Effect of Temperature on the Floral Development of Blueberries (Vaccinium corymbosum L.)

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The United States is the largest producer of blueberries in the world with a production value of almost $800 million. Blueberries are an economically important crop that is dependent on pollinators for fruit set. The primary role of a flower is to attract pollinators. The longer flowers remain open there is an increased likelihood that pollinators will visit the flower and pollinate them. Studies on flower longevity have focused mainly on floriculture crops, despite the dependence of fruit production on successful pollination of viable flowers. Changes in climate have yielded warmer temperatures impacting flower development and activity of pollinators, potentially decreasing fruit yield. In this study the effect of temperature on floral development was investigated. Two cultivars of highbush blueberry (Vaccinium corymbosum L.) 'Blueray' and 'Jersey' were grown at five temperatures 18, 20, 23, 28, and 31 °C under natural irradiance in a greenhouse. Floral longevity and number of floral clusters were measured in addition to the rate of development from bud stage through senescence. Open flowers were first observed on plants grown under 28 °C and last under 18 °C. Plants grown under 20 and 23 °C had the greatest number of flowers. Almost all floral clusters of both cultivars aborted when grown at 31 °C. Our data suggested that even small changes in temperature could negatively affect floral development. Lack of synchronization between flowers and their pollinators could disrupt the plant-pollinator relationship, resulting in severe reduction of blueberry production.

Challenge of Greenhouse Model on High Tunnel Temperature Prediction

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High tunnels (HTs), also known as hoophouses, are becoming popular for growing season extension. Although they have been practiced for a long time, there are increasing interests on maximizing growing season extension and effective microclimate management. Therefore, this research aimed to develop a tool to assist growers on their cultivation planning by predicting potentially the longest allowed growing period and alerting growers on abnormal temperature change throughout growing season. This research intended to evaluate feasibility of an existing greenhouse model for HT application. To evaluate suitability of the model, a data acquisition system was set up to collect aerial and soil information, and the challenges of adaption were documented. A preliminary experiment showed that ground absorption of solar radiation affected HT's temperature prediction. Without considering energy reduction due to ground absorption, major error occurred during day time, when radiation was rising and ground was absorbing heat. A significant improvement on day time prediction was found when a partial of HT's measured net radiation was reduced using regression analysis. In conclusion, the greenhouse model has limited application that is suitable for night time and sunset, when ground was not absorbing heat. Ground effect on rising and high radiation time has to be addressed, such as including soil thermal effect model.

Light intensity and temperature effects on the regrowth of newly-grafted tomato plants in growth chambers

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Grafting successfully and efficiently requires levels of light, temperature and humidity that promote vascular reconnection and plant growth. Tomato plants are routinely grafted successfully in practice; however, it may be possible to further optimize the process with a heightened understanding of the separate and interactive effects of key environmental variables on healing as measured by plant growth. Therefore, we completed a study involving four levels of light intensity and temperature. All newly grafted plants, regardless of light-temperature treatment, were held at standard levels of relative humidity based on time after grafting (90%, 80% and 60% beginning at Days 0, 7 and 10, respectively). Three week-old ‘Cherokee Purple’ and ‘Maxifort’ tomato seedlings were splice-grafted and placed in two growth chambers, each illuminated with one Metal Halide 400 Watt lamp and one High Pressure Sodium 400 Watt lamp for 12 hr each day. One growth chamber was set at 30/25 °C and the other at 25/20 °C. Two zones differing in light intensity (50 and 150 $\mu mol/m^2/s$) were created in each chamber using plant distance from the chamber lamps and open frames covered with black, knitted shade cloth. The study employed a split-plot design (temperature as main plot, light as subplot) and was repeated three times April-May, 2015. Temperature alone did not affect healing variables but light alone did. Also, the light by temperature interaction was often significant. Leaf fresh and dry weight, stem fresh and dry weight, total plant and scion length, scion stem diameter and compactness were greater under higher light intensity, while specific leaf area was less. Increases in four variables (leaf and stem fresh weight, total plant and scion length) following exposure to 150 $\mu mol/m^2/s$ were greatest at 30/25 °C. The effect of light intensity on leaf area reversed with temperature. At 30/25 °C, leaf area was greatest at 150 $\mu mol/m^2/s$. However, at 25/20 °C, leaf area was greatest at 50 $\mu mol/m^2/s$. These results suggest that the conditions under which newly grafted tomato plants are healed warrant further study since increased efficiency and broadening these conditions may be possible.

