NCERA-101 Station Report from Georgia, 2018

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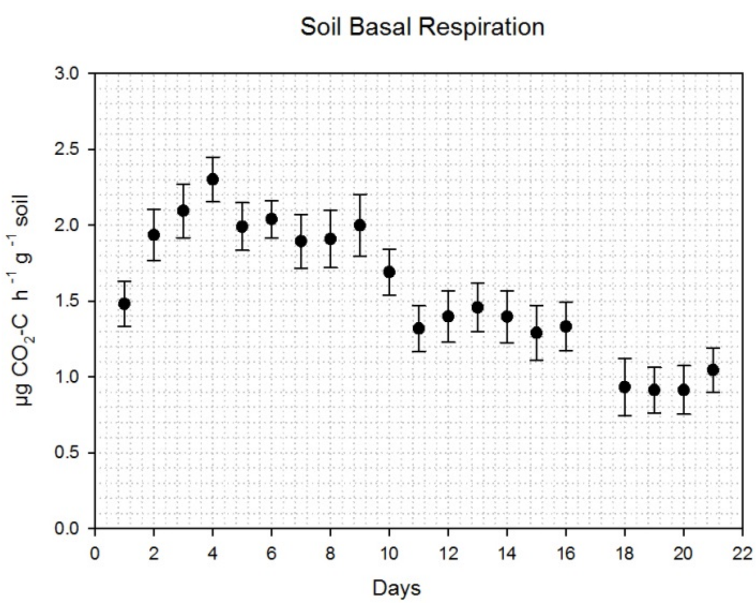
1. New Facilities and Equipment

A new plant factory was installed inside an old walk-in cooler at the Horticulture greenhouses in Athens, GA. The plant factory consists of three racks with three 2' x 8' shelves. Each shelf is divided into two sperate growing spaces, resulting in a total of 18 growing spaces. The cooler has temperature, humidity and CO_2 control. Light is provided using SpydrX Plus LED grow lights (Fluence BioEngineering, Austin, TX). Each shelf is light using the SpydrX LED bars. The drivers for the LEDs are interfaced with a Campbell Scientific datalogger, which can send voltage signals to the drivers, providing complete control over dimming of the LED lights. The *PPFD* at the canopy level can be controlled precisely in a range of 100 to 800 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

