(1)Title Page

ERA (CCEMC) Project ID:
E120149

Title:
Wavelength-Selective Solar Collectors for Power Generating Greenhouses and Carbon Capture

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Completion Date:
December 31, 2016

Funds Requested: $419,753
Funds Paid: $371,119
Remaining Funds: $48,634

Report Date:
February 15, 2016

(II) Executive Summary

Agriculture is a low margin business and energy is an increasing and unstable cost. This project will allow farm land to simultaneously generate food AND electricity with the use of a low cost and highly durable power generating greenhouse panel that generates electricity and facilitates plant growth. It uses a proprietary luminescent window to selectively absorb the green portion of the solar spectrum that is not used by plants and downshifts this light to the red spectrum to match the photosythetically active region for plants and the efficiency maximum of Si photovoltaic cells. The color tuning associated with converting green light to red light will better match photosynthesis efficiency, reduce plant stress and facilitate plant growth while

Alberta has 1.4 million square meters (325 acres) of greenhouses in production. These greenhouses consume a large amount of energy for heating and supplemental lighting. Energy costs are increasing rapidly in Alberta and making it difficult for Alberta growers to compete against imported produce. A typical cucumber grower in Alberta will spend $\$11/m^2$ on natural gas and $\$12/m^2$ of electricity which represents the largest expense behind labor costs. The ability to reduce energy costs with an integrated renewable energy source would be a great benefit to Alberta Greenhouse growers. If all of the greenhouse space in Alberta were converted to Soliculture greenhouse panels if would represent 70MW of potential power and save 70,000 tonnes of CO_2/year.

With the support of the ERA, greenhouse trials at the University of California, Santa Cruz and AITF in Vegreville, AB have demonstrated that it is possible to combine greenhouse growing with electricity production with no negative impact on crop production. This results is contrary to the generally accepted belief in greenhouse growing that “1% light is 1% yield”. It is possible to absorb potions of the solar spectrum and use these wavelengths to generate electricity with no negative impact on plant growth. This opens the possibility for combined high productivity agriculture with electrical energy production.

The outcome of this project has been the release of a commercial-ready greenhouse integrated photovoltaic panel that can be integrated into the roof of a greenhouse with no negative impact on plant growth. The first large scale installation was in July of 2015 of a 10kW system at a commercial flower greenhouse in Watsonville, CA. Soliculture has other commercial installation scheduled for, 2017 in Carpinteria, CA and Riverside, CA and Akron, OH.

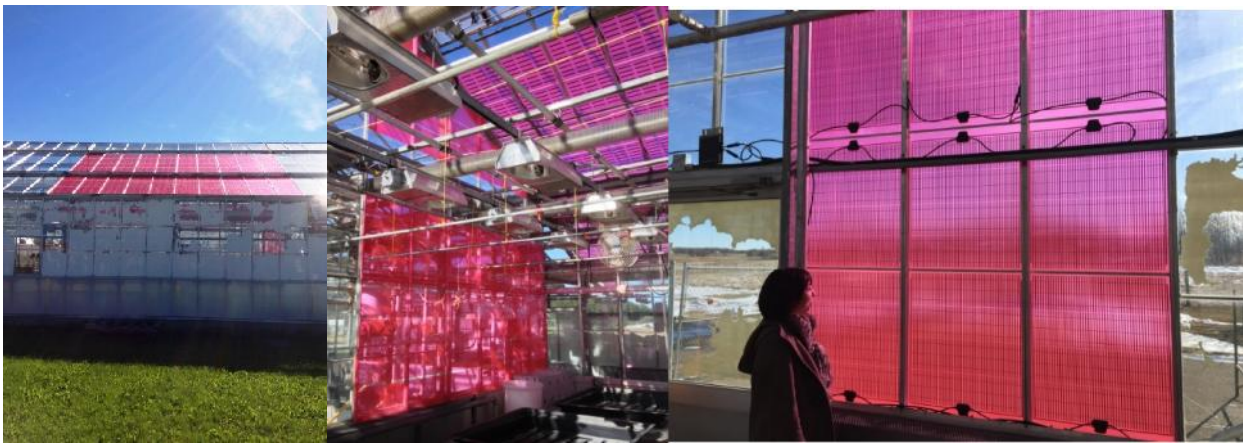

Figure 1: Trial installation in greenhouse at AITF greenhouse in Vegreville, AB

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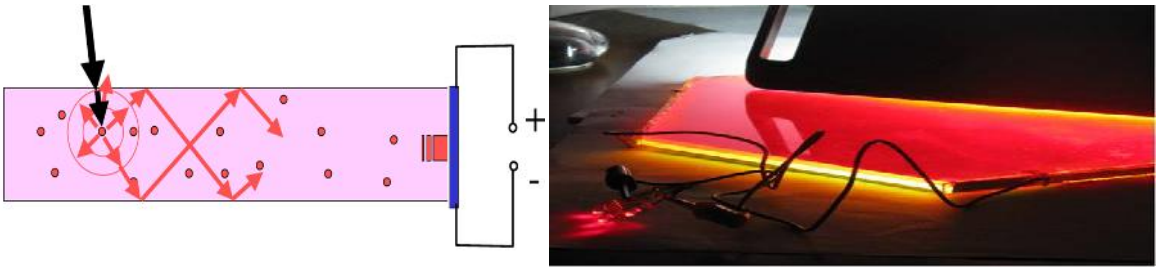
Introduction to Luminescent Solar Collectors

The power generating greenhouse cover developed by Soliculture and the University of California at Santa Cruz is a low-concentration version of a luminescent solar collector that was first proposed in 1951 for scintillators and 1976 for solar energy collection.The basic principal of a luminescent solar collector is illustrated in Figure 2. Incident sunlight causes photoluminescence of a material incorporated in a large area sheet. The emitted light is captured within the sheet by total internal reflection and can be collected by photovoltaic cells places at the edge of the sheet. Luminescent solar collectors were investigated extensively in the early 1980's by NREL and



(a) (b)

Figure 2: (a) Principal of conventional luminescent solar concentrator with cell on the edge. Light from sun is absorbed by a luminescent dye and re-admitted in all directions. Light is then trapped within the film by total internal reflection and transferred to the edge. (b) Example of a conventional luminescent solar concentrator with emission from the edge and PV cells that light a diode.

several large companies including Corning, ARCO and EXXON. The technology was abandoned for a number of reasons including (1) The luminescent dyes available on the market at the time did not meet the long term degradation requirements for solar energy. This issue has been addressed with the incorporation of perylene based pigments into a highly stable matrix as discussed below. (2) Power conversion efficiencies for large area luminescent solar collectors are low due in part to the semi-transparent nature of the solar collector. Large scale solar deployments with <8% efficiency are not cost effective due to installation and balance of system costs.[3] This issue is addressed with co-use of the solar windows for plant growth and power generation.

Light tunning for a greenhouse.

Soliculture has developed a luminescent solar collector with an absorption / emission spectrum that is optimized for plant growth and power generation, thus providing a second harvest

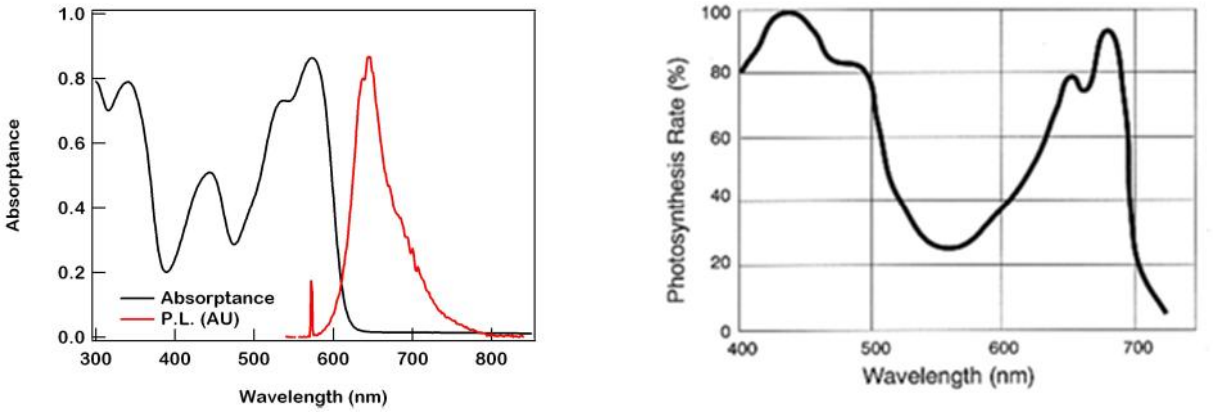


Figure 3: (a) Absorptance and Emission of the perylene based luminescent dye used in the greenhouse windows. The quantum yield of this dye is greater than 90%. (b)Typical photosynthesis rate for chlorophyll.

of crops AND electricity. The absorption/emission spectrum of the luminescent materials has been optimized for plant growth, not just power output. Optimizing for power output requires that the maximum amount of light is absorbed, thus reducing transmission and potentially hurting plant growth. For crop applications, the total transmission in the PAR region of the spectrum needs to be greater than 50% which would greatly reduce the efficiency of most thin film photovoltaics. Figure 3a shows the absorption spectrum of the perylene pigment chosen for this application. Absorption is maximum at 570nm, the region of the spectrum that is not efficiently utilized by the plants, and emission is peaked at 670nm – the region that is best utilized by plants shown in Figure 3b.

Reliability of Luminescent Solar Collectors

Many of the fluorescent dyes investigated in the early evaluations of luminescent solar collectors were developed for dye lasers and focused on quantum yield and not long term stability. Since the early 80's, great advances have been made in highly stable coloring agents driven primarily by the automotive industry. Paints for cars now last much longer than they did in the 1970's. Perylene based pigments have been shown to be exceptionally stable, although generally too expensive for wide spread use as a automotive pigment.

One of the initial tests of dye stability is high intensity UV aging in a controlled environment and at a controlled temperature. Accelerated degradation in the sun can be measured by testing under many suns equivalent of only UV illumination. High intensity UV aging tests performed on the photoluminescence of our plastic sheets showed that they can withstand the

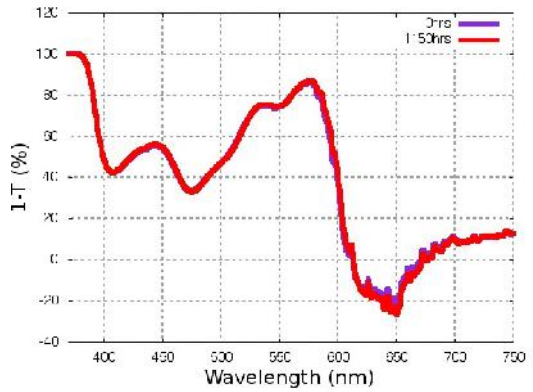


Figure 4: Reliability of PETx copolymer backsheet with luminescent dye that includes adhesion after 1000 hours of damp heat testing (above) and after 1150 hours under under high intensity UV illumination equivalent to 20 years of ourdoor exposure (lower)

equivalent of 20 years of UV dosage with no degradation in absorption photoluminescence as shown in Figure 4. Years of experience in the photovoltaics industry has come upon a set of "torture tests" that if passed can assure long term reliability in the field. These Additional environmental reliability test were performed on small 8" x 8" test samples of the complete package including luminescent sheet laminated to glass with PV cells. These tests are based on IEC 61215 qualification test for photovoltaic panels. The results are summarized below.

Test	Conditioin	IEC Requirement	Test Panels (pass-0 fails)
Damp Heat	85°C / 85% RH	1000 hours	>1000 hours
Humidity-Freeze	-40 to 85°C / 85% RH	10 cycles	200 cycles
Thermal Cycle	-40 to 85°C	200 cycles	200 cycles
UV soaking	UVA + UVB / 60°C	15 kW-hr/m^2	2000 kW-hr/m^2

Table 1: IEC 61215 Environmental Qualification Tests

ERA (CCEMC) Project Milestones

The first 5 tasks of this project were completed by the University of California at Santa Cruz. Effective November of 2015 the work was transferred to Soliculture, a sub-contractor of the University of California. The work plan for Soliculture called for a second trial in Vegreville to collect more data on the plant response of these panels (Task 6 and 7), continued product improvement (Tasks 8 and 10) and quatification of the economic and carbon reduction benefits of greenhouse integrated panels (Task 11 and 12).

CCEMC Task	Start Date	End Date	New End Date	CCEMC Budget (Canadian Dollars)	CCEMC Budget Expended (CAD)
Task 1: Design for Power Generating Greenhouse #1	2013/11/01	2014/03/31	2014/12/31	$20,000	$19,862
2: Manufacture and Install WSSC Panels Trial #1	2014/01/01	2014/06/30	2014/12/31	$70,000	$64,449
3: Improving IR Absorption	2014/01/01	2014/09/30	2015/06/30	$70,000	$69,704
4. Design for Power Generation Greenhouse #2	2014/07/01	2015/03/01	2015/03/01	$20,000	$12,020
5. Improving UV Absorption	2014/07/01	2015/03/31	2015/04/31	$30,000	$16,061
UCSC Totals	2013/11/01	2015/03/31	**2015/06/30**	**$220,000**	**$1182.096**
Soliculture Remaining Budget for Tasks 6 through 12				**$243,413**	
6. Manufacture and Install WSSC Panels Trial #2	2015/01/01	2015/06/01	2015/11/30	$28,741	$28,741
7: Alberta Plant Growth Data	2015/07/01	2015/12/31	2016/12/31	$28,466	$28,488
8: Demonstrate crop yield, +$1/W, 6% power efficiency and reliability 15 years	2014/03/01	2015/12/31	2016/3/31	$42,087	$42,087
9: Optimize Optical Performance	2015/01/01	2016/03/31	2016/3/31	$40,827	$40,827
10: Demonstrate crop yield, + 0.75/W, 8% power efficiency and reliability 20 years	2015/01/01	2016/06/30	2016/11/30	$80,392	$80.391
11: Quantify reduction in CO2 Emissions	2015/10/01	2016/10/30	2016/11/30	$11,450	$11,416
12: Determine manufacturing cost	2016/07/01	2016/10/30	2016/11/30	$11,450	$11,214
Soliculture Totals				243,413	
Totals				420,000	

Table 2: ERA milestones for Soliculture and University of California at Santa Cruz.

(VI) Outcomes and Learning

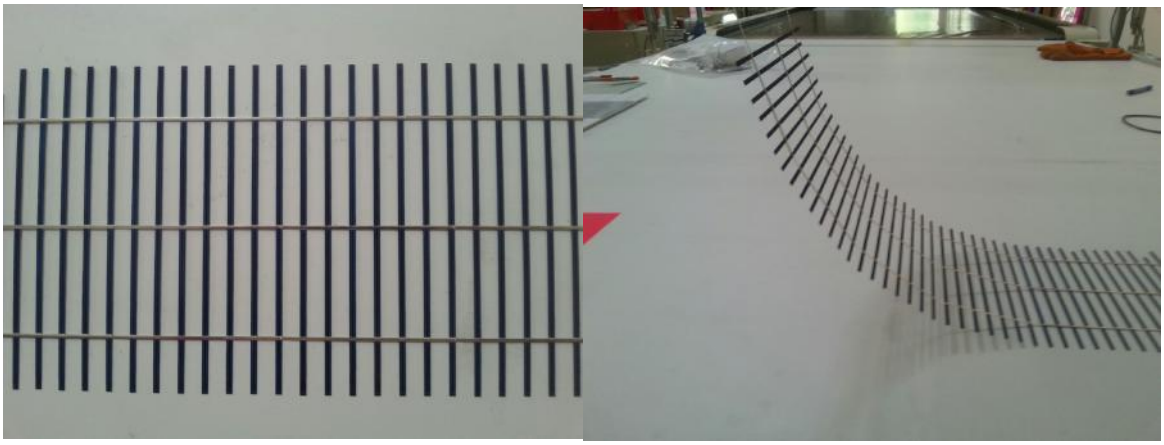
Commercial Viability

Manufacturability: Solicultrure has made great strides in improving the reliability, maufacturability and cost of their greenhouse integrated photovoltaic panel utilizing the invaluable help of CCEMC funding. The solar panels have reached commercial status with several retrofit sales to existing greenhouses and UL certification in progress. At the beginning of the CCEMC grant period, Soliculture and UCSC used acrylic as a dye impregnated backsheet that could be laminated into a photovoltaic module using aliphatic thermoplastic urethane (TPU) as an encapsulant and cut crystalline silicon solar cells that were soldered by hand. During the grant period, Soliculture made several improvements to make our panel more reliable, lower cost and compatible with contract manufacturing at a standard solar panel manufacturing facility. The initial material set allowed Soliculture to install demonstrations at several greenhouses in California and at the AITF facility in Vegreville, Canada. But this material set was not scalable to high volume manufacturing. The acrylic backsheet had several major problems going forward as a large scale product. (1) Adhesion between the acrylic and the standard photovoltaic encapsulant EVA is poor leading to delamination after thermal cycling. TPU had very good adhesion to Acrylic, but it is expensive and not commonly used in the PV industry. Contract manufacturing requires that the materials set should be as standard as possible. (2) Acrylic sheets are brittle and can crack due to thermally induced stress. Cracking becomes a larger problem as the size of the module is increased. Soldering diced silicon cells by hand was very labor intensive and expensive. Soliculture has partnered with Solaria that has a unique automated cell dicing, singulation and soldering technology. Following is a list of technical achievements that Soliculture was able to accomplish during the CCEMC period. Figure 5 show the production of Soliculture GIPV panels at the Solaria facility in Fremont, CA.

Solaria singulated strings: Soliculture has partnered with Solaria Inc. in Fremont, CA. to incorporate their solar cell singulation technology with Soliculture light tuning technology. Solaria has the IP and tool set to dice cells into 3mm strips and provide the interconnection into strings as shown in Figure 6. Strings comprised of narrow strips is essential for the luminescent light to couple into the silicon cell. The ability to dice and string these cells with an automated tool significantly reduces the cost or building Soliculture panels such as the one shown in Figure 5 Soliculture signed a license areement with Solaria to grant Soliculture exclusive rights to Solaria technology

Figure 5: Manufacturing 300 Soliculture panels at Solaria in Fremont, CA in June of 2015. Workers lay out the encapsulant and strings before lamination.

for greenhouse products sold in North America. Solaria has 7 issued patents that cover the cell dicing and singulation process. Solaria made a strategic equity investment in Soliculture in July, 2015 for $250k and has an option for an additional $250k investment.



(a) (b)

Figure 6: Proprietary stringing technology used in Soliculture panels. 6" square silicon solar cells are diced into thin 3mm wide strips and connected with wires with 12mm spacing as shown in (a). The strings of narrow cells allow more light to pass through and give a degree of flexibility for the strings shown in (b). The flexibility of the strings allows them to be manufactured and shipped from California to Canada with no damage.

Manufacturing partner in Canada: Solaria in Fremont, CA is capable of supporting manufacturing of Soliculture panels on the 10kW/month range. Solaria can support the production of singulated strings at much higher volume with final assembly done with a contract manufacturing site that is focused on manufacturing. Several companies in the San Jose area can provide solar module contract manufacturing services, but the cost and minimum orders are prohibitive. Soliculture has contracted with Heliene in Ontario, Canada for the production of greenhouse integrated panels. Figure 7 shows the semi-automated production facility of Heliene. The market for Soliculture panels in Canada is very strong, especially in Ontario with high feed in tariffs for solar electricity and a large greenhouse vegetable industry. Soliculture is in discussions with Got Produce for a project to install a 2.5 acre trial greenhouse in Akron, Ohio.

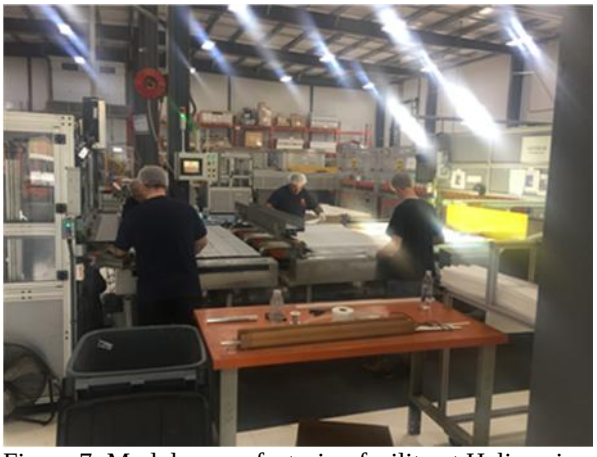


Figure 7: Module manufacturing facility at Heliene in Sioux St. Marie, Ontario.

Potential Market for Conventional Backsheet: Soliculture has identified a copolyester system that can be used to for a highly reliable mono-layer backsheet that exceeds IEC61215 standards for adhesion to EVA, damp heat and UV stability. Commercially available backsheets for conventional cSi modules typically use a multilayer of Flourinated polymer (Tedlar), PET (Mylar) and adhesive layer (PET/EVA)

because none of these materials alone cannot meet the cost and reliability requirements for solar modules. Combining these three individual films into one film adds significant cost and introduces two additional interfaces that can fail with long term outdoor exposure. The ability to use one materials for the backsheet that satisfies all of the reliability requirements has the potential to radically change the solar backsheet market with a lower cost and more reliable backsheet. Soliculture is currently seeking funding to develop this auxiliary application of the copolyester backsheet that has been developed. Work will involve adding a white pigment to the backsheet instead of the luminescent dye that is currently in use and market it as a backsheet to the conventional cSi PV market. The backsheet market is $2B/year and has the potential to be a new and exciting market for Soliculture.

Advancement of the Technology

New Luminescent backsheet: A highly stable luminescent backsheet was developed that is compatible with solar industry standard manufacturing practices. The backsheet uses a recently developed PETx copolymer that is engineered for high strength and resistance to humidity and outdoor exposure. The previous acrylic backsheet had problems with cracking and poor adhesioin to EVA. This grade of PET copolymer does not crack like acrylic as shown in Figure 8 and is particularly robust to damp heat. No hazing or loss of adhesion was detected after 1000 hours at 85^{o}C / 85% RH. The typical minimum adhesion specification for the PV industry is >3 N/mm and the PETx exceeds this even after 1000 hours. The combined stack of PETx and UV absorbing EVA has undergone 20 years of equivalent UV dosage with no degradation of optical properties including absorption and luminescence as shown in Figure 3. The EVA/PETx stack also showed no loss of mechanical properties with high intensity UV exposure with 36 suns equivalent. Testing continues with a lower intensity UV source with no detectable degradation after the equivalent of 15 years UV dosage.

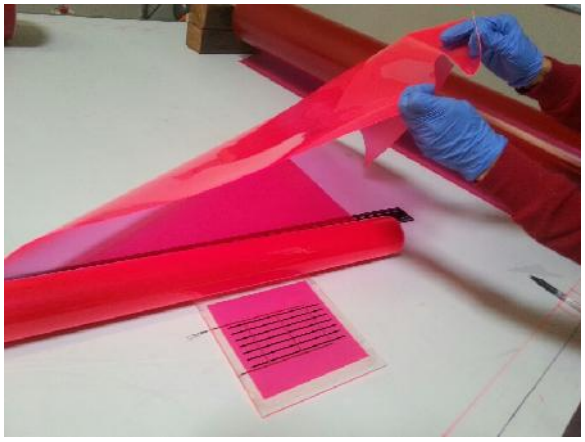


Figure 8: High strength PETx copolymer backsheet with luminescent dye that can be laminated to glass. The film is more flexible, reliable and compatible with standard PV module

Bifacial cells and improved optics: The narrow cells from Solaria technology receive a significant amount of luminescent light on the back/edge of the cell as shown in Figure 9. The 2cm wide cells used in the previous version of Soliculture modules received most of the luminescent light on the front surface of the cell from total internal reflection because the width of the cell is much larger than the thickness behind the cell. But when the cell used is less than 3mm in width then the 1mm combined thickness of encapsulant and backsheet are comparable to the capture cross section on the rear of the cell. Bifacial cells capture light on both sides of the cell and improves efficiency of the module by better coupling in the luminescent light. The bifacial nature also couples in light that is reflected from within the greenhouse. A large improvement in efficiency is observed from 3.6% using narrow monofacial cells to 5.4% using bifacial cells. Several companies currently provide Bifacial cells at a cost roughly 2x higher than monofacial cells. The higher cell cost is mitigated by the fact that only 20% of the module is covered by the bifacial cells. Suppliers include NSP in Taiwan, PVGS in Japan and Sunprime in USA. Currently, the supplier of bifacial cells for Soliculture is NSP which is one of the largest Si cell suppliers in the world.

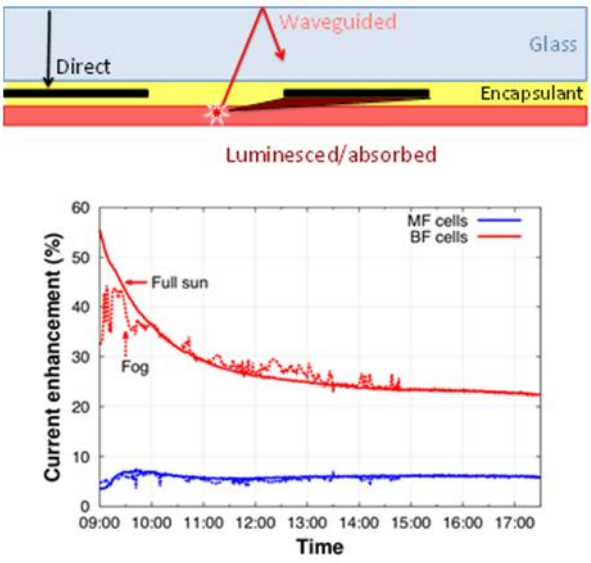
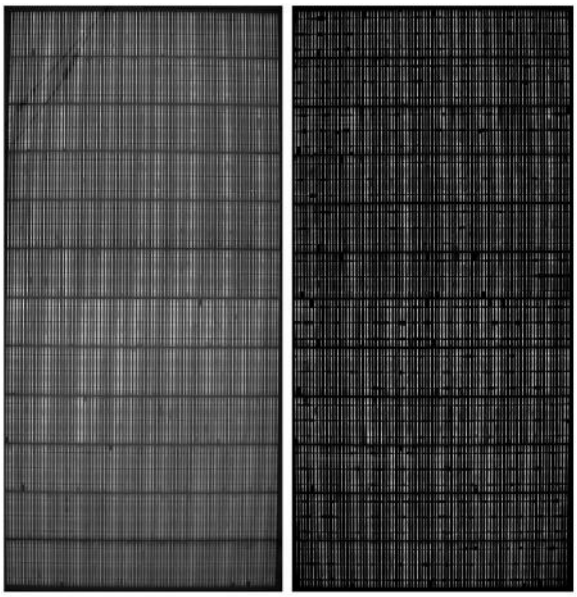


Figure 9: Current enhancement from luminescent film using monofacial cells vs. bifacial cells with 40% coverage of cells. The narrow cells from Solaris strings couple in light more effectively from the rear of the cell than waveguided from the front of the cell. The larger enhancement from the backreflected light is with off-angle illumination in the morning hours as shown below. For a west facing solar panel..

Figure 10: Sample of semi-transparent greenhouse module using Solaria singulated PV strings and Soliculture luminescent backsheet, including Soliculture senior staff.

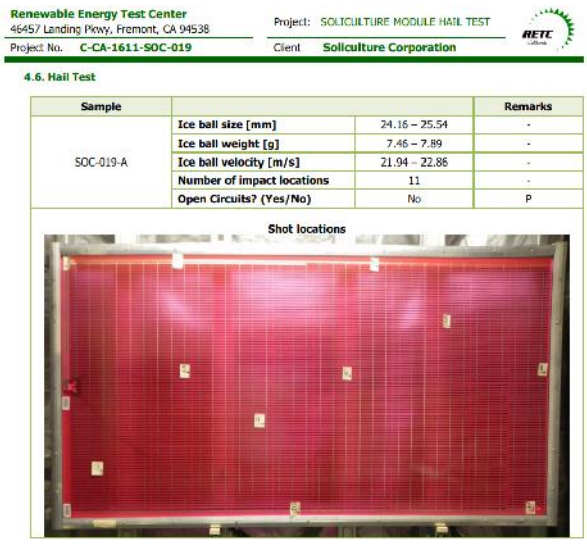
The improved coupling from the bifacial cells has allowed Soliculture to produce a module with 6% power efficiency as shown in Figure 10

Certification of Modules: IEC 61215 qualification tests have been performed on full size Soliculture modules as engineering tests to assure that the modules will pass the full suite of certification tests at the testing agency. For example, Figure 9 shows the before and after results of IEC 61215 standard damp heat test of 1000 hours at 85% humidity and 85ºC. Soliculture panels had a 1% increase in power output after this torture test. Panels have passed other IEC certification tests at the



Sample ID	Voc	Vmp	Isc	Imp	Pmax	FF %
C-CA-1511-SOC-015-C_Precon	15.29	12.22	10.59	9.82	120.07	74.16
C-CA-1511-SOC-015-C_DH1000	15.33	12.52	10.47	9.69	121.40	75.67
Degradation	0.26%	2.47%	-1.14%	-1.32%	1.11%	2.02%

Figure 11: Electroluminescence and IV characteristics of Soliculture module after IEC 61215 standard damp heat test of 1000 hours at 85% relative humidity and 85ºC. Efficiency improved by 1% after testing.



Renewable Energy Test Center
46457 Landing Pkwy, Fremont, CA 94538
Project No. C-CA-1611-SOC-019
Project: SOLICULTURE MODULE HAIL TEST
Client Soliculture Corporation

4.6. Hail Test

Sample			Remarks
SOC-019-A	Ice ball size [mm]	24.16 – 25.54	-
	Ice ball weight [g]	7.46 – 7.89	-
	Ice ball velocity [m/s]	21.94 – 22.86	-
	Number of impact locations	11	-
	Open Circuits? (Yes/No)	No	P

Shot locations

Figure 12: Results of hail test of 1m x 2m Soliculture module. Module passed impact of 11 25mm ice balls traveling at 22m/s

engineering level run by both Soliculture and Solaria. The certification agency ETL, a subsidiary of Intertek, has been selected for final UL certification of modules for US and Canadian standards. The testing process were initiated in April, 2016 on 20 modules. Final certification is dependent on location for final manufacturing.

Greenhouse growers in Alberta are very concerned about hail storms that are common in Alberta. Figure 12 shows the results of hail tests performed on Soliculture modules. No damage to the module was observed after the impact of 11 25mm hail balls traveling at 22m/s. The laminated structure of the modules increases the resistance to hail relative to standard glass.