Using Light to Manipulate the Nutritional and Sensory Properties of Greenhouse Tomatoes with LED and HPS Fixtures

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Purdue University

Greenhouse tomatoes tend to have a reputation of inferior nutritional and sensory quality compared to their field-grown counterparts. It has been long known that light is a critical mediator of secondary metabolism in plants; signaling the production of nutritionally important phytochemicals and regulating the emission of volatile organic compounds that can alter the sensory perception of a tomato. By leveraging photobiological principles, we are using supplemental light from high-pressure sodium lamps as well as light-emitting diodes (LEDs), including research-grade fixtures and Philips interlighting fixtures, to determine the effects of light on the fruit quality of greenhouse tomatoes. We hypothesize that enriching the amount of blue light tomatoes receive will positively impact the amount of carotenoids and phenolic compounds that accumulate in tomato fruits through cryptochrome and/or phototropin-dependent signaling pathways. We also hypothesize that unsupplemented controls will be nutritionally inferior to their supplementally lit counterparts. To test these hypotheses, tomato fruits were subjected to a battery of physicochemical metrics that include total soluble solids, citric/ascorbic acid content, pH, and electrical conductivity. Additionally, phenolic compounds were quantified using the Folin-Ciocalteu method in addition to a more targeted approach using HPLC-ESI(-)-MS, which was used to quantify specific flavonoids in fruit tissues, such as Quercetin-3-O-rutinoside. Lycopene and β-carotene were quantified spectrophotometrically. Lastly, consumer sensory panels were used to assess the impact of supplemental light quality on the flavor and overall perceived quality of tomato fruits.

Evaluation of silicon as a nutrient solution supplement for downy mildew control in hydroponic basil production

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Basil (Ocimum spp.) is a member of the mint family, and is the most important annual culinary herb consumed in U.S. [1]. First reported in 2007, downy mildew (Peronospora belbarhii) has rapidly become a serious foliar disease in basil production across the U.S. Many sweet basil cultivars demonstrate strong susceptibility to downy mildew [2]. Adding silicate ions (SiO_3^{2-}) to the nutrient solution has been shown to increase yield and quality of various crops. In addition, silicate has shown efficacy at controlling fungal disease such as downy mildew [3]. This study aimed to evaluate silicon as a nutrient solution supplement for downy mildew control in hydroponic basil production. In addition, physiological effects of the silicate treatment were evaluated. Using a nutrient solution amended with 50 ppm potassium silicate, basil plants were grown for 30 days in a deep trough hydroponic system. The plants showed a significant increase of shoot biomass and plant height. When inoculated with downy mildew spores, silicate treated basil showed a decrease in disease incidence and severity. In summary, the experiments confirmed that adding potassium silicate to the nutrient solution used for growing hydroponic basil increased plant growth and reduced downy mildew disease.

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Moderate-intensity Blue Radiation as a Night Interruption Can Regulate Flowering of Photoperiodic Ornamentals

