides mechanical support and thermally connects the chip to a heat pad on the substrate, an electrical interconnect layer to a cathode and anode on the bottom of the substrate, a silicone lens shielding the chip, and a transient voltage suppressor (TVS) under the lens to protect the emitter against electrostatic discharge. Permission to use the image courtesy of Philips Lumileds.**



light that otherwise would be an inefficient energy burden.

Another, major advantage of LEDs over all other lamp types used for plant lighting is that the technology is evolving in electrical-use efficiency at a rapid pace. For example, blue LEDs that were only 11% efficient a few years ago (Massa et al., 2006) were reported to be 49% efficient converting electrical energy to photon energy last year (Philips data sheet #DS68). LED efficiency, in general, is projected to rise considerably over the coming decade (Haitz and Tsao, 2011). A dynamic requiring almost immediate change is the imminent phasing out of incandescent (INC) lamps (IEA paper, 2010). Although INCs have been used in the greenhouse industry almost exclusively for low-intensity photoperiod control, they are short-lived, are very electrically inefficient, and can cause undesirable stem elongation due to their high far-red (FR) output. LED technology represents a promising replacement. HID lamps traditionally used in greenhouses to supplement solar light for photosynthesis also emit significant amounts of long-wave radiation (Brown et al., 1995) that increase temperature of the foliar canopy without increasing air temperature. LEDs emit no such long-wave radiation. Rather, waste heat is dispersed through the base of the device. Thus, LEDs are well positioned to be phased into service for multiple greenhouse-lighting applications following suitable testing and technology innovations.

## HISTORY OF LEDS AND PLANT GROWTH

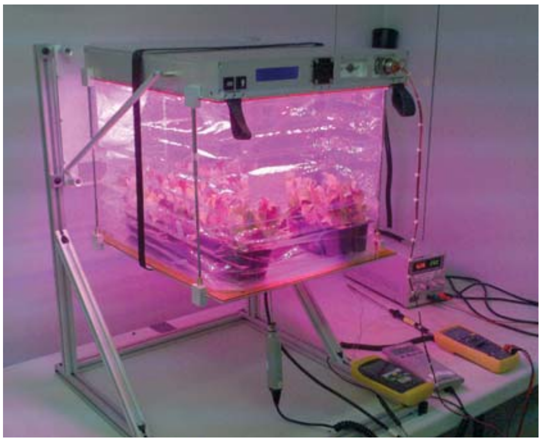
LEDs were first used for sole-source plant lighting more than 20 years ago when lettuce was grown under red (R) LEDs supplemented with blue (B) fluorescent lamps (Bula et al., 1991). Seedlings grown only under R LEDs became elongated, but if as little as 15 $\mu mol.m^{-2}.s^{-1}$ of B was added, plants developed normally (Hoenecke et al., 1992). Diverse species have been grown successfully under LEDs as a sole source of lighting, including wheat, brassica (Barta et al., 1992; Morrow et al., 1995), potato (Croxdale et al., 1997), arabidopsis (Stankovic et al., 2002), and soybean (Zhou, 2005). Photosynthesis in kudzu was similar under equivalent photosynthetic photon flux (PPF) from white xenon lamps or R LEDs (Tennessen et al., 1994), and R LEDs gave higher quantum efficiency for strawberry photosynthesis than did B LEDs (Yanagi et al., 1996). However, R + B LEDs gave higher photosynthetic rates in rice than did R alone (Matsuda et al., 2004). For wheat, 1 to 10% B combined with R LED light was needed for normal tillering, leaf expansion, and seed yield (Goins et al., 1997). Yield of lettuce, spinach, and radish grown under R LEDs alone was less than if 35 $\mu mol.m^{-2}.s^{-1}$ of B radiation was included to give the same final PPF, and yield under R + B LEDs was equivalent to that under fluorescent (Fl) lamps at the same PPF (Yorio et al., 1998). Pepper leaf thickness depended more upon the level of B light than the R : FR ratio (Schuerger et al., 1997). Lettuce grown under R + B LEDs with up to 24% green (G) light developed more biomass and larger leaf area than plants grown under equivalent PPF from Fl or R + B alone (Kim et al., 2004). Even a small amount of G light makes assessment of stress or disease symptoms much easier for the human eye than if plants are grown under R + B only (Massa et al., 2008).

