Purdue NCERA-101 Station Report for 2013-2014

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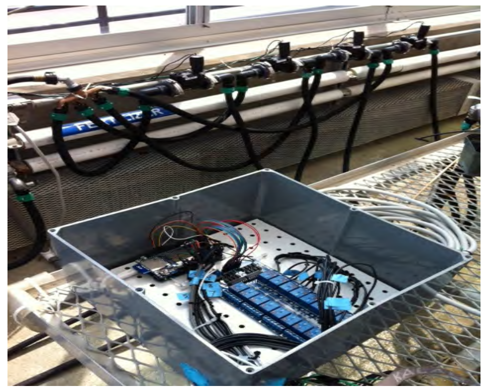
New Facilities and Equipment (Plant-Growth Facilities, Eddy):

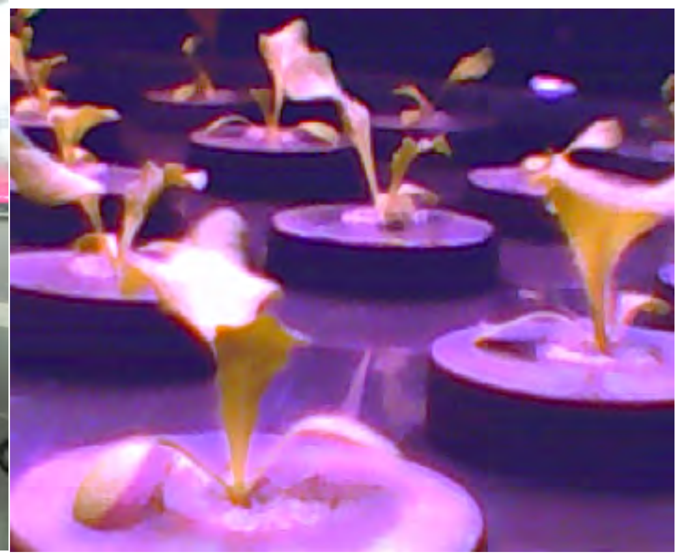
SOIL-MOISTURE-TRIGGERED IRRIGATION SYSTEM
Under the direction of Marc van Iersel at the University of Georgia, we assembled a standalone soil-moisture sensor and irrigation system that provides eight independent irrigation events. The system is used to conduct water-stress studies in a greenhouse room, and can be expanded to 14 sensors and irrigation valves without additional controllers. Data are collected and irrigation initiated according to programming by an Arduino Mega 2560 microcontroller, datalogging shield, and 16-channel 5V Relay Shield Module. Software is free and open source. A standard laptop runs the programming written for us by Dr. van Iersel. Decagon 10HS soil-moisture sensors measure volumetric water content. Water is delivered in pulses of less than five seconds using Jain pressure-regulated drippers to maintain a desired water content. The Arduino microcontroller (image) activates valves in the background based on readings from the soil-moisture probes. The system required about 85 hours to assemble, including assembly of microcontrollers, wiring, and installation of irrigation valves and drippers. The microcontroller cost less than $150. Total cost of the project was $1700, not including the laptop or installation labor.



GROWTH CHAMBER CONTROLLER AND HOST PC UPGRADE
We replaced model 4030 controllers in twenty-three Conviron growth chambers with model 5090 controllers. This eliminated many failures of the chambers associated with the aging controllers. We chose not to upgrade to the newest model 6050 series because of greater cost, the fact that the 6050s would have required new door panels to fit, and because we like the larger, color display of the 5090. We also upgraded our two PC hosts on campus to Conviron CM 8 Central Management systems.

