NCERA-101 Station Report from Georgia, 2021

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1. New Facilities and Equipment

Although not exactly a new facility or equipment, the University of Georgia's department of Horticulture is pleased to welcome Dr. Rhuanito Ferrarezi as a new faculty member with a research focus n CEA. Dr. Ferrarezi's research program will focus on CEA production systems and nutrient management. Hew ill also teach a split-level course in greenhouse management and an undergraduate course in controlled environment agriculture.

Inspired by prior work with a commercial multi-spectral imaging system, we have developed a low-cost multi-spectral imaging system. The system uses a Raspberry Pi microcomputer and Arducam monochrome camera. The system takes images under red, green, blue, and infra-red light, as well as an image of chlorophyll fluorescence emitted by plants. Other colors can easily be added if desired. The Raspberry Pi automatically analyzes the images, applying a mask to separate plant from background and creates normalized difference vegetation index (NDVI) and anthocyanin content index (ACI) images. The spatial distribution of NDVI and ACI is automatically quantified. The system can be assembled for ~ $400.

2. Unique Plant Responses

Quantification of Canopy Size Using Automated Chlorophyll Florescence Image Analysis

Chlorophyll fluorescence imaging (CFI), a technique that captures fluorescence emitted by chlorophyll, is a simple but powerful tool to quantify the projected canopy size of crops. Projected canopy size determines light interception and can be a good predictor of crop biomass. Processing CFI images can be done using ImageJ or other image analysis software. However, analyzing lots of images is time consuming, although ImageJ has a 'macro' tool that allows partial automation of image analysis. Automated tools for image analysis are also available, but there are few fully-automated programs to quantify canopy size or leaf area. Here, we developed an automated CFI analysis program called 'Pixel Extractor' written in Python. The program and its accompanying instructions are kept as simple as possible to facilitate use by novel users with no background in programming. The program performs a few basic functions: automatically finding the pixel intensity threshold to distinguish background (dark and low pixel intensity) from canopy (brighter and higher pixel intensity), counting the number of bright pixels to determine projected canopy size, removing noise in the image by ignoring small objects (despeckling), and applying a calibration factor to convert the number of pixels to canopy area. The program exports (1) a csv file with the image names, the total pixel numbers within an image, threshold value used to separate background from canopy, and the projected canopy size, (2) a binary (black and white) image showing canopy area for easy verification of accurate image processing, and (3) a histogram of the pixel intensity of the CFI image, to verify that the program uses an appropriate threshold to separate background from canopy. The program requires only a few simple user inputs: (a) the lower and upper boundaries of the pixel number used for despeckling, (b) pixel number of a known distance for converting pixel numbers into a canopy area, (c) file type of images to be analyzed, (d) minimum and maximum range of intensity used for automated thresholding, (e) name of a csv output file, and (f) the folder where the images are located. Although it depends on the computing power, the program typically can analyze dozens of CFI images within a few seconds. Because of the simplicity of the approach, a fully-automated imaging system that can collect, analyze, and upload images to the cloud can easily be assembled for ~$200. *Researchers: Changhyeon Kim, Limeng Xie, Alexander Bucksch, Lynne Seymour and Marc W van Iersel*

Lowering the Target DLI Following Sunny Days Can Reduce Lighting Costs in Greenhouse Lettuce Production