The relative coolness of energized LED surfaces allowed the development of intra-canopy lighting systems for self-shading crop stands in which vertical LED strips extend throughout leaf canopies (Massa et al., 2005a, b). These air-cooled LED "lightsicles" had the desirable effects of reduced electrical input for crop lighting, increased biomass produced per $kW.h^{-1}$ consumed, and eliminated premature senescence and abscission of lower leaves that otherwise occurs in closed crop canopies (Massa et al., 2006). Not all effects of using LEDs for sole-source plant-growth lighting have been positive. Some solanaceous and leguminous species develop abnormal intumescence growth on leaves and shoot tips under narrow-band LED lighting (Massa et al., 2008). Such abnormal growth typically does not occur if broad-band light provided to plants includes ultraviolet (UV) wavelengths (Lang and Tibbitts, 1983). It also is promoted by R light and inhibited by FR, so sole-source LED lighting could be either a problem or a solution (Morrow and Tibbitts, 1988).

## NEWLY INITIATED WORK WITH LEDS RELATED TO GREENHOUSE CROP PRODUCTION

Much less is known about effects of LED lighting in a greenhouse setting, where solar radiation provides part or most of the light used for crop production. A multi-institutional group of U.S. researchers working with industrial stakeholders is investigating the feasibility of using LEDs for diverse horticultural lighting applications and evaluating the socio-economic-environmental implications of LEDs entering the greenhouse lighting market. Greenhouse lighting requirements typically fall into three general categories: propagation and transplant production that involve both photosynthetic and photomorphogenic lighting; photoperiodic lighting to induce early or out-of-season flowering; and supplemental lighting to enhance photosynthesis for crop production, especially during light-limited periods of the year. This multi-disciplinary group has been funded by the National Institute of Food and Agriculture Specialty Crop Research Initiative (SCRI) Program for a project entitled *Developing LED Lighting Technology and Practices for Sustainable Specialty-Crop Production.* Institutions involved in the project include the University of Arizona, Michigan State University, Purdue University, Rutgers University, and the Orbital Technology Corporation (ORBITEC). The LED project website can be found at http://leds.hrt.msu.edu/.

**Figure 2. ORBITEC's "Veggie" unit designed to light crops growing on the International Space Station with LEDs. The accordion walls of the unit expand as the crop grows in height to keep the LED light bank a constant distance above the crop.**

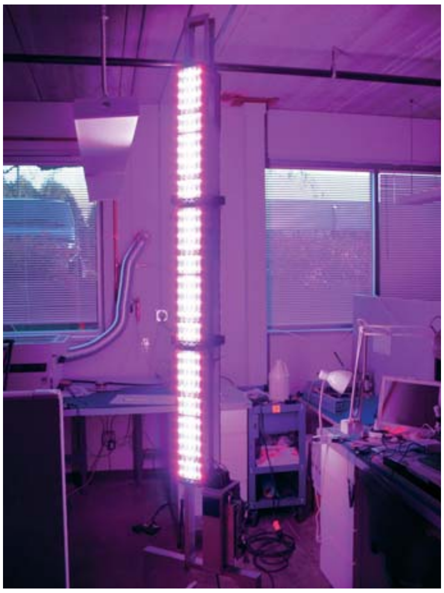


## CUSTOM LED ARRAY DEVELOPMENT

Solid-state lighting devices (LEDs) have electrical, physical, and operational properties not available in existing horticultural lighting that allow new modes of plant lighting to be explored. ORBITEC has been developing custom LED systems for specialty applications such as lighting for space-based plant-growth research (Fig. 2), as well as for ground-based research applications (Emmerich et al., 2004). ORBITEC's role in the SCRI project is to develop and test new designs for LED lighting systems and new techniques for their fabrication that facilitate manufacturability and ease of maintenance, while allowing customization of spectral composition and device configuration. A critical component of this work is to apply fundamental thermal knowledge to improve LED array cooling techniques (critical to device function and operating life) and advanced control systems to improve energy efficiency and crop manipulation capabilities. ORBITEC has fabricated and delivered LED supplemental lighting units to Purdue University for crop-production research. Two lighting configurations have been developed, including distributed horizontal lighting arrays (Fig. 3), and vertical intra-canopy lighting (Fig. 4). These systems allow independent control of R and B LEDs, and the overhead bar systems also are capable of providing FR light. The overhead systems allow maximum passage of solar light between widely spaced bars during the day. Both systems allow exploration of alternative thermal-management systems and

**Figure 3. Mike Bourget, ORBITEC's Electrical Engineering Manager, and Purdue Graduate Student Celina Gomez calibrate red : blue ratio and total photon flux on an overhead open-bar LED array that minimizes shading of solar irradiance throughout the day in the greenhouse.**

**Figure 4. A newly constructed ORBITEC light tower to provide intra-canopy lighting of tall greenhouse crops in two directions within rows. Two-foot-long panels of red and blue LEDs can be switched on or off individually.**



wireless control capabilities that make large-scale use of such systems manageable.