Crop Gas-Exchange Cuvette / LED Lighting Array / Hydroponic Culture System (Mitchell Lab):
Undergraduate Purdue students (Cannon Cheng, Mechanical Engineering, David Lotz, and Connor Hartford, both Electrical Engineering Technology) teamed to integrate and troubleshoot a plant-growth / gas-exchange / hydroponic culture system that has been under development in the CAMLab for several years. The system accommodates a crop stand of ~0.4 m^2 (e.g., 48 lettuce plants) and permits

photosynthetic gas exchange to be monitored continuously by an open gas-exchange system throughout a cropping cycle (image, lower left). An adjustable-height overhead LED lighting array is interfaced with the cuvette and a recirculating hydroponic system. Parameters that presently can be controlled include CO_2 concentration of air flowing into the system as well as red : blue ratio and total PPF of the lighting unit. Issues of cuvette leakage were addressed with help from Jerry Shepard, custom designer / builder of the cuvette. The student team also interfaced a Peltier cooling device with the cuvette to help maintain cuvette temperature during the lighting cycle, installed atmosphere-mixing fans within the cuvette, and deployed thermocouples within the cuvette to measure actual temperature. A lettuce test crop was grown within the cuvette and it was determined that a detectable CO_2 differential between cuvette outlet and cuvette by-pass air streams could be established as soon as first leaf emergence for lettuce (image, lower right). Air-flow rate through the system controlled by mass-flow valves is used to minimize CO_2 differential as crop stands grow in leaf area and maturity. The system continues to evolve now that it can be tested with plants.



LED/Cuvette/hydroponic System TV image of lettuce seedlings growing within the cuvette.

Unique Plant Responses (Lopez Lab):

In order to produce uniform and high-quality annual bedding plant seedlings or plugs in late winter through early spring, supplemental lighting (SL) must be used to maintain a photosynthetic daily light integral (DLI) of 10 to 12 $mol \cdot m^{-2} \cdot d^{-1}$. The objectives of this study were to: 1) quantify bedding plant seedling quality under greenhouse SL from light-emitting diodes (LEDs), high-pressure sodium lamps (HPS), or plasma lamps (PL); 2) quantify seedling quality under sole-source LED lighting in a growth room environment; and, 3) compare seedlings grown under a

DLI of ≈10.5 mol·m^{-2}·d^{-1} from ambient solar light plus SL or sole-source lighting to those grown under ambient solar light. Upon hypocotyl emergence, seedlings of *Catharanthus roseus*, *Impatiens walleriana*, *Pelarganium ×hortorum*, *Petunia ×hybrida*, and *Tagetes patula* were placed under ambient solar light plus SL delivering a photosynthetic photon flux (*PPF*) of 70 µmol·m^{-2}·s^{-1} in the greenhouse for 16-h or under sole-source light delivering a *PPF* of 185 µmol·m^{-2}·s^{-1} in a growth room for 16-h. Supplement light treatments consisted of HPS, PL, and LED arrays providing a red:blue light ratio of 87:13, and sole-source light treatments were made up of LED arrays providing a red:blue light ratio of 87:13 or 70:30. Stem elongation of *Pelargonium* and *Petunia* seedlings decreased by 18% and 69%, respectively, for plants grown under sole-source LEDs providing 70:30 red:blue light, and *Tagetes* decreased by 13% for plants grown under sole-source LEDs providing 87:13 red:blue light, compared to ambient solar light. Root dry mass of *Petunia* seedlings grown under sole-source LEDs providing 70:30 red:blue light increased by 127% compared to those under the ambient control. The quality index, a quantitative measurement of quality, increased by 157% and 132% for *Impatiens* and *Pelargonium*, respectively, for plants grown under sole-source LEDs providing 70:30 red:blue light, compared to the ambient control. These results indicate that annual bedding plant seedlings grown under controlled environments with LED sole-source lighting are generally of higher quality than seedlings grown in a traditional greenhouse with or without SL.