2. Unique Plant Responses

SOIL MICROBIAL RESPIRATION MEASUREMENT DEPLOYING NON-STEADY-STATE CHAMBERS INTEGRATED INTO CONVIRON GROWTH CHAMBERS

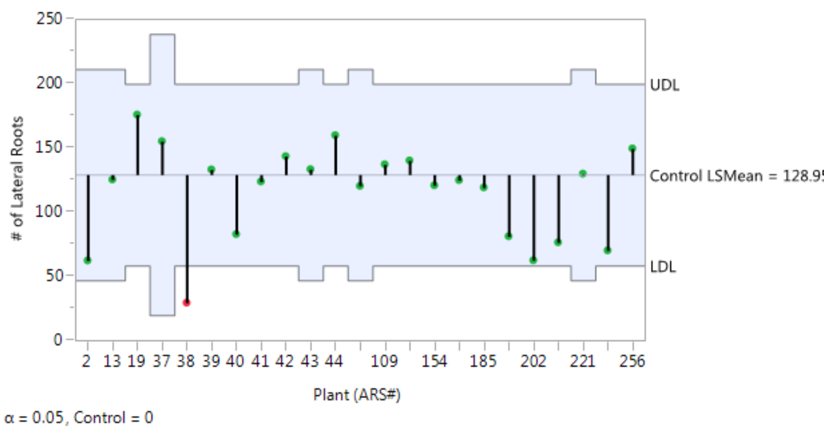


Soil basal respiration measurement is widely used in studies of soil C cycling, net crop photosynthesis estimations, overall soil biological activity estimations, heterotrophic microbiological activity studies etc. Chamber technique can be adapted to a wide range of experimental objectives and commonly used approach in soil respiration estimations. To efficiently and economically measure soil respiration in large number of samples over extended incubation period, we chose non-steady-state chamber design (static system) that allowed us to integrate Vaisala GMP 222 carbon dioxide probe (widely used in Conviron chambers) into small-volume soil respiration chamber and perform real-time CO_2 measurement under controlled environment conditions (PGW36 Conviron chamber). Time-dependent CO_2 diffusion error was reduced by adding ventilation inside the respiration chamber (resembling flow-through chamber type), taking measurements at constant chamber deployment intervals, and increasing soil sample surface area. Based on continuous CO_2 concentration measurements (18 second interval), the rate of CO_2 accumulation ($\Delta C/\Delta T$)

was estimated from the slope of the linear regression line. Experimental trial in the Calcisol soil sample showed initial two-fold increase in the respiration rate during the first 3-4 days of incubation and then gradually decreased for 3 weeks. *(Viktor Tishchenko (Envirotron, Univeristy of Gerogia) in collaboration with Nosir Shukurov (Institute of Geology and Geophysics, Uzbekistan))*

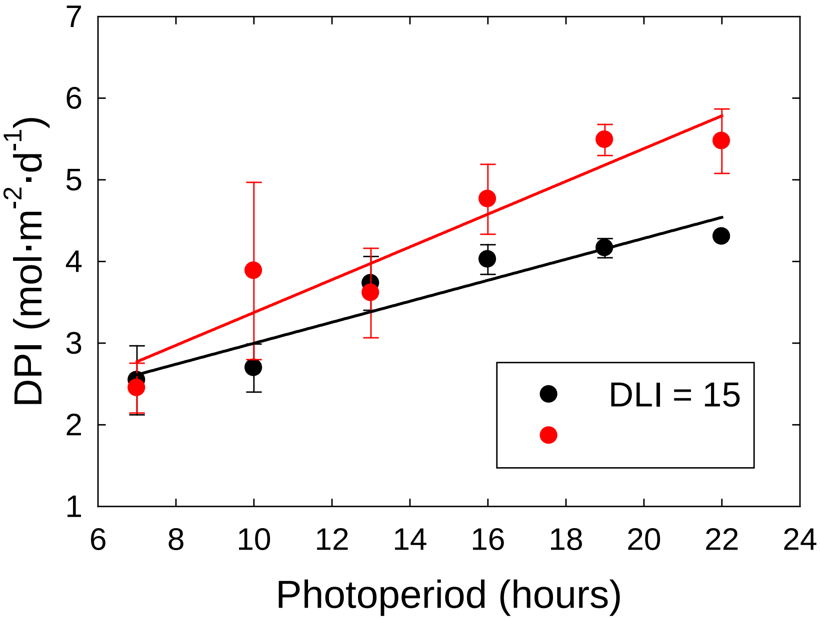
NON-DESTRUCTIVE HIGH-THROUGHPUT ROOT SYSTEM PHENOTYPING FOR SELECTIVE GENE FUNCTION SCREENING OF CHEMICALLY INDUCED MUTANT SORGHUM POPULATION

There is growing interest in finding genes responsible for environmental stress resistances such as drought, heat, nutrient deficiency. Root morphology plays a crucial role in such adaptations but relatively fewer researches focused on the belowground phenotyping due to its complexity. Our goal was to develop a non-destructive high-throughput root system phenotyping platform to screen plants for various abiotic stress resistances. Ethyl methanesulfonate (EMS)-mutagenized sorghum population of the BTx623 wild type was used as germplasm material for identification of candidate genes. In the first phase of preliminary screening, sorghum plants were grown hydroponically and using paper pouches technique. Plants were grown until they reached paper edges (7-8 days), scanned on a scanner (Plustek OpticPro A320 scanner), and processed with root phenotyping software (RootReader2D). Preliminary generic root morphology data provides access to find association candidate genes with genotype variation or abiotic stress adaptations. Number of lateral roots, length of upper lateral roots, and root/shoot ratios characteristics were used to select candidate plants to screen for P-efficiency using sand-alumina culture. This media provides stable, diffusion limited, slow-release, controlled P availability conditions which closely resembles natural soil environment. Loose sand texture allows to efficiently separate roots from the media and to phenotype root morphology following the same procedure as in hydroponics/paper pouches. The platform we developed here would be useful for plant root morphology assays. *(Viktor Tishchenko (Envirotron) in collaboration with Ming Li Wang (USDA, PGRCU))*