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When the photoperiod is naturally short, lighting at the end of a day (day extension, DE) or during the middle of a night (night interruption, NI) can regulate flowering of photoperiodic crops. A low intensity (1–2 $\mu mol \cdot m^{-2} \cdot s^{-1}$) of red (R; 600–700 nm) and far-red (FR; 700–800 nm) radiation controls flowering of a wide range of plants, whereas low-intensity blue (B; 400–500 nm) radiation generally does not. However, the effects of moderate-intensity (up to 30 $\mu mol \cdot m^{-2} \cdot s^{-1}$) B radiation, alone or when added to R and FR radiation, on flowering and photomorphogenesis have not been fully elucidated. We grew five long-day plants [calibrachoa (Calibrachoa × hybrida), coreopsis (Coreopsis grandiflora), petunia (Petunia × hybrida), rudbeckia (Rudbeckia hirta), and snapdragon (Antirrhinum majus)] and two short-day plants [chrysanthemum (Chrysanthemum × morifolium) and marigold (Tagetes erecta)] at a constant set point of 20 °C under a 9-hour short day with or without 5.5-hour DE and/or 4-hour NI lighting from light-emitting diodes in a controlled-environment research greenhouse. B radiation was delivered at 0, 1, 15, or 30 $\mu mol \cdot m^{-2} \cdot s^{-1}$, in most cases with R+white (W)+FR radiation at 2 $\mu mol \cdot m^{-2} \cdot s^{-1}$ between 400 and 800 nm. The peak wavelengths of B, R, and FR radiation were 450, 666, and 738 nm, respectively. In most crops, B radiation at 30 $\mu mol \cdot m^{-2} \cdot s^{-1}$ created a long day as effectively as R+W+FR radiation. Flowering of calibrachoa and petunia was 2–4 days earlier, and flowering of chrysanthemum was 11 days later, when B radiation at 30 $\mu mol \cdot m^{-2} \cdot s^{-1}$ was added to R+W+FR radiation. For all crops except rudbeckia and marigold, an NI was more effective than a DE. Rudbeckia and chrysanthemum were 14–19% and 22–36% shorter, respectively, at flowering under B radiation at 30 $\mu mol \cdot m^{-2} \cdot s^{-1}$ than under mixtures of B and R+W+FR radiation, but there were few or no height differences among treatments in other crops. We conclude that an NI with moderate-intensity B radiation is usually as effective as an NI with low-intensity R+W+FR and in some cases, the additional B radiation can create a stronger long-day response.

Engineering modeling and analysis to develop sustainable mushroom production systems in semi-arid climates

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University of Arizona

The popularity of specialty mushrooms, such as shiitake and oyster mushrooms, has increased significantly since the 1980s and commercial efforts have increased to meet the demand. A substantial amount of mushroom production comes from more mild, wet climates (such as Pennsylvania), while potential feasibility of mushroom production in semi-arid climate is still unknown. To better understand the resource use efficiency and basic design requirements of controlled environment mushroom production systems in semi-arid climate, an initial steady-state analysis of energy, CO_2 and water balances of a selected production system was completed. The energy and mass balance models developed for the analysis allowed estimation of the necessary ventilation rate to maintain the CO_2 concentration below the critical point 500 μmol mol^{-1} for a given system size and production scale (e.g., 14.6 m^3 m^{-2} h^{-1} for a system volume of 150 m^3 with 460 kg mushroom-substrate mixture mass). The electrical energy and water consumption was also determined in respect to the outdoor seasonal climate changes, in order to maintain a desired air temperature and vapor pressure deficit suitable for different production stages of oyster mushroom. Currently, the internal system air properties are being evaluated as a valuable resource for a plant production system, when integration of mushroom and plant production systems is intended for enhancing the resource and energy use efficiency of both systems. If particular combinations of mushroom house and greenhouse are successful at steady-state conditions, then dynamic modeling and simulation methods will be used to gain further insight into the behavior of these integrated systems.

Re-examining photoperiodic flowering responses of American strawberry cultivars

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Time to flower is critical in fruiting crop production and is regulated principally by photoperiod and temperature. In US, where most strawberries are produced in open field, precise experiments evaluating photoperiodic flowering responses of American strawberry cultivars have not been conducted. Strawberry cultivars are classified into 3 groups: June-bearing (short-day), ever-bearing and day-neutral based on field performances and/or genetic background. For developing off-season strawberry production in greenhouses under different climate conditions, is required to re-examine photoperiodic responses of commercially important cultivars in the US. Following a methodology applied for herbaceous perennial crops (Heins et al., 1997) we examined flowering responses of strawberry under varied photoperiods. June-bearing plants were grown under non-flowering long-day conditions (16 h photoperiod) and then subjected to 8 h, 10 h, 12 h, 14 h or 16 h photoperiod for 8 weeks. Ever-bearing and day-neutral cultivars will be grown under short-day conditions (8 h photoperiod) before treatments. Photoperiod was created by extension lighting inside growth chambers after 7 h of natural light in greenhouse. The light source was a LED flowering lamp (Pfr/Ptotal = 0.66; GreenPower LED flowering DR/W/FR E26, Philips, the Netherlands) and the biological active radiation (BAR, 300-800 nm) over the plant canopy was adjusted at 2±0.5μmol m-2 s-1 inside the growth chamber controlled at 14±0.39°C air temperature. Flower development were observed weekly and a dissection microscope was used to classify apical meristems into different developmental stages after 8 weeks. Reference cultivars, 'Nyoho' and 'Tochiotome', were used to validate this methodology and flowering responses. Results showed significant difference in apical meristem stage of development ($p < 0.0001$) between the short-day treatments (8 h and 10 h photoperiod) and long day treatment (16h), where 100% of meristems where determined as vegetative. Presented methodology can be applied to re-evaluate American strawberry cultivars.

