NASA LEADS THE WAY WITH LEDS

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Carl Wilhelm Siemens coined the term 'electro horticulture' in the 1980's to define this application of electric lamps and postulated that "the horticulturist will have the means of making himself practically independent of solar light for producing a high quality of fruit at all seasons of the year" (1881). A decade later, the great horticulturist Liberty Hyde Bailey wrote "There is every reason, therefore, to suppose that the electric light can be profitably used in the growing of plants" and concludes with "On the whole, I am inclined towards Seimens view that there is a future for electro-horticulture" (Bailey, 1891). Both these predictions have been realized, with supplemental lighting being routinely used in commercial greenhouse production worldwide to promote growth and extend daylength.

A century later, the National Aeronautics and Space Administration's (NASA) funded scientists grew a number species under low output red (~660 nm) LEDs as lighting sources: findings which resulted the first plants to be grown in space under LEDs in 1994. NASA has continued to incorporate LED's and is currently has VEGGIE onboard the International station for production of leafy greens.

In preparation for human colonization of space, NASA beginning integrating a food production system for production of continuously produced fresh vegetables to increase the quality of crew diets. This operational system is required to fit into an existing habitat, and not interfere of ongoing work, science and living operations. Various designs were incorporated in the NASA's Deep Space Habit and deployed at NASA Desert Research and Technology Studies (DRATS) test site. A design of automated watering, and LED lighting were incorporated into an atrium area between the laboratory and living modules and mizuna, lettuce, basil, radish and sweet potato grown, with eating the radishes and leafy greens.

Fig. 1. International Space Station crew member, Dr. Steve Swanson tending the Vegetable Production System (Veggie) on ISS during Expedition 40. Veggie is a plant growth system installed on ISS which uses a LED lighting system that is designed to produce salad-type crops to provide the crew with fresh food while on orbit. (Photo courtesy of NASA Public Affairs Office).

In addition to developing specialized lighting system for space flight, NASA funded research in both public and private sector have advanced the understanding of the narrow spectrum lighting on plant performance, and provided scientific and technical basis for commercial development of the technology. This has included requirements for blue light, beneficial effects of green light, and increasing concentration of bioactive compounds.

(Figure 4; Effect of light quality on anthocyanin in lettuce)

These early findings from NASA have since been demonstrated in a number of species, including lettuce, kale, broccoli, strawberry and tomato and specialized spectra are being developed to increase the antioxidant and nutritional content of horticultural. LED lighting is being shown to be a valuable management tools in production of ornamental species during tissue culture, vegetative and seed propagation as well as manage the morphology of seedlings, transplants, and grafted seedlings.

The publication of results from NASA funded research in 1989 signaled the beginning of an exponential increase research reports on use of LEDs horticulture. Figure 1 illustrates the exponential increase in research for the 25 year period from 1990 to 2015 using criteria {"Light emitting diodes" and 'Horticulture" on scholar.google.com accessed 14 July, 2014} returned 102 items (journals articles, patents, journal citations) in the five years (1990-1995) following the first reports of successful growth of plants under red LED's. A decade later (2001-2005) the same search criteria returned 1,130 results, a 10-fold increase, and it's on track to approach 10,000 articles, or over 2000/year, for the period from 2011 to 2015!

(Figure 5, publication of LED related research)

Concurrent with increase in research, increased access to the internet has arguably driven the proliferation of research reports, field observations, and user experiences with LEDs being distributed to scientists, hobbyists, commercial growers, lighting manufacturers and distributors. The amount of publically available information available is staggering. A search (www.google.com accessed 14 December, 2014) of "LED Lighting" resulting in an estimated 32,500,000 web pages!

The sheer volume of information indicates that research on LEDs and plant growth, both professional and amateur, is being widely-distributed and presumably informing decision makers on the selection and use of LEDs in horticultural production. The explosion in information also presents a unique challenge to end users to accept the risk that misinformation is being perpetuated and acknowledge their responsibility to critically review information retrieved from online sources.

NASA supported research use of LEDs to grow plant in space in the late 1980's laid the groundwork for the

Fig. 2. NASA's Deep Space Habitat Module on location for field testing in Arizona Desert. A food production system was integrated as an atrium between the living (upper) and working (lower) areas.