Pennisetum setaceum (Forssk.) Chiov. 'Rubrum' is a popular dark purple-pigmented ornamental grass when grown under high-light conditions. However, under low-light greenhouse conditions, such as those found in northern latitudes, foliage is often green to light purple and not as aesthetically appealing to consumers. Our objective was to quantify the effect of end-of-production supplemental light (SL) of different intensities and sources on foliage color of *P. setaceum*. Plants were placed at 23 °C and under a DLI of 7.5 mol·m^{-2}·d^{-1} (control) or provided with 16-h of additional SL from a high-pressure sodium (HPS) lamp providing 70 µmol·m^{-2}·s^{-1} or LED arrays providing 25, 50, or 100 µmol·m^{-2}·s^{-1} blue light, or 100 µmol·m^{-2}·s^{-1} red light. Chromametric and SPAD values of *P. setaceum* foliage were significantly different among all treatments after 3, 5, 7, 14, and 21 days of SL. For example, plants grown under 100 µmol·m^{-2}·s^{-1} blue light were the darkest in color with an L* (lightness) value of 33.07. Chromametric a* (change from green to red) and b* (change from yellow to blue) values increased as blue light intensity increased from 25 to 100 µmol·m^{-2}·s^{-1}. Chromametric a* and b* values of plants grown under 100 µmol·m^{-2}·s^{-1} blue light were -0.86 and 7.19, respectively. Our data suggests that seven days of 100 µmol·m^{-2}·s^{-1} blue LED light promotes purple pigmentation of *P. setaceum* foliage when the crop is finished under a low greenhouse light environment.

Unique Plant Responses (Mitchell Lab):

Quality Attributes of fruits from greenhouse tomato. Fall 2013 marked the final set of quality attribute analyses of fruits from a 2-year supplemental lighting study of greenhouse high-wire tomato conducted by M.S. graduate student **Michael Dzakovich**. Those data are included in a manuscript that is currently in progress. Furthermore, Michael conducted background research and established collaborations for M.S. thesis projects aimed at improving consumer acceptability of greenhouse tomatoes and/or their nutritional value.

At the beginning of 2014, Michael set up a greenhouse study to compare tomato fruits from plants grown with or without supplemental short-waveband radiation. A thought-provoking phenomenon is the fact that glass-glazed greenhouses exclude radiation below 320 nm from entering the greenhouse environment. This region of the electromagnetic spectrum includes UV-B, which is an important regulator of plant growth and mediator of plant secondary metabolism. It is hypothesized that supplementation of UV-B radiation incident upon greenhouse crops will create produce that is both nutritionally and organoleptically similar to garden-grown produce.

Michael calibrated UV-emitting lamps to emit 17 $kJ/m^2/day$ (normalized to the Flint-Caldwell BSWF (2003)), which is roughly equivalent to what a plant would receive on an average June day in West Lafayette, Indiana. However, strange phenotypes that were abnormal in both field and greenhouse settings were observed, and the duration of irradiation was reduced until symptom development slowed considerably. The sepals of developing fruit clusters were observed to thicken and curl in response to short-waveband radiation, and some fruits developed a tough, brown callous on the exocarp facing the radiation source. It was subsequently discovered that a filter material being used to screen out UV-C radiation (110-280nm) that the lamps also produce was defective and allowed unnaturally short wavelengths of radiation to reach the plants. It was also noticed that during a brief outbreak of Powdery Mildew, a fungal pathogen, that control plants were affected, but UV-B supplemented plants were not, suggesting that those wavelengths reduced the fecundity and virulence of the fungal pathogen.

During the summer of 2014, Michael will analyze tomato fruits for carotenoid and phenolic composition using HPLC coupled with an electrochemical detection unit, as well as basic physicochemical attributes such as total soluble solids, titratable acidity, and ascorbic acid content. Additionally, tomato-fruit volatiles will be analyzed using GC-MS allowing for inference of the metabolic changes associated with exposure to short-waveband radiation. This greenhouse study will be complemented with an outdoor field trial, which will seek to establish chemical profiles of "garden-grown quality" for tomatoes of the same variety.

Lastly, Michael will once again collaborate with labmate Celina Gomez to analyze fruits from her experiments comparing novel intracanopy supplementation of high wire greenhouse tomatoes using LEDs. The shared use of the newly acquired PP-Systems CIRAS-3 photosynthesis/fluorescence device is of great interest to further understand the roll of short-waveband radiation on photosynthetic efficiency of greenhouse crops.

A cluster of tomatoes exposed to short-waveband radiation.