Daily light integral and light quality from sole-source light-emitting diodes impact growth, morphology, and relative chlorophyll content of Brassica microgreens

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Multi-layer vertical production systems using sole-source (SS) lighting can be used for microgreen production; however, traditional SS lighting can consume large amounts of electrical energy. Light-emitting diodes (LEDs) offer many advantages over conventional light sources including: high photoelectric conversion efficiencies, narrow-band spectral light quality, low thermal output, and adjustable light intensities. The objectives of this study were to: 1) quantify the effects of SS LEDs of different light qualities and intensities on the growth, morphology, and relative chlorophyll content of Brassica microgreens; and 2) quantify the electrical energy required to operate SS LEDs of different light qualities and intensities. Purple kohlrabi (Brassica oleracea L. var. gongylodes), mustard (Brassica juncea L. Czern. 'Garnet Giant'), and mizuna (Brassica rapa L. var. japonica) were grown in hydroponic tray systems placed on multi-layer shelves in a walk-in growth chamber. A daily light integral (DLI) of 6, 12, or 18 $mol \cdot m^{-2} \cdot d^{-1}$ was achieved from SS LED arrays under a 16-h photoperiod with light ratios (%) of red:green:blue 74:18:8 (R_{74}:G_{18}:B_8), red:blue 87:13 (R_{87}:B_{13}), or red:far-red:blue 84:7:9 (R_{84}:FR_7:B_9) with total photon flux (TPF) from 400 to 800 nm of 105, 210, or 315 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Regardless of light quality, as the DLI increased from 6 to 18 $mol \cdot m^{-2} \cdot d^{-1}$, hypocotyl length decreased and percent dry weight increased for kohlrabi, mustard, and mizuna microgreens. With increasing DLI, leaf area of kohlrabi also generally decreased and relative chlorophyll content increased. Additionally, regardless of light quality, as DLI increased, electrical energy consumption progressively increased. The results from this study can help growers select light qualities and intensities from SS LEDs to achieve preferred growth characteristics of Brassica microgreens.

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Precise irrigation of greenhouse crops based on plant water needs not only allows for optimal plant growth, but also conserves water and alleviates environmental pollution from fertilizer and pesticide runoff. A thorough understanding of crop-specific water requirements is essential for more efficient irrigation. However, plant water use changes on a daily basis, driven by variations in environmental conditions as well as increases in plant size over time. While environmental conditions are relatively easy to measure, direct determination of plant size is often destructive and time consuming. Remote sensing of vegetation indices, such as the normalized difference vegetation index (NDVI), provides a continuous and non-destructive method to estimate canopy size for use in water use models. The objective of this study was to develop quantitative models that predict daily water use (DWU) of four bedding plant species based on environmental factors and NDVI, a proxy for plant size. In addition, we also wanted to determine the feasibility of using NDVI in place of 'crop coefficients' (the ratio of crop DWU to reference evapotranspiration) that are commonly used in agronomic applications. NDVI was highly correlated with plant growth, especially during plants' vegetative growth. However, as flowers reflect light at the wavebands of interest (centered at 650 nm & 810 nm) differently from green leaves, NDVI measured from a red-flowering petunia cultivar – 'Dreams Red' – declined gradually when flowers started to form and shade the leaves. Crop coefficient increased linearly over time as plants grew, but NDVI increased quadratically with increasing crop coefficient, indicating decreased sensitivity of NDVI to increasing plant size. Nevertheless, a multiple linear regression model developed using reference evapotranspiration and NDVI explained 87% of variation in DWU of petunia 'Tidal Wave Cherry', suggesting that NDVI may be used as a reliable proxy for plant size.