Cost Reduction: The use of Solaria cells and strings combined with the new PET backsheet has dropped the materials cost for Soliculture panels from \$94/m^2 to \$53/m^2 (not including labor), as shown in Figure 12. The target selling price for Soliculture panels is \$100/m^2. Neither Soliculture nor Solaria are actively producing panels. Therefore, labor costs are high to start/stop production for each project. Staff need to be trained and quality control procedures must be established and enforced for each build. In contrast,. Heliene has an active facility in Ontario that produces conventional solar modules. Soliculture panels are compatible with standard photovoltaic manufacturing practices and can utilize any conventional solar module manufacturing facility. Heliene can do the final assembly and testing of our modules for \$15/m^2(USD). This is less than half the cost of manufacturing at Solaria because the costs of running a fully operating manufacturing line can be leveraged. The cost of ramping up / ramping down production adds significant cost and confirms the value of contract manufacturing to get a high quality product to market quickly.

Phase II installation at Alberta Innovated Technology Futures (AITF), AB.

The objective of this project was to demonstrate and compare in-field performance of two models of greenhouse-integrated photovoltaic (GIPV) panels designed for the southern face of a greenhouse in northern climates like Alberta. One model of GIPV panel, called LUMO-35, has a high density of solar cells (approx. 50%), leading to decreased light transmission through the panel and high power efficiency. The second model of GIPV panel, called LUMO-20, has a lower density of solar cells (approx. 25%), leading to increased light transmission through the panel and lower power efficiency. Figure 13 shows a schematic of the two types of panels. Both models have a film that alters the light spectrum that transmits through the panel, via an embedded luminescent dye. The light transmission through the LUMO panels is optimized for crop photosynthetic efficiency, identical to the transmission for the phase 1 panels. The LUMO also exhibits an increase in the power efficiency, due to the diffuse nature of the light-altering film. A set of each type of GIPV panel is incorporated into a greenhouse at Alberta Innovates Technology Futures (AITF) in Alberta, Canada.

Given that the light transmission is identical between phase 1 and phase II panels, there was no need to replace the panels in the phase I greenhouse which could continue for the growth studies. The emphasis for the phase II installation was on power production for a southern facing wall relative to a roof mounted panel.

- LUMO-20 power efficiency at standard test conditions (STC) greater than 4.5%
- LUMO-35 power efficiency (STC) greater than 8.0%

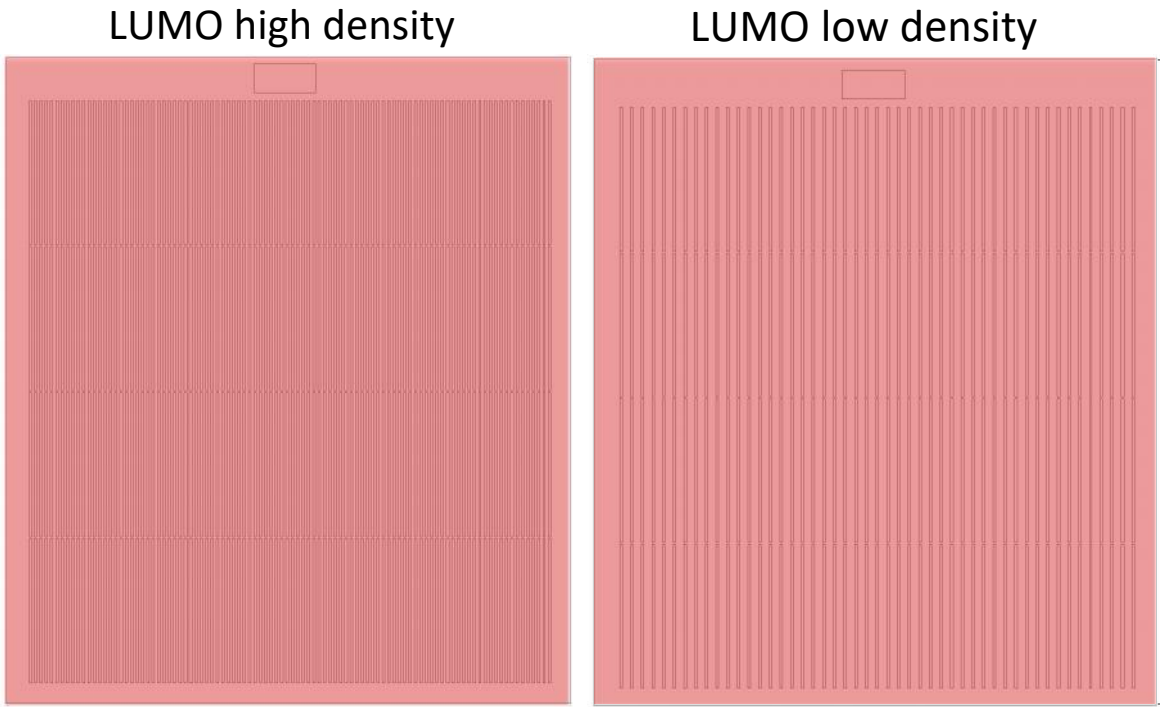


Figure 13: Depiction of LUMO-35 (left) and LUMO-20 (right) solar panels.

Installation at AITF greenhouse in Vegreville: During the week of February 24th, 2016, eighteen LUMO solar panels were installed in the south-facing wall of one greenhouse range at AIFT Vegreville, as shown in Figure 14. There were two types of panels installed, nine LUMO-20 and nine LUMO-35. The panels replaced panes of glass that were originally installed as the greenhouse wall. The focus of this installation was on power production from a south facing wall only, no crop yield. The optical transmission of the phase II panels are identical to the optical transmission of the phase I panels. Only the cell technology was changed. Therefore the compartment with the phase I panels would continue to be used for phase II plant trials of Lettuce as discussed in conclusions section.

Figure 14. LUMO solar panels installed on a south-facing wall at AITF Vegreville.

Figure 15. Hourly power performance for March 22-28, 2016 of all panels combined

Performance data for these LUMO panels are collected by two Enphase micro-inverters. Each micro-inverter is connected to nine panels, connected in series. The low-density and high-density panels are each connected to a single micro-inverter, respectively. Thus, we are able to gather data and compare the performance of the two types of panels. The eighteen solar panels produced 43.4 kWh in March, where 28.0 kWh (65%) were produced by the LUMO-35 panels and 15.4 kWh (35%) were produced by the LUMO-20 panels. The total system peak power in March was 419 W which met expectations. Sample performance data for the installed panels is shown in Figure 15.

Phase II installation at UCSC Arboretum

(a) (b)

Figure 16: Phase II test greenhouse at the Arboretum of the University of California at California, Santa Cruz. The greenhouse in the rear was buiilt using Phase I panels similar to those installed in Vegreville, AB. The greenhouse in the forefront contains 10 Phase II - HD panels .for further tests of plant growth. Also shown in the picture are Jessica Rosenthal and Nick Pai of Soliculture. The phase I greenhouse currently contains an aquaponics test bed.

LUMO High density modules with 8% efficiency were installed at the University of California at Santa Cruz Arboretum in September of 2016. Figure 16 shows the greenhouse forefront with 10 LUMO-HD panels installed in the roof. The greenhouse in the rear used the phase I LUMO panels similar to what was installed for Phase I in Vegreville. Only one half of the second greenhouse was covered in LUMO panels for plant trials in the same greenhouse to assure that the climate was identical for both clear illumination and red illumination. The panels were connected to a battery bank in the greenhouse that provided power for water circulation and aeration. Power output was monitored using Morningstar charge converters. The output/panel of was 70W/panel that was 2x higher than the phase I panels in the previous greenhouse. The phase II panels appear darker than the phase I panels because more of the luminescent emitted red light is captured by the cells, increasing efficiency.

Test crops of microgreens were grown in the phase II greenhouse under the clear portion and the red portion. Microgreens were chosen because it is a new greenhouse crop that is gaining more acceptance. Figure 17(a) shows an example of a microgreens greenhouse outside of Toronto, Ontario. The test microgreen crops grown at UCSC consisted of Arugula, Sunflower, Basil and Wheatgrass. These are typical microgreen crops that will go into a "spring mix". Figure 17(b) shows an example of Arugula and Basil grown in the UCSC phase II greenhouse. Two six week crop cycles were performed with the microgreens. An unexpected frost terminated the Basil crop early and no data was available

(a)

(b)

Figure 17: (a) Greenbelt Microgreens outside of Toronto, ON growing organic microgreens for salad mixes. Greenbelt Microgreens expressed an interest in LUMO greenhouse integrated solar panels, prompting tests in the Phase II greenhouse at UCSC. (b) Trays of Basil and Aurgula microgreens grown under LUMO panels in the UCSC Phase II greenhouse.

Data on fresh weight, dry weight and plant height were collected for multiple trays of each crop. Table 3 gives a summary of the results. The wheat grass responded positively to the altered light spectrum with greater fresh weight and dry weight. Arugula and Sunflower were neutral in the plant response. The basil crop needed to be abandoned due to an early frost at the greenhouse. The difference in response of the crops will need to be verified for different growing seasons.

	Fresh Weight (Clear)	Fresh Weight (Red)	Dry Weight (Clear)	Dry Weight (Red)	Plant Height (Clear)	Plant Height (Red)	Response
Wheat Grass	23.2 g +/-10%	56.3 g +/-10%	4.5 g +/-10%	9.7 g +/-10%	52 mm +/-17%	63 mm +/-17%	Positive
Arugula	370g +/20%	380g +/-10%	20g +/-5%	19g +/-10%	25 mm +/- 15%	25 mm +/- 15%	Neutral
Sunflower	221g +/-5%	220g +/-5%	9.6 g +/-5%	8.6 g +/-5%	28 mm +/- 13%	28 mm +/- 13%	Neutral

Table 3: Results from microgreen growth tests in phase II UCSC greenhouse.

Trial at Kitayama Brothers Growers, Watsonville, CA:

Figure 18: Installation of greenhouse panels at KB Farms in Watsonville, CA in June, 2015.

The first commercial installation of our panels was completed on June 15, 2015. The panels were manufactured at Solaria as shown in Figure 18. The installation was a 9kW trial that covered the west facing roof line of one greenhouse bay with an area of 7,000 sq.ft. of growing space. 270 panels (2430 sq.ft total) were installed in the west facing portion of the greenhouse only to allow natural light to enter the greenhouse in the morning and to better take advantage of higher electricity rates in the afternoon. Figure 18 shows the installation in progress. The power output has been monitored continuously using on-line monitoring software in the inverters as shown in Figure 14. Irradiance level and environmental conditions are also continuously monitored to measure panel efficiency. An array of Solar edge power optimizers are being used to monitor the performance of 22 sub-strings each consisting of 12 panels each and upload date to the cloud. This allows the output of different portions of the greenhouse to be monitored separately. A power loss of ~10% was observed for panels mounted directly below the greenhouse vents due to partial shading in the morning. The effect of soiling and shading have been incorporated into Soliculture

Figure 19: Final installation at KF farms of 270 Soliculture panels (left). The array provides up to 8KWac the greenhouse facility and 21 separate sections are monitored online with the inverter..

modeling software so that an accurate prediction of power generation can be made for future projects. The system has been fully operational and generating power for almost 1 year with no degradation in efficiency as shown in Figure 19.

Plant Results at Kitayama Farms. The current crops being grown in this greenhouse are organic herbs. The yields from two cycles of Chervil (an edible herb similar to Parsley) were monitored in the Soliculture section of the greenhouse relative to a control section with clear glass to the north of the Soliculture section. The quality and quantity of Chervil grown in the Soliculture section of the greenhouse consistently outperformed the control clear section of the greenhouse for an identical amount of growth time. The Chervil grown under the Soliculture greenhouse was taller and had more leaves relative to the control greenhouse, especially for the rows directly under the Soliculture panels.

	North R5 Summer/clear	South R2 Fall/clear	South R8 Fall/LUMO
Wet weight / plant (g)	1.64 +/- 0.93	2.86 +/- 0.88	3.54 +/- 1.01
Dry weight / plant (g)	0.25 +/- 0.12	0.26 +/- 0.10	0.34 +/- 0.09
Dry / wet ratio	15%	9%	10%
Height / plant (mm)	167 +/- 30	249 +/- 44	293 +/- 24

(b) (b)

Figure 20: Results from the first harvest of Chervil grown under Soliculture panels. The growing time for both the control and Soliculture bays were the same, although the start date was different (determined by production cycles of the owner). Two rows were monitored in the Soliculture section of the greenhouse, one directly under the west-soliculture panels and one row directly under the clear section on the east. Chervil grown under the Soliculture panels was taller and had more leaves resulting in 40% higher dry weight

(VII) Greenhouse Gas and Non-GHG Impacts

Solar Installations

Soliculture has installed two LUMO installations at Alberta Innovates Technology Futures' Vegreville research location. The first installation, completed in June 2014, is a 1.05kW LUMO system located on the west-facing slope of a research greenhouse. This installation has generated 2.08MWh of on-site, renewable electricity. These installation are shown in Figure 21.

The second installation compares two types of LUMO solar panels, high density and low density. Nine of each type of LUMO panel were installed on the South-facing wall of a research greenhouse. This second installation, rated at 0.5kW peak power, was completed in February 2016 and has generated a total of 0.31MWh of electricity.

Figure 21. LUMO installation #1 (*left*) and second installation #2 (*right*).

Carbon Emissions Factor

By generating on-site renewable electricity, the above described LUMO installations effectively reduce the amount of carbon emissions released into the atmosphere. Electricity that is consumed from these solar panels displace electricity that would have been consumed from the utility grid. In order to quantify the carbon emissions that are reduced by the LUMO installations, we must compare to the carbon emissions generated by grid electricity. The Alberta Environment and Sustainable Resources Development's (ESRD) Carbon Offset Emission Factors Handbook provides emissions factors for estimating the carbon emissions for various energy use scenarios in Alberta, Canada. For this report, we use the grid displacement factor for "distributed renewable displacement at point of use," which is applicable for projects with distributed renewable electricity generation at point of use. This emissions factor is set at 0.64tCO_2e/MWh, and can be found in Table 2 of the handbook, which is included below as Figure 22.

Carbon Emissions Reduction

Electricity Grid Displacement and Grid Usage Factors

Factor	tCO_2e/MWh	Description
Electricity grid displacement with renewable generation	0.59	Applicable to projects displacing grid-electricity with renewable generation.
Increased on-site grid electricity use (includes line loss)	0.64	Applicable for use in projects that increase electricity usage in the project condition.
Reduction in grid electricity usage (includes line loss)	0.64	Applicable to energy efficiency projects resulting in decreased grid electricity usage.
Distributed renewable displacement at point of use (includes line loss)	0.64	Applicable to projects displacing grid electricity with distributed renewable electricity generation at point of use.

Fig. 22. Table of emissions factors from the ESRD Carbon Offset Emission Factors Handbook

Since the initial installation (June 19th, 2014), the west-facing LUMO system has generated 2.08MWh of renewable electricity. From the ESRD Carbon Offset Emission Factors Handbook from 2015, a factor of $0.64tCO_2e/MWh$ was used to estimate the solar energy system's offset of carbon emissions. Using this emissions factor for displaying grid electricity with renewable electricity generation, the west-facing LUMO solar energy system has displaced the equivalent of 1,331kg of CO_2 emissions. In 2015, this system generated 872kWh of electricity, which was used to determine an emissions reductions rate of $21.5kgCO_2/m^2/yr$, outlined in Figure 22 from the ESRD Carbon Offset Emissions Factors Handbook.

Since installation (Feb. 23rd, 2016), the south-facing LUMO system has generated 310kWh of renewable electricity. A factor of $0.64tCO_2e/MWh$ was used to estimate the solar energy system's offset of carbon emissions. Using this emissions factor for displacing grid electricity with renewable electricity generation, the south-facing LUMO solar energy system has displaced the equivalent of 198kg of CO_2 emissions, outlines in Table 3. The low density LUMO panels are on track to generate 165kWh over the year-long period of February 23, 2016 to February 22, 2017, which is used to determine an emissions reductions rate of $27.4kgCO_2/m^2/yr$. The high density LUMO panels are on track to generate 238kWh over the year-long period of February 23, 2016 to February 22, 2017, which is used to determine an emissions reductions rate of $39.6kgCO_2/m^2/yr$. The yearly energy production for this system was calculated by using the predicted energy for the months of December, January, and February, due to the system only being installed at the end of February earlier this year. The solar radiation values shown in Figure 23 were used to estimate energy production, which in turn was used to determine the carbon emissions reductions.

	Initial installation	Second installation		Total
		High density	Low density	
Installation date	June 19, 2014	Feb. 23, 2016		
Location	West-facing roof slope	South-facing wall		
Size (m^2)	26.01	3.85	3.85	**33.71**
Rated power (kW)	1.05	0.32	0.19	**1.56**
Lifetime energy production (MWh)	2.08	0.183	0.127	**2.39**
Lifetime carbon emissions reduction ($kgCO_2e$)	1,331	117	81	**1,529**
Yearly carbon emissions per unit area ($kg/m^2/yr$)	21.5*	39.6**	27.4**	

*For 2015 energy production
**For 2016 energy production with estimated values for Dec 2016 through Feb 2017

Table 3. Performance of two LUMO installations located at AITF Vegreville

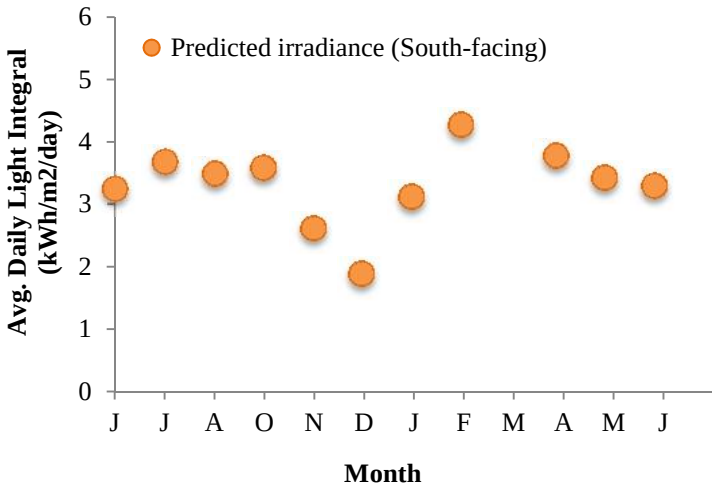
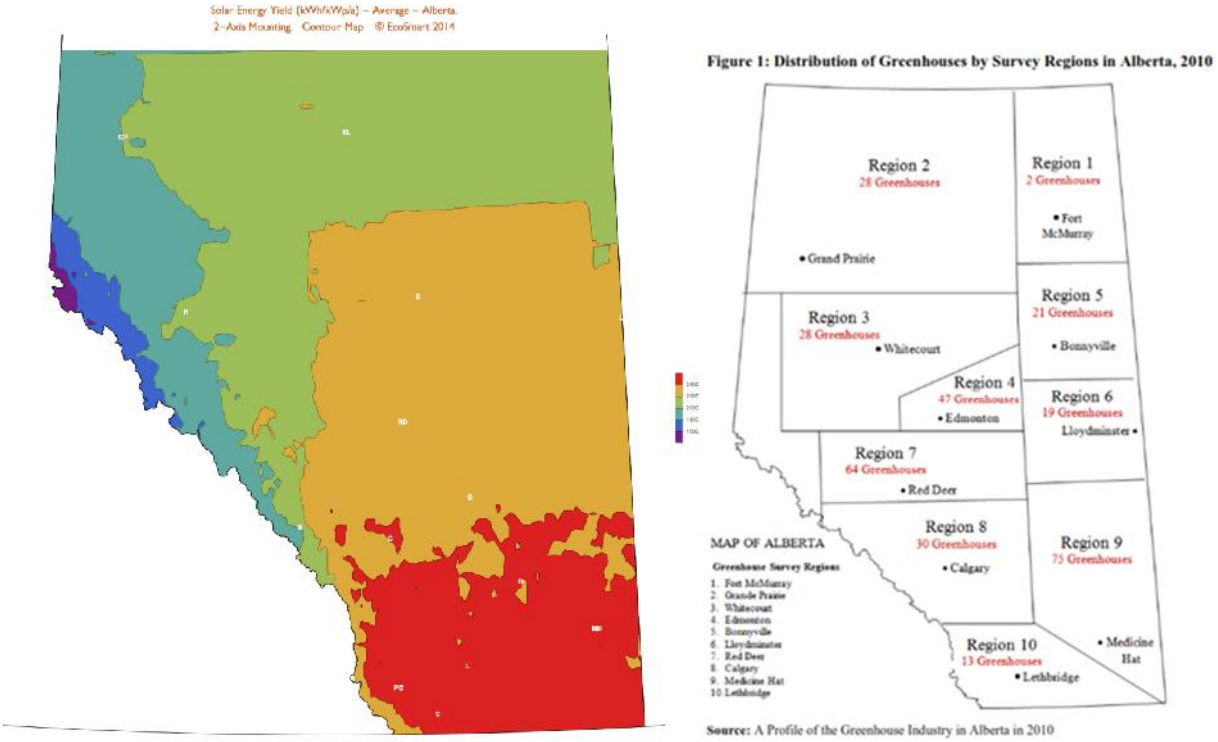


Fig 23 Predicted solar radiation at south-facing 90° tilt orientation located at AITF Vegreville

LUMO Potential in Alberta

With solar energy, location and panel orientation are paramount for maximum efficiency. There are locations in Alberta that are better suited for solar energy deployment than others. The distribution of solar radiation availability in Alberta is shown in the Figure 24, below. For the purpose of estimating the carbon emissions reduction potential for this technology in Alberta, we compare the energy generation and corresponding emissions reductions for several locations. Because solar energy production is predominately contingent on solar radiation, we are able to



(a) (b)

Figure 24. (a) Solar radiation availability in Alberta, where red indicates the highest solar radiation. (b) Location of greenhouses in Alberta.

compare between locations by scaling the Vegreville energy production and emissions reductions by local solar radiation values. Location-based solar radiation values were taken from the National Renewable Energy Laboratory's (NREL) modeling software, System Advisory Model (SAM). This software is an industry standard for solar energy generation prediction. For example, Lethbridge, Alberta receives the highest solar radiation at a south-facing tilt of 40°, which is over 150% of the solar radiation in Vegreville at a south-facing 90° tilt. Therefore, we can estimate that high-density LUMO solar panels located in Lethbridge could produce 94.6 $kWh/m^2/yr$, resulting in carbon emissions reduction of 60.5 $kgCO_2/m^2/yr$. The comparison of various locations in Alberta is shown in Table 5.

Location	Orientation	Tilt	Solar Radiation	LUMO Energy Production ($kWh/m^2/yr$)	Carbon Emissions Reductions ($kgCO_2/m^2/yr$)
Vegreville	South	90°	1105	61.8	39.6
	West	30°	1104	61.7	39.5
	South	40°	1472	82.3	52.7
Fort McMurray	South	45°	1351	75.5	48.4
Edmonton	South	90°	1135	63.5	40.6
Calgary	South	40°	1643	91.9	58.8
Lethbridge	South	40°	1691	94.6	60.5
Medicine Hat	South	90°	1188	66.4	42.5
	South	40°	1625	90.9	58.2

Table 5. LUMO performance and carbon emissions reductions potential for various locations in Alberta.

Carbon Savings from other installations.

Carbon savings to date from the 9kW installation at KB farms in Watsonville, CA has generated the equivalent of 10,972 kg of CO2 as shown in Figure 25.

Plans are in progress for a 2.5 acre greenhouse near Akron, Ohio. When operational, this facility will generate 350,000 kWhr/year of carbon free electricity. This is equivalent to 245 tons of CO_2/year in avoided CO_2 production for electricity.

Ten year projection

Projected installations of Soliculture panels going forward will be 2,500 acres after 10 years resulting in 245,000 tons of avoided CO_2/year.

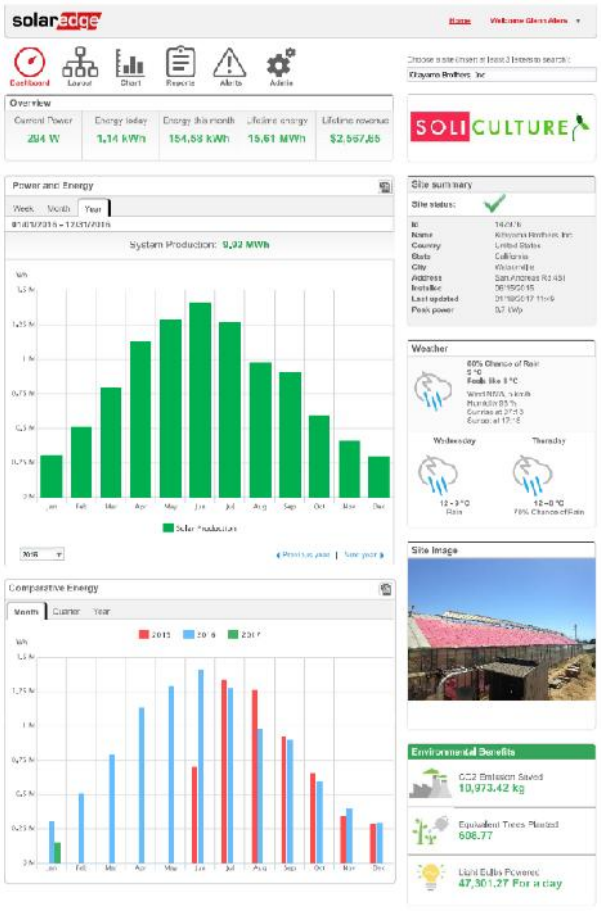


Figure 25 Carbon avoidance for installation at KB Farms discussed below.

(IIX) Conclusions

Feasibility studies at the University of California at Santa Cruz showed that certain bands of light could be selectively harvested for power generation with no negative impact on plant growth. Greenhouse growing trials in California and Canada with Soliculture photovoltaic panels have shown that it is possible achieve both high productivity greenhouse production and electrical power generation in the same facility. Work at Soliculture extended the initial feasibility studies at the University of California to develop a glass-laminate luminescent solar collector that could be mass produced at an economically feasible cost-point.This panel represents the first commercially available luminescent solar collector. The module is specifically adjusted tor greenhouse crop production. Two types of modules were developed as part of this project with the ERA and have been installed.

1) A module with 6% efficiency with higher transmission that is optimized for the roof of a greenhouse. The transmission of this module matches the transmission of the modules installed in the roof of the greenhouse at Vegreville even though the materials and cells are different.
2) A module with 8% efficiency with lower transmission that is optimized for the southern wall of a greenhouse in a northern latitude.

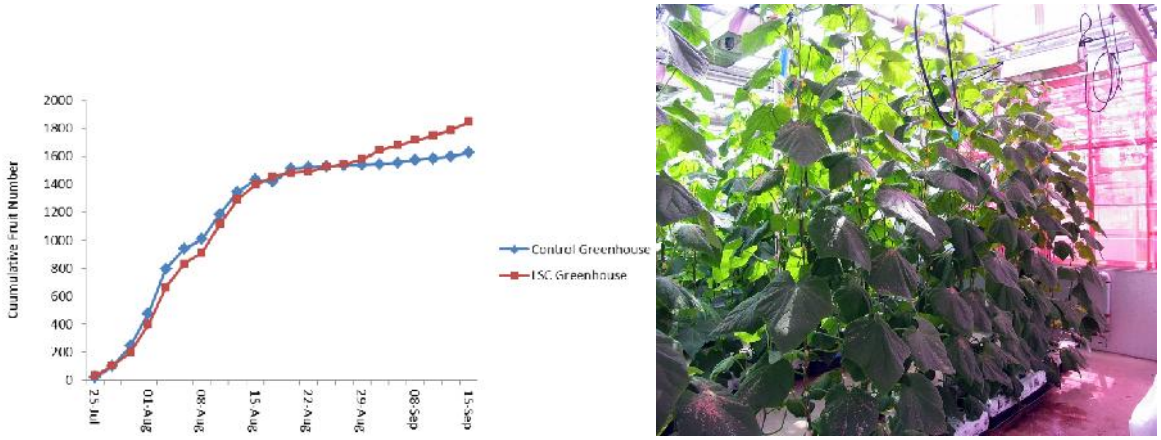


Figure 26: Results from cucumber trials in Vegreville, AB. Yields at the end of the cycle were found to be higher in the LSC greenhouse. This observation is consistent with results from central California and is attributed to less stress at the top of the canopy as the vines are longer.

. Greenhouse trials were conducted at AITF in Vegreville, AB and the Arboretum of the University of California at Santa Cruz. Two types of tests were run in Vegreville, cucumber and lettuce. Cucumber growth trials were performed at the AITF research greenhouses in Vegreville, AB. The following was the conclusion from this report: “Overall, results of the study indicate mini-cucumbers produced under LSC panels are similar to those produced under clear glass panels in Alberta. In both trials, fruit yield of mini-cucumber grown under LSC panels was found not to be significantly different compared to mini-cucumbers grown under clear glass panels; however, the number of fruit produced under LSC panels in the first trial was significantly greater compared

to clear glass panels. Stem length tended to be significantly greater under LSC panels compared to clear glass panels; whereas, differences in node number between the two panel types tended to be non-significant.

Two rounds of lettuce trials were performed at the trial location in Vegreville. The first round focused on lettuce growth and yields. The second trial focused on disease resistance. Results in the first trial found that one variety had lower fresh weight under the LSC, but in the second round of tests the fresh weight was equivalent. Other varieties showed no significant difference of fresh weight. All varieties under both treatments lettuce achieved marketable size in less than the recommended growth period.

”

Figure 27: Lettuce trials in Vegreville, AB. Lettuce fresh weight, shoot height, root weight and root dry weight showed a variety dependence that could not be reproduced in the second round. All varieties under both treatments produced marketable fresh weights within the prescribed growth period.

The second lettuce trial inoculated two varieties of lettuce with grey mold disease (positive control). A second set of lettuce received no inoculation (negative control). Figure 23 shows the effect of the grey mold spores on the roots of the lettuce. Occurance of grey mold on plants in the LSC compartment were 5% lower for New Red Fire and 27% lower for Skypos. The conclusion of the study was: “The results demonstrated that luminescent solar collector panels provided a significant reduction of gray mold disease for lettuce varieties used in the trial. Reduction of disease incidence and severity achieved by lettuce cultivated under luminescent solar collector panels was indicated to be dependent on lettuce variety, as lettuce varieties displayed a varying response to the disease. As both lettuce varieties displayed a significant reduction for gray mold disease when cultivated under luminescent concentrator panels, it can be concluded luminescent solar collector panels provide a positive influence for lettuce varieties infected with *B. cinerea*, as gray mold disease was neither as prevalent nor as severe for both varieties when compared to their cultivation under clear glass panels.”

