NCERA 101 Purdue Station Report - 2011

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1**. Impact Nugget:** LED sole-source and supplemental lighting appears to give equivalent or better plant response than traditional lighting sources for a fraction of the energy cost.

2. **New Facilities and Equipment:**

Arabidopsis Growth Room: A 6.7m x 14.6m growth room was constructed at the Whistler Agricultural Research Building from a location formerly holding aging plant-growth chambers. Three 2.4m x 4.8m industrial racks were installed to create four tiers of lighted shelves for a total capacity of 47.6 m^2, or 768 trays of Arabidopsis. Shelf height is 64 cm. All shelves are lighted with T8 4100°K fluorescent lamps capable of achieving 150 $\mu mol/m^2/s$. Each section of rack lights can be turned off to save energy if unused. Midwest GROmaster ebb-and-flood tables are used for sub-irrigation, triggered by Irritrol irrigation controllers. Fertilizer can be injected using a Dosatron D8R injector plumbed into irrigation lines. The shelves are air-conditioned using a large-capacity Liebert unit designed for a server room, with ductwork feeding each of the three racks. Airflow can be balanced manually by adjusting small louvers on each shelf. The room is kept under positive pressure, and door sweeps and Mars air-curtain doors installed to reduce pest flow into the room. Alarms are installed to turn off power in the event of high air temperature or flooded floors.

Close-canopy HELIAC lighting arrays: On June 14, 2010, the Orbital Technologies Corporation (ORBITEC) delivered two overhead High-Efficiency-Lighting-with-Integrated-Adaptive Control (HELIAC) LED lighting arrays. These "smart" lighting arrays are identical and allow complete separation of the thermal and gaseous environment of the LEDs from the plant growth environment via air-cooled heat exchangers and ductwork. Each array is arranged in four 27.5 x 27.5 cm panels containing 36 red LEDs (630 nm), 9 blue LEDs (455 nm), and 9 green LEDs (525 nm)as well as 16 photodiodes and 4 thermal sensors. Arrays can be operated manually or automatically. Automatic mode allows for detection events that occur by flashing of green LEDs and reflectance from leaves into photodiodes. Red, blue, and green intensities are controllable as are the threshold for detection and photoperiod. Power and energy consumption also are monitored via the custom HELAIC software. One array has been mounted in a walk-in growth chamber from a pulley/hoist system for raising and lowering over a hydroponic tub. The second array was mounted to a counterbalanced panel inside a custom-built gas-exchange cuvette constructed by Ideal Engineering Solutions. This cuvette will be run in an open configuration using a high-capacity blower, differential and absolute IRGAs, and mass-flow valves allowing precise mixing of air and CO_2 for the inlet air stream. It has humidification capability, temperature control, and redundant temperature and humidity sensing. In addition, the cuvette is outfitted with a computer-controlled pan/tilt stage and digital camera with zoom capability allowing observation of the canopy and lighting system within the closed cuvette. The cuvette has an integrated hydroponic system with a separate gas environment and ports for rhizosphere-head-space gas sensing. Nutrient solution recirculates between the hydroponic tub contained in the cuvette and an external reservoir where the solution is maintained, allowing long-term closed-cuvette experimentation. These close-canopy HELIAC lighting arrays and this cuvette are designed for low-profile-growth-habit crops such as lettuce and strawberry, and may also be used for semi-dwarf erectophile crops, such as wheat and rice. Debugging the system in preparation for integration testing of the lighting arrays and cuvette is underway.

Greenhouse Overhead LED lights: On June 14, 2010, ORBITEC also delivered two overhead LED supplemental-lighting arrays designed specifically for pre-grow-out greenhouse propagation studies. Each 1.2 m x 1.3 m array consists of eight aluminum bars with alternating bars mounted with 627-nm red or 450-nm blue LEDs. Each red and blue bar has 28 or 24 LEDs, respectively, along their 1.2-m length. Arrays are air-cooled via hollow aluminum mounts and powerful fans that draw greenhouse air into the middle of each bar and blow it out both ends. The LED open-bar arrays are designed to run above and across a standard 1.5-m-wide greenhouse bench on a height-adjustable mount. The 1.2-cm-wide bars are spaced with 15.5 cm between bars, thereby allowing sunlight to pass through while uniformly irradiating the bench surface.