LONGER PHOTOPERIODS WITH THE SAME DAILY LIGHT INTEGRAL INCREASE DAILY ELECTRON TRANSPORT THROUGH PHOTOSYSTEM II

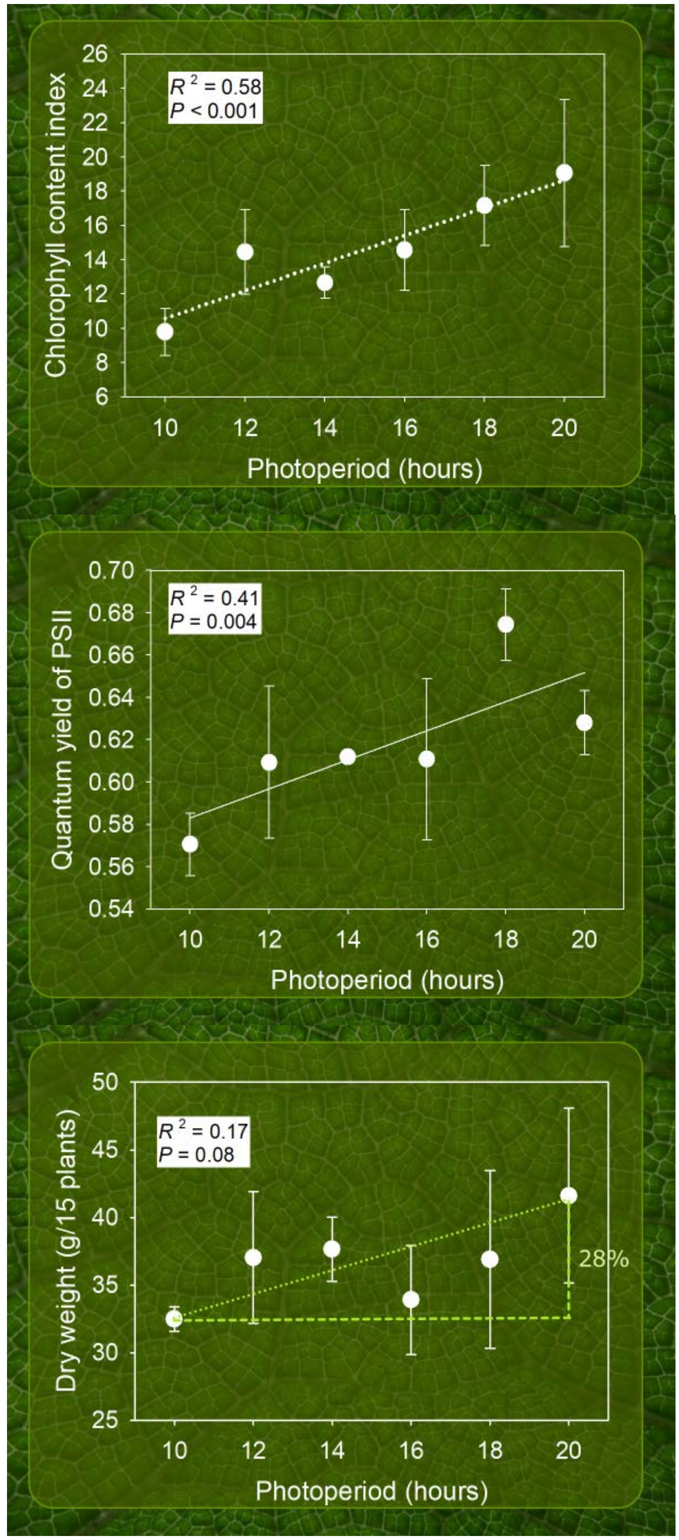
The annual energy cost for horticultural lighting in the US is approximately $600 million. To lower these costs, it is essential to provide light in a way that allows for efficient photochemistry. Because the quantum yield of photosystem II (ΦPSII), the fraction of absorbed light used for photochemistry, decreases with increasing photosynthetic photon flux density (*PPFD*), we hypothesized that electron transport through photosystem II integrated over 24 hr, the daily photochemical integral (DPI), increases if the same amount of light (daily light integral, DLI) is spread out over longer photoperiods. To test this, we measured chlorophyll fluorescence to determine ΦPSII and the electron transport rate (ETR) of lettuce (*Lactuca sativa* 'Green Towers'). Plants were grown at a *PPFD* of ~ 250 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Chlorophyll fluorescence measurements were taken in a growth chamber equipped with LED lights. A datalogger controlled *PPFD* and photoperiod and collected ΦPSII and ETR data. DLIs of 15 and 20 $mol \cdot m^{-2} \cdot d^{-1}$, provided over photoperiods of 7, 10, 13, 16, 19, and 22 hours, were tested. *PPFD* during these measurements ranged from 189 to 796 $\mu mol \cdot m^{-2} \cdot s^{-1}$. ΦPSII decreased from ~ 0.69 at a *PPFD* of 189 $\mu mol \cdot m^{-2} \cdot s^{-1}$ to ~ 0.29 at a *PPFD* of 796 $\mu mol \cdot m^{-2} \cdot s^{-1}$, while ETR increased from ~54 to 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$. DPI increased as a function of photoperiod and this increase was more pronounced at high DLI. At a photoperiod of 7 hours DPI was ~ 2.5 $mol \cdot m^{-2} \cdot d^{-1}$, regardless of DLI. However, with a photoperiod of 22 hr and a DLI of 15 $mol \cdot m^{-2} \cdot d^{-1}$, the DPI was ~ 4.2 $mol \cdot m^{-2} \cdot d^{-1}$ (68% higher than with a photoperiod of 7 hr), and with a DLI of 20 $mol \cdot m^{-2} \cdot d^{-1}$ the DPI was ~ 5.5 $mol \cdot m^{-2} \cdot d^{-1}$ (120% higher). Our results show that DPI is significantly higher with lower *PPFD* over a longer photoperiod than with higher *PPFD* over a shorter photoperiod, because the light is used more efficiently at low *PPFD*. Subsequent longer-term growth trials have shown that longer photoperiods with the same DLI do increase crop growth. These short-term physiological trials, combined with results from longer-term growth trials, indicate that applying supplemental light out over longer photoperiods results in more energy-efficient stimulation of crop growth. This research should encourage growers who use photosynthetic lighting to re-evaluate their current lighting protocols and consider using longer photoperiods. (Claudia Elkins, Michael Martin, and Marc van Iersel)