The results from trials at UCSC, KB Farms and Vegreville all show that it is possible to combine greenhouse growing with electricity production with no negative impact on crop production. This results is contrary to the generally accepted belief in greenhouse growing that “1% light is 1% yield”. It is possible to absorb potions of the solar spectrum and use these wavelengths to generate electricity with no negative impact on plant growth. This opens the possibility for combined high productivity agriculture with electrical energy production.

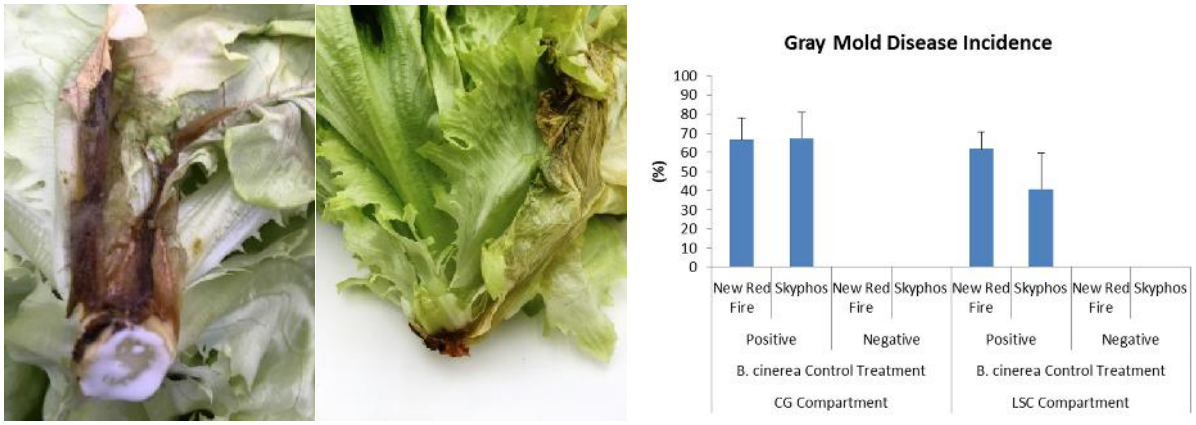


Figure 28: Grey mold disease (Botrytis) for two varieties of lettuce with and without inoculation treatment. Lettuce grown in the LSC compartment had a lower occurrence of grey mold, especially with the Skyphos variety.

(IX) Scientific Contributions

Soliculture is working with UCSC and researchers at AITF/InnoTech Alberta to publish results from the above mentioned crop trials in scientific journals.See reports in appendix. The current focus of Soliculture is product development followed by marketing to commercial growers in North America.

(X) Next Steps

Soliculture has several commercial installation in the pipeline and will be the focus for bringing this product to market.

Everbloom, Carpinteria CA: Soliculture will be installing a 20kW trial at Ever-bloom greenhouses in Carpinteria, CA in the fall of 2016. Ever-bloom was successful in getting a USDA REAP grant to fund 25% of the trial installation. The grant was in competition with other projects that add a stand alone PV array to a farm. This funding gives third party validation that Soliculture greenhouse integrated photovoltaics are a good value proposition. The grant was approved in April of 2015 and the project needs to be completed within two years of the award date. The installation is currently scheduled for late 2016 when there will be a crop change at the greenhouse

Riverside, CA: The University of California at Riverside is planning to move their research greenhouses off campus. UC-Riverside is installing a 1,000 sq. ft. greenhouse with Soliclture panels near the new location and the riverside campus to demonstrate Solicutlure greenhouse integrated PV technology so that it will be considered for the next expansion. Construction will start in September 2016 once the permit process is complete.

Akron, Ohio. Soliculture has entered into an agreement with Got Produce near Akron, Ohio for 2.5 acre lettuce greenhouse that will include Soliculture panels. The greenhouse will include 3,000 Soliculture LUMO panels with a power generation capacity of 300kW. Panels will be produced either in Tracy, California or Ontario, Canada. Figure 29 shows the site for constructing the greenhouse in spring of 2017.

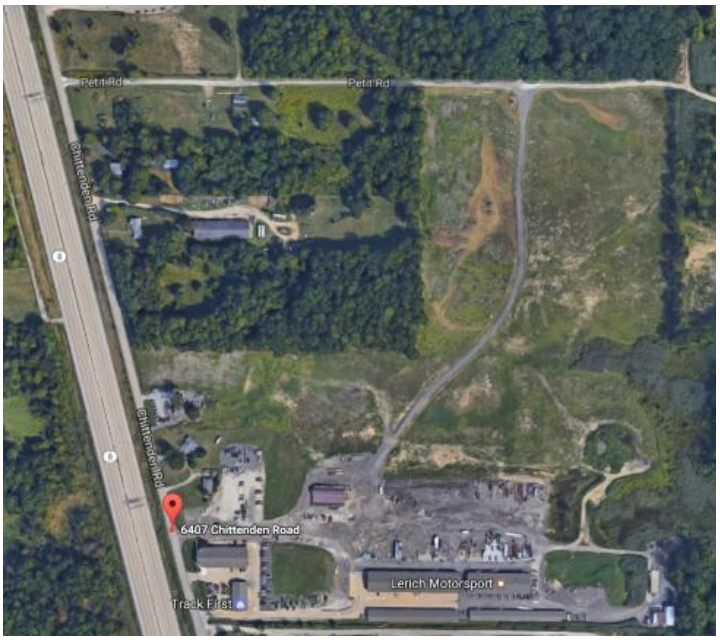


Figure 29: Location for 2.5 acre lettuce greenhouse with LUMO panels located between Akron and Cleveland, Ohio scheduled for spring of 2017.

Nature Fresh in Leamington: Discussions are in progress with Nature Fresh in Leamington, Ontario Canada. This is one of the top 5 greenhouse vegetable growers in Canada and they also operate a greenhouse manufacturing company. Nature Fresh would like to be the exclusive channel partner for distribution or our panel in Canada. As part of the arrangement, Nature Fresh would build a 2 acre demonstration addition to their 60 acre facility in Ontario Canada. Nature Fresh is currently in progress of building 200 acres of new greenhouses in Canada and 150 acres in Ohio.

(XI)Technology Transfer Plan

11.1). PRODUCT / SERVICE OFERING

Greenhouse Market Opportunity

Increasing electricity costs can erase the profitability of a greenhouse grower. For example, supplemental lighting in a Canadian greenhouse adds \$10-20/m^2 to the cost of a crop that sells for less than \$70/m^2. Some growers in Ontario have stop production in the winter because the energy costs for lighting are too high. Stability of operating costs is essential to compete in a global market and growers are willing to make capital expenses to lock in lower (or zero) electricity costs. Many European greenhouse growers are also under regulatory pressure to reduce their carbon footprint. North America has over 3,000 hectacres (30 million sq. meters) of glass greenhouse in production for vegetables and flowers. The greenhouse vegetable industry in particular has been growing at a rate of roughly 20% annually in North American driven by a transition away from field grown vegetables to greenhouses as a result of the ability to grow year round combined with the higher yield, higher consistency and lower water/pesticide usage of a greenhouse. A consolidation of retail food sales into a small number of large distributors has also increased supply chain standards that can only be met in a controlled environment like a greenhouse. For example, Figure 30 shows a recently installed 25 acre greenhouse in Medecine Hat installed by Rolling Acres Greenhouse. The electricity costs for running a greenhouse can be substantial for providing refrigeration of product, clomate control and supplemental lighting during the winter months. The product developed here addresses the energy costs of running a greenhouse and also targets changes in the

Figure 30: A new 25 acre greenhouse expansion was recently installed at Rolling Acres Greenhouse, part of the RedHat Cooperative in Medecine Hat, AB.

food and energy business that are opening new markets for combined grow locally / generate locally.

33

Introduction to Luminescent Solar Collectors

The power generating greenhouse cover developed by Soliculture is a low-concentration version of a luminescent solar collector that was first proposed in 1951 for scintillators and 1976

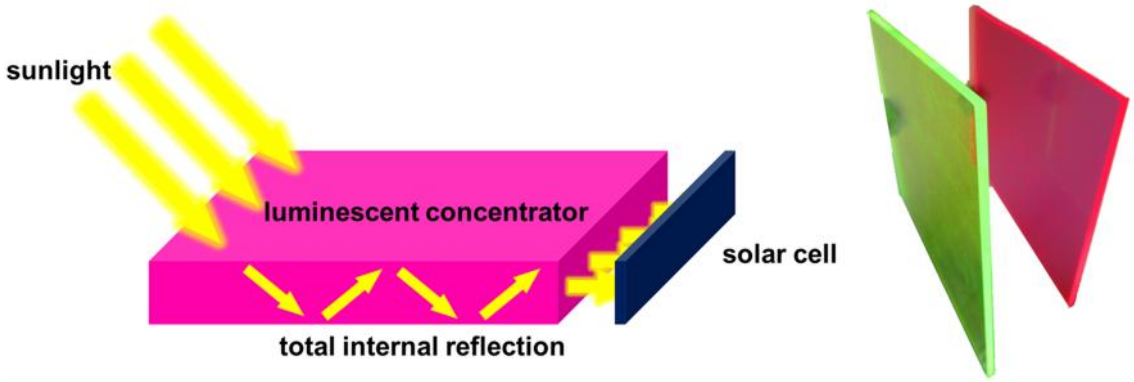


Figure 31: (a) Principal of conventional luminescent solar concentrator with cell on the edge. Light from sun is absorbed by a luminescent dye and re-admitted in all directions. Light is then trapped within the film by total internal reflection and transferred to the edge. http://www.thesolarspark.co.uk/

for solar energy collection. The basic principal of a luminescent solar collector is illustrated in Figure 31. Incident sunlight causes photoluminescence of a material incorporated in a large area sheet. The emitted light is captured within the sheet by total internal reflection and can be collected by photovoltaic cells places at the edge of the sheet. Luminescent solar collectors were investigated extensively in the early 1980's by NREL and several large companies including Corning, ARCO and EXXON. The technology was abandoned for a number of reasons including (1) The luminescent dyes available on the market at the time did not meet the long term degradation requirements for solar energy. This issue has been addressed with the incorporation of perylene based pigments into a highly stable matrix as discussed below. (2) Power conversion efficiencies for large area luminescent solar collectors are low due in part to the semi-transparent nature of the solar collector. Large scale solar deployments with <8% efficiency are not cost effective due to installation and balance of system costs. This issue is addressed with co-use of the solar windows for plant growth and power generation, such as shown in Figure 32.

The Soliculture Greenhouse Integrated Photovoltaic Panel (GIPV) is the first commercially available, mass produced luminescent solar concentrator to be ingtroduced into the market place.

(a) (b)

Figure 32: Greenhouse demonstration sites at AITF greenhouse in Vegreville. The combined greenhouse solar panels generates up to 1000W of power.

Value Propositions:

Value Proposition 1: Offsetting Energy Costs of Operating a Greenhouse with Net Metering.

The two largest costs for greenhouse growers of vegetables and flowers are labor and energy. The energy costs can take several forms. In the northern latitudes, supplemental lighting during the short days of the winter or for spring flowering is a major consumer of electricity. As time-of-use metering becomes more common, electricity credits can be built up in the summer months and then used for supplemental lighting in the winter to increase yields when the price of vegetables is high. In the southern latitudes, electricity for cooling and pumping water are the primary energy costs. Electricity bills for typical greenhouse growers in Alberta range from $3/Sq.M. to $15 / year

Alberta Greenhouse Crops	Area Sq.M.	Revenue $ / Sq.M.	Gross $ / Sq.M.	Gas $ / Sq.M.	Electricity $ / Sq. M.
Cucumbers	327,897	$107	$11.12	$10.84	$11.96
Tomatoes	196,859	$107	$20.39	$12.73	$ 3.83
Peppers	81,320	$103	$3.82	$10.35	$14.12
Ornamentals	56,479	$154	$48.92	$7.29	$ 2.90
Cut Flowers	41,250	$149	$46.75	$11.36	$11.30
Tree Seedlings	165,058	$101	$18.66	$11.97	$ 4.66

Table 5: Annual energy expenses (2011) from survey of Alberta greenhouse growers relative to revenue and gross profit. Energy costs are a significant cost, comparable to gross profit. Area is for all of Alberta. Data taken from (Laate, 2013).

as illustrated in Table 5. These energy expenses are comparable to the gross profit for the grower. Profit margins are small for greenhouse growers and spikes in energy costs can be devastating to the economics of a greenhouse operation. Therefore, farmers put a high value on having electricity rates that are not subject to price increases. The risk of rate increases is especially high in regions that import much of the energy needs. For example, electricity rates in Japan have begun to rise with the shutting down of many nuclear pants. Taiwan recently announced a 30% electricity rate increase. The product being developed by this ERA grant can offset these electricity costs with a payback time of less than 5 years for the capital investment.

The Soliculture panel product can provide all of the (substantial) electricity needs for a greenhouse grower without removing any land from production. Net-metering can be used to store electricity credits generated in the summer for supplemental lighting in the winter.

Value Proposition 2: Regulations against converting agriculture land to photovoltaic farms.

Many agricultural areas are pushing back on the installation of large solar farms. In Canada and France, generous feed-in tariffs for solar panels explicitly exclude ground based PV arrays that remove productive farm land from use. Our product would avoid these regulations by combining crop production with power production. A California law knows as the Williamson Act allows cities and counties to establish agricultural preserves within which landowners can voluntarily enter into contracts restricting their land to agricultural use in exchange for property tax reductions. Once the land is restricted to agriculture, it cannot be used for solar energy even though the land is close to transmission lines with ample sunlight.

Value Proposition 3: Grow Locally, Generate Locally.

A recent USDA report estimates that locally grown food will be a $7 billion dollar industry in 2012 relative to a $4.8 billion dollar industry in 2008. The main market for locally grown food are large metropolitan areas like Toronto and Calgary. The higher crop yields and year round growing provided with a greenhouse combined with favorable local grid-tied renewable energy subsidies make the suburban market an ideal candidate for a combined power generating greenhouse. A commercial property owner that wants to reduce their energy expenses could build an energy generating greenhouse next to a commercial building and then rent the greenhouse space to a grower. Leasing greenhouse space is a common practice for small specialty growers that do not have large amounts of capital. Greenhouse space near urban areas is particularly valuable due to the proximity to restaurants, farmers markets and local consumers. For example, greenhouse space in the northeast typically rents for $2-5/sq. ft / year (not including supplies and utilities). Compare this to the ~$2/sq.ft / year that the greenhouse will generate from electricity and the ROI for a PV array can be reduced significantly by renting out the space to a local organic grower. Increased interest in locally grown vegetables and flowers is revitalizing local farms near urban centers on the east and west coasts.

Surveys with greenhouse manufacturers like Rough Brothers of Cleveland, Ohio have confirmed that a growing segment in new greenhouse construction is near urban centers to provide locally grown organic food. Sites near urban centers can best utilize favorable power feed-in tarrifs associated with time-of-use metering and cooperative power generation agreements.

Value Proposition 4: Color Tuning for Enhanced Fruit and Flower production.

Conventional photovoltaic cells can be integrated into the roof of a greenhouse, but the solar cells remove beneficial light from the plants, thus reducing crop yields. Our unique panels remove only the portion of the spectrum that is not used by plants and simultaneously enhances portions that are used by the plants as illustrated in Figure 33. It has long been recognized that plants use only a portion of the solar spectrum. This portion is referred to as the Photosythetically-Active Radiation region (PAR). Plants generally have a green color because the green portion of the spectrum is not absorbed and only the blue and red portions are absorbed. Using photoluminescence, photons can be transferred (down-converted) from the inefficient green portion of the spectrum to the more efficient red portion of the PAR spectrum then photosynthetic activity can be increased. Color tuning is used extensively for indoor LED grow lights to optimize plant growth with lower energy consumption of the light source. Figure 34 shows an example of commercial grow lights that have the same color as our greenhouse windows. Studies have shown that luminescent dyes infused into the greenhouse plastic can improve tomato crop yields by up to 20% and increase rose production

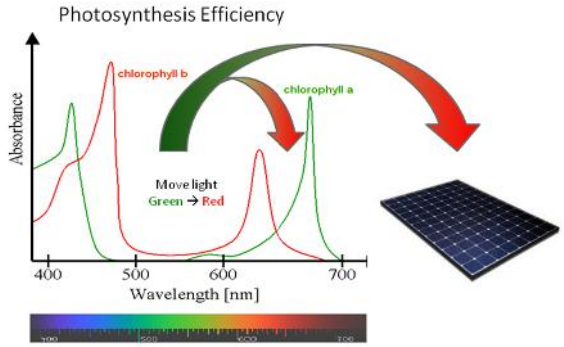


Figure 33: PAR region of the spectrum showing which wavelengths are most efficient for photosynthesis.[1]

Figure 34: Example of high efficiency LED grow light that provides optimum wavelengths for growth.

11.2) Third Party Vendors

The solar photovoltaics industry has gone through dramatic changes in just the last two years. In spite of continued growth in installed photovoltaic capacity, many well funded thin film photovoltaic companies have gone bankrupt. The primary change has been a dramatic drop in the price of conventional silicon based photovoltaic modules and cells. The spot price for poly-Si modules has dropped from over $2/watt in 2010 to less than $1/watt now. This drop in prices for silicon photovoltaics has removed the cost advantage of CIGS, CdTe and organic photovoltaics that have lower efficiency. Many promising thin film photovoltaic companies such as Konarka (organic), Abound Solar (CdTe), Global Solar and Miasole (CIGS) have not been able to compete with silicon and have exited the market for large scale solar installations.

The product being developed by Soliculture is for a niche market in the solar power generation area and is not competing directly with opaque silicon solar panels for large scale energy production. The manufacturing processes of our panels leverages off the existing silicon panel manufacturing process by using conventional silicon solar cells and a modified lamination process for assembly. In contrast, many of the thin film technologies required a specific and

specialized tool set for manufacturing, thus higher capital expenditures. We plan to pursue a contract manufacturing model until volumes can justify in-house manufacturing to increase profits. Our intellectual property resides in the specific optical density and spectral transmission of the panels that both facilitates plant growth and generates power.

BOM Sheet - Manufacturing Cost, 2016

Assembly Number: 16-01	**Length (m):** 2
Assembly Name: Certification Module, Model 98	**Width (m):** 1.05
Approval Date: 28-Nov-16	**Thickness (m):** 0.0032

BOM Level	Part Number	Part Name	QTY.	Unit of Measure	$/module	$/ft2	$/w
1	C-01	Textured PV Solar Glass	1	SQM	$ 11.72	$ 0.52	$ 0.12
2	C-02	EVA F806-S	1	SQM	$ 3.15	$ 0.14	$ 0.03
3	T-01	Mono-19+ 3BB Cells (19.8%)	1	ea.	$ 28.36	$ 1.26	$ 0.29
4	C-03	EVA F806-UT	1	SQM	$ 5.25	$ 0.23	$ 0.05
5	A-01	230 Glass Paper - Scrim	1	SQM	$ 2.23	$ 0.10	$ 0.02
6	A-02	Luminescent Backsheet	1	SQM	$ 27.01	$ 1.20	$ 0.28
7	C-04	TL-BOX029S-4	1	ea.	$ 2.00	$ 0.09	$ 0.02
8	L-01	Solaria (Cell Dicing+Stringing) Process	1	SQF	$ 144.00	$ 6.37	$ 1.47
8	L-03	String Lamination Process	1	SQF	$ 56.49	$ 2.50	$ 0.58
				Total:	**$ 280.20**	**$ 12.40**	**$ 2.86**

Table 6: Build of Materials (BOM) for Soliclutre Panels. Each of these items is standard for the PV industry with multiple suppliers with the exception of the luminescent backsheet (PolyOne) and strings (Solaria).

Most components for the Soliculture GIPV panel are standard to the PV industry and can be sourced from multiple vendors. The only two critical components that are proprietary with a single source are the luminescent sheet that was developed by Soliculture and the cell singulation that is provided by Solaria. Both of these components are protected by patents and give Soliculture a competitive advantage relative to standard PV modules.

As the price of silicon photovoltaics continues to drop, so will the cost of Soliculture panels. We use silicon cells and standard manufacturing methods combined with a transmission that is optimized for the agricultural market.

11.3) COMPETITION

Stand alone PV array. Table 1 illustrates that electricity is a significant cost for greenhouse growers. Farms that use supplemental lighting in the winter have particularly high electricity needs. The ability to offset these electricity costs using favorable net-metering rates has motivated many farms to install photovoltaic panels in unused portions of a farm such as on warehouse roofs or unused fields. The installation of conventional opaque PV panels on unused space is the primary competition for the implementation of photovoltaics on a farm.

The GIPV panels integrated into the greenhouse roof represents a significant advantage over opaque panels installed adjacent to a greenhouse. The primary cost disadvantage of a stand alone

			Soliculture		
		Grond Mounted Conventional PV	Suburban Rental Greenhouse Integrated	New Commercial Greenhouse integrated	Retrofit Commercial Greenhouse integrated
Capital Cost	**Units**				
Panel Cost	$/watt	$1.00	$1.50	$1.50	$1.50
Panel Cost	$/sq.ft	$15.00	$7.50	$7.50	$7.50
Mounting frame + BOS cost	$/sq.ft	$15.00	$15.00	$15.00	$0.25
Power Generation	W/sq.ft.	15	5	5	5
Installed Power Cost	$/watt	$2.00	$3.00	$3.00	$1.75
Total Area Cost	$/sq.ft	$30.00	$22.50	$22.50	$7.75
Revenue					
Annual sunlight (California)	kW-hr / sq. ft	200	200	200	200
Panel Efficiency	%	15%	5%	5%	5%
Peak daytime rate (California)	$/kW-hr	$0.16	$0.16	$0.16	$0.16
Annual Power Revenue	$/sq. ft.	$4.80	$1.60	$1.60	$1.60
Annual Rental revenue	$/sq. ft.	0	$5		
Annual Crop Profit (estimate)	$/sq. ft.			$5	
Total Annual Revenue	$/sq. 5t	$4.80	$6.60	$6.60	$1.60
ROI - Cost / Revenue	**Years**	**6.3**	**3.4**	**3.4**	**4.8**

Table 7: Comparison of costs and return on investment time for stand alone ground based PV array and greenhouse integrated PV array for three markets.

photovoltaic system is the cost of the frame and mounting hardware. The price of the solar panels has dropped to ~$1/watt but the price of mounting hardware and balance of system has remained constant at ~$1/watt. Therefore, the mounting hardware is now a substantial cost of a stand alone PV system for both roof mounted and ground based PV systems. Many greenhouse companies like Rough Brothers have formed divisions for mounting PV panels due to the similarity in construction for greenhouses and supporting large arrays of PV panels. Our integrated greenhouse panels would use the existing structure of the greenhouse and therefore avoid the additional cost of the mounting structure for a savings of ~$1/watt or 25-50% for a conventional PV installation. In addition, integrating the PV panels into an operational greenhouse adds additional revenue/acre and ultimately accelerates the return on investment for the greenhouse. The additional revenue can come from improved crop yields relative to a clear greenhouse as observed at the UCSC arboretum greenhouse or from rental of greenhouse space for small local growers. Through the lower costs

associated with an integrated PV greenhouse roof, we can achieve a return on investment that is shorter than a conventional ground-mounted PV array.

Table 7 illustrates the return on investment for three potential markets relative to a stand alone PV array. The values used for the return on investment calculation are typical values for Northern California and assume that we can utilize in-house manufacturing. Actual return on investment will depend strongly on local utility rates, sun exposure and subsidies. The shortest return on investment is for a new installation that either rents out the greenhouse space or produces a crop from the greenhouse. The income from renting the greenhouse space or growing crops is greater than the income from the power and can dramatically reduces the return on investment time. An annual rental rate of $4/sq. ft. is typical for greenhouse space near an urban area. This table illustrates the advantage of building integrated photovoltaics over conventional photovoltaics. In this case the building is a simple greenhouse structure that uses a similar frame that a conventional ground mounted PV array would use. **The dual use of the land and structure reduces the payback time for the photovoltaic structure to less than 5 years.**

Thin film photovoltaics for greenhouses.

Another potential competition for greenhouse integrated photovoltaics is a variety of thin film photovoltaics that are developed for building integrated photovoltaics. These products are feasible for a double pane commercial grade building window that can charge $100/sq. ft. Several companies such as SunWell in China and PolySolar in England are marketing a greenhouse window that uses semi-transparent amorphous silicon to generate power. However, thin film photovoltaics inherently have a high cost associated with the deposition of many layers including a transparent conductor, p-type absorber, n-type absorber and transparent top contact layer. The semi-transparent nature of the windows means that less light is absorbed and the therefore the efficiency will be lower than their opaque counter parts. The cost and ROI of thin film photovoltaics can barely be justified at 12% efficiency. A semi-transparent panel with ~50% the absorption would have ~50% of the efficiency with the same cost. (2) A more fundamental problem thin film photovoltaics for greenhouses is that ***the absorption spectrum of any semiconductor based thin film photovoltaic will kill the plants*****!** Semiconductor based photovoltaics use all photons above a band edge to generate electron-hole pairs. If the bandgap of the semiconductor layer is chosen to absorb the green portion of the spectrum then it will also absorb the blue portion of the spectrum which the plants need for photosynthesis as seen in Figure 3. It would be very difficult to design a semiconductor layer that absorbs only the green portion of the spectrum without also absorbing the blue portion needed for chlorophyll production. The narrow band wavelength selectivity of the luminescent dye used in this panel is therefore fundamentally better than a thin film based panel for growing plants.

Most thin film photovoltaics cannot be used in a greenhouse application because they absorb too much of the blue portion of the spectrum to achieve reasonable power conversion efficiency and will harm the plants.

LED lighting in greenhouses

One of the main consumers of electricity (and the driving forces for summer energy credits) in a greenhouse is supplemental lighting during the winter months in northern climates. If a grower in a northern climate could reduce their electricity bills with high efficiency LED lights, then the demand for our product might be limited. LED lighting has made great advances for plant growth, especially for indoor growing. However, LED lights have not yet been able to displace less

efficient high pressure sodium lamps in greenhouses for two reasons. First, Supplemental lighting is only used during the short days of the winter when temperatures are low and the heat provided to the top of the plants by the inefficient lamps is very important. Secondly, the light output of an LED lamp is very directional so that a large "panel" of LED lights is required to get enough intensity over a large area. This large footprint is acceptable for indoor growing but in a clear greenhouse during the day it blocks out almost as much light as it provides at night.

11.4) Market Overview

Greenhouse Industry Overview in Alberta and World

The greenhouse market is segmented into two categories. The first is premium greenhouses for vegetables and flowers that use either glass or twin-wall polycarbonate for the glazing and lasts greater than 20 years. The installation cost for a premium greenhouse is typically \$300/m^2 including the infrastructure. The second class of greenhouses are made of thin plastic sheets on an open frame. This class of greenhouse costs ~\$50/m^2 installed and lasts only 1-2 years. Growers will pay a premium for the power generation portion of these panels and therefore the product must last at least 20 years. ***Therefore, the initial target market for these power generating panels is the premium glass greenhouse market with greater than 20 year lifetimes. A second generation product will target the lower-cost crop cover market.***

Figure 35: 1.5 million sq.ft. high tech glass greenhouse at Big Marble Farms in Medicine Hat, Alberta.

Commercial greenhouse operations range from a few acres to hundreds of acres. For example, Big Marble Farms operates a 1.5M sq. ft. (35 acres) glass greenhouse in Medicine Hat AB shown in Figure 35. If the Big Marble farm in were constructed using the power generating windows developed by Soliculture operating at ~5% efficiency then this vegetable farm would produce 7.5 MW of power. Alberta has 14M sq.ft of greenhouses in total as specified in Table 8. If all of this area were converted to Soliculture greenhouse panels, it would represent 70 MW of power generation capacity. Applying the average CO_2 offset of 50 kg CO_2/m^2-y Given in table 5,

Region	Land Area		Greenhouse Area			Number of Growers by Region
	Acres	Hectares	(sq. ft.)	(sq. m.)	Per cent of Total	
1. Fort McMurray	-	-	-	-	-	-
2. Grande Prairie	541	192	803,437	74,642	5.4%	18
3. Whitecourt	781	250	210,066	19,516	1.4%	21
4. Edmonton	1,853	564	1,324,036	123,007	9.0%	43
5. Bonnyville	40	7	974,410	90,526	6.6%	11
6. Lloydminster	79	29	330,496	30,704	2.2%	14
7. Red Deer	3,007	1,140	2,283,922	212,184	15.5%	43
8. Calgary	1,159	460	1,004,641	93,334	6.8%	22
9. Medicine Hat	367	2	6,670,955	619,753	45.2%	42
10. Lethbridge	394	40	1,109,244	103,052	7.5%	15
Total	**8,294**	**2,714**	**14,743,207**	**1,369,690**	**100.0%**	**230**

Table 8: Installed Alberta greenhouse area by region in. .Alberta is the third larges greenhouse producer in Canada behind Ontario (

this would result in 70,000 tonnes of CO_2 reduction / year. The Almeria region of Spain provides fresh vegetables for most of Europe and covers more than 20,000 hectacres (200 million square meters) in greenhouses, visible by satellite from space. The two fastest growth sectors for greenhouses are large scale vegetable production and local produce production. In total, glass greenhouses cover over 40,000 hectacres (400M sq. m.) and rigid plastic greenhouses cover 700M hectacres (2 billion sq. m.).

The overall market trend for vegetable production in North America is in transition from field produced vegetables to greenhouses for higher yields and greater consistency. Field tomato production in Florida peaked in 1992 and has declined by 51% by 2011. In California, production has dropped by more than 43% from 1999 to 2011. In contrast, production of greenhouse tomatoes has grown in Canada, California and Mexico by 28%, 17% and 240% respectively from 2005 to 2011.

Greenhouse farming is a growth industry due to year round production, greater product consistency and lower use of water / pesticides.

Greenhouse market

The United States is one of the smaller markets for greenhouses. Northern climates including Canada and Holland uses glass greenhouses extensively to extend their growing season. Table 8 summarizes the greenhouse area by region in Alberta. Alberta ranks fourth in greenhouse production in Canada after Ontario (13M Sq.M), British Columbia (5M Sq.M.) and Quebec (3M Sq.M.).