## ORNAMENTAL PROPAGATION

Most herbaceous ornamentals are propagated from seed (plugs) or cuttings (liners) and are considered to be high quality transplants if they are compact, have a thick stem, high root mass, and flower shortly after transplanting (Lopez and Runkle, 2008; Pramuk and Runkle, 2005). In order to reduce propagation and shipping costs, seedlings are grown in dense plug trays that promote unwanted stem elongation due to the shade-avoidance response (caused by low R : FR). In addition, flowering of ornamental bedding plants is influenced by photoperiod and irradiance (Mattson and Erwin, 2005). In northern regions, propagation typically begins in January or February when ambient light levels are low and day lengths are short (Korczynski et al., 2002). This is problematic in that bedding-plant species have different photoperiodic response groups that flower earlier or only under long days (LD). Graduate student Michael Ortiz is evaluating R and FR LEDs as end-of-day (EOD) light treatments to control stem elongation during the seedling stage for potential to reduce time to flower (TTF) of LD species. A long-term goal is to determine species-specific minimum FR light requirements that avoid stem elongation and potentially reduce TTF.

In northern climates, supplemental lighting is required in winter and early spring to produce high-quality transplants (Lopez and Runkle, 2008; Torres and Lopez, 2011; Oh et al., 2010; Currey et al., 2012). This information will help growers reduce their square meter weeks (SMW) and save on energy costs by reducing overall propagation time. Further savings of space and energy may be realized by shorter finishing times for crops propagated using supplemental light to increase the photosynthetic daily light integral (DLI). The objectives of the research of graduate students Chris Currey and Michael Ortiz are to identify the best R : B ratio to reduce propagation time and produce high-quality, marketable bedding-plant plugs and liners (Fig. 5). We postulate that plants grown under LEDs will be comparable in output quality to those grown under high pressure sodium (HPS) lamps as a source of supplemental light. While there are several beneficial plant responses to B light, the level of supplemental B light required to elicit desired responses in combination with ambient solar light is unknown. There exists potential for narrow-spectrum supplemental lighting to control plant growth and development at the young-plant stage for cuttings and seedlings.

**Figure 5. Herbaceous New Guinea Impatiens cuttings being propagated under red + blue supplemental lighting from LEDs. Image was taken after sunset at Purdue University.**

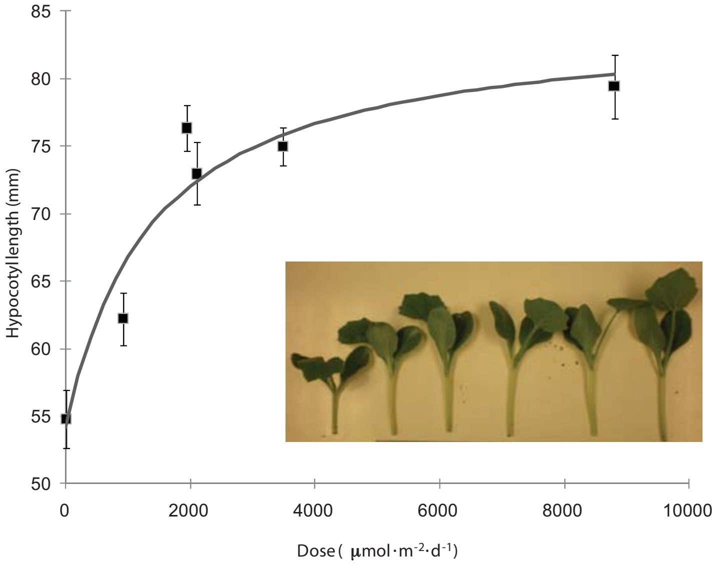
**Figure 6. Young tomato seedlings growing under 80% red + 20% blue supplemental lighting (left) or 100% red supplemental lighting (right) with both treatments at the same total photon flux from LEDs. Image was taken after sunset at Purdue University.**