Effects of different photoperiods with constant daily light integral on growth and photosynthesis of mizuna, lettuce, and basil.

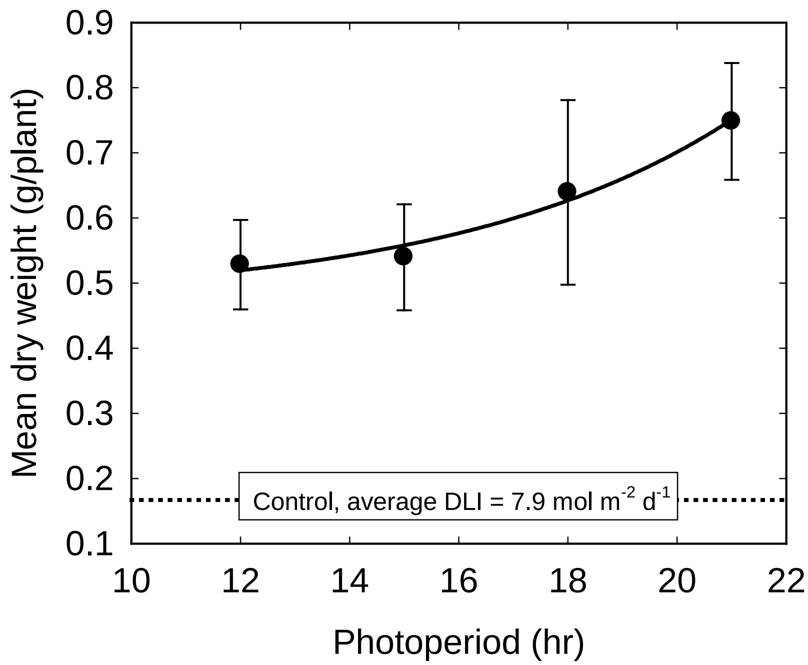
Most studies of photoperiodic effects on plant growth have used constant instantaneous photosynthetic photon flux densities (*PPFD*), which leads to different total daily light integrals (DLI) received in each photoperiod. Our objective was to quantify the effect of different photoperiods, all providing the same DLI, on crop growth. Because photosynthesis is more efficient at lower *PPFD*, we hypothesized that longer photoperiods with lower *PPFD* would result in faster growth than shorter photoperiods with higher *PPFD*. Mizuna (*Brassica rapa* var.