	TAM sq. m.	SAM	SAM sq. m.	Cost $/m	Sales
North America Retrofits	40 M	2%	0.8 M	$80	$64 M
North America New Installations	15 M	10%	1.5 M	$80	$120 M
Total North America					$184 M
International Glass Retrofits	400M	1%	4.0 M	$100	$400 M
International Plastic Retrofits	1,000M	1%	10 M	$50	$500 M

Table 9: Total Accessible Market (TAM) for North America and international in 2006. Service Available Market (SAM) assumes 2% penetration for retrofit of existing greenhouse and 5% penetration for new greenhouse installations in North America. Marketing internationally is more difficult and therefore we assume a 1% penetration.

Table 9 summarizes the total accessible market for the world that includes the total area in square meters of existing glass greenhouses and the area of new greenhouse installations in North America. We estimate that the serviceable markets will be 2% of the existing greenhouses for retrofit installations. This is based on the average lifetime for greenhouse coverings of 20 years and a 30% market penetration. For new greenhouses, we estimate that we can capture 10% of new greenhouse sales. Assuming a selling price of $80/m2, this corresponds to a serviceable market of $64M for retrofits and $120M for new installations. A second generation product that can access the plastic crop cover industry will have a total accessible market of 200 billion square meters or 5 billion dollars .

11.5) MARKETING AND DISTRIBUTION

Sales Channels.

The greenhouse supply industry can be broken down into four segments as illustrated in Table 10. Large commercial installations are dominated by three large commercial greenhouse companies based in Holland. North America is dominated by one installer, Kubo. These companies specialize in the installation of the greenhouse, not the materials. They have a set of materials suppliers that they call upon for particular jobs. Our goal will be to become the premier supplier of greenhouse integrated photovoltaics to these installers. These suppliers have been in the industry for many years and know many of the growers personally. They know who is looking to expand and who is interested in new technology. The typical minimum size for a vegetable greenhouse is 2 acres or 8,000 sq.m.. With coverage of the west facing roof only, this would be roughly 4,000 sq.m. of GIPV panels for a revenue of $400,000 / job. The large revenue / job for the vegetable market will minimize marketing costs.

Soliculture will focus on the North American market to gain market acceptance. Once the product has gained market acceptance then distribution can proceed to the international market including

Cannabis represents a new market for greenhouse integrated photovoltaics. As cannabis cultivation becomes legal, growers are moving out of indoor growing environments and into greenhouses. The greenhouses tend to be small because the revenue/area is high. A typical greenhouse might be a few thousand square feet. But the cost/area of the greenhouses is also high thus reducing the fractional cost or Soliculture panels.

Segment	Region	Sales Channel
Large Commercial Installations	**International.** Dominated by three large Dutch companies.	**Kubo** (~90% of US market)
Medium Installations and greenhouse supplies.	**Local.** California and Ontario have the highest electricity rates and will be the first target market.	**System USA** (California) **South Essex** (Ontario)
Specialty greenhouses and photovoltaic installations	**National.** Custom frames are integrated with building or photovoltaic arrays	**Rough Brothers** (Supports both greenhouses and photovoltaics)
Cannabis	**Canada, Select states in US**	**Ceres (Boulder, CO)** and other small greenhouse suppliers.

Table 10: Sales channels through greenhouse manufacturing companies.

11.6) LEGAL

Soliculture technology is protected by patents filed through Soliculture including a design patent for a red solar module and an application for the backsheet made with an amorphous PET + Luminescent dye. In addition, Soliculture has an exclusive license to a patent from the University of California and exclusive license to Solaria singulation technology applied to greenhouses.

The activity in the late 70's and early 80's on Luminescent Solar Concentrators covered most of the basic patents on the principle of luminescent solar concentrators. These patents have now expired and are in the public domain. A review of the early patents demonstrates that most patents are conceptual in nature and are not focused on manufacturability or reliability of the full package. This is understandable because no company currently manufactures a luminescent solar concentrators. The expired patents in the public domain effectively gives us the freedom to operate but will also require very specific patents to protect our product against infringement. A provisional patent was filed in February 2012 through the University of California at Santa Cruz that covers the specific range of absorption and emission that is best for plant growth *and* power generation. Windows that are too "dark" will remove too much of the transmitted light and inhibit growth. Windows that are too "light" will not benefit from the photoluminescence in the PAR region. The UCSC patent application defines this specific range of optical densities that are can both benefit plants *and* generate power -- a very specific application in agriculture

Soliculture Patents

- Application 14/372,389 Luminescent Electricity Generating Window for Plant Growth
- Design Patent D754,597 Solar Module
- Application 15/179749 Amorphous Copolyester based material in a photovoltaic module

Solaria Patents

- 8766086 System and methof for laminating photovoltaic structures

- 8563848 System and method for placement of photovoltaic strips
- 8513095 Method and system for separating photovoltaic strips
- 8409898 Assembly system for photovoltaic packages
- 8361259 System and method for determining placement of photovoltaic strips using displacement sensors
- 7910822 Fabrication process for photovoltaic cells
- 7910392 Method and system for assembling a solar cell package

11.7) FINANCIAL

Depending on payment terms, Soliculture can deliver on a multi-acre greenhouse installation using contract manufacturing. Below is an example of cash flow for including Soliculture panels in an upcoming 2.5 acre greenhouse in Ohio. Soliculture was recently awarded a grant from the S

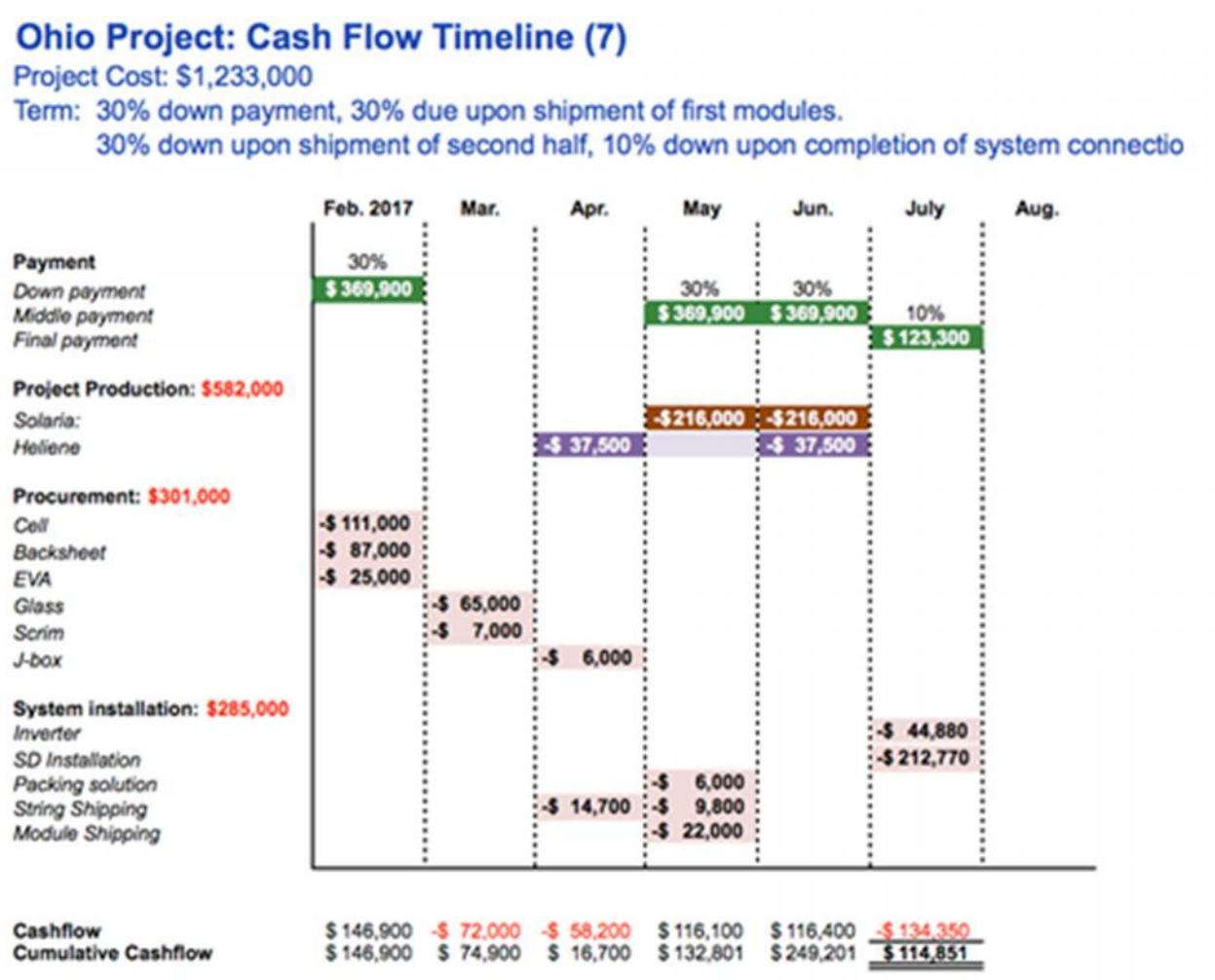


Figure 36: Example of cash flow for 2.5 acre greenhouse installation near Akron Ohio. Payment terms of 30%-30%-20%-20% with 4 milestones will keep cash reserves always positive.

Department of energy that will provide operating costs for most of 2017. At the end of 2017, Soliculture expects to have a positive cash flow and will be profitable.

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The Effect of Luminescent Solar Concentrators (LSC) on Growth of Greenhouse Mini-Cucumbers in Alberta

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Introduction

A study, comprised of two trials conducted during 2014-2015, was undertaken at the Alberta Innovates Technology Futures greenhouse complex in Vegreville, Alberta in order to evaluate the effect of luminescent solar concentrators (LSC) on growth of greenhouse mini-cucumbers. This objective was accomplished by comparing fruit weight, fruit number, main stem node number and main stem length of cucumbers grown under LSC panels to cucumbers grown under clear glass panels.

In addition to the plant growth study, solar panel energy was collected and recorded (data presented at end of report).

Materials and Methods

Experimental Design

To test the response of cucumbers to LSC panel technology, 70 west-facing clear glass panels were removed from one greenhouse compartment and the adjacent corridor and replaced with LSC panels (Figure 1). In addition, a translucent plastic film of identical color to that used in the LSC panels was placed over the clear glass panels located on the west half of the south-facing vertical sidewall of the LSC treatment compartment (Figure 2). A second greenhouse compartment of identical size and orientation was used as the comparison treatment, control, where neither LSC panels nor sidewall film were present.

Greenhouse compartments were 44 m^2 in size; sidewalls were 3.6 m in height of which the upper 2.7 m contained glass panels and height from floor to ridgeline peak was 5.5 m. Each treatment compartment contained 20, 400 watt high pressure sodium lights (HPS; General Electric Lucalox LU/H/ECO). Treatment compartments were physically separated by a distance of 6.2 m and shared a common corridor.

The first trial, Trial 1, was conducted from July 4 to September 16 and was repeated, Trial 2, from October 9 to January 19; dates refer to when cucumber seedlings were transplanted into greenhouse environments and when the trials were terminated, respectively. LSC and control treatments each contained 60 cucumber plants; a completely randomized design was used. Within each treatment compartment, three paired rows of grow bags consisting of 10 bags/paired row, where each bag

Figure 1. Alberta Innovates Technology Futures greenhouse structure.

contained two cucumber plants, were used for data collection. Rows were orientated north-south with the greenhouse ridgeline.

Figure 2. LSC greenhouse compartment.

Environmental Data and Solar Energy Collection and Recording

Temperature, relative humidity and photosynthetic active radiation (PAR) were monitored in real-time and recorded within each compartment; sensors for each parameter were located at the center of each compartment and were raised on a weekly basis to equal the average height of the cucumber plants. Solar radiation was monitored and recorded by two pyranometer sensors located outside and above, on the west-facing slope of the LSC compartment where one pyranometer sensor was level to the horizon and one was level to the slope of the greenhouse roof. Monitoring and recording of environmental data was accomplished by using a HOBO U30-ETH (Onset Computer Corporation).

Solar energy harvest, monitoring in real-time and measurement were accomplished by using an Enphase Energy Microinverter system comprised of Enphase Microinverters, an Envoy Communications Gateway and an Enphase Enlighten Monitor (Enphase Energy Inc.).

Cucumber Production Techniques

For both trials, mini cucumber seed, "Picowell RZ" (RZ Seeds) were planted in 2.5 cm^2 mineral fiber cubes (Grodan) and placed in a growth chamber (Conviron Model PGV36) programmed to maintain 25/22 ^oC day/night temperature regime with an 18-h photoperiod supplemented with 300 $\mu E\ m^2\ s^{-1}$ illumination provided by both fluorescent and incandescent lighting. After nine days, cucumber seedlings were transplanted to 10 cm^2 mineral fiber cubes (Fibrex Insulation Inc.). Seedlings were fertilized weekly with a nutrient solution containing 150 ppm nitrogen, 33 ppm phosphorous, 125 ppm potassium, 0.375 ppm iron, 0.15 ppm boron, 0.1875 ppm manganese, 0.1875 ppm zinc, 0.1125 ppm molybdenum and 0.1875 ppm copper. Eighteen days after seeding, cucumber plants were transferred to greenhouse compartments where they were placed on top of pre-wetted coconut coir growing medium contained in white polyethylene covered bags. Grow bags were 2902 cm^3 (Milleniumsoils Coir) and 3274 cm^3 (Go Green Imports Inc.), Trial 1 and 2, respectively; volumes are based on non-wetted dimensions.

In both treatments, cucumber plants were fed a nutrient solution at each irrigation cycle using fertilizer injectors (Dosatron, D14MZ2-14 gpm) and a drip-line system; water flow was regulated with an inline pressure regulator; programmable timers (Sterling 8, Superior Controls Co.) were used to schedule feedings. For the duration of each trial, irrigation scheduling was based on maintaining a target of 10-20% daily leachate excess. Troughs were placed under grow bags to divert leachate into collection pans; three collection pans were present in each treatment compartment. The pH of the nutrient feeding solution was targeted between 5.5 and 6.5; pH and electrical conductivity of both feed and leachate were measured throughout the duration of each trial. The water source for this study was treated municipal, originating from the North Saskatchewan River and its contributions to the nutrient solution were included.

For Trial 1, a nutrient solution was provided with nitrogen levels increased from 158 ppm at transplanting to 316 ppm after five days and maintained at 316 ppm until final harvest. Phosphorous, potassium, sulphur and calcium were increased from 26 ppm, 116 ppm, 0 ppm and 127 ppm from transplanting to 52 ppm, 405 ppm, 72 ppm and 254 ppm, respectively, after five days until final harvest. Iron, boron, manganese, zinc, molybdenum and copper were increased from 0.5 ppm, 0.1 ppm, 0.25 ppm, 0.25 ppm, 0.0025 ppm and 0.25 ppm at transplanting to 1 ppm, 0.2 ppm, 0.5 ppm, 0.5 ppm, 0.005 ppm and 0.5 ppm, respectively, after 5 days until final harvest. It should be noted an omission occurred and no magnesium sulphate was provided during Trial 1. Nutrient solution pH was adjusted using phosphoric acid.

For Trial 2, a nutrient solution was provided with nitrogen levels increased from 316 ppm at transplanting to 321 ppm after 22 days and maintained until final harvest. Potassium, magnesium, sulphur, calcium, iron, boron, manganese and molybdenum were increased from 233 ppm, 97 ppm, 127 ppm, 253 ppm, 1.002 ppm, 0.2 ppm, 0.502 ppm and 0.005 ppm from transplanting to 348 ppm, 109 ppm, 215 ppm, 319 ppm, 2.002 ppm, 0.475 ppm, 1.252 ppm and 0.01875 ppm, respectively, after 22 days and maintained until final harvest. Phosphorous, zinc and copper were reduced from 52 ppm, 0.502 ppm and 0.502 ppm at transplanting to 39 ppm, 0.477 ppm and 0.402 ppm, respectively, after 22 days and maintained until final harvest. Nutrient solution pH was adjusted using citric acid.

No supplemental greenhouse lighting was provided during Trial 1, executed during summer months. For Trial 2, executed during winter months, a daily photoperiod of 16 hours light consisting of both natural daylight and light supplied by 400W HPS lamps was targeted for both compartments.

For both trials, cucumber plants were individually trellised on twine attached to an overhead horizontal support line. Twine was attached to the base of each plant with a plastic clip and as the plants developed, were twisted around the twine; clips were also used for support as plants matured.

Pruning techniques differed between trials. For the duration of Trial 1, emerging fruit from the base of the plant to the 5th stem node were removed and discarded, at which time one fruit per node was permitted to remain and mature for cucumber number and weight determinations. Developing side shoots were removed from the cucumber stem until the stem reached the height of the HPS lights, located 2.55 m from the floor of the greenhouse. The growth point of the main stem was clipped when it reached the position of the HPS lights and one side shoot was allowed to develop near the location of the clipping, becoming the replacement stem. Further developing fruit on the new stem were kept to one per node and collected. Additional developing side shoots were removed.

For Trial 2, horizontal support piping was introduced into both compartments and positioned over each row of cucumbers at a height of 2.45 m from the floor of the greenhouse. For the duration of the trial, emerging fruit from the base of the plant to the 5th node were removed from the stem, at which one fruit per node was permitted to remain and mature. Side shoots present above the 5th node were allowed to develop on the stem and were clipped after the presence of a second node; a maximum of four fruits were allowed to develop on side shoots. When plants reached the support they were trained to grow horizontally along the pipe for approximately 25 cm, whereupon they were allowed to grow down to the greenhouse floor.

Biological control insects were released in both compartments during both trials on a weekly basis to provide control of thrips; sticky cards were also placed to trap and monitor insect pest populations. Shuttle 15 SC (acequinocyl, Arysta LifeScience) was applied in both compartments once per trial for the control of spider mites. Vectobac 600L *(Bacillus thuringiensis* subspecies *israelensis*, Valent BioSciences Incorporated) was applied in both compartments twice per trial for the control of fungus gnats.

No disease in either treatment was observed during both trials.

Cucumber Data Collection, Statistical Design and Analysis

Cucumber main stem length was measured at one, two, three weeks after transplanting into treatment compartments and at trial termination. Cucumber stem node number was counted at one, two, three weeks after transplanting into compartments for both trials and at trial termination for the second trial only. Fruit weight and number were determined when fruit when reached a length of 12.7 cm; fruit were removed, counted, weighed and grouped by cucumber row.

Data obtained from both trials were subjected to analysis of variance using SAS (SAS, 2002 Institute Inc., Cary, NC, USA) software. Two-way ANOVA with a general linear procedure was used and least significant difference (LSD; P = 0.05) values were used to compare treatment means. Preliminary analysis using a

general linear model was conducted on pooled data over Trials 1 and 2, and included trial, treatment, trial x treatment, sampling period, trial x sampling period, treatment x sampling period, trial x treatment x sampling period and a dependent variable as factors. Significant ($P < 0.0001$) trial by treatment interactions occurred, for the cucumber variables and thus, subsequent analyses were conducted separately for each trial. Pooled data from both trials is presented at the end of the report.

Results and Discussion

Trial 1

Plant Growth and Fruit Production

As previously described, the main growing point was clipped when plants reached the height of the HPS lights, conducted as part of the overall pruning technique employed. The side shoot that was allowed to develop was included in total stem length determinations, measured on a per plant basis, at the trial termination sampling period. Observations made after the removal of the growing point revealed a greater number of plants in the control treatment did not develop a side shoot near the location where the removal of the growing point occurred compared to plants in the LSC treatment.

Cucumber stem length from both treatments were determined not to be significantly different from each other, measured one week after transplanting into the greenhouses; however, subsequent sampling periods determined stem length in the LSC treatment was significantly greater than stem length in the control treatment (Table 1).

Table 1. Cucumber stem length in Trial 1.

Cucumber Stem Length (cm)				
	Sampling Period*			
Treatment	1	2	3	Trial Termination
Control	24.57a	69.49b	133.14b	266.86b
LSC	24.68a	73.07a	145.89a	352.54a
$LSD_{(0.05)}$	1.85	3.27	4.52	36.24

Means within a column with the same letter are not significantly different according to the Least Significant Difference (LSD) at a 0.05 probability level; n = 59.

* Sampling period numbers represent weeks after transplanting into greenhouse.

Cucumber stem node number was identical in both treatments measured one week after transplanting into the greenhouse. At the second sampling period, node number was significantly greater for plants grown under the LSC treatment compared to plants grown under the control treatment. At the third sampling period, node number for both LSC and control treatments were not significantly different from

each other. At the trial termination sampling period, a data collection oversight occurred and consequently, node number data was not collected (Table 2).

Table 2. Cucumber stem node number in Trial 1.

Cucumber Stem Node Number				
	Sampling Period*			
Treatment	1	2	3	Trial Termination
Control	6.64a	11.19b	20.46a	**
LSC	6.64a	12.03a	20.69a	**
$LSD_{(0.05)}$	0.30	0.43	0.44	**

Means within a column with the same letter are not significantly different according to the Least Significant Difference (LSD) at a 0.05 probability level; n = 59.

* Numbers represent weeks after transplanting into greenhouse.

** Data for final node number was not collected.

Cucumber fruit were sampled at 22 periods. Overall, the LSC treatment produced a significantly greater number of fruit compared to the control treatment. Fruit weight did not differ significantly between treatments. Although the LSC treatment produced greater fruit number and fruit weight, average fruit weight was less in the LSC treatment compared to the control treatment (Table 3).

Table 3. Cucumber fruit production in Trial 1.

Cucumber Fruit Production					
	Fruit Number		Fruit Weight		
Treatment	Fruit number/sampling period/row*	Total fruit number for trial	Fruit weight (kg)/sampling period/row*	Total fruit weight (kg) for trial	Average fruit weight (g)
Control	12.33b	1628	1.021a	134.72	82.8 [1]
LSC	14.00a	1848 [2]	1.095a	144.52 [3]	78.2
$LSD_{(0.05)}$	1.14		0.11		

* Data are sampling period (22) x cucumber row (6) means; means within a column with the same letter are not significantly different according to the Least Significant Difference (LSD) at a 0.05 probability level; n = 132.

[1] Equivalent to 5.5% greater individual fruit weight compared to the LSC treatment.

[2] Equivalent to 11.9% greater total fruit number compared to the control treatment.

[3] Equivalent to 6.8% greater total fruit weight compared to the control treatment.

Similar fruit number and weight were collected from both treatments for the first two sampling periods. However, data collected from the following three sampling periods determined 22% greater fruit number and 27% greater fruit weight were produced by the control treatment compared to the LSC treatment. The control treatment's yield advantage over the LSC treatment remained until August 5 when peak fruit production occurred, as subsequent sampling periods determined plants in the LSC treatment began to out-produce plants in the control treatment. Data collected on August 22 determined cucumber production in both treatments had reached their lowest levels and after this date, plants in the LSC treatment recovered and began to consistently out-produce the control treatment. Both treatments continued to produce fruit until the trial was terminated (Figures 3, 4, 5 and 6).

Figure 3. Trial 1 cucumber fruit number by sampling date.

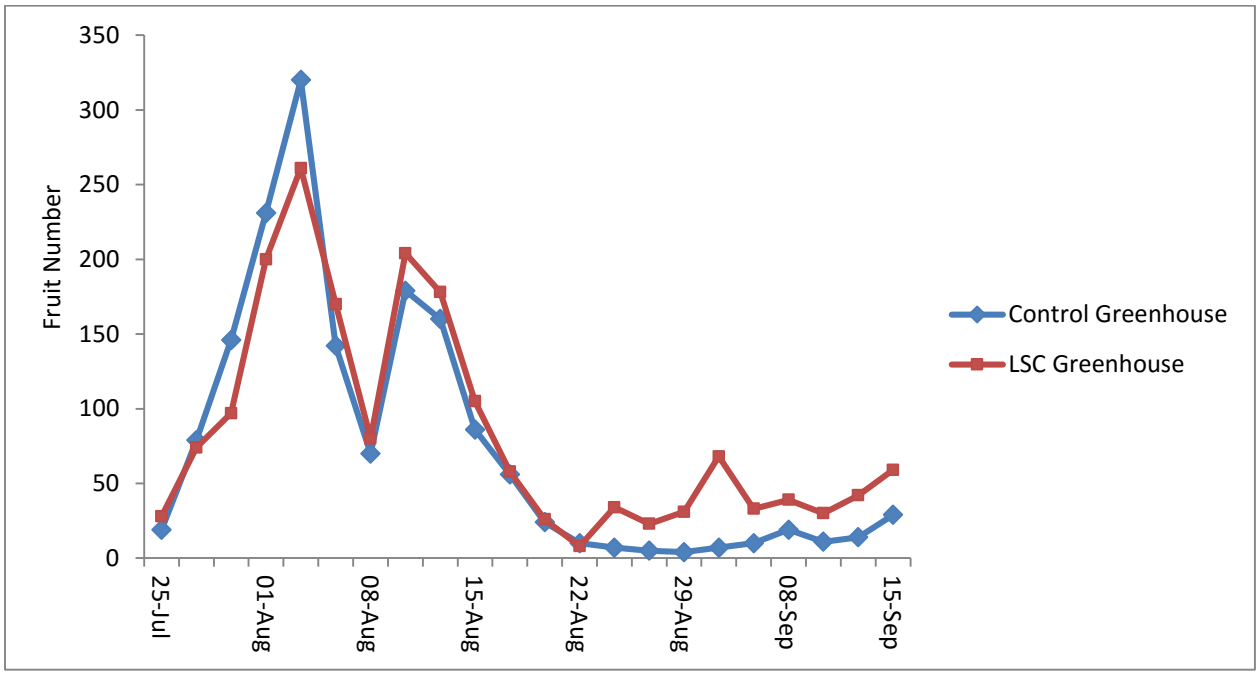


Figure 4. Trial 1 cucumber fruit weight by sampling date.

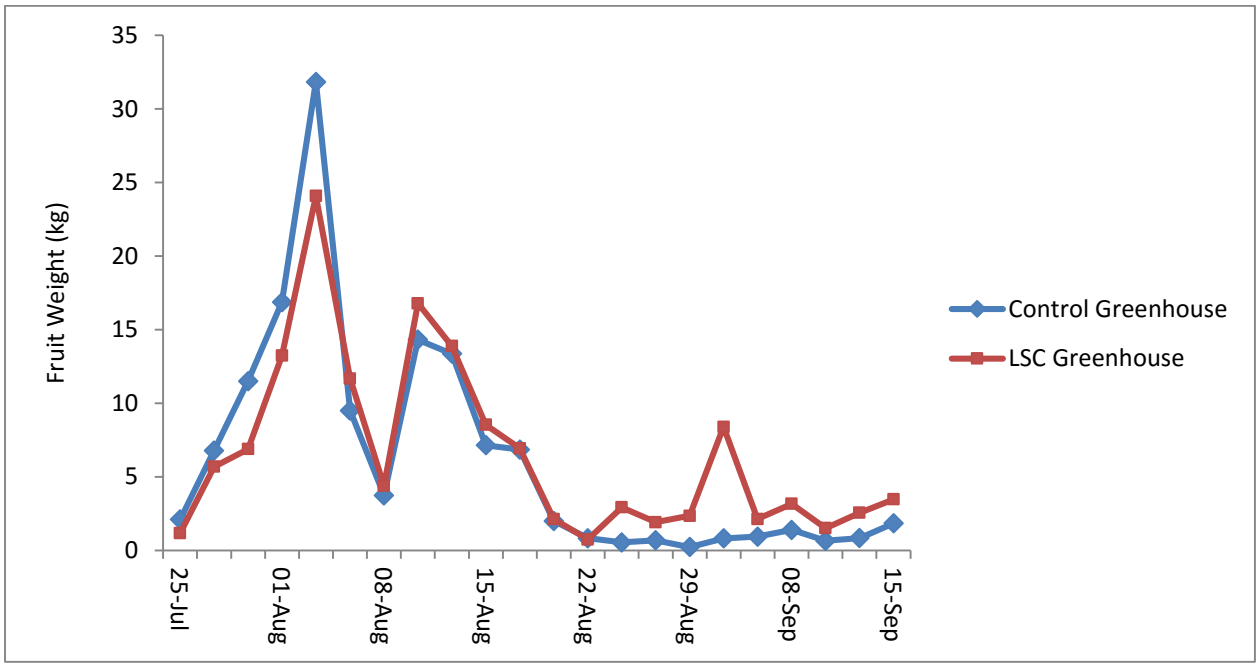


Figure 5. Trial 1 cumulative cucumber fruit number by sampling date.