**Figure 7. Cucumber seedlings growing under red + blue LED lighting after sunset in a greenhouse at the University of Arizona.**

## VEGETABLE PROPAGATION

Supplemental lighting is needed for greenhouse vegetable propagation during winter when DLI is a major factor limiting transplant production. In sunny Arizona and less-sunny Indiana, growth, development, and morphology of tomato and other vegetable transplants are being compared under different R : B ratios of supplemental LED or HID lighting (Figs. 6 and 7). Electrical energy consumption by the two different supplemental lighting sources also is being compared. A preliminary study conducted by University of Arizona graduate student Ricardo Hernandez suggests that R LED supplementation alone is sufficient for growing tomato seedlings under different DLIs in Arizona. A parallel study conducted at Purdue University by graduate student Celina Gomez propagating various cultivars of tomato at

**Figure 8. End-of-day far-red (EOD-FR) light dose-responses of interspecific squash rootstock hypocotyl elongation after ten consecutive days of EOD-FR treatment. Different doses were achieved by combinations of different light intensities and durations (Yang et al., 2012). Seedlings in the inset are aligned in the increasing order of doses from left to right.**



different times of year is defining the spectral and DLI requirements for transplant propagation. Some B supplementation may be needed during the most light-limiting times of year in the cloudier northern climate. In Arizona, a potential low-intensity application of LEDs for EOD lighting is being explored to improve the stem morphology of seedlings (Chia and Kubota, 2010; Yang et al., 2012). The dose of FR needed to induce maximum hypocotyl elongation for grafting is saturated at 2-4 mmol.m$^{-2}$.d$^{-1}$ (Chia and Kubota, 2010; Yang et al., 2012) (Fig. 8). EOD R and FR lighting can be a potential non-chemical means to control plant morphology. EOD lighting with LEDs will allow specific spectral and dose requirements to be defined for FR to extend rootstock hypocotyls for better grafting, as well as to prevent seedlings from becoming too leggy. It also was demonstrated that moving LED fixtures for EOD lighting are as effective as stationary fixtures (Yang et al., 2012).

## ORNAMENTAL PHOTOPERIODIC FLOWERING

Flowering of many specialty crops, especially ornamentals, is hastened under a particular photoperiod (Erwin and Warner, 2002; Heins et al., 1997). To induce flowering for predetermined market dates, photoperiod is commonly modified using low-intensity (photoperiodic) lighting. R and FR are known to influence the flowering of photoperiodic plants, and in some LD plants a minimal amount of FR light is required for the most rapid flowering (Downs and Thomas, 1982; Runkle unpublished). Incandescent lamps have been a common choice to deliver photoperiodic light because of their efficacy and low purchase cost. However, their energy efficiency is very low, they have a short operating life, they emit light that is rich in FR light (which promotes undesirable elongation growth), and are being, or have been, phased out of production. We are developing guidelines for the development and implementation of LED fixtures to deliver photoperiodic lighting to inhibit flowering in short-day and promote flowering in long-day specialty crops. We are testing the hypothesis that LEDs containing R and FR light will be as or more effective than conventional light sources at inducing flowering of plants with a photoperiodic flowering response, while growers will benefit from reduced operating and maintenance costs, increased durability, etc. Experimental LEDs were developed by CCS (Kyoto, Japan) containing different ratios of R and FR, and a number of SD and LD plants are being grown with night-interruption lighting (Fig. 9). Preliminary research conducted by Michigan State graduate student Daedre Craig indicates that flowering is promoted most when night-interruption lighting is provided by both R and FR LEDs; using only R or FR was less effective.

**Figure 9. Bedding plant species receive different red: far-red ratios from CCS experimental LEDs during night-interruption studies of floral induction and development being conducted at Michigan State University.**