japonica), 'Little Gem' lettuce (*Lactuca sativa*), and ‘Genovese’ basil (*Ocimum basilicum*) were grown from seed in a controlled environment chamber (20°C and 800 ppm CO_2) under six photoperiods (10, 12, 14, 16, 18, and 20 hr). White LEDs provided light and *PPFD* was adjusted so each treatment received a DLI of 16 mol·m^{-2}·d^{-1}. Mizuna, lettuce, and basil were harvested 30, 41, and 55 d after planting, respectively. Light interception, chlorophyll content, and quantum yield of PSII were positively correlated with duration of photoperiod in all three species. Mizuna plants grown with a 20 hr photoperiod had 10.9% greater light interception, 94.6% higher leaf chlorophyll content index, and 10.1% greater quantum yield near the end of the growing period than those grown with a 10 hr photoperiod. Lettuce plants grown with a 20 hr photoperiod had 11.4% greater light interception, 13.7% higher leaf chlorophyll content index, and 10% greater quantum yield than those grown with a 10 hr photoperiod. Mizuna and lettuce plants both also had greater shoot dry mass (28.1% and 18% greater, respectively) when grown with 20 hr photoperiods compared to 10 hr photoperiods. There was no apparent correlation between photoperiod and dry mass in basil. Basil plants grown with a 20 hr photoperiod had 13.7% higher leaf chlorophyll content index and 10% greater quantum yield than those with a 10 hr photoperiod. Lettuce plants grown under shorter photoperiods had notably yellower leaves, steeper leaf angle, and more upright growth than those in longer photoperiods. These results show that plants receiving the same DLI can have markedly faster growth when provided light over a longer photoperiod, but the effect appears to be species-specific. This is an important consideration when determining optimal lighting strategies for crop growth. Photoperiod, *PPFD*, and DLI cannot be studied isolation without accounting for simultaneous effects of the other two variables on plant responses. (Shane Palmer, Eric Stallknecht, and Marc W. van Iersel)