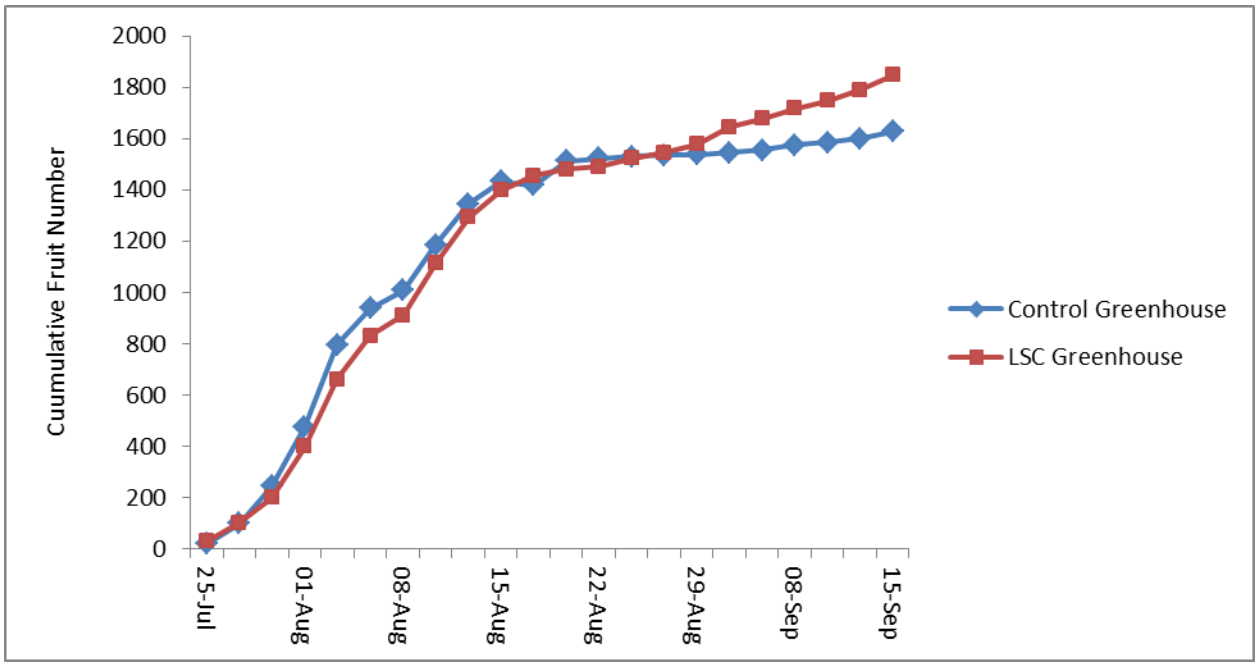
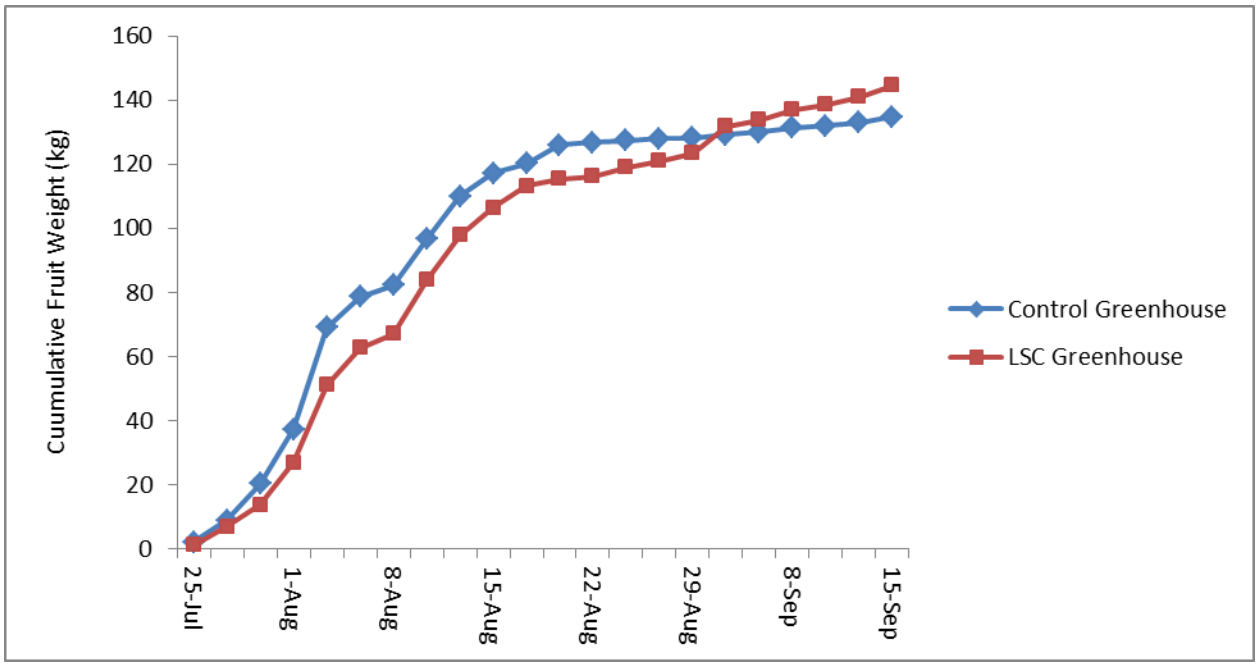


Figure 6. Trial 1 cumulative fruit weight by sampling date.



Cucumber plant growth and fruit production from within the treatments during the conduct of Trial 1 are presented below (Figure 7).

Figure 7. Trial 1 cucumber plants and fruit yield. Control greenhouse, top photos; LSC greenhouse, bottom photos. Photos taken August 1, 2014.

Tissue Nutrient Analysis

Due to observing a magnesium deficiency in cucumber leaf tissue shortly after the main stem clipping procedure, plants in both treatments were sampled to determine tissue nutrient levels; leaves with petioles attached were removed from near the top of the stem and submitted for analysis.

Tissue analysis results for the control treatment determined nitrogen was present in excess of the targeted range; phosphorous, zinc and copper were present in the medium to high range; calcium, potassium, boron and iron were present in the low to medium range; magnesium and manganese were present below the targeted range. Although sodium and sulfur were detected, no interpretation was provided by the laboratory regarding their target ranges; molybdenum was below the detection limit (Figure 8).

Figure 8. Trial 1 control treatment cucumber leaf and petiole tissue analysis; samples collected August 5, 2014; analysis by Exova.

Analyte	Units	Results	Target Range	Very Low / Low / Medium / High / Very High
Plant Tissue Results				
Total Nitrogen	%	6.73	4.50 - 5.99	
Calcium	%	1.48	1.40 - 2.49	
Phosphorus	%	0.88	0.40 - 0.99	
Potassium	%	3.97	3.90 - 4.99	
Magnesium	%	0.27	0.40 - 0.99	
Sodium	%	0.05		No Interpretation
Sulfur	%	0.721		No Interpretation
Zinc	ug/g	63.2	25.0 - 75.0	
Boron	ug/g	35.1	25.0 - 60.0	
Manganese	ug/g	49.4	50.0 - 200.0	
Copper	ug/g	13.4	6.0 - 20.0	
Iron	ug/g	75	50.0 - 200.0	
Molybdenum	ug/g	<0.5		Below Detection Limit

Tissue analysis for the LSC treatment determined that nitrogen was present in excess of the targeted range; phosphorous, zinc, copper and were present in the medium to high range; potassium, boron and iron were present in the low to medium range; magnesium, calcium and manganese were present below

the targeted range. Although sodium and sulfur were detected, no interpretation was provided by the laboratory regarding their target ranges; molybdenum was below the detection limit (Figure 9).

Figure 9. Trial 1 LSC treatment cucumber leaf and petiole tissue analysis; samples collected August 5, 2014; analysis by Exova.

Although the same nutrient feeding formula was used for both greenhouses and measures were taken to ensure equal distribution of nutrients to plants within both treatments, differences between treatments for individual nutrient levels were detected by tissue analysis. Comparing the results for both treatments, a pattern of similarity between treatments emerges for most nutrient; however, calcium levels present in tissue from the control treatment was approximately 30% greater compared to the LSC treatment, whereas, iron present in tissue from the LSC treatment was approximately 40% greater compared to the control treatment. Whether differences in growing conditions produced by the treatments contributed to differences in calcium and iron levels in cucumbers is unclear.

Trial 2

Plant Growth and Fruit Production

Cucumber stem length data collected from the first three sampling periods determined plants grown under LSC conditions were significantly greater in length than plants grown under control conditions. At trial termination, stem length did not differ significantly between the treatments (Table 4).

Table 4. Trial 2 cucumber stem length.

Cucumber Stem Length (cm)				
	Sampling Period*			
Treatment	1	2	3	Trial Termination
Control	34.70b	80.07b	132.83b	363.70a
LSC	41.20a	92.55a	146.77a	367.78a
$LSD_{(0.05)}$	2.55	3.08	3.29	9.93

Data are means; means within a column with the same letter are not significantly different according to the Least Significant Difference (LSD) at a 0.05 probability level; n = 60.
* Sampling period numbers represent weeks after transplanting into greenhouse.

Cucumber stem node number was similar in both treatments when measured one week, three weeks and at trial termination; however, at the second sampling period, node number was significantly greater for plants grown under LSC conditions compared to plants grown under control conditions (Table 5).

Table 5. Trial 2 cucumber stem node number.

Cucumber Stem Node Number				
	Sampling Period*			
Treatment	1	2	3	Trial Termination
Control	7.72a	15.38b	21.98a	55.78a
LSC	7.55a	16.10a	22.13a	55.67a
$LSD_{(0.05)}$	0.27	0.42	0.47	1.79

Data are means; means within a column with the same letter are not significantly different according to the Least Significant Difference (LSD) at a 0.05 probability level; n = 60.
* Numbers represent weeks after transplanting into greenhouse.

Cucumber plant growth and fruit production from within the treatments during the conduct of Trial 2 are presented below (Figure 10).

Figure 10. Trial 2 cucumber plants. Control greenhouse, top photos; LSC greenhouse, bottom photos. Photos taken November 7, 2014.

Cucumber fruit were sampled at 42 periods. Overall, both fruit number and weight did not differ significantly between treatments. Observations made during fruit sampling periods determined fruit in the LSC treatment would generally be of smaller diameter when removed at the target length compared to the control treatment (Table 6).

Table 6. Trial 2 cucumber fruit production.

Cucumber Fruit Production					
	Fruit Number		Fruit Weight		
Treatment	Fruit number/sampling period/row*	Total fruit number for trial	Fruit weight (kg)/sampling period/row*	Total fruit weight (kg) for trial	Average fruit weight (g)

Control	14.58a	3673	0.979a	246.67 [1]	67.2 [2]
LSC	15.27a	3847 [3]	0.965a	243.15	63.2
$LSD_{(0.05)}$	0.79		0.05		

*Data are sampling period (42) x cucumber row (6) means; means within a column with the same letter are not significantly different according to the Least Significant Difference (LSD) at a 0.05 probability level; n = 252.

[1] Equivalent to 1.4% greater total fruit weight compared to the LSC treatment.

[2] Equivalent to 5.9% greater average fruit weight compared to the LSC treatment.

[3] Equivalent to 4.5% greater total fruit number compared to the control treatment.

Similar fruit number and weight were collected from both treatments for the first three sampling periods; however, data collected from subsequent sampling periods determined the control treatment tended to out-produce the LSC treatment. This trend remained in effect until fruit data was collected on December 29, as from this point forward the LSC treatment surpassed the control treatment and consistently out-produced the control treatment. Both treatments continued to produce fruit until the trial was terminated on January 19; fruit production under LSC growing conditions appeared to be relatively stable and possibly on the rise, whereas, fruit production in the control treatment began to decline on January 5 (Figures 11, 12, 13 and 14).

Figure 11. Trial 2 cucumber fruit number by sampling date.

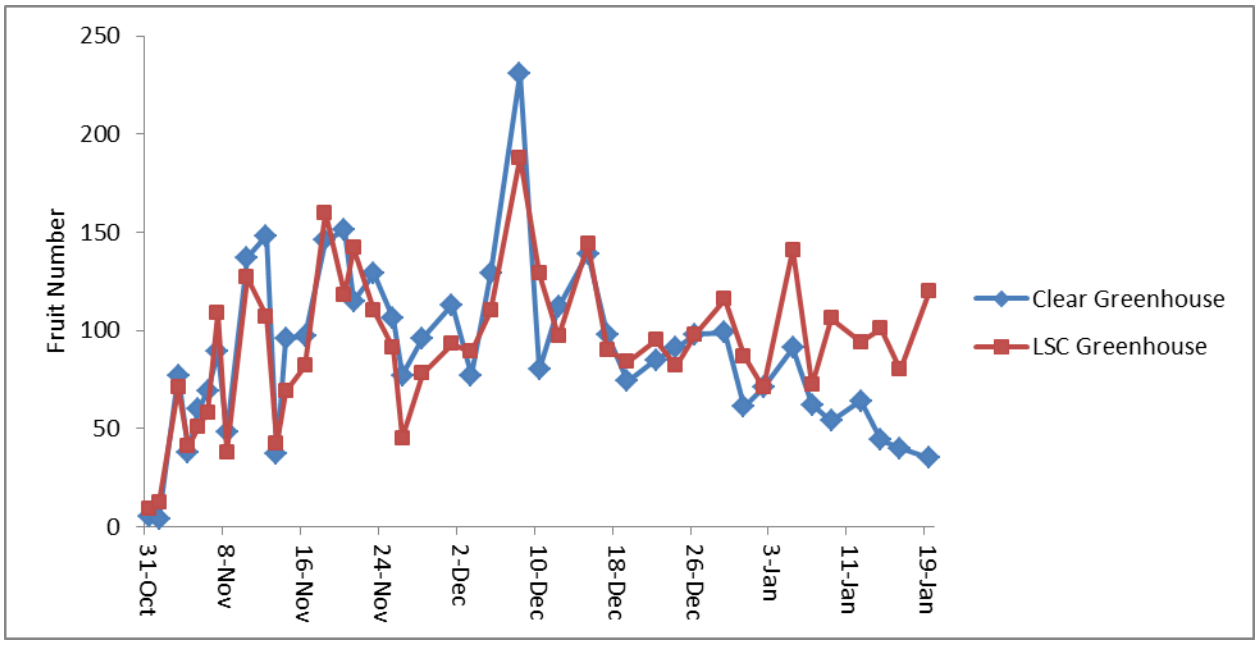


Figure 12. Trial 2 cucumber fruit weight by sampling date.

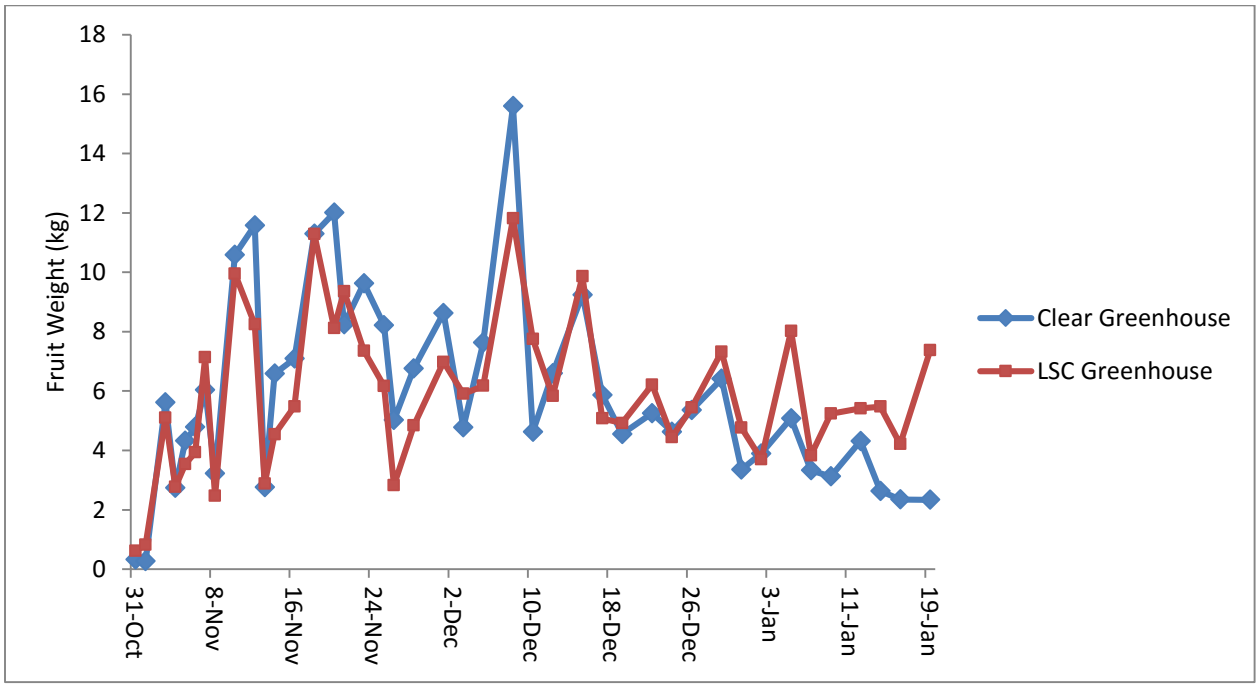


Figure 13. Trial 2 cumulative cucumber fruit number by sampling date.

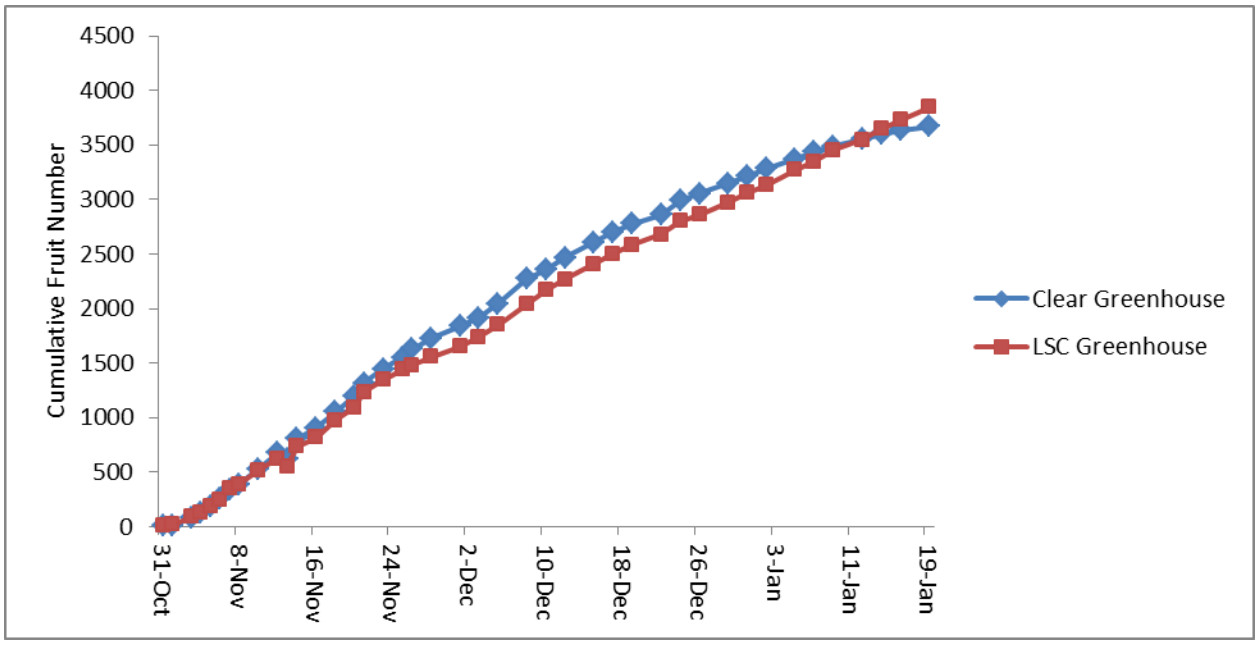
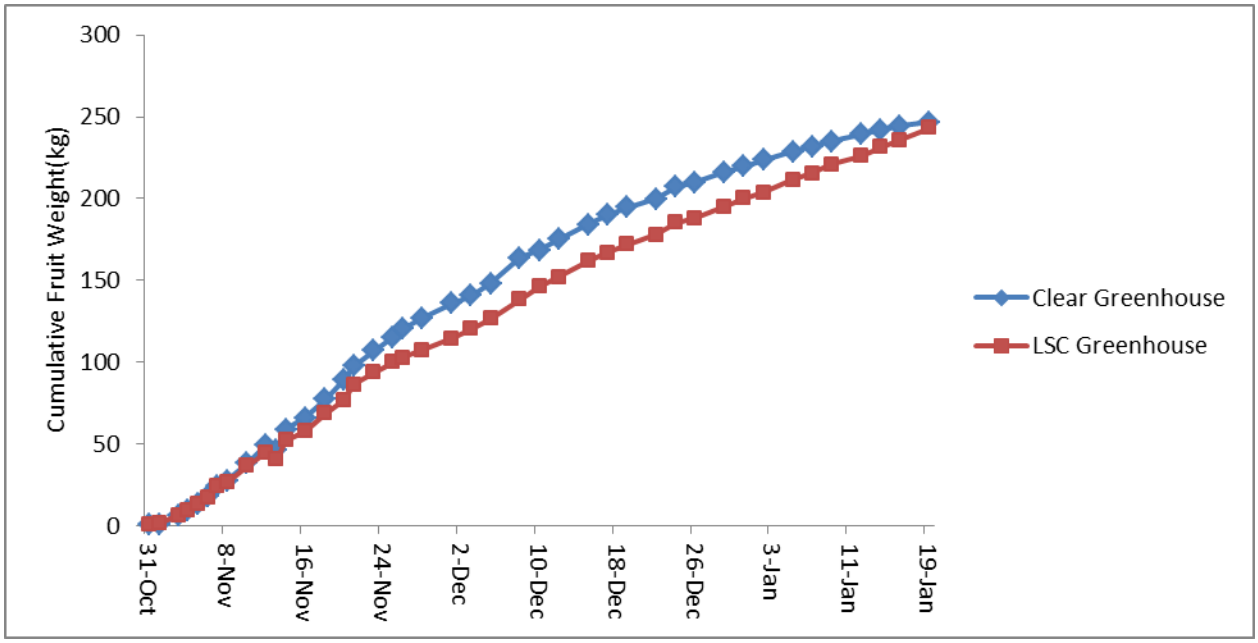


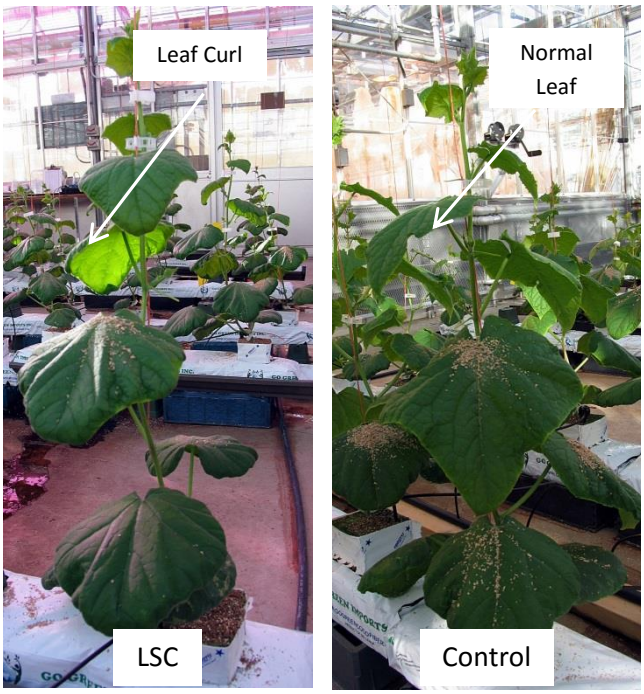
Figure 14. Trial 2 cumulative cucumber fruit weight by sampling date.



Cucumber Leaf Curl in the LSC Treatment during Trial 2

Approximately two weeks after cucumber seedlings were transplanted into treatment compartments, all plants within the LSC treatment began to express downward and inward leaf curling; in contrast, plants within the control treatment did not (Figure 15). This effect was not present in Trial 1.

Figure 15. Trial 2 cucumber plants; LSC greenhouse left photo, control greenhouse right photo. Photos taken October 17, 2014.



Observations made to cucumber plants within the LSC treatment determined cucumber leaves appeared normal upon emergence and for approximately two weeks thereafter; however, leaf margins would eventually curl downward and inward, occurring to all leaves.

In order to reason the cause of leaf curl, supplemental lighting duration and time of day of supplemental lighting provision were altered as both were theorized as influencing leaf tissue. Changes to supplemental lighting were applied equally to both greenhouse compartments beginning October 23 (Table 7).

Table 7. Trial 2 HPS supplemental lighting schedule.

Date	Supplemental lighting on/off time (24 hour time)	Supplemental lighting duration (hours)
October 9 - 22 (post-transplant)	03:00-09:00	6
October 23 -26	03:00-12:00	9
October 27 - November 5	12:00-19:00	7
November 6	05:00-09:00; 16:00-19:00	7
November 7 - 20	03:00-19:00	16
November 21 - January 22	15:30-23:00	8.5

On November 20, after two weeks of 16 hours of daily supplemental lighting, it was concluded that alterations to the time of day of providing supplemental light and the duration of supplemental light did not prevent further development of leaf curl.

Downward leaf curl can also be attributed to a calcium deficiency resulting from greenhouse relative conditions in excess of 80%. Although recorded relative humidity data indicated relative humidity levels never exceeded 60% within both treatment compartments, calcium content of cucumber leaf was investigated. To substantiate calcium levels, 5th true leaves were removed, with petioles attached, from plants within both treatments and submitted for analysis.

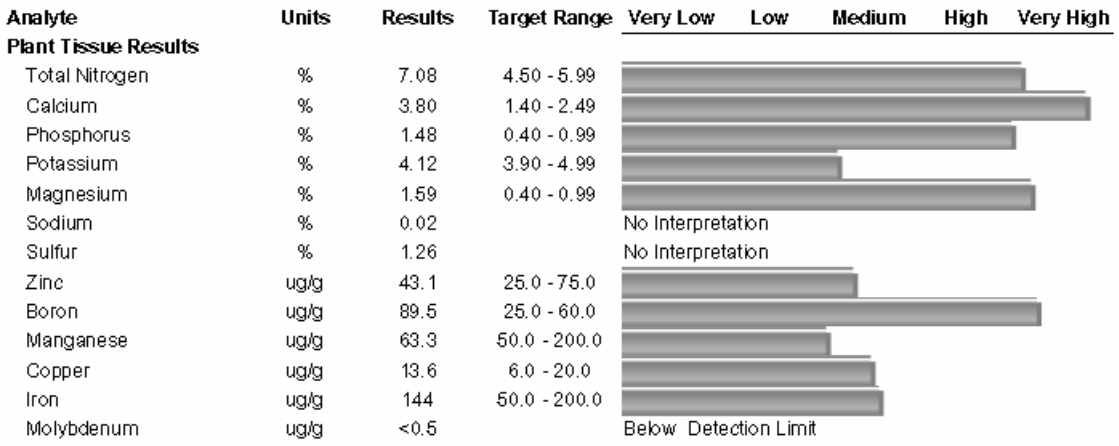
Plant tissue analysis conducted on control treatment plants determined calcium was present in a very high amount, in excess of the high end of the targeted range by approximately two-fold. In addition, nitrogen, phosphorous, magnesium and boron were also present in excess of the targeted range, and potassium, zinc, manganese, copper and iron were present within their targeted ranges. Although sodium and sulfur were detected, no interpretation was provided by the laboratory regarding their target ranges; molybdenum was below the detection limit (Figure 16).

Figure 16. Trial 2 control treatment cucumber leaf and petiole analysis; samples collected Oct. 30, 2014; analysis by Exova.

Analyte	Units	Results	Target Range	Very Low Low Medium High Very High
Plant Tissue Results				
Total Nitrogen	%	6.76	4.50 - 5.99	
Calcium	%	4.59	1.40 - 2.49	
Phosphorus	%	1.29	0.40 - 0.99	
Potassium	%	3.73	3.90 - 4.99	
Magnesium	%	1.67	0.40 - 0.99	
Sodium	%	0.02		No Interpretation
Sulfur	%	1.32		No Interpretation
Zinc	ug/g	40.7	25.0 - 75.0	
Boron	ug/g	85.9	25.0 - 60.0	
Manganese	ug/g	82.5	50.0 - 200.0	
Copper	ug/g	13.6	6.0 - 20.0	
Iron	ug/g	146	50.0 - 200.0	
Molybdenum	ug/g	<0.5		Below Detection Limit

Similar plant tissue nutrient values were found in the LSC treatment compared to the control treatment; however, LSC treatment plants contained approximately 17% less calcium than control treatment plants Calcium was present in excess of the target range, this classification rating also occurred in the control treatment. Nitrogen, phosphorous, magnesium and boron were also found to be in excess of their targeted range; whereas, zinc, manganese, copper and iron were present within their targeted ranges. Potassium was present below the target range. Although sodium and sulfur were detected, no interpretation was provided by the laboratory regarding their target ranges; molybdenum was below the detection limit (Figure 17).

Figure 17. Trial 2 LSC treatment cucumber leaf and petiole analysis; samples collected Oct. 30, 2014; analysis by Exova.



Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High
Plant Tissue Results								
Total Nitrogen	%	7.08	4.50 - 5.99					
Calcium	%	3.80	1.40 - 2.49					
Phosphorus	%	1.48	0.40 - 0.99					
Potassium	%	4.12	3.90 - 4.99					
Magnesium	%	1.59	0.40 - 0.99					
Sodium	%	0.02		No Interpretation				
Sulfur	%	1.26		No Interpretation				
Zinc	ug/g	43.1	25.0 - 75.0					
Boron	ug/g	89.5	25.0 - 60.0					
Manganese	ug/g	63.3	50.0 - 200.0					
Copper	ug/g	13.6	6.0 - 20.0					
Iron	ug/g	144	50.0 - 200.0					
Molybdenum	ug/g	<0.5		Below Detection Limit				

Based on plant tissue nutrient analysis, the theory that leaf curl present in the LSC treatment was due to a calcium deficiency can be negated, as more than adequate amounts of calcium were present.

Additional potential causes of downward leaf curl that were explored during the execution of Trial 2 are as follows:

1. During Trial 2, nutrient feed solution pH was observed to be greater than the maximum targeted value of 6.5 in both treatments and accordingly, measures were undertaken to reduce nutrient feed solution pH to within the targeted range of 5.5 - 6.5. Approximately 14 days after pH reduction of the feed solution, leaf curl became less evident on newly developed leaves on most, but not all plants within the LSC treatment. Based on this outcome, it was considered that leaf curl could possibly be attributed to a higher than recommended feed solution pH.

2. As leaf curl was not present in Trial 1, also considered was nitrogen rate of the nutrient feeding solution, as different levels of nutrients, primarily nitrogen, were used in both trials. During Trial 1, cucumbers were provided 158 ppm nitrogen at time of transplanting into the treatment compartments and increased to 316 ppm after five days until trial termination. In contrast, cucumbers in Trial 2 were provided 316 ppm nitrogen at transplanting time into the treatment compartments for the first 22 days and increased to 321 ppm until trial termination.

Based on the above findings and observations during the latter stages of Trial 2, a non-replicated demonstration trial was established to examine the effect of nutrient feed solution nitrogen rate in combination with a differing pH on cucumber leaf development. The following treatment combinations of nitrogen rate and pH value of feeding solution were used:

1. High nitrogen (300 ppm) and high pH (6.5)
2. High nitrogen (300 ppm) and low pH (5.5)
3. Standard nitrogen (150 ppm) and high pH (5.5)

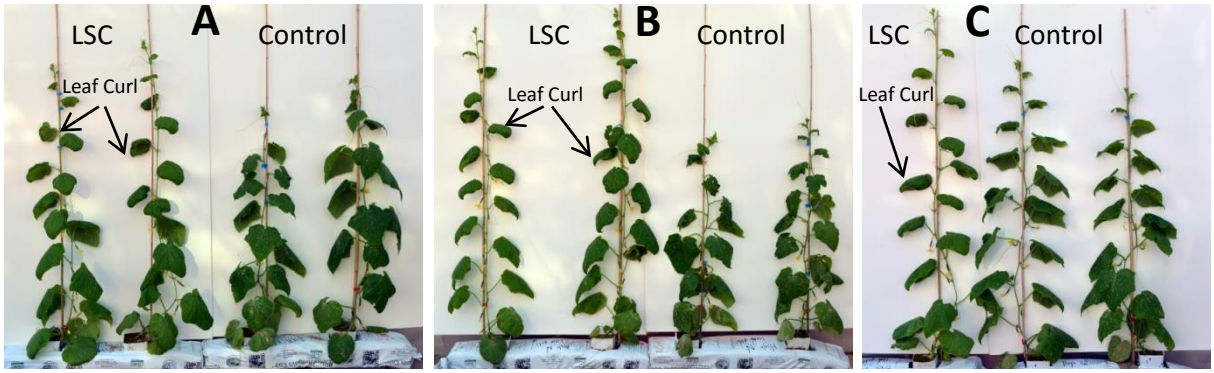
Note: the combination of standard nitrogen and low pH was not included in the demonstration trial.