## HIGH-WIRE TOMATO PRODUCTION

Overhead supplemental lighting for greenhouse crop production is problematic. For one thing, overhead-mounted HID lighting fixtures including reflectors, lamps, and ballasts block substantial sunlight throughout the day. Thus, a minimum number of high-power HID lighting fixtures typically are installed high above crop canopies to minimize shading and to ensure maximum uniformity of light distribution. HID lamp surfaces are very hot, also requiring considerable separation between lamps and crop surfaces. Equally problematic is that not all greenhouse crops have a low vertical profile. In fact, high-wire greenhouse crops such as tomato, cucumber, or pepper utilize indeterminate cultivars that grow in length throughout production cycles approaching a year. Greenhouses designed to accommodate high-wire crops may exceed 25 ft (7.62 m) in height. High-wire crops are trained to grow up a support line. As fruit are harvested from the bottom of the vine, the lower vine is defoliated and coiled, leaned, or wound to keep the top of the crop at constant height, which is considerably above the greenhouse floor and considerably below overhead HID lamps. Levels of overhead supplemental lighting decline below the top of a high-wire crop due to beam spreading and light absorption by the upper leaf canopy. Another factor contributing to light deficiency in the lower canopy of high-wire crops is that they form tall "hedges" or solid "blocks" of vegetation that shade themselves or adjacent rows as the sun tracks across the greenhouse daily. Intra-canopy lighting has been shown to prevent mutual shading and to enhance the productivity of closed-canopy crops (Frantz et al., 1998, 2000, 2001; Staziac et al., 1998). Because of their relatively cool photon-emitting surfaces, LEDs are amenable for intra-canopy lighting, either as a sole source (Massa et al., 2005a, b, 2006) or for supplemental inter-lighting in the greenhouse (Dueck et al., 2011; Philips, 2011; Trouwborst et al., 2010). For the SCRI project, vertical LED light towers straddling troughs within rows of high-wire tomato irradiate R + B light in two directions within and along rows populated by tomato plants (Fig. 10). The ORBITEC light towers have LED panels that switch on (or off) incrementally with independent control of R and B LEDs. Research by graduate student Celina Gomez is underway at Purdue University to investigate effects of R : B ratio, DLI, cultivar, and time of year on yield and fruit quality of high-wire tomato grown with LED vs. HPS light supplementation.

## ECONOMIC ANALYSIS / LIFE-CYCLE ASSESSMENT

Even with mounting evidence that there are technical advantages to using LEDs for specialty crops, there are significant unknowns that could affect LED viability or rates of adoption. Using INC or HID lighting is a known practice with much history. There is little risk of adopting these technologies (other than the fact that INCs are disappearing) as they are known to work successfully. LED technology is still maturing. There are unknowns regarding dominant design, parameters of use, mix of wavelengths, effects upon crop yield and quality, capital investment, and subsequent return on investment. The intent of the current effort is to determine usage scenarios that are economically viable and which permit risk-adjusted, positive economic value added. These scenarios will take several forms. LEDs could be used to supplement current systems to better control plant growth and improve value. This could mean that LEDs either lead to improvements in plant value itself or improvements in supply chain such as better control of flowering during the wholesale and retail stage. It also is possible that LED systems could fully replace current systems. Replacement represents risk in that it is a large departure from current industry norms and ignores the large sunk cost of current systems. This scenario of replacement of current practice to LED is much more likely only after the usage science of LEDs is better developed and as manufacturing cost of LED systems is reduced. Further, industries such as specialty crop production, which operate on thin margins and low free cash flow, are relatively intolerant of financial risk. Yet, the better we understand the benefits and pitfalls, the more incentive there may be to drive LEDs into practice. We must be cautious to understand the total life cycle impact of new products and processes. A positive economic driver in use could be nullified if there was a negative effect economically at the end of the product's life cycle, a negative environmental effect, by-product, or side effect.

**Figure 10. The young tomato plants in the foreground are receiving supplemental side lighting from LED towers during the cloudy days of January in Indiana. Only the lowest LED panel is energized while the plants are small to save electrical energy. Unlighted control and HPS-supplemented plants are being grown for comparison in the background.**

## BEST MANAGEMENT PRACTICES AND STANDARDS FOR LEDS IN THE GREENHOUSE INDUSTRY

Parallel to the development and testing of LED lighting prototypes, we plan to develop Best Management Practices (BMPs) and design and operating standards. BMPs are a set of evaluation tools that growers can use to assess, implement, and operate LED lighting systems. The assessment of LED lighting systems for a particular application should include an evaluation of crop needs, installation requirements and constraints, and an economic analysis that includes, for example, installation and operating costs and a return on investment analysis. BMPs are often based on experiences gathered over longer periods of time and by a multitude of users. Since LED lighting systems are relatively new to the green industry, the BMPs will initially be largely a set of dynamic evaluation tools that will go through multiple iterations before they will be widely adopted by the industry. Additionally, LED lighting standards for the green industry can be useful for both growers and manufacturers. Standardized features will allow for more easy application in a wide array of situations and crops, as well as provide design guidelines for manufacturers and installers. Such standards cover not only operating specifications (e.g., energy consumption and efficiency, power supply, light intensity and distribution, spectral output, color rendering, cooling requirement, control strategy, life expectancy), but also manufacturing specifications (e.g., component materials used, lens shape, beam angle, manufacturing tolerances), mounting specifications (e.g., distance, pattern, wiring, serviceability), and other specifications (e.g., the degree of light pollution, psychological impact of different color schemes on workers). Plant growth facilities are typically humid environments, and occasionally chemicals are used to control diseases and pests. Therefore, it is likely that LED systems used for plant lighting will require special design features that should be captured in the proposed standards. Like the proposed BMPs, the new LED lighting standards are intended to aid the industry-wide adoption process.