Brian Poel, Erik Runkle
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In temperate climates, seedlings are often grown in controlled-greenhouse environments under supplemental lighting (SL) during the winter to increase plant quality. During this period, a low mean daily light integral (DLI) causes a reduction in seedling quality and increases time to transplanting. To increase the DLI, SL is usually provided by high-pressure sodium (HPS) lamps, but the spectral output of light-emitting diodes (LEDs) can be modified to match wavelengths efficient in photosynthesis, morphological signaling, or both. Previously red and blue light have been identified as the most effective for SL, but increasing research shows other wavebands can also promote photosynthesis and regulate plant development. LEDs have the potential to replace HPS fixtures in greenhouse crop production because they can more efficiently deliver the key wavelengths, have increasing energy efficiency, and an increased lifespan. During my graduate research, I am investigating the responses of a range of annual seedlings under red, blue and white (broad spectrum) LEDs applied as SL in controlled greenhouse environments. Four types of LED fixtures containing red+blue or red+blue+white light, or HPS lamps, are delivering SL at 90 µmol·m-2·s-1. Greenhouse temperature is controlled at 20 °C and quantum sensors and infrared thermocouples are measuring incident radiation and canopy temperature under each lighting treatment. After growing seedlings under the treatments for 4 to 5 weeks, we will measure parameters that describe seedling quality (e.g., plant height, leaf area, and shoot and root mass) and determine the applicability of these lighting fixtures for use in high-value seedling production in greenhouses.

Naturally Ventilated Augmented Cooling (NVAC) Greenhouse: A Greenhouse Design for Tropical Climates in the Caribbean.

Lucas McCartney, Mark Lefsrud
McGill University

Greenhouses create an optimal growing environment for crop and protect crops from pests. To achieve this, traditional tropical greenhouse designs utilize a standard fan ventilation system to decrease temperature and provide fresh air. Such fans are energy intensive and are prone to failure in storms making them not suitable for tropical locations. The proposed solution is a natural ventilation augmented cooling greenhouse (NVAC greenhouse). A NVAC greenhouse is an arched, open-roof airflow design improved by coupling natural ventilation with controlled aeration using a water misting system. The misting system runs just below the roof-ridge, where uprising warm air meets incoming fresh air. A internal, third roof, was constructed below the higher of the half roof, leaving a space between the end of the third roof and the side wall. The misting system produces a fine mist causing the air to cool and flow down along the third roof into the lower space of the greenhouse. Three prototypes were built at the Macdonald Campus of McGill University in Montreal and a commercial sized and fully functional prototype was built in Trents, Barbados. Temperature, relative humidity and solar radiation sensors, placed in key areas throughout a NVAC greenhouse prototypes, provided data to detect air movement and cooling. At least 2°C of cooling compared to non-misting conditions was observed in the greenhouse at the time of highest solar radiation (11:00am-3:00pm) on the warmest (>30°C) days of 2012 and 2013 at the Macdonald Campus of McGill University. At least 2°C of cooling compared to non-misting conditions was observed in the greenhouse in Barbados with the system running at 15-minute intervals. Such results were obtained by comparing outside temperatures to inside temperatures with the misting system functional and then with the system nonfunctional.

Chase Snowden, Bruce Bugbee
Utah State University

The relative quantum efficiency curve indicates that red light (RL) is more efficient than blue light (BL) and green light (GL) in driving photosynthesis. However, this curve was measured with single leaves at low photosynthetic photon fluxes (PPFs) and therefore may not be representative of whole plants or plant communities grown at high PPFs. It also indicates only the photosynthetic efficiency and not the combined effects of photosynthesis and development. The optimal combination of wavelengths of light (spectral quality) is thus not well characterized. Eight light spectra at two PPFs were examined for their effects on growth and development of six crops. Spectra were differentiated on a percent BL basis ranging from 0 to 100 percent BL. Our results indicate that broad spectrum light sources with varying amounts of BL significantly affect growth in the crops tested, especially at higher PPF. Tomato, cucumber, radish and pepper had significantly decreased dry mass, leaf area index and stem length as BL increased. Chlorophyll, however, significantly increased with increasing BL for these crops. Results were also looked at on a GL basis and produced similar findings. Collectively, these results indicate that plant growth and development are affected by complex interactions between spectral quality and chlorophyll production that indicate there is an optimal chlorophyll to BL ratio that if surpassed could indicate that energy produced by photosynthesis is used for plant functions other than growth.