IMPROVED PHOTOCHEMICAL EFFICIENCY OF SUPPLEMENTAL LIGHTING INCREASES DRY MASS AND LEAF AREA OF GREENHOUSE-GROWN LETTUCE

Photosynthetic responses to light intensity are generally asymptotic; light is used more efficiently to drive photosynthesis at lower light intensity. Thus, providing supplemental light at low intensities over longer periods should lead to increased photosynthetic gains, compared to an equivalent amount of light at higher intensities and shorter periods. To test this hypothesis, we used an adaptive LED lighting system in a greenhouse, which dynamically controls supplemental LED light intensity to reach, but not exceed, a specified light intensity. Using this system, 'Little Gem' lettuce (*Lactuca sativa*) plants were grown under a constant daily light integral (DLI) of 17 $mol \cdot m^{-2} \cdot d^{-1}$ provided over 4 different photoperiods; 12, 15, 18, and 21 hours. The average DLI in the control treatment (no supplemental light) was 7.89 ± 3.02 $mol \cdot m^{-2} \cdot d^{-1}$. Thus, the 4 treatments received slightly more than half of their light from the LED lights. Threshold light intensity was calculated as: Threshold PPFD ($\mu mol \cdot m^{-2} \cdot s^{-1}$) = 1,000,000 x [17 $mol \cdot m^{-2}$ – Current DLI]/Time remaining (s)]. Hence, while each treatment received the same amount of light within each 24-hour period, extending the photoperiod allowed the same amount of supplemental light to be provided at lower instantaneous intensities. The study was terminated after 22 days. Dry weight increased quadratically with photoperiod (R^2 = 0.50, p=0.003), from an average of 0.53 g/plant with 12-hour photoperiods to 0.75 g/plant with 21-hour photoperiods. In the control treatment, average dry weight was 0.17 g/plant. Leaf chlorophyll content and leaf size of the fully expanded leaves increased linearly as photoperiod increased. Leaf size increased from 57.2 cm^2 in the 12-hour treatment to 68.2 cm^2 in the 21-hour treatment (p = 0.023), and chlorophyll content index similarly increased from 9.81 to 12.1 (p = 0.0015). Leaf area and chlorophyll content were higher in all supplemental lighting treatments than in the control (p < 0.0001). These results may be partly attributed to an increased photosynthetic light use efficiency as photoperiod increased and supplemental lighting was provided at lower intensities over longer photoperiods. However, morphological acclimation to photoperiod or light intensity also occurred, as plants developed larger leaves with higher chlorophyll content under longer photoperiods. In conclusion, providing supplemental light in a photochemically-efficient manner improves overall growth of this lettuce variety. (Geoffrey Weaver and Marc van Iersel)



RAPID LIGHT RESPONSE CURVES AS A HIGH-THROUGHPUT SCREENING METHOD FOR PHOTOCHEMICAL RESPONSES OF BEDDING PLANTS

Understanding plant photochemical responses to photosynthetic photon flux density (*PPFD*) is important for developing energy-efficient supplemental lighting strategies. However, the photochemical light response varies greatly among species and cultivars, and a rapid, reliable method to describe species- and variety-specific photochemical responses is needed. Chlorophyll fluorescence measurements were used to determine the electron transport rate (ETR) of six bedding plant species: *Begonia semperflorens* 'Ambassador Scarlet' (begonia), *Catharanthus roseus* 'Jams N Jellies Blackberry' (vinca), *Impatiens walleriana* 'Super Elfin Violet' (impatiens), *Pelargonium* x *hortorum* 'Maverick Violet'(geranium), *Petunia* x *hybrida* 'Daddy blue'(petunia), and *Salvia splendens* 'Mojave' (salvia). Diurnal measurements were conducted in a greenhouse with fluorescence measurements taken every 15 min during the day and hourly at night with 5 measurement days per species. Additional measurements were taken in a growth chamber using a hyperbolic series of *PPFD*s (0, 50, 150, 300, 500, 750, 1050, 1400 $\mu mol \cdot m^{-2} \cdot s^{-1}$), with 20 min acclimation at each intensity, and 5 replications per species. For 4 species, the data collected in the growth chamber was similar to the greenhouse data, but for impatiens and petunia observed ETR was generally lower in the greenhouse. This may have been due to physical damage to the leaves induced by the fluorometer leaf clip. In all cases, an asymptotic rise to a maximum function fit the data well. This function uses only two variables: the initial slope and the asymptote of the ETR response curve: ETR= [asymptote of ETR] x [1- *e*^[-(initial slope of ETR/asymptote of ETR) x PPFD]. Accordingly, it was hypothesized that the photochemical light response could be adequately described by determining only the initial slope and asymptote: a rapid light response curve. This was tested in a growth chamber by measuring the ETR of each species at a very low (≈3 $\mu mol \cdot m^{-2} \cdot s^{-1}$) and very high (≈2100 $\mu mol \cdot m^{-2} \cdot s^{-1}$) light intensity for 5 min. The equation generated from this data fit the greenhouse ETRs with a mean R^2=0.93 and slope of 0.89; the estimated values were generally 11% higher than the observed ETRs. Similarly, it fit the previous growth chamber data with mean R^2=0.96 and slope of 0.94 (estimated ≈6% higher than observed) for all species except for impatiens, which had a much higher slope (m=1.5, R^2=0.94), suggesting that the high PPFD used to determine the asymptote was photoinhibitory for impatiens. This high-throughput method accurately describes the ETR response for 5 of the 6 species. (Geoffrey Weaver and Marc van Iersel)