High Tunnels: The Floriculture Research group began utilizing two single-layer polyethylene, 7.9 m x 14.6 m high tunnels at the Throckmorton-Purdue Agricultural Center Meigs Farm. High tunnels are ventilated with manually operated transoms on the end walls and roll up polyethylene side walls. Tunnels are fitted with two injectors (Chemilizer) to provide a variety of watering options including acidified water and fertigation, manually or through drip irrigation. UV-treated woven polypropylene flooring has been installed for production of containerized annuals in one tunnel. The other tunnel has been modified for cut-flower research by installation of four 1.2 m x 12.2 m x 15.2 cm raised beds amended with a 60% leaf litter compost/40% topsoil-sand mix. Identical beds were constructed on an adjoining field plot allowing for field-high tunnel production comparisons. Portable data loggers (Spectrum Technologies) are on site to record air, soil temperature, and daily light integral for both the tunnels and field. Refrigeration is located at this facility for cut-flower storage and handling.

Propagation system: In 2010 the Floriculture Research group at Purdue installed a new propagation zone in one of the research greenhouses. This propagation zone has the infrastructure to independently manipulate light, substrate temperature, and mist frequency, durations, fertility level, and pH. In addition to 1000-W high-pressure sodium (HPS) lamps, a frame has been built to support 38, 61, or 86 % spectrum-neutral shade cloth (Ludvig Svennson). Benches have bench-top radiant hot water heating (True Leaf Technologies) with four independently programmable temperature set points, four mist lines that have independently controlled mist frequencies and durations (Phytotronics), plus in-line micro-injectors for each line to provide four different fertility regimes, and a mico-injector for acidifying mist (Dosmatic). In addition to Priva greenhouse sensors, quantum sensors (Apogee Instruments), and temperature sensors (Spectrum Technologies) were installed to measure irradiance and air and substrate temperatures, respectively, and connected to data loggers (Spectrum Technologies) for monitoring environmental conditions under numerous environments.

3. **Unique Plant Responses.**

Bedding plant production: The production of 11 bedding plant species is currently being conducted in a greenhouse and high-tunnel environment. These species include: *Petunia*, *Celosia*, *Viola, Pelargonium, Antirrhinum, Angelonia,* Catharanthus, *Tagetes*, *Dianthus,* and *Osteospermum*. The purpose of this study is to assess whether production of cold tolerant and some cold sensitive species is possible in a low input high tunnel setting without a significant delay in development and quality. This study is also being conducted at Cornell University in Ithaca, New York to determine the effects of different latitudes. Plants were received as plugs and transplanted into 10-cm plastic pots. After transplant, plants were placed in either a water-soluble fertilizer treatment or a controlled-release fertilizer treatment in a high tunnel and at the Purdue Horticulture Research Greenhouse Facility with a temperature set point of 18 °C. Environmental data are being recorded along with flowering data (flower bud number and time to flower), height data (weekly and at time of harvest), and shoot dry weight data. The experiment is expected to be complete once all species have flowered and will be repeated the following spring.

Lettuce-HELIAC Testing: The aim of this project is to reduce energy and cooling requirements for plant lighting in space and for CEA. Since LEDs have relatively cool photon-emitting surfaces and can be placed much closer to plant surfaces than traditional light sources, power requirements for effective lighting are reduced. ORBITEC's HELIAC overhead-lighting system is "smart" in that it detects the location of individual plants within a crop stand and subsequently switches on red and blue LEDs directly above where a plant was just detected. Such a select lighting system saves energy compared to one in which all LEDs are energized simultaneously. Detection of plant location is accomplished by periodically flashing green light onto a crop stand and analyzing the reflection signal. Since green is the least absorbed PAR waveband by plants, photodiode detection of strong reflectance signals indicates the presence of a nearby plant as opposed to empty space. Treatments being compared include all overhead LEDs energized all the time vs. manual switching of selected LEDs vs. the smart system. At the end of each experiment, plant dry weight is measured and correlated with the kWh of electrical energy used to grow each crop. Labor inputs also are recorded. The data will be used to calculate ESM for different lighting scenarios. In a crop cuvette fitted with a HELIAC overhead-lighting system, the gas loop including inlet CO_2 concentration will be controlled. This will enable a real-time evaluation of crop photosynthetic rate, which is directly linked to the crop's energy demand. We thus will be able to determine the best combination of LED light intensity, blue/red ratio, CO_2 concentration, and temperature on photosynthesis and yield of leaf lettuce with the least energy consumption.