For the demonstration trial, cucumber seedlings were established according to the protocol used for Trial 2 and transplanted into LSC and control treatment compartments.

Nitrogen feeding rates of 150 and 300 ppm were achieved by manipulating ammonium nitrate amount in each nutrient treatment. Phosphorous, potassium, magnesium, sulphur, calcium, iron, boron, manganese, zinc, molybdenum and copper were provided at 56, 229, 43, 75, 129, 1.982, 0.525, 0.782, 0.282, 0.05, 7.6 and 0.128, respectively, for nutrient treatments; pH was adjusted using citric acid. Plants were fed manually daily.

After 14 days, plants in the LSC treatment began to exhibit downward leaf curl. Furthermore, previously developed non-curled leaves began to curl downward and inward (Figure 18).

Figure 18. Cucumber plants in the demonstration trial with different treatments: (A) high nitrogen and high pH; (B) high nitrogen and low pH and (C) standard nitrogen and high pH.



The demonstration trial corroborated leaf curl observed in Trial 2, as leaf curl only occurred under LSC conditions and not control conditions. Furthermore, leaf curl developed under LSC conditions irrespective to different nitrogen and pH levels used between Trial 1 and Trial 2.

Presently, the occurrence of leaf curl can be considered a deviation from normal leaf growth that resulted from a physiological plant disorder. Without further investigation, it appears LSC technology influences

the cucumber plant differently compared to cucumbers grown under clear glass panels, resulting in the curl response of leaf tissue.

Although leaf curl is of obvious concern, leaf curl in cucumbers grown under LSC conditions does not appear to be deleterious to achieving similar fruit yield and numbers compared to those grown under clear glass panels, as determined by this study.

The author believes this phenomenon should be further investigated to ascertain the direct cause of leaf curl, as the alteration to the greenhouse growing environment by the addition of LSC panels may result in leaf curl that could be also experienced by commercial greenhouse cucumber producers during the winter months in Alberta.

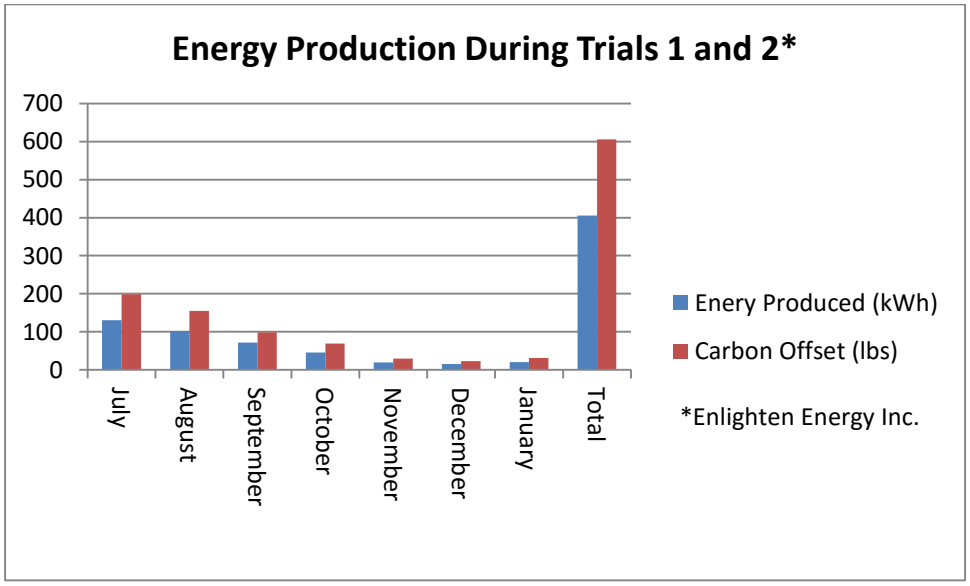
Conclusions

Growth of mini-cucumbers

Overall, results of the study indicate mini-cucumbers produced under LSC panels are similar to those produced under clear glass panels in Alberta.

In both trials, fruit yield of mini-cucumber grown under LSC panels was found not to be significantly different compared to mini-cucumbers grown under clear glass panels; however, the number of fruit produced under LSC panels in the first trial was significantly greater compared to clear glass panels. Stem length tended to be significantly greater under LSC panels compared to clear glass panels; whereas, differences in node number between the two panel types tended to be non-significant.

Energy Production



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The Effect of Luminescent Solar Concentrators on Growth of Greenhouse Lettuce in Alberta

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9/27/2016

Executive Summary

The effect of luminescent solar collectors on growth of lettuce grown hydroponically in a greenhouse was studied from December 2015 to March 2016 at Alberta Innovates – Technology Futures, Vegreville, Alberta, Canada. Two trials comprised of two treatments, a clear glass panel greenhouse compartment and a luminescent solar collector panel greenhouse compartment, using three lettuce varieties, Green Bay M.I., New Red Fire M.I. and Skyphos M.I., were performed separately. Environmental parameters and energy collection were monitored and recorded in both greenhouses, and solar radiation was monitored and recorded above the luminescent solar collector greenhouse.

A semi-closed, floating raft technique was used to grow lettuce in greenhouses after lettuce seedlings were reared in a growth chamber. During the greenhouse phase, lettuce was subjected to natural daylight during dawn and day hours and supplemental high pressure sodium lighting was operated during dusk and night hours to provide additional photosynthetically active radiation. Plant growth response was measured using shoot fresh weight and height, and root fresh and dry weight as variables.

The results of the study suggest differences exist between lettuce varieties in their response to luminescent solar collector panels. In both trials, shoot fresh weight produced by Green Bay M.I., New Red Fire M.I. and Skyphos M.I. under luminescent solar collector panels was less than that of clear glass panels. However, shoot fresh weight achieved by all varieties grown under luminescent solar collector panels was within the weight range for commercially grown hydroponic lettuce. Shoot fresh weight produced by Green Bay M.I. and Skyphos M.I. was significantly greater under clear glass panels compared to luminescent solar collector panels in one of the two trials conducted whereas, New Red Fire M.I. produced under luminescent solar collector panels was not significantly different to that of clear glass panels in both trials. Results of one trial where significant differences were detected between treatments for Green Bay M.I. could not be validated by repetition as Green Bay M.I. was negatively influenced by unidentified factors that caused leaf damage in the subsequent trial. However, a slight difference was detected in leaf damage incidence favouring the luminescent solar panel treatment over the clear glass panel treatment.

Energy produced by the luminescent solar collector panels during the conduct of both trials while lettuce was within the greenhouse environment was approximately 78 kWh.

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Introduction

The response of lettuce, *Lactuca sativa* L., grown hydroponically under luminescent solar concentrator (LSC) panels installed at the Alberta Innovates - Technology Futures greenhouse complex in Vegreville, Alberta, Canada, was studied from December 2015 to March 2016. Shoot fresh weight and height, and root fresh and dry weight were measured for three lettuce varieties from two trials conducted separately.

Materials and Methods

Experimental Design

A greenhouse compartment and its adjacent corridor, previously fitted with 70 west-facing LSC panels was used to evaluate the growth response of lettuce to LSC influenced greenhouse conditions and a greenhouse compartment and its adjacent corridor of identical size and orientation containing clear glass panels was used as a comparison treatment (control) environment. In addition, a translucent plastic film identical in color to that used in LSC panels was placed over clear glass panels located on the west half of the south-facing vertical sidewall of the LSC greenhouse compartment (Figure 1).

Figure 1: AITF greenhouse compartment fitted with LSC panels.

Greenhouse compartments were 44 m^2 in size. Sidewalls were 3.6 m in height of which the upper 2.7 m contained glass panels. Height from floor to ridgeline peak was 5.5 m. Each treatment compartment contained 20, 400 watt high pressure sodium lights (HPS Lucalox LU/H/ECO; General Electric). Treatment compartments were physically separated by a distance of 6.2 m and shared a common corridor.

The first trial of the study, Trial 1, was conducted from December 7 to January 26 and was repeated, Trial 2, from January 22 to March 8. Dates refer to when lettuce seeds were placed to germinate in a growth chamber (Model PGV36, Conviron) to when trials were terminated in greenhouse compartments.

For each trial, both LSC and control greenhouse compartments contained 200 lettuce plants. However, a reduced sample size was used for statistical analyses due to the occurrence of non-representative lettuce growth in two of the eight replicates in each greenhouse compartment. Visual observations conducted during both trials revealed replicates one and eight were subjected to a greater level of shading produced by the greenhouse structure compared to that of the other replicates and therefore, were removed from statistical analyses. Replicates one and eight were positioned in identical physical locations within each greenhouse compartment.

Environmental Data and Solar Energy Collection and Recording

Temperature, relative humidity and photosynthetically active radiation were monitored in real-time and recorded within each compartment. Sensors for each environmental parameter were located at the center of each compartment and were approximated to the average height of lettuce plants in each greenhouse compartment. Solar radiation was monitored and recorded by two pyranometer sensors located outside and above, on the west-facing slope of the LSC compartment where one pyranometer sensor was level to the horizon and one was level to the slope of the greenhouse roof. Monitoring and recording of environmental data was accomplished by using a HOBO U30-ETH (Onset Computer Corporation).

Solar energy harvest, monitoring in real-time and measurement were accomplished by using an Enphase Energy Microinverter system comprised of Enphase Microinverters, an Envoy Communications Gateway and an Enphase Enlighten Monitor (Enphase Energy Inc.).

Lettuce Production Techniques

The use of three lettuce varieties in the study provided the opportunity to examine whether differences exist between varieties in their response to LSC and control environments. Lettuce varieties used in trials were selected based on type, number of days to maturity and colour (Table 1).

Table 1. Lettuce varieties used in study.

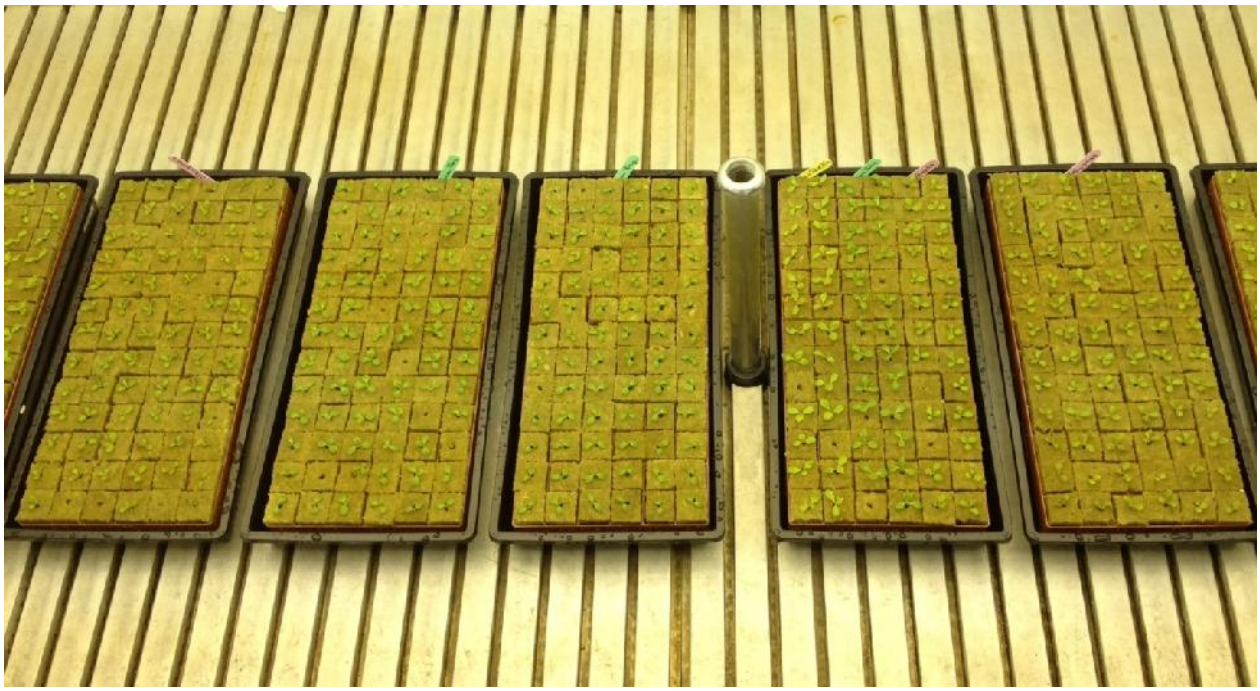
Variety	Type	Days to Maturity*	Colour	Traits
Green Bay M.I.	loose leaf	48	green	tip burn tolerant [1,2]
New Red Fire M.I.	loose leaf	43	red	bolting tolerant [3,4,5,6] tip burn resistant [4,5] downey mildew resistant [4,5] bottom rot resistant [4,5] white mold resistant[5] heat tolerant [5,6] cold tolerant [5,6]
Skyphos M.I.	Butterhead	47	red	heat tolerant [7] *Nasonovia ribisnigri* (lettuce aphid) resistant [7,8] lettuce mosaic virus tolerant [7,8] downey mildew races 1-26 tolerant [7,8] bolting tolerant [7,8]

** information provided by seed supplier.*

Growth Chamber Environment

For both trials, clay coated seed (Stokes Seed Ltd.) of Green Bay M.I., New Red Fire M.I. and Skyphos M.I. lettuce was placed to germinate in 3.8 cm mineral cubes (A-OK Starter Plugs, Grodan) conditioned in municipal water modified to pH 5.58 [9] with pH Down (phosphoric acid, citric acid, mono ammonium phosphate, General Hydroponics). Seeded mineral cubes were positioned in a cell tray (Gro-Smart Tray, Grodan) contained in a 25 cm x 50 cm x 6 cm seedling tray and covered with a clear humidity dome. Seedling trays were placed in a growth chamber for seed germination and seedling development (Figure 2).

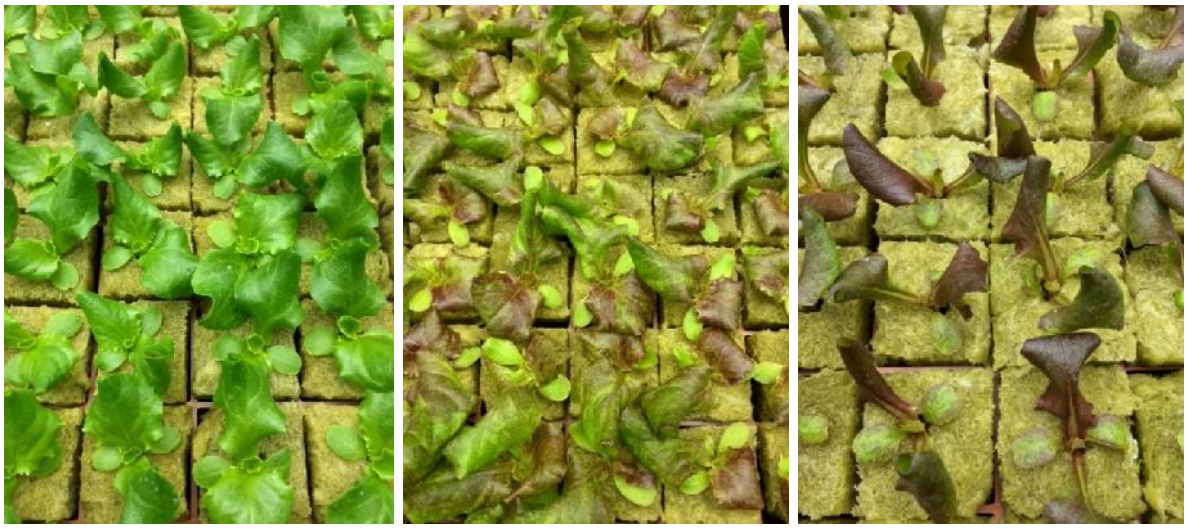
Figure 2. Trial 1 lettuce seedlings in growth chamber (December 15, 2015).



For Trial 1, seedling trays were exposed to 20°C and 50 µE $m^2 s^{-1}$ illumination provided by fluorescent lighting (F96T12/CW/VHO, Philips) for the initial 24 hours after placement into the growth chamber. After 24 hours, temperature and lighting was increased to 25°C and 250 µE $m^2 s^{-1}$, respectively, for the remainder of seedling development. Illumination duration was 24 hour constant [10]. Humidity domes were removed three days after seeding with germination occurring the following day. After 16 days of incubation in the growth chamber, lettuce seedlings ranging from two to four leaves per plant were transplanted to floating rafts contained in greenhouse compartments.

For Trial 2, seedling trays were exposed to 20°C and 50 µE $m^2 s^{-1}$ illumination provided by fluorescent lighting for the initial 24 hours after placement into the growth chamber. After 24 hours, illumination was increased to 250 µE $m^2 s^{-1}$ constant and temperature remained at 20°C for the duration of seed germination and seedling development. Humidity domes were removed three days after seeding with germination occurring the same day. After 14 days of incubation in the growth chamber, lettuce seedlings ranging from two to three leaves per plant were transplanted to floating rafts contained in greenhouse compartments (Figure 3).

Figure 3. Trial 2 Green Bay M.I., New Red Fire M.I. and Skyphos M.I. seedlings, from left to right, respectively (February 5, 2016).



For the duration of lettuce germination and seedling development within the growth chamber, a solution comprised of a pre-mix fertilizer blend, HydroVeg 7-11-27 (Plant-Prod Inc.), Calcium Nitrate Plus K (14-0-3+18Ca, TerraLink Horticultural Inc.) and magnesium sulphate (Epsom Salt, 9.8% Mg, 12% S; TerraLink Horticulture Inc.) with a N:P:K ratio of 3.3:1:5.1 [11] was used to supply nutrients to seedlings (Table 2). The water source for this study was treated municipal [12], originating from the North Saskatchewan River and its contributions to the nutrient solution were included. Nutrient solution pH was adjusted to 5.6-6.0 [10] using pH Down (17% phosphoric acid, HydroTek) and was provided daily by hand. Remnant nutrient solution contained within seedling trays was discarded prior to the addition of fresh nutrient solution.

Table 2. Nutrient feed levels utilized during growth chamber phase.

Nutrient (ppm)	N	P	K	S	Ca	Mg	Fe	Bo	Mn	Z	Mo	Cu
							Trial 1					
Period*												
1	63	19	97	79	91	25	0.4020	0.1092	0.03420	0.1220	0.0036	0.0184
6	95	29	144	85	113	37	0.6020	0.1638	0.5120	0.1820	0.0054	0.0266
9 -16	127	38	192	91	136	50	0.8020	0.2184	0.6820	0.2420	0.0072	0.0348
							Trial 2					
1-12	63	19	97	79	91	25	0.4020	0.1092	0.03420	0.1220	0.0036	0.0184
13	95	29	144	85	113	37	0.6020	0.1638	0.5120	0.1820	0.0054	0.0266
14	127	38	192	91	136	50	0.8020	0.2184	0.6820	0.2420	0.0072	0.0348

** days after placement in growth chamber.*

Of note, during transplanting of seedlings in Trial 1, observations revealed seedlings contained excessive roots and thus, temperature was reduced and nutrient solution strength was modified in Trial 2 during the growth chamber phase to limit lettuce root development.

Greenhouse Environment

Lettuce was grown using a semi-closed hydroponic system [13,14] employing a floating raft technique [15] (Figure 4). Floating rafts were constructed of 5 cm thick polystyrene panels (Foamular C-300, Owens-Corning) where 5 cm diameter holes were prepared in a 5 x 5 pattern spaced 20 cm apart. At transplanting, lettuce seedlings were removed from the growth chamber to the greenhouse, placed in 5 cm net pots (unknown manufacturer), and further positioned in holes of the rafts. Each polystyrene panel floated on an aerated nutrient solution contained in 1.2 m x 1.8 m x 0.15 m, black ABS plastic, 140 liter capacity reservoir (unknown manufacturer). Eight reservoirs were present in each greenhouse compartment.

Figure 4. Trial 2 lettuce seedlings in control and LSC treatments, from left to right, respectively (February 5, 2016).

Reservoirs were prepared to receive lettuce transplants by the addition of nutrients and 130 liters of municipal water. A nutrient solution containing 127 ppm nitrogen, 38 ppm phosphorous, 192 ppm potassium, 91 ppm sulfur, 136 ppm calcium, 50 ppm magnesium, 0.8020 ppm iron, 0.2184 ppm boron, 0.6820 ppm manganese, 0.2420 ppm zinc, 0.0072 ppm molybdenum and 0.0348 ppm copper, comprised of HydroVeg 7-11-27, Calcium Nitrate Plus K and magnesium sulphate was contained in each reservoir. A nutrient solution pH range of 5.5 to 6.0 was targeted for each reservoir and was adjusted by the addition of either pH Down or pH Up (potassium hydroxide, Grotek).

An air compressor (EcoAir, EcoPlus) was operated continuously to supply air to four, 30.5 cm long air stones (Hagen, Marina) placed on the bottom of each reservoir in the nutrient solution and connected to the compressor using clear PVC vinyl tubing (Hagen, Marina). A dissolved oxygen level of 8 ppm was targeted [10]. Two air circulation fans were operated continuously [16] in each greenhouse compartment.

Nutrient solution pH, electrical conductivity and dissolved oxygen of nutrient solutions contained in reservoirs were measured throughout the duration of each trial. Reservoir solution volumes were replenished by the addition of reverse osmosis water with a complete nutrient solution replacement provided to each reservoir 21 days after initiation of Trial 1 and 28 days after initiation of Trial 2.

Lettuce was exposed to natural daylight and supplemental HPS light while in the greenhouse. In Trial 1, natural daylight length was approximately 7.5 and 8.5 hours at trial initiation and conclusion, respectively. Day length was extended using nine hours of HPS light daily at trial initiation commencing near dusk until one week prior to harvest where it was reduced by one hour with the intent to slow lettuce growth. In Trial 2, natural daylight length was approximately nine and eleven hours at trial initiation and conclusion, respectively. Day length was extended using six hours of HPS light daily commencing near dusk at trial initiation until approximately one week prior to harvest where it was reduced to five hours.

Greenhouse temperature set-points of 25/18^{O}C (day/night) were targeted for Trial 1 and 20/18^{O}C (day/night) were targeted for Trial 2. However, temperature set-points were activated by a timer also controlling HPS light operation and as HPS lighting was provided during dusk and night hours, day temperature occurred during this period. Upon daily termination of the HPS lighting cycle, night temperature was initiated and remained until HPS lighting was activated at dusk the following day.

Biological control insects (*Neoseiulus cucumeris, Stratiolaelaps scimitus*, Applied Bio-nomics) were released in both compartments during both trials on a weekly basis as a preventive measure for the control of *Frankliniella occidentalis* (western flower thrips) . Sticky cards (Dongbu Blue 25 cm x 15 cm, Crop Defenders Ltd.) were placed to trap and monitor insect pest populations. BotaniGard ES (*Beauveria bassiana* Strain GHA, Bioworks Inc.) was applied in both compartments once during Trial 1 for the control of western flower thrips; no pesticide application was performed for Trial 2.

Lettuce Data Collection, Statistical Design and Analyses

A completely randomized design was used where each floating raft contained all three lettuce varieties randomized within each floating raft. Each reservoir was considered one replicate of an experimental treatment where each floating raft had a unique randomization. An identical floating raft and reservoir set-up was present in both greenhouse compartments. Each raft contained 25 plants with three lettuce varieties where eight plants of each variety were present on a floating raft. This configuration provided the location for one additional plant to be present, used for tissue nutrient analyses upon termination of each trial.

Harvest of lettuce in both trials was conducted at two intervals. Initial harvest of Trial 1 was conducted after 49 days from seeding where replicates one and two for both treatments were collected and the remaining replicates were harvested one day later. Harvest of Trial 2 was conducted 41 days and 46 days after seeding, respectively, where replicates one through four were harvested initially followed by replicates five through eight.

Shoot fresh weight and height, and root fresh weight were determined at harvest. Shoot biomass was separated from mineral cubes and root biomass was removed from the sides and bottom of mineral cubes; mineral cubes were discarded and not used in root weight determinations. Fresh root biomass was oven dried at 70^{o}C constant for dry weight determination.

Data were subjected to analysis of variance (ANOVA) using SAS (SAS Institute Inc. 2011. Base SAS® 9.3 Procedures Guide: Statistical Procedures. Cary, NC: SAS Institute Inc.). When the F test indicated statistical significance, the Least Significant Difference (LSD) test was used to determine the significance between means.

Results and Discussion

Plant Growth

Bolting of lettuce occurred in both trials (Table 3). In Trial 1, bolting was first observed to Green Bay M.I. plants located in replicates one and eight for both treatments approximately 35 days after seeding. It is likely when bolting was first observed to Green Bay M.I. in Trial 1 harvest of Green Bay M.I. was possible. However, the majority of New Red Fire M.I. and Skyphos M.I. plants appeared less mature than Green Bay M.I. plants in all replicates. Day temperature was reduced by 2^{O}C in Trial 1 one week prior to harvest with the intent to slow lettuce growth.

Bolting was also documented during Trial 2 harvest where Green Bay M.I. plants displayed a greater propensity to bolt than those of New Red Fire M.I. and Skyphos M.I. plants. As in Trial 1, New Red Fire M.I. and Skyphos M.I. plants appeared less mature than Green Bay M.I. plants in all replicates when bolting to Green Bay M.I. was first observed. In Trial 2, harvest of replicates one to four in both greenhouse compartments was performed at 41 days after seeding to capture data at early onset of bolting. Harvest of the remaining replicates was performed at 46 days after seeding to capture data when New Red Fire M.I. and Skyphos M.I. plants appeared more mature. Of note in Trial 2 was a lower incidence of bolting to Green Bay M.I. in the LSC treatment to that of the control treatment.

If bolting to Green Bay M.I. was indicative of Green Bay having reached maturity, bolting of Green Bay M.I. in Trial 1 was in contradiction to the information provided by the seed supplier, as days to maturity for Green Bay M.I. was referred to be greater than that of New Red Fire M.I. and Skyphos M.I..

The incidence of bolting in both trials was most likely variety dependent. As previously described, tolerance to bolting is characterised for New Red Fire M.I. and Skyphos M.I. but not for Green Bay M.I. however, bolting incidence was greater in Trial 1 compared to Trial 2. Bolting of lettuce can be attributed to the amount of cumulative light received and exposure to warm temperatures [17]. While the duration of Trial 1 was less than Trial 2, cumulative day length may have differed between trials due to the time of year trials were conducted and in addition, differences in the amount of supplemental light that was provided to trials. Furthermore, temperature in was reduced in growth chamber and greenhouse environments for Trial 2. The aforementioned influences may provide an explanation for the greater incidence of bolting in Trial 1 compared to Trial 2.

Table 3. Lettuce bolting at harvest.

Lettuce Variety	Bolting (%)			
	Trial 1		Trial 2	
	Control	LSC	Control	LSC
Green Bay M.I.	85.4	87.5	87.5	66.6
New Red Fire M.I.	39.5	54.1	0	0
Skyphos M.I.	65.2	60.4	0	4.1

Observations made to lettuce seedlings soon after transplanting to floating rafts in Trial 2 revealed Green Bay M.I. plants in control and LSC treatments displayed lower leaf necrotic lesions (Figure 6) whereas, New Red Fire M.I. and Skyphos M.I. plants did not. As leaf damage affected Green Bay M.I. plants only, it was proposed to be a variety dependant disorder. For the duration of Trial 2, lower leaves of Green Bay M.I. plants perished and subsequently, shoot biomass was negatively affected. Tissue samples of Green Bay M.I. were collected and evaluated, and diagnostic tests revealed the presence of both *Trichoderma* and yeast however, positive identification could not be made. Thus, it remains unclear whether leaf damage was caused by these potential pathogens.

Figure 5. Green Bay M.I. plants displaying leaf damage February 26, 2016.

Leaf damage was further investigated at Trial 2 harvest to determine whether differences between treatments existed pertaining to incidence. Leaves of Green Bay M.I. plants displaying damage were separated from unaffected leaves for both treatments and quantified. Visual leaf assessments revealed Green Bay M.I. plants produced in the LSC treatment contained 3.6% less damaged leaves compared to that of the control treatment (data not presented) which could be interpreted as advantageous.

Analysis of variance revealed trial significantly affected shoot fresh weight ($P < 0.01$), root fresh weight ($P < 0.001$) and shoot height ($P < 0.001$) but not root dry weight. Variety significantly affected all variables tested ($P < 0.001$). Treatment significantly affected shoot and root fresh weight ($P < 0.001$) and root dry weight ($P < 0.001$) but not shoot height (Table 4).

As data analysis detected significant differences existed between trials, data from both trials could not be pooled together. Treatment data are presented with trials and lettuce varieties analysed separately. To provide an overall response of lettuce within each treatment, pooled data analyses are presented following the presentation of separated analyses.

Table 4. Dependant variable mean squares data analysis.

Source of variation	DF	Shoot fresh weight	Root fresh weight	Root dry weight	Shoot height
Trial	1	5332 **	720 ***	0.14 ns	78.4 ***
Replicate	5	1438419 ***	15198 ***	35.0 ***	7626 ***
Replicate x Trial	5	8018 ***	167 ***	0.13 ns	52.9 ***
Treatment	1	46552 ***	373 ***	0.71 ***	21.1 ns
Variety	2	948101 ***	26746 ***	40.9 ***	3901 ***
Treatment x Variety	2	9145 ***	151 **	0.13 ns	2.97 ns
Trial x Treatment	1	13669 ***	176 **	0.21 ns	0.14 ns
Trial x Variety	2	1109856 ***	14957 ***	23.7 ***	503 ***
Trial x Treatment x Variety	2	12779 ***	288 ***	0.43 ***	15.2 ns

, **, * significant at 0.05, 0.01 and 0.001 probability level, respectively; ns = non-significant.*

Green Bay M.I. Growth Response

Figure 6. Trial 1 Green Bay M.I. lettuce at harvest (left photo). Green Bay M.I. plants from control and LSC treatments, left to right, respectively, from identical replicate and location on floating raft (right photo).