## THE FUTURE OF LED HORTICULTURAL LIGHTING RESEARCH

Anticipated technology advancements should continue to make LEDs more electrically efficient and robust over time. UV and FR-emitting LEDs should be among the types improved in efficacy, as well as LEDs emitting maximally at wavelengths corresponding to peak absorbance by major plant pigments. Adaptive control systems will be developed, including use of sensor feedback providing information regarding ambient solar light conditions at different times and locations in the greenhouse. Such data will trigger switching and/or dimming systems so that greenhouse LED supplemental lighting can occur where, when, and to the extent needed at any given time. Adaptive control of DLI needs to respond to seasonal, daily, and momentary swings in solar availability. As well, physical configurations of LED lighting systems for greenhouses need to be optimized for intra-canopy and overhead light distribution. Waste-heat-distribution systems will be refined to direct heat into crop canopies when desired or reject it from greenhouses as needed. Power systems also will be improved for greater efficiency.

Horticultural research is needed to optimize wavelength and intensity of LED supplemental lighting needed for a range of important plant responses at various stages of crop development. Researchers will use targeted lighting to enhance crop timing, yield, and specific responses such as antioxidant content, organoleptic and ornamental quality, and post-harvest shelf life. LED technology also will be applied in horticultural facilities used for propagation, graft healing, sorting, and grading of harvested products. LEDs would appear to have a very bright and colorful future in commercial controlled-environment agriculture.

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# Chronica Horticulturae
# Author Information

*Chronica Horticulturae* is the quarterly publication of the International Society for Horticultural Science (ISHS) and is received by all members of the Society and numerous libraries throughout the world. Members and non-members are urged to contribute articles for consideration. However, it needs to be understood that *Chronica* is not to be construed as a scientific journal that publishes original research. Research articles appropriate for *Acta Horticulturae* or horticultural science journals are usually inappropriate for *Chronica*. We seek horticultural articles of interest to a broad audience composed of ISHS members and the horticultural, scientific, and academic communities.

*Chronica Horticulturae* is currently made up of as many as eight sections as follows:

**News & Views from the Board.** This section is usually confined to editorials from Board Members as well as general announcements of the Society.

**Issues.** Articles of a broad focus that often involve controversial topics related to horticulture, including broad social issues and economic development, are appropriate for this section. These articles are intended to stimulate discussion. Often, guest writers are asked to contribute articles.

**Horticultural Science Focus.** This section is intended for in-depth articles on a topic of horticulture, generally, but not always, scientific in nature. Many articles are mini-reviews, and bring current topics of interest to the horticultural community up to date. We encourage these articles to be illustrated.

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**The World of Horticulture.** This section highlights articles on horticultural industries and research institutions of particular countries or geographic regions throughout the world. They are meant to be profusely illustrated with figures and tables. This section also includes book reviews, which are requested by the Science Editor. Members who wish to recommend a book review should arrange for a copy of the book to reach the Secretariat.

**Symposia and Workshops.** Meetings under the auspices of ISHS are summarized, usually by a participant of the meeting. These articles are delegated by the symposium organizers.

**News from the ISHS Secretariat.** This section contains information on membership, memorials for deceased ISHS members, and a calendar of ISHS events. Brief memorials (up to 500 words) should be sent to the Secretariat.

Authors who wish to contribute articles for *Chronica* should contact headquarters and their request will be transmitted to the Science Editor or another appropriate editor. Authors should be aware that most articles should have a broad international focus. Thus, articles of strictly local interest are generally unsuited to *Chronica*. Illustrated articles are usually 1500 to 5000 words. There are no page charges for *Chronica Horticulturae*. Photographs submitted should be of high resolution. We encourage electronic submission. Send articles or ideas for articles to:

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