Curled sepals of developing fruit clusters exposed to short-waveband radiation.

Greenhouse supplemental lighting (SL) for high-wire tomato production. Research related to the PhD project of **Celina Gomez** in the **Mitchell lab** is comparing SL from either traditional overhead HPS lighting with that from intracanopy LED lighting from ORBITEC LED towers and with unsupplemented controls. Two 5-month high-wire tomato-production experiments were conducted in the greenhouse during 2013. One was a winter-to-summer study replicating a similar study in 2012, and the other was a summer-to-winter study replicating a similar 2012 study. In the winter-to-summer replicate study, LED and HPS SL treatments gave the same tomato-fruit yield, but LED SL did so using 73% less energy than did HPS SL. One change made to the 2013 winter-to-summer experiment was to install incandescent photoperiod lamps above control treatments, which was not done during either 2012 experiment. Interestingly, there were no significant differences in fruit yield between controls and either LED or HPS SL treatments in that experiment. Two things may have contributed to that rather surprising outcome: our measurements of daily light integral (DLI) in the greenhouse indicated much higher solar DLI during late winter in 2013 than during 2012. Incandescent photoperiod lighting of the control added an additional minor contribution to total DLI ($<0.5\ mol \cdot m^{-2} \cdot d^{-1}$) for that experiment, but what was most noticeable was much larger plants with larger leaves for control treatments than for previous-year controls, possibly due to the far-red component of incandescent supplementation. Because of this outcome, incandescent supplementation was not provided to control treatments during the subsequent summer-to-winter experiment of 2013. In that experiment, both the number and total mass of fruit were not different between LED and HPS treatments, but both SL treatments yielded 25% more fruit and had 35% more fruit mass than did controls.

Greenhouse SL for tomato transplant production. A propagation experiment was concluded for which different tomato cultivars were grown for 2 weeks per month over a 14-month period. A supplemental DLI of 5.1 $mol \cdot m^{-2} \cdot d^{-1}$ from either HPS, control, or three different red:blue ratios of overhead supplemental LEDs was provided to seedlings growing in the greenhouse under seasonally changing solar DLIs from January 2012 through February 2013. Growth benefits of SL were greatest during low-ambient solar DLI. Light-quality effects of SL varied with season. The combination of R and B in SL typically stimulated growth and productivity of young tomato seedlings during winter and summer (lowest- and highest-solar DLI, respectively), whereas fewer SL treatment differences occurred during milder-solar-DLI spring and fall.

Accomplishment summary (Mitchell Lab):

The combined LED lighting array / crop-stand gas-exchange cuvette / hydroponic culture system will be a powerful tool allowing real-time optimization of light, CO_2, and temperature conditions at every developmental stage of a small-statured crop stand. Instead of having to wait for entire crop-production cycles to be completed under fixed set points of these three environmental factors, a computer operator can quickly challenge photosynthetic rate responses whenever desired with incremental up/down tweaks of the growth environment and observe real-time photosynthetic rate responses. As growth-optimizing levels change with crop-development stage, adjustments can be applied one or more times daily. For high-energy inputs such as light, this tool has potential to define when such inputs are needed for productivity, and when they are not.

Impact Statements (Mitchell Lab):

Intracanopy lighting with LEDs allows significant power and energy savings for greenhouse high-wire tomato supplemental lighting compared to traditional overhead lighting with hot light sources because LEDs are cool enough to be placed close to photosynthetic tissues without overheating them. Thus, adequate photon fluxes of highly efficient wavelengths can be applied from within the foliar canopy of an otherwise overhead shaded crop with very low power density and thus significant electrical energy savings.

Published Written Works (Lopez Lab):

Paparozzi, E.T., N.S.Mattson, M. Grossman, S. Burnett, and **R. Lopez**. Creative thinking, creative funding: research, extension, and teaching programs and consortiums—The 2013 national floriculture forum. HortTechnology 23(6):794–795.