Lighting systems are commonly utilized in the greenhouse industry to supplement sunlight. Numerous studies have focused on the optimal daily light integral (DLI) that specific crops need for good growth. However, making lighting decisions based only on DLI might not be optimal. The main objective of this study was to determine the effect of fluctuating DLI levels on lettuce plants growth. Specifically, if a crop receives more than the required DLI one day, can growers provide less light during the following day or days, without a negative impact on growth? To answer this question, lettuce 'Waldmann's Dark Green' and 'Rouxai' were grown in a growth chamber under different lighting treatments and the following conditions: temperature of 25° C, relative humidity of ~50%, and a CO2 concentration of 800 µmol·mol-1. Light was provided using dimmable white LED fixtures. The photoperiod was 20 h each day, but DLI varied. Plants received one day of high DLI (DLIHI, 22.5 mol·m-2·d-1), followed by one to five days with low DLI, so that the average DLI was 15 mol·m-2·d-1 in all treatments. Plants grown under a constant DLI of 15 mol·m-2·d-1 were used as a control. Before canopy closure (16 days after seeding), chlorophyll and anthocyanin content index did not differ among treatments. In contrast, projected canopy size (PCS) was 16% and 13% lower in in the treatments with 1 and 3 days of low DLI compared to the control. Those differences disappeared after canopy closure. At harvest, total dry weight was 13% lower in the treatment with one day of low DLI compared to the control. No differences in projected canopy size or light use efficiency (g of biomass/mol of incident light, Chlorophyll Content Index) were found among treatments and the control plants at harvest. These results suggests that alternating days with high and low DLI may reduce growth. However, lowering the target DLI for several days, following a day with high DLI had no negative affect on crop growth. Thus, after a day with high DLI, growers can lower the target DLI for several days after that, and reduce energy consumption and electricity costs, resulting in increased profitability. *Researchers: Andres M Mayorga-Gomez, University of Georgia and Marc W van Iersel*

Lettuce Dry Matter Partitioning and Canopy Development of Five Different Cultivars over a Growing Cycle

Characterization of dry matter (DM) partitioning among different plant parts is important for development of mechanistic crop growth models, which simulate growth based on physiological processes, dry matter allocation, and morphological characteristics of the crop. Although there are many reports on lettuce DM partitioning into shoot or root and specific leaf area (SLA) at harvest, few studies quantified changes throughout a growing cycle. Additionally, morphological and physiological differences among cultivars are commonly overlooked. That indicates a requirement for empirical studies, with periodic destructive measurements, of different cultivars. We studied DM partitioning of five lettuce (Lactuca sativa) cultivars ('Cherokee', 'Green tower', 'Rouxai', 'Rex', and 'Teodore') over a growing cycle. These cultivars represent a wide range of morphological variation in lettuce. Plants were grown in a glasshouse and harvested biweekly, at which times projected canopy size (PCS), leaves number (LN), total leaf area (LA), shoot dry weight (SDW), and root dry weight (RDW) were measured. Photosynthetic photon flux density (PPFD) was monitored and integrated over cropping cycle as cumulative light integral (CLI; mol m-2). From these measurements, the fraction of shoot (SF) and root DM (RF), canopy overlap ratio (COR; LA / PCS) and SLA (LA / SDW) were calculated. SF was around 0.94 at 5 days after germination (DAG) and decreased to 0.81 until 16 DAG suggesting an emphasis on root growth during this period. Shoot fraction subsequently increased gradually to 0.91 at 47 DAG, which is associated with rapid increase in PCS starting around 17 DAG. COR was positively correlated to LN (R = 0.96). Therefore, the butter head lettuces ('Rex' and 'Teodore'), having a high LN, showed a rapid increase in COR, from 1.1 to 6.0, at 5 and 47 DAG, respectively. COR in other cultivars increased from 1.1 to 4.0. SLA was decreased over time (and with increasing CLI). Until 16 DAG, SLA ranged from 420 to 700 cm2 g-1. However, SLA then decreased to 280 to 500 cm2 g-1 due to large increase in SW. SF, RF, SLA, and COR differed among cultivars, although the changes over time were similar across all cultivars. Because all cultivars have different morphological and genetic backgrounds, their morphology and DM partitioning differ. Therefore, our results suggest that cultivar-specific changes in dry matter allocation and morphology should be accounted for in crop growth models. *Researchers: Changhyeon Kim and Marc W van Iersel*

Reducing Energy Requirements for Greenhouses Lighting through Carry-over of 'Excess' Light to the Next Day