Maize Production in a Controlled Environment: A maize crop was grown to the post-fertilization stage of embryo development in a 12-foot-tall EGC walk-in growth chamber for work done in collaboration with Dr. Yang Yang of Dow-Agro Sciences (DAS). Two growth media were compared and PPF of HID lighting was set in accordance with prescribed experimental goals. Although specific conditions and outcomes of the experiment are proprietary to DAS, a significant general outcome is that a crop like maize with complex environmental requirements for tassel unfurling leading to shed of viable pollen synchronized with silk receptivity at the ear can be achieved for successful pollination leading to full seed set and ear development in controlled environments. Years of prior experimentation with maize in the Mitchell lab relative to the future pharma-crop industry has shown that this is not a trivial endeavor.

Propagation of un-rooted cuttings: Cuttings of *Angelonia*, *Argyranthemum*, *Diascia*, *Lantana*, *Nemesia*, *Osteospermum*, *Scaevola*, *Sutera*, and *Verbena* were harvested and propagated in a glass- glazed greenhouse with a 23 °C air and substrate temperature set points. After callusing (≈5 $mol \cdot m^{-2} \cdot d^{-1}$ for 7 d) cuttings of each species were placed under no shade or one of three different shade cloths providing ≈38, 61, or 86% shade with 16 h of supplemental irradiance for 14 d. The experiment was repeated two additional times resulting in 12 different DLIs during root development ranging from 1.2 to 12.3 $mol \cdot m^{-2} \cdot d^{-1}$. Cuttings were then transplanted and placed under a common finishing environment of 21.5 °C and a DLI of 10 to 12 $mol \cdot m^{-2} \cdot d^{-1}$. Data were collected at the end of propagation for rooted cuttings and at first open flower for transplanted cuttings.

Sesame: Several sesame lines were donated by Sesaco for testing as potential life-support oil-seed crops. Breeding lines selected for testing included relatively dwarf lines: T100d, TGDwd, TKO5d, TG32D, TKHAd, and TK55. Plants were grown in either-peat based or arcillite media under greenhouse conditions and automatic fertigation. All seeds germinated well and plants grew vigorously with flowers forming approximately 1 month after planting. All plants flowered and set seed, although most became top-heavy and had to be staked. Following seed set, plants were allowed to dry down and seeds were collected. Manual seed harvest was challenging and required significant labor. Since some capsules opened sequentially while others were still filling, seed losses were likely. Although all plants produced seed, line TKHAd produced more capsules and seed than others, mostly due to more branches with apical inflorescences. In general, plants were challenging to grow in a pot-cultivation scenario, and even the dwarf varieties tested were likely too large for a space life-support environment, where available growing volume is at a premium. Recommendations for further testing include better structural support including possibly clipping to suspended twine, and harvesting pods individually as they ripen. Environmental and growth-regulator approaches to height control that do not compromise seed yield also may prove useful.

Tomato- Greenhouse testing: Hybrid production varieties of DeRuiter tomato seeds were donated by the parent seed company Monsanto to evaluate potential cultivars for comparing year-round fruit production in greenhouses using LEDs as appropriate for supplemental lighting. A preliminary propagation study tested cultivars 'Maxifort' (rootsctock), 'Komeett' (generative scion), and 'Success' (vegetative scion). Seedlings have been grown for up to 30 days in a late-winter/early-spring greenhouse maintained at 26°C days and 18°C nights. Three lighting treatments were compared: natural light (control), natural + supplemental LEDs (75% red + 25% blue), and natural + supplemental LEDs (50% red + 50% blue). Seedlings under LEDs were irradiated for 16 h/day at a photosynthetic photon flux (PPF) of 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Plants grown under LEDs produced greater shoot biomass and thicker hypocotyls compared to controls, regardless of the red: blue ratio. The wider hypocotyls could suggest that LED supplementation may be unsuitable prior to grafting. A physiological disorder known as "intumescence" was observed in 'Maxifort'. However, damages were not severe enough to affect the plant-growth variables evaluated in this study. Future work will use appropriately lighted transplants in a high-wire production system containing side-/ intracanopy-lighting arrays of high-intensity red and blue LEDs.