Currey, C.J., A.P. Torres, D.F. Jacobs, and **R.G. Lopez**. 2013. The quality index – A new tool for integrating quantitative measurements to assess quality of young floriculture plants. Acta Hort. 1000:385–392.

Currey, C.J., R.G. Lopez, V.K. Rapaka., J.E. Faust, and E.S. Runkle. 2013. Exogenous applications of benzyladenine and gibberellic acid inhibit lower-leaf senescence of geraniums during propagation. Hortscience 48(11):428–434.

Camberato, D.M., J.J. Camberato, and **R.G. Lopez**. 2013. Comparing the adequacy of controlled-release and water-soluble fertilizers for bedding plant production. HortScience 48(4):556–562.

Currey C.J. and **R.G. Lopez**. 2013. Cuttings of Impatiens, Pelargonium, and Petunia propagated under light-emitting diodes and high-pressure sodium lamps have comparable growth, morphology, gas exchange, and post-transplant performance. HortScience 48(4):428–434.

Extension

Currey, C.J., **R.G. Lopez**, and E.S. Runkle. 2013. Managing photoperiod in the greenhouse. HO-253-W:1−6. http://www.extension.purdue.edu/extmedia/HO/HO-253-W.pdf

Lopez, R.G. 2013. Managing temperature and light to reduce shrink and increase quality. e-GRO Alert 2(20):1–4.

Lopez, R.G., C.J. Currey, and B.A. Krug and 2013. New web-based supplemental light calculator (DLICALC). e-GRO Alert 2(16):1–4.

Lopez, R.G. and Currey, C.J. 2013. Improving the rooting success of challenging petunia cultivars. e-GRO Alert 2(10):1–4

R.G. Lopez. 2013. Understanding the differences between photoperiodic and supplemental lighting. Greenhouse Grower 31(13):26–30.

Mattson, N.S., B.A. Krug and **R.G. Lopez**. 2013. Promising trends for the future of floriculture education and extension. Greenhouse Grower 31(14):94–96.

Currey, C.J. and **R.G. Lopez**. 2013. Comparing LED lighting to high-pressure sodium lamps. Greenhouse Grower 31(11):34–40.

Randall, W.C. and **R.G. Lopez**. 2013. Comparing LED lighting to HPS lamps for plug production. Greenhouse Grower 31(12):32–38.

Currey, C.J., R.G. Lopez, V. Rapaka, J. Faust, and **E. Runkle**. 2013. Keeping it green - how to reduce lower-leaf yellowing of geranium cuttings in propagation. GrowerTalks 77(12):76–81.

Camberato, D.M., J.J. Camberato, and **R.G. Lopez**. 2013. Poinsettia reduced temperature finishing. OFA – An Association of Floriculture Professionals Bulletin 937(1):23−24.

Lopez, R.G. and C.J. Currey. 2013. Parboiled rice hulls in substrates to finish greenhouse crops. Greenhouse Grower 31(6):33–36.

Currey, C.J., **R.G. Lopez**, and B.A. Krug. 2013. DLICALC online tool helps growers calculate daily light integral. Greenhouse Grower 31(5):31–33.

Currey, C.J. and **R.G. Lopez**. 2013. Parboiled rice hulls in propagation substrates. Greenhouse Grower 31(4):30–34.

Miller, W., N. Mattson, **R. Lopez**, C. Currey, K. Clemens, M. Olrich, and E. Runkle. 2013. A new height control possibility for daffodils and hyacinths. Greenhouse Product News 23(3):14–18.

Runkle, E., C. Currey, K. Clemens, **R. Lopez**, W. Miller, and N. Mattson. 2013. Ethephon drenches on bedding plants. Greenhouse Product News 23(4):20–23.

Scientific and Outreach Oral Presentations (Lopez Lab):

Randall, W.C. and R.G. Lopez. Determining the effectiveness of red and blue light-emitting diodes as supplemental lighting during seedling propagation. ASHS Annual Meeting, 21−22 July, 2013. Palm Desert, CA. HortScience. Third Place Award.