HIGHER DAILY LIGHT INTEGRALS WITH ADAPTIVE LED LIGHTING CONTROL SPEED UP ORNAMENTAL SEEDLING GROWTH

Supplemental lighting in greenhouse industry is often needed from late fall through early spring and can account for up to 30% of the value of crops produced. Reduction of this energy cost can be beneficial for profitable greenhouse crop production. Our study focused on quantifying the effect of daily light integral (DLI) on seedling production of bedding plants. We used an adaptive light-emitting diode (LED) control system to precisely control supplemental lighting by taking advantage of the dimmability of LED grow lights. The power of the LEDs was adjusted to provide only enough supplemental photosynthetic photon flux density (PPFD) to reach the threshold PPFD underneath the light bars. The threshold PPFD was recalculated every 2 seconds to assure that the crop received a specific DLI by the end of the 14-hour supplemental lighting period. This high-precision lighting control system provides supplemental light when plants can use it most efficiently, i.e., when there is little sunlight available. Therefore, we hypothesized that our adaptive LED control system stimulates plant growth more than ordinary lighting systems. We compared three adaptive lighting control treatments to achieve DLIs of 8, 12, and 16 $mol·m^{-2}·d^{-1}$ in 14 hours of supplemental lighting (10 am to midnight) to a treatment that supplied a PPFD of ~100 $\mu mol·m^{-2}·s^{-1}$ of supplemental light during the same 14 hours (average DLI was 8.6 $mol·m^{-2}·d^{-1}$), and a sunlight-only control treatment (average DLI was 5.4 $mol·m^{-2}·d^{-1}$). We used impatiens (*Impatiens walleriana*) 'Accent Premium Violet F1' and vinca (*Catharanthus roseus*) 'Jams 'n Jellies Blackberry' for the study. Seedlings were harvested 40 days after seeding. The number of leaves, shoot fresh and dry weight, and plant compactness (shoot dry weight/ plant height) of both species were greatest in the treatment receiving a DLI of 16 $mol·m^{-2}·d^{-1}$, followed by the treatment receiving a DLI of 12 $mol·m^{-2}·d^{-1}$. Similar patterns were observed for root dry weight of impatiens, but not for vinca. Seedlings in the treatment that received a supplemental PPFD of ~100 $\mu mol·m^{-2}·s^{-1}$ had similar growth as those in the treatment with a DLI of 8 $mol·m^{-2}·d^{-1}$. The sunlight-only control treatment had the slowest seedling growth. These results suggest that our adaptive LED control system is capable of controlling LED's precisely while stimulating the plant growth more at higher DLIs. However, growers should determine whether the better growth from more supplemental lighting is worth the cost of providing that light. (T.C. Jayalath and Marc van Iersel)

NIGHT INTERRUPTION WITH LIGHT EMITTING DIODES APPLIED USING SIMULATED MOVING GREENHOUSE BOOMS PROMOTES FLOWERING OF *PETUNIA X HYBRIDA*