4. **Accomplishment Summaries.**

Floriculture Group: There were no clear trends for stem length of rooted cuttings in response to DLI across species. Stem caliper of *Argyranthemum*, *Diascia*, and *Nemesia* increased by 35%, 119%, and 89%, respectively, as DLI increased from 1.2 to 12.3 $mol \cdot m^{-2} \cdot d^{-1}$. Depending on the species the total, shoot, and root dry mass of rooted cuttings increased by 64% to 465%, 50% to 384%, and 156% to 1137%, respectively, as DLI increased from 1.2 to 12.3 $mol \cdot m^{-2} \cdot d^{-1}$. The quality index, a new integrated and quantitative measurement of rooted cutting quality we are introducing to floriculture, increased for all species by 176% to 858% as DLI increased from 1.2 to 12.3 $mol \cdot m^{-2} \cdot d^{-1}$. As propagation DLI increased from 1.4 to 12.3 $mol \cdot m^{-2} \cdot d^{-1}$ days from transplant to first open flower decreased by 24 and 15 d in *Angelonia* and *Nemesia*, respectively. In general, shoot dry mass at flowering was lower for plants propagated under high DLI treatments. For example, shoot dry mass at flowering of *Angelonia* decreased from 1.2 to 0.38 g as propagation DLI increased from 1.4 to 12.3 $mol \cdot m^{-2} \cdot d^{-1}$. However, shoot dry mass accumulation per day increased with increasing DLI for *Nemesia*, *Sutera*, *Diascia*, and *Osteospermum*, while shoot dry mass accumulation per day was variable for *Argyranthemum, Scaevola,* and *Angelonia.* Our results indicate that providing a DLI of ≈8 to 12 $mol \cdot m^{-2} \cdot d^{-1}$ after callusing can increase both growth quality of rooted cuttings of all species in this study, though there are clearly different growth and development responses among species during finishing to propagation DLI.

Mitchell Lab: All accomplishment summaries are included in the "Unique Plant Responses" section of this report.

5. **Impact Statements.**

The Mitchell lab at Purdue has been working with engineering and LED lighting designers to develop custom gas-exchange cuvette and smart-lighting systems for small crop canopies. These systems will allow us to measure productivity responses of crops to overhead LED lighting in real-time. These dynamic systems will enable rapid determination of optimum combinations of light, temperature, and carbon dioxide at different growth stages of crop stands such as strawberry and lettuce. The debugging and retrofitting of such complex systems is a slow process with a promising eventual outcome.

6. **Published Written Works.**

Burnett, S.E., B.A. Krug, N.S. Mattson, R.G. Lopez and C.J. Currey. 2010. Ten ways to heat your house. GrowerTalks 74(7):64–69.

Currey, C.J., D.M. Camberato, A.P. Torres, and R.G. Lopez. 2010. Plant growth retardant drench efficacy is not affected by substrate containing parboiled rice hulls. HortTechnology 20(5):863–866.

Currey, C.J. and R.G. Lopez. 2010. Paclobutrazol pre-plant bulb dips effectively control height of 'Nellie White' easter lilies. HortTechnology 20(2):357–360.

Krug, B.A .and R.G. Lopez. 2010. Revisiting poinsettia cold finishing. Greenhouse Grower 28(9):30–34.

Massa, G.D., J.B. Santini, and C.A. Mitchell. 2010. Minimizing energy utilization for growing strawberries during long-duration space habitation. Adv. Space res. 46: 735-743.

Schluttenhoefer, C.M., G.D. Massa, and C.A. Mitchell. 2011. Use of uniconazole to control plant height for an industrial/pharmaceutical maize platform. Industrial Crops & Products 33: 720–726.

Torres, A.P., C.J. Currey, and R.G. Lopez. 2010. Getting the most out of light measurements. Greenhouse Grower 28(10):46–54.

Torres, A.P., C.J. Currey, J.E. Faust, and R.G. Lopez. 2010. Measuring daily light integral. Purdue Cooperative Extension Publication. HO-238-B-W:1–2. http://www.extension.purdue.edu/extmedia/HO/HO-238-B-W.pdf

Torres, A.P. and R.G. Lopez. 2010. Measuring daily light integral in a greenhouse. Purdue Cooperative Extension Publication. HO-238-W:1–7. http://www.extension.purdue.edu/extmedia/HO/HO-238-W.pdf

Torres, A.P., M.V. Mickelbart, and R.G. Lopez. 2010. Leaching fraction effects on pH and electrical conductivity measurements in containers obtained using the pour thru method. HortTechnology 20(4):608–611.