Currey, C.J. and R.G. Lopez. Impatiens, Pelargonium, and Petunia cuttings propagated under light-emitting diodes and high-pressure sodium lamps have comparable growth, morphology, gas exchange, and post-transplant performance. NCERA-101 Committee on Controlled Environment Technology & Use Annual Meeting. West Lafayette, Indiana. March 9–May 12, 2013. Second Place Award

Gerovac, J.R. and R.G. Lopez. Energy efficient bedding plant production using root-zone heating in combination with reduced air temperatures. NCERA-101 Committee on Controlled Environment Technology & Use Annual Meeting. West Lafayette, Indiana. March 9–May 12, 2013.

Randall, W.C. and R.G. Lopez. Comparing high-pressure sodium, lamps to light-emitting diodes as supplemental lighting during seedling propagation. NCERA-101 Committee on Controlled Environment Technology & Use Annual Meeting. West Lafayette, Indiana. March 9–May 12, 2013.

Extension

Getting Your Annuals and Perennials into Flower on Time Every Time Vegetative Propagation Principles: 201 Effectively Using CRFs in the Greenhouse	Kentucky Small Farms Conference	Pembroke, KY	12/4/13
Energy Efficient Bedding Plant Production Using Controlled Released Fertilizers in the Greenhouse	Landscape Alberta	Edmonton, Alberta, Canada	11/15/13
Alternative Growing Substrates Using Photoperiod to Control Flowering and Tuber Formation of Dahlia How do CRFs Stand Up Against each Other in the Greenhouse?	Indiana Flower Growers Assoc. Annual Meeting	West Lafayette, IN	10/10/13
PGR Primer: Understanding Plant Growth & How PGRs Work Alternative Plant Height Management Strategies Reconociendo los Requisitos y Problemas Abióticos y Culturales en el Invernadero	OFA Disease, Insect and Growth Conference	Portland, OR	9/10/13
Greenhouse Learning & Diagnostic Tour Managing Light During Plug & Liner Production Bedding Plants 101	OFA Short Course	Columbus, OH	7/13/13 to 7/16/13
Ornamental LED Propagation Research	USDA-SCRI Stakeholder Conf.	West Lafayette, IN	6/5/13
Using LEDs during Propagation Energy-Efficient Bedding Plant Production	Indiana Flower Growers Assoc. Bedding Plant Conf.	Indianapolis, IN	2/21/13

Published Written works (Mitchell Lab):

Gómez, C. and C.A. Mitchell. 2014. Supplemental lighting for greenhouse-grown tomatoes: intracanopy LED towers vs. overhead HPS lamps. Proc. in Symp. New technologies for environment control, energy-saving and crop production in greenhouse and plant factory. Acta Hort. (in press).

Yang, Y., G.D. Massa, and C.A. Mitchell. 2014. Temperature DIP at the beginning of the photoperiod reduces plant height but not seed yield of maize grown in controlled environments. J. Industrial Crops and Products 53: 120-127.

Scientific and Outreach Presentations (Mitchell Lab):

Gomez, C. and C.A. Mitchell. 2013. Supplemental lighting for greenhouse-grown tomatoes: Intracanopy LED towers vs. overhead HPS lamps. Oral presentation at the International Society of Horticultural Science, GreenSys 2013 Conference. October 6-11, Jeju, S. Korea.

C.A. Mitchell, R.G. Lopez, and C.J. Currey. 2013. Growth, morphology, gas exchange,and post-transplant performance of vegetatively propagated cuttings under light-emitting diodes and high-pressure sodium lamps is comparable. Invited presentation at Greensys 2013: new technologies for environment control, energy-saving, and crop production in greenhouse and plant factory. October 6-11, Jeju, Korea.

C.A. Mitchell. 2013. LEDs for the commercial greenhouse industry. Invited presentation at LEDs + the SSL Ecosystem 2013: the path to profit. Smithers Apex, Boston, October 28-29.

Gomez, C. and C. Mitchell. 2013. Supplemental lighting for greenhouse-grown tomatoes: Intracanopy LED towers vs. overhead HPS lamps. Oral presentation at the American Society for Horticultural Sciences (ASHS) conference, July 23, Palm Desert, CA.