Long-day plants (LDP) require night interruption to promote flowering when grown out-of-season (i.e., early spring). Accelerating flower development shortens the cropping cycle and thus reduces crop inputs like water and fertilization. There are multiple ways to promote flowering in LDP. Cyclic night interruption, night interruption applied in many short periods rather than one long continuous period, is less studied than other methods but can effectively provide night interruption. Many greenhouses use moving booms to apply irrigation, fertilization, and pesticides. Small lighting fixtures attached to these booms can successfully provide cyclic night interruption, often termed "boom lighting". We hypothesize that boom lighting from light emitting diodes (LEDs) can promote flowering of *Petunia x hybrida* as well as traditional methods. A growth chamber with programmable lighting fixtures can accurately mimic moving irrigation booms by gradually increasing and decreasing the provided light intensity. The effects of cyclic night interruption on flowering was tested using night interruption lighting provided at 30, 60, 120, and 240 second intervals between simulated boom passes. Cyclic night interruption applied to seven-week-old petunia seedlings slightly reduced days to first open flower, by up to 3 days. Our highest cyclic night interruption frequencies, boom passes every 30 and 60 seconds, increased total number of visible inflorescences, but also increased plants height and resulted in less compact plants. To account for additional light from night interruption we also calculated days to flower and the number of inflorescences divided by the total light over a 24-hour period (daily light integral + treatment light integral). This showed that increasing cyclic night interruption frequency does not proportionally reduce days to flower but does proportionally increase the number of inflorescences. Further exploration into the lowest light intensity and lowest frequency that promote flowering are required to make boom lighting more commercially viable. (Eric Stallknecht and Marc van Iersel)

3. Accomplishment Summaries

The University of Georgi has shown that ‘adaptive’ lighting control, which adjusts the amount of supplemental light provided based on the amount of current sunlight, can be used to provide precise daily light integrals in user-defined photoperiods. The method provides growers a consistent day-to-day light environment, even if weather conditions are highly variable.

The University of Georgia has shown that identical daily light integrals result in greater photosynthetic efficiency and biomass production when that light is spread out over longer photoperiods. For non-photoperiodic crops, longer photoperiods can increase production without increasing power use.

4. Impact Statement

Electricity costs for supplemental lighting can be a major cost for greenhouses. The adaptive LED lighting control system, developed in the Horticultural Physiology Lab at the University of Georgia, automatically provides supplemental light when it can be used most efficiently by the plants (when there is little sunlight). The adaptive LED lighting control system also can assure that specific, consistent daily light integrals are provided to crops, regardless of weather conditions. Using the adaptive lighting control to provide the same daily light integral over longer photoperiods can enhance crop growth.

5. Published Written Works

Refereed journal articles

Wheeler, W.D., J. Williams-Woodward, P.A. Thomas, M. van Iersel, and M.R. Chappell. 2017. Impact of substrate volumetric water on *Pythium aphanidermatum* infection in *Petunia* x *hybrid*a: A case study on the use of automated irrigation in phytopathology studies. *Plant Health Progress* 18:12-125. http://dx.doi.org/10.1094/PHP-01-17-0006-RS

South, K.A, P.A. Thomas, M.W. van Iersel, C. Young, and M.L. Jones. 2017. Ice cube irrigation of potted *Phalaenopsis* orchids does not decrease display life or cause chilling damage to roots. *HortScience* 52:1271–1277. http://dx.doi.org/10.21273/HORTSCI12212-17

Zhen, S. and M.W. van Iersel. 2017. Photochemical acclimation of three contrasting species to different light levels: Implications for supplemental lighting. *Journal of the American Society for Horticultural Science* 142:346-354. http://dx.doi.org/10.21273/JASHS04188-17

Zhen, S. and M.W. van Iersel. 2017. Far-red light is needed for efficient photochemistry and photosynthesis. *Journal of Plant Physiology* 209:115-222. http://dx.doi.org/10.1016/j.jplph.2016.12.004

van Iersel, M.W. and D. Gianino. 2017. An adaptive control approach for LED lights can reduce the energy costs of supplemental lighting in greenhouses. *HortScience* 52:72-77.

Symposium proceedings

Lea-Cox, J.D., B.E. Belayneh, J. Majsztrik, A.G. Ristvey, E. Lichtenberg, M.W. van Iersel, M. Chappell, W.L. Bauerle, G. Kantor, D. Kohanbash, T. Martin, and L. Crawford. 2017. Demonstrated benefits of using sensor networks for automated irrigation control in nursery and greenhouse production systems. *Acta Horticulturae* 1150:507-514. DOI: 10.17660/ActaHortic.2017.1150.70