The amount of sunlight greenhouse crops receive varies and often is not enough for consistent year-round growth. Therefore, supplemental lighting is often used to provide adequate light. The cost of greenhouse lighting can account for 10–30% of operating costs and affects the greenhouse profitability and sustainability. To provide adequate light for crop growth, greenhouse lights are typically turned on and off, depending on the sunlight intensity. However, if plants can tolerate lower DLI levels following a sunny day (with more than the required DLI) without reducing the growth, the energy requirement for supplemental lighting can be lowered. To determine whether excess light received one day can be 'carried-over' to the next day, we grew oakleaf lettuce (Lactuca sativa 'Green Salad Bowl' and 'Red Salad Bowl') under six lighting regimes inside a growth chamber. Plants in all treatments received an average DLI of 15 mol･m-2·d-1, but DLIs alternated from day-to-day (15/15, 17.5/12.5, 20/10, 22.5/7.5, 25/5, and 27.5/2.5 mol･m-2·d-1), resulting in DLI fluctuations from 0 to 25 mol･m-2·d-1. Plants had similar leaf area (~800 cm2/plant) and dry weight (~1.8 g/plant) when grown with DLI fluctuations from 0 to 15 mol·m-2·d-1, while higher DLI fluctuation reduced growth. To confirm this DLI "carrying-over" effect on plants grown under sunlight with supplemental light, we conducted a second study in a greenhouse with 'Green Salad Bowl' lettuce. In this study, plants were grown with five different DLI fluctuations (15/15, 16.75/13.25, 18.5/11.5, 20.25/9.75, and 22/8 mol·m-2·d-1), ranging from 0 to 14 mol·m-2·d-1, while maintaining an average DLI of 15 mol·m-2·d-1 in all the treatments. We observed similar leaf area (~750 cm2/plant) and dry weight (~1.8 g/plant) in lettuce plants grown with DLI fluctuations from 0 to 10.5 mol·m-2·d-1. Higher DLI fluctuations reduced growth. Thus, carry-over of excess light from a sunny to an overcast day is possible, within limits. We conclude that, following a sunny day with a DLI ≥ 20.25 mol·m-2·d-1, the DLI target can be reduced by ~5.25 mol·m-2·d-1 the following day. To quantify the energy savings that can be obtained by 'carrying-over' excess DLI to the following day, we used historical weather data for five US locations. In Athens, GA, Elmira, NY, Kalamazoo, MI, Seattle, WA, and Yuma, AZ, annual energy savings for greenhouse lighting were ~56, 77, 69, 57, and 21 MWh/acre, respectively. Such reductions in greenhouse energy requirements for supplemental lighting will improve the profitability and sustainability of the greenhouse industry. *Researchers: Theekshana C. Jayalath and Marc W van Iersel*

Estimating the Electricity Use and Cost of Supplemental Greenhouse Lighting Using an on-Line App

Greenhouses throughout the US depend on supplemental lighting for the year-round production of high-quality plants. The electricity costs associate with that lighting are high and can have a significant impact on profitability. Choosing the optimal type of lighting system is an important, but difficult decision. To facilitate this decision-making process, we developed an on-line app that can estimate the annual costs associated with different lighting systems and for different locations. Grower input for the app is simple: zip code, target DLI, greenhouse light transmission and size, fixture efficacy, and electricity price. Using the zip code, historical weather data is retrieved and used to estimate the daily light integral (DLI) for each day of the year. Using the greenhouse transmission, the DLI inside the greenhouse is then calculated. The amount of supplemental light that needs to be provided is then computed as the difference between the target DLI and actual DLI in the greenhouse. Using the light fixture efficacy and size of the greenhouse, the app then calculates the electricity required to provide the needed supplemental light. Finally, the app calculates the cost of that electricity, based on the electricity price. If desired, growers can specify the fraction of total greenhouse space where lighting is used on a monthly basis. The results are provided on a month-by-month, as well as annual basis and can be exported as a CSV file. The app makes it easy to compare different lighting scenarios, such as HPS versus LED fixtures, and can provide valuable information to greenhouses planning to replace or install a lighting system. Shortcomings of the app include the assumption that the lighting system is powerful enough to provide enough supplemental light to reach the target DLI on even the darkest day of the year, which is not realistic. In addition, the app is not capable of accounting for variable electricity prices. Upgrades to the app to incorporate additional functionality are planned. The lighting app is freely available at https://uga-lighting-calc.shinyapps.io/lightingcalcapp/. We are currently working on upgrades that will allow users 1) to enter their own lighting configuration. In addition to estimating electricity costs, the app determines how many days of the year the target DLI can be reached, and 2) users can enter how many days a year they want to reach the target DLI. The app will calculate the required lighting capacity and associated electricity costs. *Researchers: Jarryd Wannenburg, Dalton Croy, Marc W van Iersel, Maria Twedt, Richard Watson and Marie-Claude Boudreau*