In Trial 1, Green Bay M.I. shoot and root fresh weight and root dry weight in the control treatment was determined to be significantly greater when compared to the LSC treatment; shoot height was determined not to be significantly different between treatments. In contrast to Trial 1, Trial 2 shoot height in the LSC treatment was determined to be significantly greater when compared to the control treatment. Differences between treatments for other variables tested were non-significant (Table 5).

Although Green Bay M.I. shoot and root fresh weight and root dry weight produced in the LSC treatment in Trial 1 were determined to be significantly less when compared to the control treatment, shoot fresh weight in the LSC treatment averaged 359.52 g per plant (Table 5). In comparison, shoot biomass of lettuce produced hydroponically can vary from 150-360 g per plant depending on variety and growing

conditions [18,19] with commercial fresh weights of 100-200 g per plant [20] and thus, shoot fresh weight produced in the LSC treatment should be considered acceptable.

Table 5. Green Bay M.I. growth response.

Treatment	Shoot fresh weight (g)		Shoot height (cm)		Root fresh weight (g)		Root dry weight (g)	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Control	422.03a	118.26a	39.93a	29.02b	47.18a	12.59a	2.02a	0.57a
LSC	359.52b	112.86a	39.86a	29.77a	39.57b	12.87a	1.74b	0.58a
$LSD_{(0.05)}$	26.63	8.27	1.32	0.60	4.84	1.10	0.19	0.05

Means within a column with the same letter are not significantly different according to the Least Significant Difference (LSD) at a 0.05 probability level; n = 48.

Due to the presence of leaf damage to Green Bay M.I. plants in Trial 2, results should be interpreted with caution. However, it is of interest that differences detected between treatments tended to be non-significant in Trial 2 when compared to Trial 1. The similar biomass produced by both treatments in Trial 2 provide a basis to consider whether Green Bay M.I in the LSC treatment may have responded more favourably to factors that negatively influenced biomass production, as it may not be expected to find similar biomass results to both treatments based on biomass results revealed in Trial 1.

New Red Fire M.I. Growth Response

Trial 1.New Red Fire M.I. lettuce at harvest (left photo).New Red Fire M.I. plants from control and LSC treatments, left to right, respectively, from same replicate and location on floating raft (right photo).

Figure 7. Trial 1.New Red Fire M.I. lettuce at harvest (left photo).New Red Fire M.I. plants from control and LSC treatments, left to right, respectively, from same replicate and location on floating raft (right photo).

New Red Fire M.I. shoot and root fresh weight and shoot height did not differ significantly between treatments in both trials, and root dry weight did not differ significantly between treatments in Trial 1. However, root dry weight in the control treatment was significantly greater when compared to the LSC treatment in Trial 2. Although most variables tested were greater in the control treatment compared

those in the LSC treatment in both trials, results indicate the growth displayed by New Red Fire M.I. in the LSC treatment is similar to that of the control treatment (Table 6).

Table 6. New Red Fire M.I. growth response.

Treatment	Shoot fresh weight (g)		Shoot height (cm)		Root fresh weight (g)		Root dry weight (g)	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Control	167.03a	139.05a	31.07a	24.37a	9.07a	8.09a	0.57a	0.42a
LSC	155.68a	131.20a	31.90a	23.87a	8.88a	7.06a	0.54a	0.36b
$LSD_{(0.05)}$	21.77	10.74	1.19	0.63	2.52	1.08	0.11	0.05

Means within a column with the same letter are not significantly different according to the Least Significant Difference (LSD) at a 0.05 probability level; n = 48.

Skyphos M.I. Growth Response

Figure 8. Trial 1.Skyphos M.I. lettuce at harvest (left photo). Skyphos M.I. plants from control and LSC treatments, left to right, respectively, from same replicate and same location on floating raft in both treatments (right photo).

No significant differences between treatments were detected for all variables tested for Skyphos M.I. in Trial 1. In Trial 2, shoot fresh weight and root dry weight in the control treatment were significantly greater when compared to the LSC treatment, whereas root fresh weight did not differ significantly between treatments. Shoot height in the LSC treatment was determined to be significantly greater when compared to the control treatment in Trial 2. Although shoot fresh weight in the LSC treatment was determined to be significantly less when compared to the control treatment in Trial 2, the LSC treatment average shoot fresh weight of 114.21 g per plant should be considered acceptable as it is within the weight range of commercially grown lettuce[20] (Table 7).

Table 7. Skyphos M.I. growth response.

Treatment	Shoot fresh weight (g)		Shoot height (cm)		Root fresh weight (g)		Root dry weight (g)	
	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2	Trial 1	Trial 2
Control	123.63a	125.71a	27.88a	23.72b	6.57a	7.92a	0.40a	0.40a

LSC	114.42a	114.21b	29.39a	24.52a	6.30a	7.17a	0.38a	0.36b
$LSD_{(0.05)}$	19.72	7.48	1.60	0.68	1.97	0.84	0.10	0.04

Means within a column with the same letter are not significantly different according to the Least Significant Difference (LSD) at a 0.05 probability level; Trial 1, Control n = 48, LSC n = 46; Trial 2, n = 48.

Pooled Data Analyses

As previously stated, analysis of variance detected significant differences for lettuce dependant variables thus, consequently preventing trial data and lettuce variety data from being pooled. However, both pooled and separated trial and variety data analyses is of interest, as it provides a overall assessment of the performance of lettuce grown under both treatments.

When lettuce varieties were pooled in Trial 1, shoot and root fresh weight and root dry weight were significantly greater in the control treatment when compared to the LSC treatment. Shoot height did not differ significantly between treatments (Table 8).

Table 8. Pooled lettuce variety dependant variable averages in Trial 1.

Treatment	Shoot fresh weight (g)	Root fresh weight (g)	Root dry weight (g)	Shoot height (cm)
Control	237.56a	20.94a	1.00a	32.96a
LSC	211.21b	18.42b	0.89b	33.45a
$LSD_{(0.05)}$	13.19	2.06	0.08	0.78

Means within a column with the same letter are not significantly different according to the Least Significant Difference (LSD) at a 0.05 probability level; Control, n = 144; LSC, n = 142.

When lettuce varieties were pooled in Trial 2, shoot and root dry weight was significantly greater in the control treatment when compared to the LSC treatment. Root fresh weight and shoot height did not differ significantly between treatments (Table 9).

Table 9. Pooled lettuce variety dependant variable averages in Trial 2.

Treatment	Shoot fresh weight (g)	Root fresh weight (g)	Root dry weight (g)	Shoot height (cm)
Control	127.67a	9.53a	0.46a	25.70a
LSC	119.42b	9.03a	0.43b	26.06a
$LSD_{(0.05)}$	5.13	0.62	0.03	0.37

Means within a column with the same letter are not significantly different according to the Least Significant Difference (LSD) at a 0.05 probability level; n = 144.

When Trials 1 and 2 were pooled, Green Bay M.I. shoot and root fresh weight and root dry weight were significantly greater in the control treatment when compared to the LSC treatment. Shoot height did not differ significantly between treatments (Table 10).

Table 10. Pooled Trial 1 and 2 Green Bay M.I. dependant variable averages.

Treatment	Shoot fresh weight (g)	Root fresh weight (g)	Root dry weight (g)	Shoot height (cm)
Control	270.14a	29.88a	1.29a	34.48a
LSC	236.19b	26.22b	1.16b	34.82a
$LSD_{(0.05)}$	13.85	2.46	0.09	0.72

Means within a column with the same letter are not significantly different according to the Least Significant Difference (LSD) at a 0.05 probability level; n = 96.

When Trials 1 and 2 were pooled, New Red Fire M.I. in both the control and LSC treatments were determined not to be significantly different from each other for all dependant variables tested (Table 11).

Table 11. Pooled New Red Fire M.I. dependant variable averages in Trials 1 and 2.

Treatment	Shoot fresh weight (g)	Root fresh weight (g)	Root dry weight (g)	Shoot height (cm)
Control	153.04a	8.58a	0.50a	27.72a
LSC	143.44a	7.97a	0.45a	27.88a
$LSD_{(0.05)}$	12.05	1.36	0.06	0.67

Means within a column with the same letter are not significantly different according to the Least Significant Difference (LSD) at a 0.05 probability level; n = 96.

When Trials 1 and 2 were pooled, Skyphos M.I. in both the control and LSC treatments were determined not to be significantly different from each other for all dependant variables tested (Table 12).

Table 12. Pooled Skyphos M.I. dependant variable averages in Trials 1 and 2.

Treatment	Shoot fresh weight (g)	Root fresh weight (g)	Root dry weight (g)	Shoot height (cm)
Control	124.67a	7.24a	0.40a	25.80a
LSC	114.31a	6.75a	0.37a	26.42a
$LSD_{(0.05)}$	12.05	1.05	0.05	0.85

Means within a column with the same letter are not significantly different according to the Least Significant Difference (LSD) at a 0.05 probability level; Control, n = 96; LSC, n = 94.

When lettuce varieties and Trials 1 and 2 were pooled, shoot and root fresh weight and root dry weight in the control treatment were significantly greater when compared to the LSC treatment; however, shoot height did not differ significantly between treatments (Table 13).

Table 13. Pooled variety x pooled trial dependant variable averages.

Treatment	Shoot fresh weight (g)	Root fresh weight (g)	Root dry weight (g)	Shoot height (cm)
Control	182.62a	15.24a	0.73a	29.73a
LSC	165.00b	13.69b	0.66b	29.33a
$LSD_{(0.05)}$	7.04	1.07	0.04	0.43

Means within a column with the same letter are not significantly different according to the Least Significant Difference (LSD) at a 0.05 probability level; Control n = 288, LSC n = 286.

Lettuce Leaf Tissue Nutrient Analyses

At trial harvest, shoot biomass was collected from supplementary plants of each variety in both treatments and submitted for leaf tissue nutrient analysis. Laboratory (Exova Canada Inc., Surrey, BC) analysis provided detection values for each nutrient analyte and in addition, optimal range classifications for analytes except sulfur, molybdenum and sodium were also provided. Optimal range classifications are presented in Tables 14 and 15 where, above = above the optimal range, within = within the optimal range, below = below the optimal range and ni = no interpretation provided for the detected value. Detection values of analytes are presented in the appendix of the report.

Analysis of Green Bay M.I. and New Red Fire M.I. leaf tissue revealed equivalent nutrient range classifications for most nutrients were present in both treatments and equivalent nutrient range classifications for all nutrients were present for Skyphos M.I. leaf tissue in both treatments. Exceptions for equivalent nutrient range classifications in Trial 1 are as follows: total nitrogen in Green Bay M.I. and New Red Fire M.I. leaf tissue was above the optimal range in the control treatment when compared to the LSC treatment, where it was within the optimal range. Iron in New Red Fire M.I. leaf tissue was above the optimal range in the control treatment when compared to the LSC treatment, where it was below the optimal range. Dissimilar nutrient range classifications between treatments are highlighted in bold text in Table 14.

Table 14. Trial 1 lettuce leaf tissue nutrient analyses.

Analyte	Green Bay M.I.		New Red Fire M.I.		Skyphos M.I.	
	Control	LSC	Control	LSC	Control	LSC
Total nitrogen	**above**	**within**	**above**	**within**	above	above
Phosphorous	above	above	above	above	above	above
Potassium	above	above	above	above	above	above
Calcium	below	below	below	below	below	below
Magnesium	below	below	below	below	below	below
Zinc	within	within	within	within	within	within
Boron	within	within	within	within	within	within
Manganese	within	within	within	within	within	within
Copper	below	below	below	below	below	below
Iron	within	within	**above**	**below**	above	above
Sulfur	ni	ni	ni	ni	ni	ni
Molybdenum	ni	ni	ni	ni	ni	ni
Sodium	ni	ni	ni	ni	ni	ni

Results of leaf tissue nutrient analyses for Trial 2 determined equivalent nutrient range classifications for most nutrients were present in both treatments for all lettuce varieties. Exceptions for equivalent nutrient range classifications in Trial 2 are as follows: iron in Green Bay M.I. leaf tissue was above the optimal range in the control treatment when compared to the LSC treatment, where it within the

optimal range. Iron in Skyphos M.I. leaf tissue was within the optimal range in the control treatment when compared to the LSC treatment, where it was above the optimal range. Potassium in New Red Fire M.I. leaf tissue was below the optimal range in the control treatment when compared to the LSC treatment, where it was above the optimal range. Copper in New Red Fire M.I. and Skyphos M.I. leaf tissue was below the optimal range in the control treatment when compared to the LSC treatment, where it was within the optimal range. Dissimilar nutrient range classifications between treatments are highlighted in bold text in Table 15.

Table 15. Trial 2 lettuce leaf tissue nutrient analyses.

Analyte	Green Bay M.I.		New Red Fire M.I.		Skyphos M.I.	
	Control	LSC	Control	LSC	Control	LSC
Total nitrogen	within	within	above	above	above	above
Phosphorous	above	above	above	above	above	above
Potassium	above	above	**below**	**above**	above	above
Calcium	within	within	below	below	below	below
Magnesium	below	below	below	below	below	below
Zinc	within	within	within	within	within	within
Boron	within	within	within	within	within	within
Manganese	above	above	above	above	within	within
Copper	within	within	**below**	**within**	**below**	**within**
Iron	**above**	**within**	within	within	**within**	**above**
Sulfur	ni	ni	ni	ni	ni	ni
Molybdenum	ni	ni	ni	ni	ni	ni
Sodium	ni	ni	ni	ni	ni	ni

Conclusions

Results of the study suggest a differential varietal response exists for lettuce when grown under LSC panels and of the three varieties tested, New Red Fire M.I. appears to perform equally when grown under LSC panels compared to that of clear glass panels.

- Shoot fresh weight produced by Green Bay M.I. in Trial 1 under LSC panels was determined to be significantly less than that of clear glass panels however, shoot fresh weight achieved under LSC panels should be considered acceptable as marketable weights were achieved.
- Shoot fresh weight produced by New Red Fire M.I. and Skyphos M.I. in Trial 1 was determined not to be significantly different under LSC and clear glass panels. Although shoot fresh weight of New Red Fire M.I. and Skyphos M.I. produced under LSC panels was less than that of clear glass panels, shoot fresh weight achieved by both varieties were within the weight range for commercially grown hydroponic lettuce.

- Shoot fresh weight produced by Green Bay M.I. and New Red Fire M.I. in Trial 2 was determined to be not significantly different under LSC and clear glass panels. Results for Green Bay M.I. in Trial 1 could not be validated in Trial 2 as Green Bay M.I. was negatively influenced by unidentified factors that caused leaf damage however, of interest was the slight difference in leaf damage incidence detected favouring the LSC panel treatment over the clear glass panel treatment.
- Shoot fresh weight produced by Skyphos M.I. in Trial 2 was significantly less under LSC panels to that of clear glass panels however, shoot fresh weight achieved under LSC panels should be considered acceptable as marketable weights were achieved.
- Of the three lettuce varieties tested in this study, shoot fresh weight produced by New Red Fire M.I. was determined not to be significantly different between LSC and clear glass panels indicating this variety of lettuce can be produced under LSC panels with minimal negative outcome.
- Energy produced by the luminescent solar collector panels during the conduct of both trials while lettuce was within the greenhouse environment was approximately 78 kWh.

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Appendix

Trial 1 Green Bay M.I. control treatment leaf tissue analyses.

Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High	Method Reference
Plant Tissue Results									
Total Nitrogen	%	5.63	4.70 - 5.50						AOAC-990.03
Calcium	%	1.42	2.00 - 3.00						AOAC-985.01
Phosphorus	%	1.24	0.50 - 1.00						AOAC-985.01
Potassium	%	10.9	7.50 - 9.00						AOAC-985.01
Magnesium	%	0.34	0.50 - 0.80						AOAC-985.01
Sodium	%	0.05	No Interpretation						AOAC-985.01
Sulfur	%	0.347	No Interpretation						
Zinc	ug/g	52.7	25.0 - 150.0						AOAC-985.01
Boron	ug/g	40.1	23.0 - 50.0						AOAC-985.01
Manganese	ug/g	124	15.0 - 200.0						AOAC-985.01
Copper	ug/g	6.67	8.0 - 25.0						AOAC-985.01
Iron	ug/g	89	50.0 - 100.0						AOAC-985.01
Molybdenum	ug/g	2.2	No Interpretation						AOAC-985.01

Trial 1 Green Bay M.I. LSC treatment leaf tissue analyses.

Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High	Method Reference
Plant Tissue Results									
Total Nitrogen	%	5.24	4.70 - 5.50						AOAC-990.03
Calcium	%	1.02	2.00 - 3.00						AOAC-985.01
Phosphorus	%	1.31	0.50 - 1.00						AOAC-985.01
Potassium	%	10.0	7.50 - 9.00						AOAC-985.01
Magnesium	%	0.32	0.50 - 0.80						AOAC-985.01
Sodium	%	0.04	No Interpretation						AOAC-985.01
Sulfur	%	0.349	No Interpretation						
Zinc	ug/g	52.7	25.0 - 150.0						AOAC-985.01
Boron	ug/g	36.2	23.0 - 50.0						AOAC-985.01
Manganese	ug/g	98.6	15.0 - 200.0						AOAC-985.01
Copper	ug/g	5.60	8.0 - 25.0						AOAC-985.01
Iron	ug/g	96	50.0 - 100.0						AOAC-985.01
Molybdenum	ug/g	1.8	No Interpretation						AOAC-985.01

Trial 1 New Red Fire M.I. control treatment leaf tissue analyses.

Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High	Method Reference
Plant Tissue Results									
Total Nitrogen	%	5.83	4.70 - 5.50						AOAC-990.03
Calcium	%	0.65	2.00 - 3.00						AOAC-965.01
Phosphorus	%	1.20	0.50 - 1.00						AOAC-985.01
Potassium	%	11.7	7.50 - 9.00						AOAC-985.01
Magnesium	%	0.31	0.50 - 0.80						AOAC-985.01
Sodium	%	0.04		No Interpretation					AOAC-985.01
Sulfur	%	0.266		No Interpretation					
Zinc	ug/g	50.6	25.0 - 150.0						AOAC-965.01
Boron	ug/g	28.1	23.0 - 50.0						AOAC-985.01
Manganese	ug/g	82.6	15.0 - 200.0						AOAC-985.01
Copper	ug/g	5.36	8.0 - 25.0						AOAC-985.01
Iron	ug/g	116	50.0 - 100.0						AOAC-985.01
Molybdenum	ug/g	1.3		No Interpretation					AOAC-985.01

Trial 1 New Red Fire M.I. LSC treatment leaf tissue analyses.

Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High	Method Reference
Plant Tissue Results									
Total Nitrogen	%	5.49	4.70 - 5.50						AOAC-990.03
Calcium	%	0.97	2.00 - 3.00						AOAC-965.01
Phosphorus	%	1.31	0.50 - 1.00						AOAC-985.01
Potassium	%	12.6	7.50 - 9.00						AOAC-985.01
Magnesium	%	0.38	0.50 - 0.80						AOAC-985.01
Sodium	%	0.04		No Interpretation					AOAC-985.01
Sulfur	%	0.351		No Interpretation					
Zinc	ug/g	42.9	25.0 - 150.0						AOAC-965.01
Boron	ug/g	38.3	23.0 - 50.0						AOAC-985.01
Manganese	ug/g	142	15.0 - 200.0						AOAC-985.01
Copper	ug/g	5.89	8.0 - 25.0						AOAC-985.01
Iron	ug/g	101	50.0 - 100.0						AOAC-985.01
Molybdenum	ug/g	1.8		No Interpretation					AOAC-985.01

Trial 1 Skyphos M.I. control treatment leaf tissue analyses.

Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High	Method Reference
Plant Tissue Results									
Total Nitrogen	%	6.39	4.70 - 5.50						AOAC-990.03
Calcium	%	1.40	2.00 - 3.00						AOAC-965.01
Phosphorus	%	1.38	0.50 - 1.00						AOAC-985.01
Potassium	%	13.2	7.50 - 9.00						AOAC-985.01
Magnesium	%	0.43	0.50 - 0.80						AOAC-985.01
Sodium	%	0.04		No Interpretation					AOAC-985.01
Sulfur	%	0.276		No Interpretation					
Zinc	ug/g	36.6	25.0 - 150.0						AOAC-965.01
Boron	ug/g	44.2	23.0 - 50.0						AOAC-985.01
Manganese	ug/g	128	15.0 - 200.0						AOAC-985.01
Copper	ug/g	5.53	8.0 - 25.0						AOAC-985.01
Iron	ug/g	120	50.0 - 100.0						AOAC-985.01
Molybdenum	ug/g	1.3		No Interpretation					AOAC-985.01

Trial 1 Skyphos M.I. LSC treatment leaf tissue analyses.

Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High	Method Reference
Plant Tissue Results									
Total Nitrogen	%	5.92	4.70 - 5.50						AOAC-990.03
Calcium	%	1.40	2.00 - 3.00						AOAC-965.01
Phosphorus	%	1.31	0.50 - 1.00						AOAC-985.01
Potassium	%	12.0	7.50 - 9.00						AOAC-985.01
Magnesium	%	0.42	0.50 - 0.80						AOAC-985.01
Sodium	%	0.04		No Interpretation					AOAC-985.01
Sulfur	%	0.263		No Interpretation					
Zinc	ug/g	30.3	25.0 - 150.0						AOAC-965.01
Boron	ug/g	47.3	23.0 - 50.0						AOAC-985.01
Manganese	ug/g	107	15.0 - 200.0						AOAC-985.01
Copper	ug/g	5.89	8.0 - 25.0						AOAC-985.01
Iron	ug/g	132	50.0 - 100.0						AOAC-985.01
Molybdenum	ug/g	1.4		No Interpretation					AOAC-985.01

Trial 2 Green Bay M.I. control treatment leaf tissue analyses.

Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High	Method Reference
Plant Tissue Results									
Total Nitrogen	%	4.97	4.70 - 5.50						AOAC-990.03
Calcium	%	2.36	2.00 - 3.00						AOAC-965.01
Phosphorus	%	1.35	0.50 - 1.00						AOAC-985.01
Potassium	%	9.64	7.50 - 9.00						AOAC-985.01
Magnesium	%	0.39	0.50 - 0.80						AOAC-985.01
Sodium	%	0.05		No Interpretation					AOAC-985.01
Sulfur	%	0.409		No Interpretation					
Zinc	ug/g	111	25.0 - 150.0						AOAC-965.01
Boron	ug/g	45.6	23.0 - 50.0						AOAC-985.01
Manganese	ug/g	395	15.0 - 200.0						AOAC-985.01
Copper	ug/g	11.3	8.0 - 25.0						AOAC-985.01
Iron	ug/g	113	50.0 - 100.0						AOAC-985.01
Molybdenum	ug/g	2.5		No Interpretation					AOAC-985.01

Trial 2 Green Bay M.I. LSC treatment leaf tissue analyses.

Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High	Method Reference
Plant Tissue Results									
Total Nitrogen	%	5.29	4.70 - 5.50						AOAC-990.03
Calcium	%	1.92	2.00 - 3.00						AOAC-965.01
Phosphorus	%	1.38	0.50 - 1.00						AOAC-985.01
Potassium	%	9.56	7.50 - 9.00						AOAC-985.01
Magnesium	%	0.34	0.50 - 0.80						AOAC-985.01
Sodium	%	0.05		No Interpretation					AOAC-985.01
Sulfur	%	0.401		No Interpretation					
Zinc	ug/g	119	25.0 - 150.0						AOAC-965.01
Boron	ug/g	39.9	23.0 - 50.0						AOAC-985.01
Manganese	ug/g	326	15.0 - 200.0						AOAC-985.01
Copper	ug/g	10.9	8.0 - 25.0						AOAC-985.01
Iron	ug/g	95	50.0 - 100.0						AOAC-985.01
Molybdenum	ug/g	2.2		No Interpretation					AOAC-985.01

Trial 2 New Red Fire M.I. control treatment leaf tissue analyses.

Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High	Method Reference
Plant Tissue Results									
Total Nitrogen	%	6.17	4.70 - 5.50						AOAC-990.03
Calcium	%	1.04	2.00 - 3.00						AOAC-965.01
Phosphorus	%	>2.73	0.50 - 1.00						AOAC-985.01
Potassium	%	>3.23	7.50 - 9.00						AOAC-985.01
Magnesium	%	0.33	0.50 - 0.80						AOAC-985.01
Sodium	%	0.04		No Interpretation					AOAC-985.01
Sulfur	%	0.310		No Interpretation					
Zinc	ug/g	81.3	25.0 - 150.0						AOAC-965.01
Boron	ug/g	30.1	23.0 - 50.0						AOAC-985.01
Manganese	ug/g	331	15.0 - 200.0						AOAC-985.01
Copper	ug/g	7.88	8.0 - 25.0						AOAC-985.01
Iron	ug/g	86	50.0 - 100.0						AOAC-985.01
Molybdenum	ug/g	1.6		No Interpretation					AOAC-985.01

Trial 2 New Red Fire M.I. LSC treatment leaf tissue analyses.

Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High	Method Reference
Plant Tissue Results									
Total Nitrogen	%	6.15	4.70 - 5.50						AOAC-990.03
Calcium	%	0.99	2.00 - 3.00						AOAC-965.01
Phosphorus	%	1.72	0.50 - 1.00						AOAC-985.01
Potassium	%	12.8	7.50 - 9.00						AOAC-985.01
Magnesium	%	0.33	0.50 - 0.80						AOAC-985.01
Sodium	%	0.04		No Interpretation					AOAC-985.01
Sulfur	%	0.262		No Interpretation					
Zinc	ug/g	82.0	25.0 - 150.0						AOAC-965.01
Boron	ug/g	30.5	23.0 - 50.0						AOAC-985.01
Manganese	ug/g	289	15.0 - 200.0						AOAC-985.01
Copper	ug/g	8.83	8.0 - 25.0						AOAC-985.01
Iron	ug/g	88	50.0 - 100.0						AOAC-985.01
Molybdenum	ug/g	1.5		No Interpretation					AOAC-985.01

Trial 2 Skyphos M.I. control treatment leaf tissue analyses.

Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High	Method Reference
Plant Tissue Results									
Total Nitrogen	%	6.23	4.70 - 5.50						AOAC-990.03
Calcium	%	1.35	2.00 - 3.00						AOAC-965.01
Phosphorus	%	1.34	0.50 - 1.00						AOAC-985.01
Potassium	%	12.8	7.50 - 9.00						AOAC-985.01
Magnesium	%	0.40	0.50 - 0.80						AOAC-985.01
Sodium	%	0.05		No Interpretation					AOAC-985.01
Sulfur	%	0.273		No Interpretation					
Zinc	ug/g	69.1	25.0 - 150.0						AOAC-965.01
Boron	ug/g	31.4	23.0 - 50.0						AOAC-985.01
Manganese	ug/g	171	15.0 - 200.0						AOAC-985.01
Copper	ug/g	7.86	8.0 - 25.0						AOAC-985.01
Iron	ug/g	74	50.0 - 100.0						AOAC-985.01
Molybdenum	ug/g	1.2		No Interpretation					AOAC-985.01

Trial 2 Skyphos M.I. LSC treatment leaf tissue analyses.

Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High	Method Reference
Plant Tissue Results									
Total Nitrogen	%	6.29	4.70 - 5.50						AOAC-990.03
Calcium	%	1.63	2.00 - 3.00						AOAC-965.01
Phosphorus	%	1.43	0.50 - 1.00						AOAC-985.01
Potassium	%	14.1	7.50 - 9.00						AOAC-985.01
Magnesium	%	0.44	0.50 - 0.80						AOAC-985.01
Sodium	%	0.05		No Interpretation					AOAC-985.01
Sulfur	%	0.256		No Interpretation					
Zinc	ug/g	80.3	25.0 - 150.0						AOAC-965.01
Boron	ug/g	36.9	23.0 - 50.0						AOAC-985.01
Manganese	ug/g	184	15.0 - 200.0						AOAC-985.01
Copper	ug/g	9.11	8.0 - 25.0						AOAC-985.01
Iron	ug/g	107	50.0 - 100.0						AOAC-985.01
Molybdenum	ug/g	1.2		No Interpretation					AOAC-985.01

Additional Photos

Trial 1 lettuce in control and LSC treatments, from left to right, respectively (January 20, 2016).*

Replicate order and lettuce randomization within reservoirs are identical in both photos.

Floating raft viewed from above in Trial 2.

Control treatment in Trial 2 (February 26, 2016).*

LSC treatment in Trial 2 (February 26, 2016)*.

Replicate order and lettuce randomization within reservoirs are identical in both photos.

Evaluation of the effect of luminescent solar concentrators (LSC) on lettuce inoculated with *Botrytis cinerea* (gray mold disease)

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Executive Summary

The effect of luminescent solar collectors on lettuce inoculated with *Botrytis cinerea* was studied from September to November 2016 at InnoTech Alberta located in Vegreville, Alberta, Canada. One greenhouse trial was conducted using two greenhouse compartments, a clear glass panel and a luminescent solar collector panel compartment. *Botrytis cinerea* positive and negative controls, and two lettuce varieties, New Red Fire and Skyphos were present in each compartment. Environmental parameters and energy collection were monitored and recorded in both compartments, and solar radiation was monitored and recorded above the luminescent solar collector compartment.

A semi-closed, floating raft technique was used to grow the lettuce in the greenhouse after lettuce seedlings were reared mineral cubes while in a growth chamber. During the greenhouse phase, lettuce was subjected to natural daylight during dawn and day hours and supplemental high pressure sodium lighting was operated during dusk and night hours to provide additional photosynthetically active radiation. Lettuce seedlings ranging in size from five to six leaves were inoculated eight days after placement into greenhouse compartments with a distilled water-based suspension containing 1 x 10^6 *Botrytis cinerea* spores/mL plus Tween 80 0.1% v/v or distilled water plus Tween 80 0.1% v/v. *Botrytis cinerea* disease incidence and intensity, lettuce shoot fresh and dry weight, shoot height, and root fresh and dry weight were used as response variables.

The results demonstrated that luminescent solar collector panels provided a significant reduction of gray mold disease for lettuce varieties used in the trial. Reduction of disease incidence and severity achieved by lettuce cultivated under luminescent solar collector panels was indicated to be dependent on lettuce variety, as lettuce varieties displayed a varying response to the disease.