Fig. 3. Wide angle view of NASA's Habit Demonstration Unit work laboratory showing effect of red/blue LED's positioned in plant atrium.

industry-wide transition from gas-discharge lamps developed in the 19th century to LED lighting. Research, government policy and information technology has resulted in an exponential increase in research into the use and application of LED technology in horticulture over the past 25 years. This research has identified many opportunities for LED lighting to optimize light spectra to promote growth, regulate morphology, increase nutrient content, and reduce operating costs in commercial horticulture. NASA's support of LED-light technology is continues to enabling the development of innovative lighting systems for production of edible, ornamental and medicinal plants.

Conclusion

The use of LEDs to support plant growth is a radical departure from traditional gas-discharge lamps developed in the mid-19th century and refined throughout the 20th century. The initial investments by NASA in solid state lighting research is enabling improved energy efficiency, reduced operating and management costs, and enhanced quality for traditional commercial crops, and are being widely adopted by emerging high value medicinal plant production and supporting the production of food in space. The adoption of this NASA technology holds great promise for the future of commercial horticulture as management tool for the production of high quality, high value products.

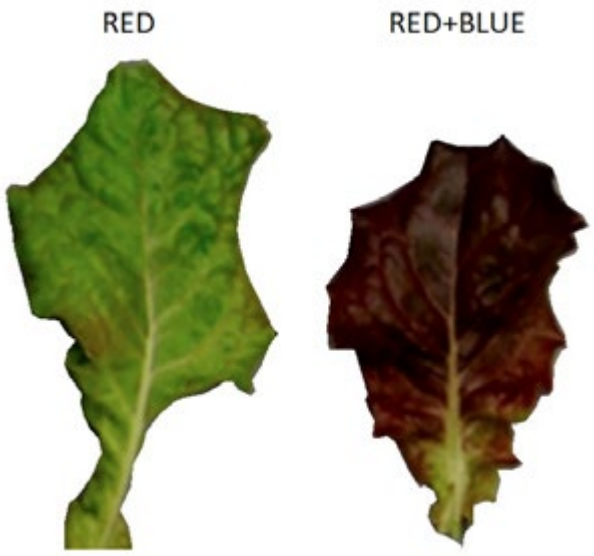

Fig. 4. Addition of blue light during results in higher concentration of anthocyanin in Lactuca sativa cv. Outredegous. Leaves were harvested 28 days after plants were grown at 280 µmol m-2 s-1 PAR under monochromatic 640 nm red LED (Red) or under red light with an additional of 20 µmol m-2 s-1 PAR 440 nm blue from day 21-28 (Red and Blue). (Adapted from Stutte et al., 2009).

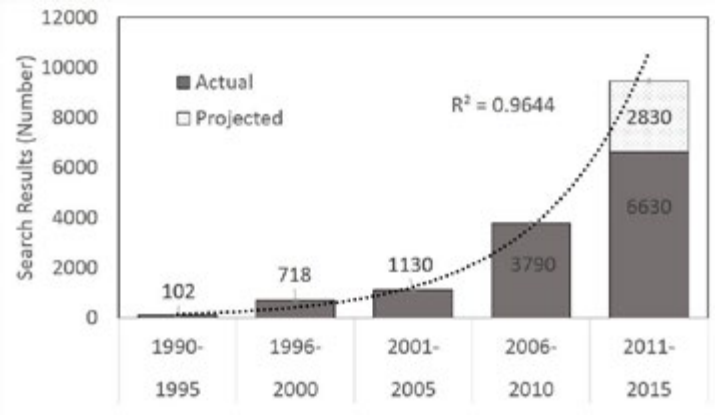

Fig. 5. Results from internet search of scholarly articles (scholar.google.com), using key words "Horticulture" and "Light Emitting Diodes". The search results include peer-reviewed papers, theses, books, abstracts and technical reports from a broad range of disciplines. The number of citations from 2015 was projected based on previous year's rate of increase. No categorization of results has been performed (Stutte, HortScience, 2015 (in press).

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