3. Accomplishment Summaries

In collaboration with electrical engineers, we have developed optimal control algorithms for supplemental lighting in greenhouses. These algorithms can be used from control of dimmable LED lights, HPS lights with a few discrete power levels, or non-dimmable lights. The algorithm can also predict sun light levels, and accounts for plant physiological responses to light. In the case of variable electricity prices, the algorithms can also minimize the cost of the electricity required for supplemental lighting. Simulations suggest that this may reduce lighting costs by up to 40%. The algorithms have been tested in a small testbed, using a Raspberry Pi for implementation and will soon be trialed on a larger scale in a greenhouse.

4. Impact Statement

Most past research on lighting requirements for CEA crops has focused on providing the same daily light integral (DLI). We have shown that lettuce does not require the same DLI and is actually quite tolerant of fluctuations in DLI. Following a day with a higher than 'required' or 'optimal' DLI, the target DLI can be lowered for one or more days. As long as the DLI fluctuations are not more than ~ 10 $mol \cdot m^{-2} \cdot d^{-1}$, and the average DLI is unchanged, fluctuating DLI levels have little or no negative impact on growth. Based on simulations, taking advantage of this 'carry-over' DLI can save greenhouses ~ $6,000 – 9,000/acre/year.

The electricity costs associated with supplemental lighting in greenhouses can be high, but are hard to estimate. We developed an app that uses location- and greenhouse-specific information to estimate the costs of supplemental lighting. The lighting app is freely available at https://uga-lighting-calc.shinyapps.io/lightingcalcapp/ and will help greenhouse growers make better-informed decisions about the cost of supplemental lighting.

5. Published Written Works

Refereed journal articles

Palmer, S. and M.W van Iersel. 2020. Longer photoperiods with the same daily light integral increase growth of lettuce and mizuna under sole-source LED lighting. *Agronomy* 10: 1659. https://doi.org/10.3390/agronomy10111659).

Wang, Y.-W., M.W. van Iersel, S.U. Nambeesan, H. D. Ludwig, and H. Scherm. 2020. Blue light does not affect fruit quality or disease development on ripe blueberry fruit during postharvest cold storage. *Horticulturae*, 6(4): 59. https://doi.org/10.3390/horticulturae6040059

Elkins, C. and M.W. van Iersel. 2020. Longer photoperiods with the same daily light integral increase daily electron transport through photosystem II in lettuce. *Plants* 9: 1172. https://doi.org/10.3390/plants9091172

Elkins, C. and M.W. van Iersel. 2020. Longer photoperiods with the same daily light integral improve growth of *Rudbeckia* seedlings in a greenhouse. *HortScience* 55: 1676–1682. https://doi.org/10.21273/HORTSCI15200-20

Wheeler, W.D., M. Chappell, M. van Iersel, P.A. Thomas. 2020. Implementation of soil moisture based automated irrigation in woody ornamental production. *Journal of Environmental Horticulture* 38: 1-7. https://doi.org/10.24266/0738-2898-38.1.1

Elkins, C. and M.W. van Iersel. 2020. Supplemental far-red LED light increases growth of *Digitalis purpurea* seedlings under sole-source lighting. *HortTechnology* 30, 564–569. https://doi.org/10.21273/HORTTECH04661-20

Weaver, G. and M.W. van Iersel. 2020. Longer photoperiods with adaptive lighting control can improve growth of greenhouse-grown 'Little Gem' lettuce (*Lactuca sativa*). *HortScience* 55:573-580. https://doi.org/10.21273/HORTSCI14721-19

Symposium proceedings

Mosharafian, S., S. Afzali, J.M. Velni, and M.W. van Iersel. 2020. Development and implementation of a new optimal supplemental lighting control strategy in greenhouses. *Proceedings of the ASME Dynamic Systems and Control Conference*, 8 p.