Optimizing Poinsettia (Euphorbia pulcherrima) Production by use of Reduced Finish Temperatures and Bench-Top Root-Zone Heating

M. Olberg and Roberto G. Lopez
Purdue University

Greenhouse heating is an essential aspect of holiday poinsettia (Euphorbia pulcherrima) production, especially during the finish stage. Previous studies have shown that cultivars with early response attributes (initiation to finish in 6 to 8 weeks), moderate to high vigor, and naturally large bracts are most suitable for reduced finishing temperatures (RFT). We postulate that RTF in combination with root-zone heating (RZH), can further reduce energy use. The objective of this study was to quantify how RTF in combination with bench-top RZH influences height, bract area, and marketability of six red poinsettia cultivars. Rooted cuttings of poinsettia 'Early Prestige Red', 'Prestige Red', 'Premium Red', 'Infinity Red', 'Viking Red', and 'Bravo Bright Red' were transplanted and grown at day/night temperature of 24/19 °C (12 h/12 h) until 15 Oct. and under a 16-h photoperiod consisting of natural daylengths with day-extension lighting until 1 Oct. On 15 Oct., the air temperature was reduced to 19/13°C [8 h/16 h; (0800 to 1600 HR)] and plants were placed on a bench without RZH (ambient), or with RZH set points of 21, 24, or 27 °C; or plants were moved to a greenhouse without RZH and an air temperature set point of 21 °C (commercial control). Significant differences were observed for time to marketability and anthesis, root to shoot ratio, height, and growth index. Time to marketability was reduced when plants were finished on RZH temperatures of 24 and 27 °C, and plants were generally larger than those on RZH temperatures of 21 °C or without RZH. This suggests that air temperatures during the finish stage can be further reduced when RZH is utilized.

Lance Stott, Bruce Bugbee
Utah State University

Moderate water stress of high value tree fruit crops results in higher fruit sugar content, but a reliable indicator of tree water status is required before precision water stress can be used. Measurements of soil moisture are unreliable because of the deep and extensive root systems of trees. Pressure bomb measurements of stem water potential are reliable, but are labor intensive and cannot be automated. Infrared measurements of leaf-air temperature differences are only partly effective. Inserting soil water content sensors into fruit tree sapwood may provide a reliable indicator of tree water status. Integrating these three methods of characterizing tree water status may provide the framework required to implement a precision water stress system in orchards. The effects of precision water stress on fruit quality and tree health can then be evaluated. If successful, this method has potential application in orchards worldwide.

Yujin Park, Erik Runkle
Michigan State University

Application of light emitting diode (LED) lighting technologies in horticultural crop production systems is of increasing interest due to their high energy efficiency and wavelength specificity. Most research and application of LED lighting has focused on red and blue LEDs. However, this limited light combination is not optimized for many plant lighting applications. In addition, red and blue light is not easy for people to detect the health of plants. During my graduate research, I am investigating the merits of using white and far-red LEDs, with red and/or blue light, to improve growth and quality attributes of high-value propagules. Also, the underlying mechanisms of the effect of white and far-red LEDs will be identified based on thorough photosynthesis and plant architecture measurements. For these white and far-red LED research, experiments will be conducted in a climate-controlled growth chamber and lighting treatments will be delivered based on repeated light quality measurements using a spectroradiometer. Also, light intensity for each light treatment, canopy temperature, and air temperature of each LED treatment will be measured by quantum sensors, infrared sensors, and thermocouples, respectively. This research can identify the important roles of white and far-red wavebands in regulating plant physiology – without confounding responses with other environmental parameters such as temperature or light intensity – and will provide useful information to users to better optimize the light spectrum to improve the quality of specific crops.