Dzakovich, M., C. Gomez, and C.A. Mitchell. 2013. A semiyearly study on the effect of light quality on flavor of greenhouse-grown tomatoes: LED vs. HPS. American Society for Horticultural Science annual conference, July 23, Palm Desert, CA.

Gomez, C. and C. Mitchell. 2013. Supplemental lighting for greenhouse tomatoes: intracanopy LED towers vs. overhead HPS lamps. Second SCRILED stakeholder meeting, June 5, Purdue University.

Dzakovich, M., C. Gomez, and C. Mitchell. 2013. Quality assessment of tomatoes grown with intracanopy LED lighting. Second SCRILED stakeholder meeting, June 5, Purdue University.

Gomez, C. 2013. Year-round production of high-wire greenhouse-grown tomatoes: Intracanopy LED towers vs. overhead HPS lamps. Invited oral presentation at the Departmental research retreat, Horticulture and Landscape Architecture Department, May 10, Purdue University.

C.A. Mitchell. 2013. Innovations for efficient crop lighting in controlled Environments May 10, HLA Research Retreat.

C. A. Mitchell. 2013. LED supplemental lighting technologies for sustainable off-season production of greenhouse vegetable crops. Pickle Packers International, Inc. April 18, Indianapolis.

M. Dzakovich, C. Gomez, and C. Mitchell. 2013. Effect of light quality on flavor of greenhouse-grown tomatoes: LED vs. HPS. NCERA-101 annual meeting, March 10, Purdue University.

Gomez, C. and C. Mitchell. 2013. Light-emitting diodes as an alternative for supplemental lighting of high-wire greenhouse tomatoes, NCERA-101 annual meeting, March 10, Purdue University.

Other Relevant Accomplishments and Activities (Lopez Lab):

Wesley Randall, 2013. Third place in the American Society for Horticultural Science (ASHS) Controlled Environment Working Group (CEWG) student oral competition. Palm Desert, California.

Roberto Lopez, Brian Krug, Brian Whipker, and Nora Catlin. 2013. Outstanding Extension Educational Materials Award, American Society for Horticultural Science (ASHS), Palm Desert, California.

Diane Camberato, Roberto Lopez and Brian Krug, 2013. Alex Laurie Award for the most significant applied floriculture research paper published in 2012 Development of *Euphorbia pulcherrima* under Reduced Finish Temperatures. *HortScience* 47(6):745–750, OFA - Association of Horticulture Professionals Short Course, Columbus, Ohio.

Josh Gerovac, 2013. First place in the graduate student poster competition ($500), Department of Horticulture and Landscape Architecture, Purdue University.

Christopher Currey, 2013. Outstanding Dissertation Award ($250), Horticulture and Landscape Architecture, Purdue University.

Garrett Owen, 2013. OFA – Scholars OFA – Association of Horticulture Professionals Scholar, Columbus, Ohio.

Alyssa Hilligoss, 2013. Laurenz Greene Summer Research Scholarship ($3,000), Purdue University.

Alyssa Hilligoss, 2013. Purdue Agricultural Centers Research Experience ($4,000), Purdue University.

Christopher Currey, 2013. Second place in the graduate student poster competition ($200), Committee on Controlled Environment Technology & Use (NCERA-101) regional working group annual meeting. Purdue University, IN.

Garrett Owen, 2013. Recipient of the Paul Ecke Jr. Scholarship ($10,000), American Floral Endowment.

Other Relevant Accomplishments and Activities (Mitchell Lab):

Celina Gomez, second place, ASHS controlled environments graduate student oral Presentation competition, ASHS annual conference, July 23, Palm Desert, CA, 2013.

Michael Dzakovich, third place, 2013 ASHS undergraduate student oral presentation competition, ASHS annual conference, Palm Desert, July 22 CA.

Michael Dzakovich, first place, 2013 ASHS undergraduate horticultural proficiency exam, ASHS Annual Conference, Palm Desert, July 22.