7. **Scientific and Outreach Oral Presentations.**

Currey, C. and R.G. Lopez. Early flurprimidol substrate drenches reduce final height of four *Euphorbia pulcherrima* cultivars. ISHS 2010, Lisbon, Portugal.

Lopez, R.G. and B. Krug. Reduced temperature finishing of *Euphorbia pulcherrima*. ISHS 2010, Lisbon, Portugal.

Massa, G.D. and C.A. Mitchell. 2010. Managing sweetpotato vines for space reduction and root yield in the greenhouse: Up, down, and all around. ASHS 2010, Palm Desert, CA, August 2-5.

Massa, G.D., C.M. Bourget, R.C. Morrow, C. Chun, and C.A. Mitchell. 2010. “Smart” LED lighting for plant growth in space. American Society for Gravitational and Space Biology, National Harbor, MD, November 4-7.

Massa G.D., E. Chase and C.A. Mitchell. 2010. Temperature affects yield and flavor of ‘Seascape’ strawberry. ASHS 2010, Palm Desert, CA, August 2-5.

Mitchell, C. 2010. Featured speaker at Purdue College of Agriculture “Science Café” on the topic “Human life support in space”, Lafayette, IN, March 10.

Mitchell, C. 2011. Keynote speaker at the Industrial Technology Research Institute: Plant Factory Workshop. “The potential of controlled environment agriculture: coming of age in the 21st century”, Hsinchu, Taiwan, April 12 and 13.

Mitchell, C.A., G.D. Massa, and D.M. Porterfield. 2010. Biology/technology/engineering synergisms needed to enable productive & affordable plant growth in space to support NASA’s missions. Synthetic Biology workshop. NASA Ames Research Center, October 30, 2010.

Mitchell C.A., G.D. Massa, B.A. Riggs, K.V. Spence, J. Shepard, C.M. Bourget, R.C. Morrow, C. Chun, Y. Yang. 2010. Evolving a novel controlled-environment gas-exchange system. ASHS 2010, Palm Desert, CA, August 2-5.

Torres, A.P., C.J. Currey, D.M. Camberato, and R.G. Lopez. Media containing bark or parboiled rice hulls affects plant growth retardant drenches differently. ASHS 2010, Palm Desert, CA.

Torres, A.P., M.V. Mickelbart, and R.G. Lopez. Leaching fraction effects on pH and electrical conductivity measurements in containers obtained using the pour-through method. ASHS 2010, Palm Desert, CA.

Torres, A.P. and R.G. Lopez. Propagation photosynthetic daily light integral influences morphological plasticity, rooting, growth, and quality of *Tecoma stans* seedlings. ISHS 2010, Lisbon, Portugal.

8. **Other relevant accomplishments and activities.**

Gioia Massa chaired a session at ASHS 2010 on "Growth Chambers and Controlled Environments", Palm Desert, August 2-5.

Gioia Massa was selected as Chair Elect of the ASHS Growth Chambers and Controlled Environments Working Group, ASHS 2010.

Gioia Massa was elected to the governing board of the American Society for Gravitational and Space Biology (ASGSB). Cary Mitchell continues to serve as a governing board member. Both attended a board meeting and visit to Capitol Hill March 21-23, 2011.

Gioia Massa has joined the ASHS National Issues Task Force.

Gioia Massa was selected as a NASA Senior Postdoctoral Fellow.

Cary Mitchell served on a USDA SCRI peer-review panel March 15-18, 2010.

Cary Mitchell, Roberto Lopez, and John Burr from Purdue, as well as academic colleagues Chieri Kubota at the University of Arizona, A.J. Both at Rutgers University, Erik Runkle at Michigan State University, plus industrial colleagues Robert Morrow and Mike Bourget at the Orbital Technologies Corporation, as well as 15 corporate partners and industrial stakeholders around the country were awarded a USDA Specialty Crops Research Initiative Grant for "Developing LED Lighting Technologies and Practices for Sustainable Specialty-Crop Production.", 2010-2014. Cary Mitchell will manage the project.