Review of lettuce growth response data revealed significant interactions between compartments and variables occurred where shoot biomass was lower for lettuce when cultivated under luminescent solar collector panels. Shoot height for both varieties were shown not to differ significantly between greenhouse compartments.

Although shoot fresh weight was reduced for both lettuce varieties cultivated under luminescent solar collector panels, biomass achieved should be considered commercially acceptable, as average yields attained for both varieties were within the commercially acceptable target range for fresh weight of lettuce.

As demonstrated in the trial, lettuce susceptibility to gray mold disease was reduced where lettuce was produced under luminescent solar collector panels and as no varieties of lettuce are known to be resistant to *B. cinerea*, utilizing a greenhouse fitted with luminescent solar collector panels would be beneficial to the greenhouse producer in complimenting current greenhouse sanitation and management efforts for reducing incidence and severity of gray mold disease.

Until gray mold disease resistant varieties of lettuce are available to greenhouse lettuce producers, cultivating lettuce while influenced by luminescent solar collector panels appears to provide an immediate solution in providing a defensive action for gray mold disease control.

Energy produced by the luminescent solar collector panels during the conduct of the trial while lettuce was within greenhouse compartments for a period of 51 days was approximately 77 kWh.

Introduction

Botrytris cinerea, the causal agent of gray mold disease, is the most common disease of greenhouse lettuce where resistant varieties are not available and chemical control options are limited. Cultural controls such as avoiding injury to plants, good sanitation practices, controlling ventilation and night temperatures to prevent condensation on the leaves are employed to reduce infections and disease development [1].

The effect of luminescent solar collectors (LSC) on greenhouse grown lettuce inoculated with *Botrytis cinerea* (*B. cinerea*) was studied during one trial conducted from September to November 2016 at InnoTech Alberta located in Vegreville, Alberta, Canada. Incidence and severity *of B. cinerea* infection, lettuce shoot fresh and dry weight, shoot height, and root fresh and dry weight for two lettuce varieties were used as response variables.

Materials and Methods

Experimental Design

To evaluate the effect of LSCs on lettuce inoculated with *B. cinerea*, a greenhouse compartment and adjacent corridor previously fitted with 70 west-facing LSC panels positioned overhead and a greenhouse compartment with clear glass (CG) panel and adjacent corridor of identical size and orientation to the LSC greenhouse compartment were used. To compliment the LSC overhead panels, a translucent luminescent plastic film of identical colour to that of LSC panels was present on the south-facing sidewall of the LSC greenhouse compartment (Figure 1).

Figure 1: InnoTech Alberta greenhouse compartments fitted with LSC panels and CG panels, left to right, respectively.

Greenhouse compartments were 44 m^2 in size. Sidewalls were 3.6 m in height of which the upper 2.7 m contained glass panels. Height from floor to ridgeline peak was 5.5 m. Each greenhouse compartment contained 20, 400 watt high pressure sodium lights (C400S51/Alto; Philips). Greenhouse compartments were physically separated by a distance of 6.2 m and shared a common corridor.

The trial was conducted from September 12 to November 3, 2016. Dates refer to when lettuce seeds were placed to germinate in a growth chamber (Model PGV36, Conviron) to when lettuce was harvested in the greenhouse compartments.

LSC and CG greenhouse compartments each contained 200 lettuce plants where 100 plants of each variety were present in four floating rafts. This design permitted two replicates comprised of 25 plants per replicate for each the *B. cinerea* positive and negative control treatments, however due to a seedling transplanting error in the LSC compartment, one replicate of the New Red Fire *B. cinerea* negative control treatment was lost and subsequently one replicate of the New Red Fire *B. cinerea* positive control treatment was gained.

Environmental Data and Solar Energy Collection and Recording

Temperature, relative humidity and photosynthetically active radiation were monitored in real-time and recorded within each greenhouse compartment. Sensors for each environmental parameter were located at the center of each greenhouse compartment and were approximated to the average height of lettuce plants in each greenhouse compartment. Solar radiation was monitored and recorded by two pyranometer sensors located outside and above, on the west-facing slope of the LSC greenhouse compartment where one pyranometer sensor was level to the horizon and one was level to the slope of the greenhouse roof. Monitoring and recording of environmental data was accomplished by using a HOBO U30-ETH (Onset Computer Corporation).

Solar energy harvest, monitoring in real-time and measurement were accomplished by using an Enphase Energy Microinverter system comprised of Enphase Microinverters, an Envoy Communications Gateway and an Enphase Enlighten Monitor (Enphase Energy Inc.).

Lettuce Production Techniques

Two lettuce varieties were included in the trial providing the opportunity to investigate whether varietal differences exist in lettuce response to gray mold disease when grown under LSC and CG panel greenhouse compartments. Lettuce seed used in the trial was indexed for mosaic virus by the vendor. Lettuce varieties used in trial were selected based on type and number of days to maturity (Table 1).

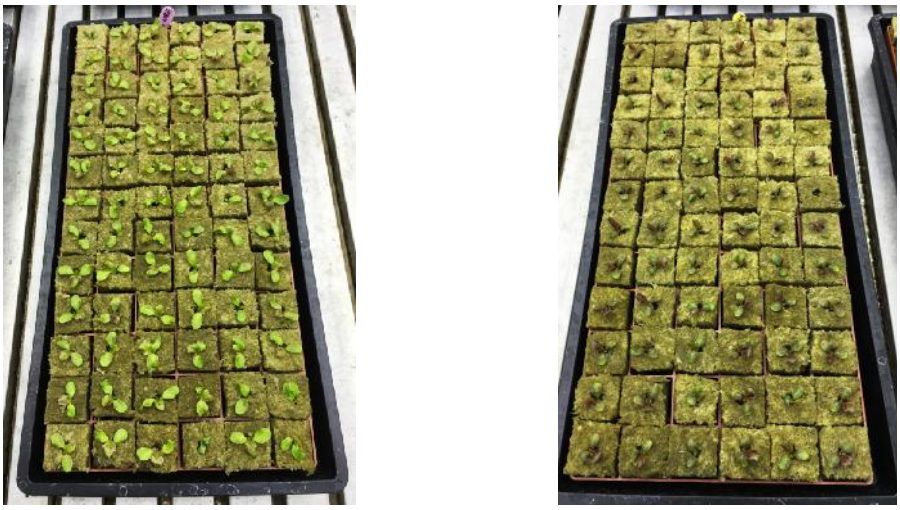
Table 1: Lettuce varieties used in trial.

Variety	Type	Days to Maturity [2,3]	Leaf Tissue Colour	Traits
New Red Fire	Loose leaf	43	red	⎫ bolting tolerant [2,4,5] ⎪ tip burn resistant [2,4] ⎪ Downey mildew resistant [2,4] ⎪ bottom rot resistant [2,4] ⎪ white mold resistant [4] ⎪ heat tolerant [5,6] ⎭ cold tolerant [5,6]
Skyphos	Butterhead	47	red	⎫ heat tolerant [7] ⎪ bolting tolerant [3,7] ⎪ Downey mildew races 1-26 tolerant [3,7] ⎪ *Nasonovia ribisnigri* (lettuce aphid) resistant [3,7] ⎭ lettuce mosaic virus tolerant [3,7]

Growth Chamber Environment

Clay coated, mosaic virus indexed seed (Stokes Seed Ltd.) of New Red Fire and Skyphos lettuce was placed to germinate in 3.8 cm mineral cubes (A-OK Starter Plugs, Grodan) conditioned in and rinsed with municipal water modified to pH 5.5 [8] with pH Down (phosphoric acid, citric acid, mono ammonium phosphate, General Hydroponics). Seeded mineral cubes were positioned in a cell tray (Gro-Smart Tray, Grodan) contained in a 25 cm x 50 cm x 6 cm seedling tray and covered with a clear humidity dome. Seedling trays were placed in a growth chamber programmed to a constant 20°C with 250 µE m^2 s^{-1} illumination provided by fluorescent lighting [9]. Humidity domes were removed three days after seeding with germination occurring the same day (Figure 2).

Figure 2: Lettuce seedlings in growth chamber (September 22, 2016). New Red Fire and Skyphos, left to right, respectively.



After 17 days of incubation in the growth chamber, lettuce seedlings ranging from three to four leaves per plant were transplanted to floating rafts contained in greenhouse compartments (Figure 3).

Figure 3: Lettuce seedlings in growth chamber at transplanting time (September 29, 2016). New Red Fire and Skyphos, left to right, respectively.

For the duration of lettuce germination and seedling development within the growth chamber, a solution comprised of a pre-mix fertilizer blend, HydroVeg 7-11-27 (Plant-Prod Inc.), Calcium Nitrate Plus K (14-0-3+18Ca, TerraLink Horticultural Inc.), magnesium sulphate (Epsom Salt, 9.8% Mg, 12% S; TerraLink Horticulture Inc.) and Librel Cu (14% chelated copper, BASF) was used to supply nutrients to seedlings. HydroVeg 7-11-27 also contained the following nutrients: magnesium 3.8%, sulphur 5.5%, born (actual) 0.0273%, copper (actual) 0.0041%, chelated iron (actual) 0.10%, manganese (actual) 0.085%, molybdenum (actual) 0.009% and zinc (actual) 0.03% (Table 2).

Table 2: Nutrient feed levels utilized during growth chamber phase.

	Nutrient (ppm)											
Period *	N	P	K	S	Ca	Mg	Fe	Bo	Mn	Z	Mo	Cu
1	56	14	74	121	92	41	0.3020	0.0819	0.2570	0.0920	0.0270	0.0388
13	84	22	111	149	114	61	0.4520	0.1228	0.3845	0.1370	0.0450	0.0449
16	113	29	148	176	137	81	0.6020	0.1638	0.5120	0.1820	0.0540	0.0756

** days after placement into growth chamber.*

The water source for this trial was treated municipal [10], originating from the North Saskatchewan River and its contributions to the nutrient solution were included. Nutrient solution pH was adjusted to 5.6-6.0 [9] using pH Down (17% phosphoric acid, HydroTek) and was provided daily by hand. Remnant nutrient solution contained within seedling trays was discarded prior to the addition of fresh nutrient solution.

Greenhouse Environment

Lettuce was grown using a semi-closed hydroponic system [11,12] employing a floating raft technique [13]. Floating rafts were constructed of 5 cm thick polystyrene panels (Foamular C-300, Owens-Corning) where 5 cm diameter holes were prepared in a 5 x 5 pattern spaced 20 cm apart. At transplanting, lettuce seedlings were removed from the growth chamber to greenhouse compartments, placed in 5 cm net pots (unknown manufacturer), and further positioned in holes of the rafts. Each polystyrene panel floated on an aerated nutrient solution contained in 1.2 m x 1.8 m x 0.15 m, black ABS plastic, 140 L capacity reservoir (unknown manufacturer). Eight reservoirs were present in each greenhouse compartment (Figure 4).

Figure 4: Lettuce seedlings in CG and LSC greenhouse compartments, from left to right, respectively (September 29, 2016).

Reservoirs were prepared to receive lettuce transplants by the addition of nutrients and 130 L of municipal water. A nutrient solution containing 113 ppm nitrogen, 29 ppm phosphorous, 148 ppm

potassium, 176 ppm sulfur, 137 ppm calcium, 81 ppm magnesium, 0.6020 ppm iron, 0.1638 ppm boron, 0.5120 ppm manganese, 0.1820 ppm zinc, 0.054 ppm molybdenum and 0.0756 ppm copper, comprised of HydroVeg 7-11-27, Calcium Nitrate Plus K, magnesium sulphate and Librel Cu was contained in each reservoir where pH of the solution was adjusted to pH 5.8 [9] and pH 5.6 [9] at trial initiation and when nutrient solution was replaced using pH Down, respectively.

An air compressor (EcoAir, EcoPlus) was operated continuously to supply air to four, 30.5 cm long air stones (Hagen, Marina) placed on the bottom of each reservoir in the nutrient solution and connected to the compressor using clear PVC vinyl tubing (Hagen, Marina). A dissolved oxygen level of 8 ppm [9] was targeted. Two air circulation fans were operated continuously [14] in each greenhouse compartment though were temporarily non-operational during application of the *B. cinerea* control treatments.

Lettuce was exposed to natural daylight and supplemental HPS light while in the greenhouse. Natural daylight length was approximately 11.75 and 9.25 hours at trial initiation and conclusion, respectively. Day length was extended using approximately 4.25 hours of HPS light daily commencing near dusk at trial initiation to approximately 6.75 hours at trial termination.

Greenhouse temperature set-points of 20/18^{o}C (day/night) were targeted. However, temperature set-points were activated by a timer also controlling HPS light operation and as HPS lighting was provided during dusk and night hours, day temperature occurred during this period. Upon daily termination of the HPS lighting cycle, night temperature was initiated and remained until HPS lighting was activated at dusk the following day. Shortly after transplanting lettuce seedlings to the greenhouse compartments, temperature was not controlled to maintain set-point and remained static providing approximately 25^{O}C for a period of six days in the CG compartment due to heating control equipment failure.

Nutrient solution pH, electrical conductivity and temperature were measured in each reservoir throughout the duration of the trial. Reservoir solution volumes were replenished by the addition of reverse osmosis water with a complete nutrient solution replacement provided to each reservoir of New Red Fire and Skyphos lettuce at 20 and 22 days, respectively, after transplanting to compartments. Reservoir pH was permitted to rise throughout the duration of each nutrient solution cycle.

Biological control insects (*Neoseiulus cucumeris, Stratiolaelaps scimitus*, Applied Bio-nomics) were released in both compartments during both trials as a preventive measure for the control of *Frankliniella occidentalis* (western flower thrips). Sticky cards (Dongbu Blue 25 cm x 15 cm, Crop Defenders Ltd.) were placed to trap and monitor insect pest populations.

B. cinerea Inoculum Preparation and Control Treatment Application

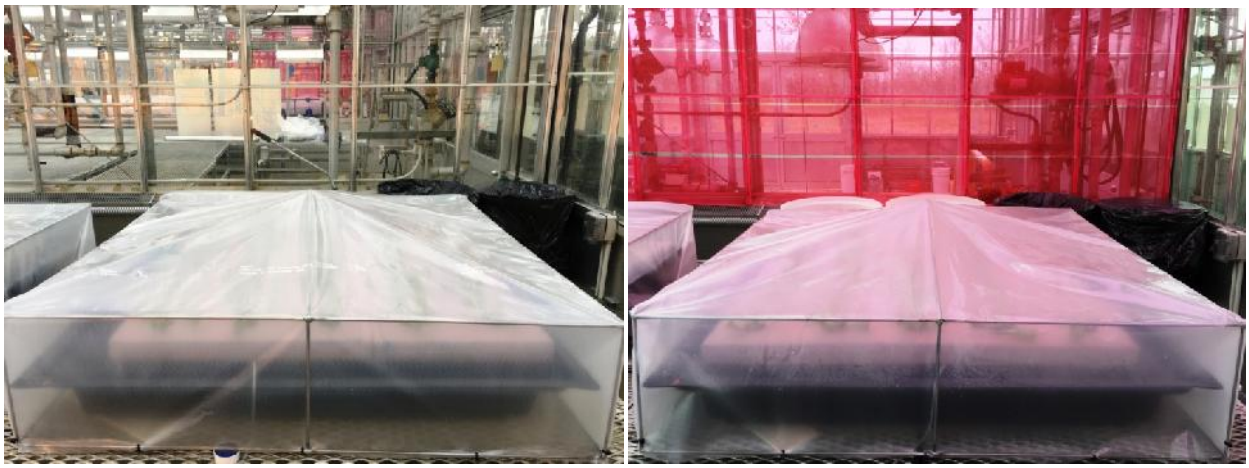
B. cinerea was cultured on potato dextrose sucrose agar contained in petri dishes in the dark at 25°C for seven to ten days until fungal spores were formed and then collected by flushing the petri dishes with sterile distilled water. Spore concentration was adjusted to approximately 1 x 10^6 spores mL^{-1}.

B. cinerea positive and negative control treatments were prepared the day of application. The positive *B. cinerea* control treatment was prepared using a mixture of sterile distilled water, *B. cinerea* 1 x 10^6 spores mL^{-1} and Tween 80 0.1% v/v (polyoxyethylene (20) sorbitan monooleate, Fisher Chemical), a non-ionic surfactant and emulsifier. The *B. cinerea* negative control treatment was prepared using a mixture of sterile distilled water and Tween 80 0.1 %v/v.

B. cinerea positive and negative control treatment solutions were applied to lettuce seedlings ranging from five to six leaves per plant. A single action external mix air brush (Paasche Airbrush Company) operated using 124 kPa of pressured air supplied by a portable air compressor (Coleman Powermate, 3 HP, 20 gallon, Model CP0302013) was used to provide a fine mist of spray solution to the lettuce. Each lettuce plant received approximately 0.5 mL of control treatment solution. Negative control treatments were applied initially in both greenhouse compartments followed by positive control treatments.

After an individual control treatment application was made to the lettuce reservoir, a polyethylene tent was placed over the reservoir to increase relative humidity within the lettuce environment. Compartment floor drains were plugged and floor surfaces were wetted with water in efforts to increase relative humidity in compartments. These measures were undertaken to encourage *B. cinerea* spore germination and aid in the development of the disease (Figure 5).

Figure 5: Floating rafts and reservoirs covered with polyethylene post *B. cinerea* application in CG and LSC greenhouse compartments, from left to right, respectively (October 7, 2016).



The polyethylene tent was removed from reservoirs after a period of 48 hours. Floors were wetted for the remainder of the trial and the automatically controlled greenhouse roofline ventilation system remained operational to assist in compartment temperature control (Figure 6).

Figure 6: Lettuce in CG and LSC greenhouse compartments 48 hours after *B. cinerea* treatment application, from left to right, respectively (October 9, 2016).

Lettuce Growth, Data Collection, Statistical Design and Analyses

A completely randomized design was used where each floating raft contained 25 plants of the same lettuce variety. Each floating raft was considered one replicate and designated as either a *B. cinerea* negative or positive control treatment (Figures 7 – 9).

Figure 7: New Red Fire lettuce treated with *B. cinerea* positive control in CG and LSC compartments, from left to right, respectively (October 13, 2016).

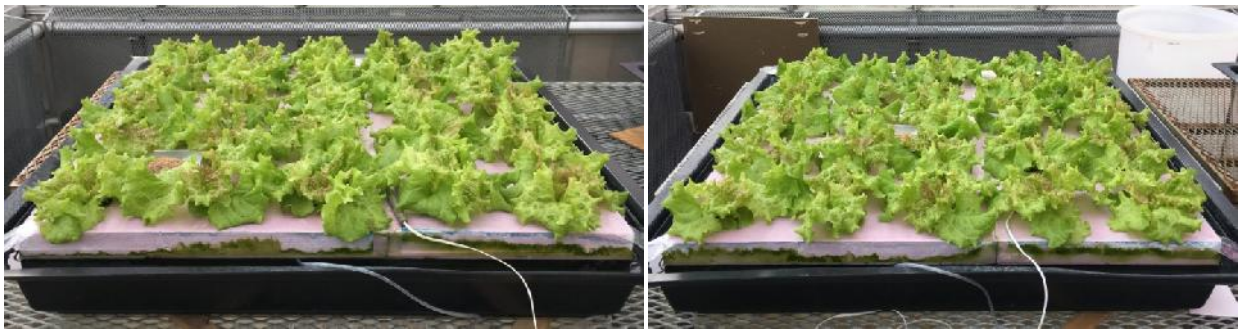


Figure 8: New Red Fire lettuce treated with *B. cinerea* positive control in CG and LSC compartments, left to right, respectively (October 23, 2016).

Figure 9: Lettuce in CG and LSC compartments, from left to right, respectively (October 24, 2016).

Observations conducted five days prior to trial harvest revealed leaf damage to Skyphos lettuce with tissue symptomology considered not associated with gray mold disease. This deviation to the trial is discussed in detail, found in the additional data and information section of this report.

Lettuce harvest and assessment was initiated 50 days from seeding and occurred over a three day period where reservoirs were harvested in one compartment after the other, in identical sequence in each compartment. Data was collected and analysed on an individual plant basis (Figure 10).

Figure 10: New Red Fire and Skyphos lettuce at harvest, from left to right, respectively (November 1, 2016).

At harvest, lettuce plants were excised from mineral cubes, weighed and measured for height, and assessed for gray mold incidence and severity. Root biomass extruding from net pots were removed and weighed. Fresh shoot and root biomass was oven dried at 70°C constant for dry weight determination.

Determination of Gray Mold Incidence

Lettuce leaves were individually assessed for gray mold incidence at harvest by counting the number of leaves per plant displaying symptoms gray mold infection. As *B. cinerea* was applied when lettuce contained up to six leaves per plant, lower leaves of plants were targeted for assessment however, plant leaves above the six leaf stage were assessed until disease presence was no longer observed. Incidence values for each plant were determined according to the following formula [15] where,

$$\text{Incidence (\%)} = \frac{\text{Total number of infected leaves}}{\text{Total number of examined leaves}} \times 100$$

Determination of Gray Mold Severity

All symptomatic leaves were further assessed where each leaf was provided a disease severity rating according to a 0-5 scale where, 0 = no disease, 1 = slightly infected, less than 5% leaf area infected, 2 = 6 – 25% leaf area infected, 3 = 26 – 50% leaf area infected, 4 = 51 – 75% leaf area infected, mold (spores) are visible and 5 = >75% leaf area infected, rotten and dead leaf (Figures 11 and 12).

Leaf data collected from the disease severity rating assessment on a per plant basis was subjected to the following formula [16] to establish a disease index value as an indicator of disease severity where the number of affected leaves per plant was tallied.

$$\text{Severity (\% Disease Index)} = \frac{\sum (n \times v)}{N \times V} \times 100$$

Where,

n = the number of leaves under each grade
v = grade values
N = total number of leaves evaluated
V = highest grade value in the scale
∑ = summation of the multiplied values of the grade value and the number of leaves under each grade

Figure 11: New Red Fire lettuce displaying gray mold leaf symptomology at harvest. Red circles indicate spore growth and infection sites.

Figure 12: Skyphos lettuce displaying gray mold leaf symptomology at harvest. Red circles indicate spore growth and infection sites.

An identical floating raft randomization in both greenhouse compartments was originally desired at trial initiation, however, as previously stated, a lettuce seedling transplanting error occurred where the location of one lettuce variety was exchanged for the other resulting in an unbalanced *B. cinerea* positive and negative control treatment data set. In addition, growth response variables for one lettuce plant were removed from the data set as the fresh weight obtained was determined to be non-representative. Furthermore, three gray mold incidence ratings were removed due to incomplete collection of data.

Data were subjected to analysis of variance (ANOVA) using SAS (SAS Institute Inc. 2016. Base SAS® 9.4 Procedures Guide: Statistical Procedures. Cary, NC: SAS Institute Inc.). When the F test indicated statistical significance, the Least Significant Difference (LSD) test was used to determine the significance between means.

Results and Discussion

Symptoms of gray mold disease on lettuce were first observed in compartments 17 days after *B. cinerea* control treatments were applied, eight days prior to harvest.

The analysis of variance revealed gray mold incidence and severity, and shoot fresh and dry weight of lettuce was dependent on compartment, *B. cinerea* treatment and variety, and interactions between compartment x *B. cinerea* treatment, compartment x variety, *B. cinerea* treatment x variety and compartment x *B. cinerea* treatment x variety (Table 3).

Table 3: Analysis of variance for gray mold incidence, gray mold severity, shoot fresh weight, shoot dry weight, root fresh weight, root dry weight and shoot height subjected to treatments (*B. cinerea* negative and positive controls) across compartments (clear glass and luminescent solar collector panels).

Source of Variation	DF	Gray Mold Incidence (%)	Gray Mold Severity (%)	Shoot Fresh Weight (g)	Shoot Dry Weight (g)	Root Fresh Weight (g)	Root Dry Weight (g)	Shoot Height (cm)
Compartment	1	2728 ***	1697 ***	79815 ***	89 ***	24 **	0.010 NS	15 NS
B. cinerea Treatment	1	377870 ***	145276 ***	66529 ***	114 ***	20 *	0.033 *	0.002 NS
Replicate	2	959 ***	1614 ***	17250 ***	14 ***	16 **	0.002 NS	100***
Plant Number	24	68 NS	57 NS	5866 ***	7 ***	24 ***	0.064 ***	15***
Variety	1	544 **	949 ***	3887 *	25 ***	30 **	0.038 **	2308***
Compartment x *B. cinerea* Treatment	1	4181 ***	3292 ***	7065 **	5 *	84 ***	0.041 **	45**
Compartment x Variety	1	2134 ***	717 ***	26142 ***	19 ***	11 NS	0.011 NS	187***
B. cinerea Treatment x Variety	1	822 ***	1047 ***	12486 ***	15 ***	3 NS	0.016 NS	0.432 NS
Compartment x *B. cinerea* Treatment x Variety	1	1639 ***	304 *	3922 *	4 *	29 **	0.110 ***	4 NS
Compartment x Plant Number	24	94 NS	62 NS	878 NS	1 NS	2 NS	0.006 NS	3 NS
Error	338	74	59	938	0.93	4	0.005	4.21

, **, * significant at 0.05, 0.01 and 0.001 probability level, respectively; NS = non-significant.*

Compartment Effect on Gray Mold Disease and Lettuce Growth

The analysis of variance revealed that compartment was highly significant for gray mold incidence and severity, and shoot fresh and dry weight ($P < 0.001$), significant for root fresh weight ($P < 0.01$) suggesting performance of lettuce is dependent on compartment. Compartment was not significant for root dry weight and shoot height (Table 3).

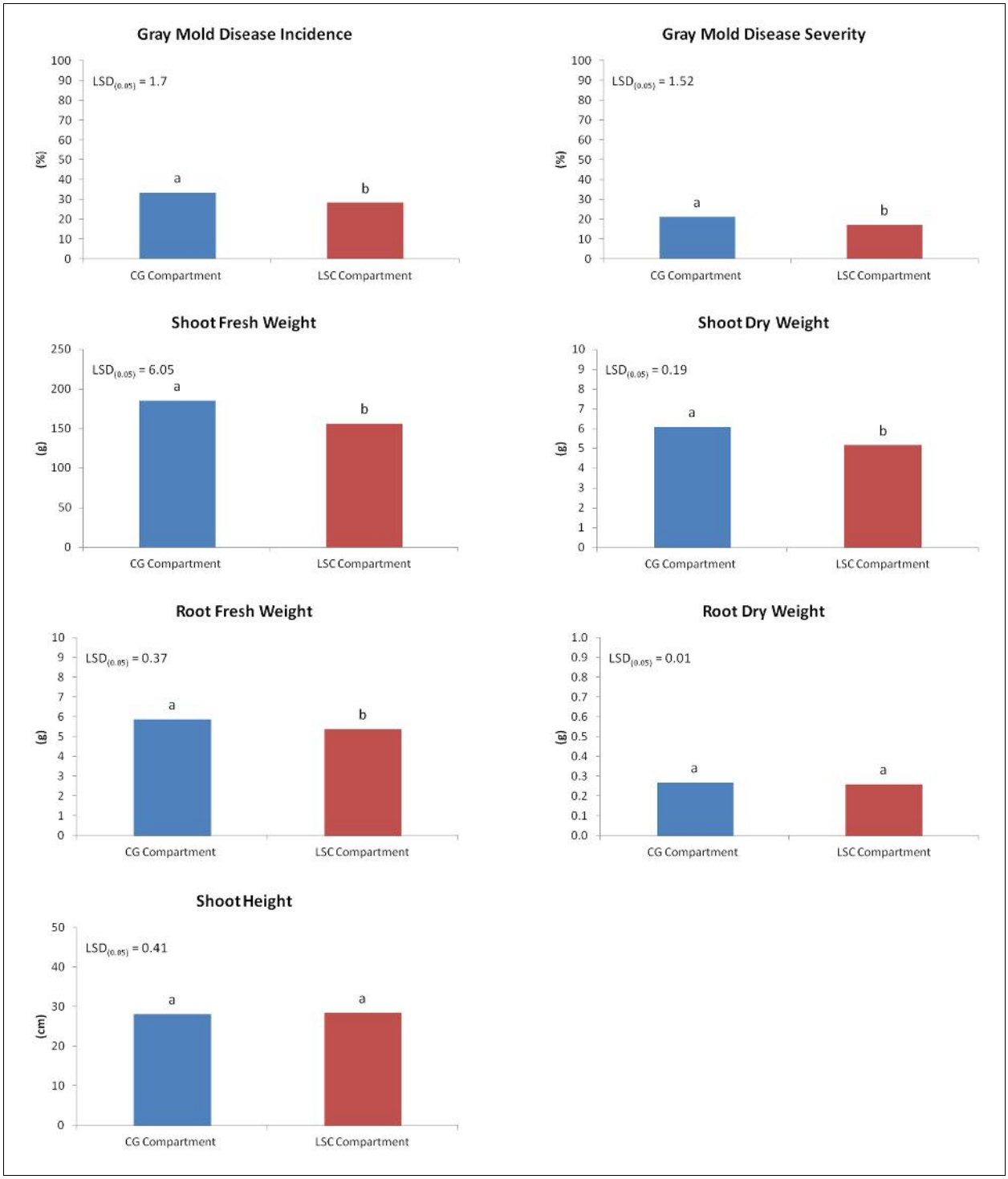
Significant effects between compartments were detected for gray mold disease incidence and severity for lettuce. Differences between compartment means showed incidence and severity of gray mold disease for lettuce were reduced by 5.3% and 4.1% in the LSC compartment and CG compartment, respectively, demonstrating a reduction of gray mold disease occurred in the LSC compartment.

Significant effects between compartments were detected for lettuce shoot fresh and dry weight, and root fresh weight, where 28.4g greater shoot fresh weight 0.9 g greater shoot dry weight was produced

in the CG compartment than that of the LSC compartment indicating lettuce growth was influenced by compartment.

Lettuce root dry weight and shoot height of lettuce were not significantly affected by compartment (Figure 13).

Figure 13: Compartment effect on gray mold disease and lettuce growth variables.



CG Compartment n = 199, LSC Compartment n = 197.

B. cinerea Control Treatment Effect on Gray Mold Disease and Lettuce Growth

The analysis of variance revealed that treatment was highly significant for gray mold incidence and severity, and shoot fresh and dry weight ($P < 0.001$) and slightly significant for root fresh weight and dry weight ($P < 0.05$) suggesting performance of lettuce was dependent on treatment. Treatment was not significant for shoot height (Table 3).

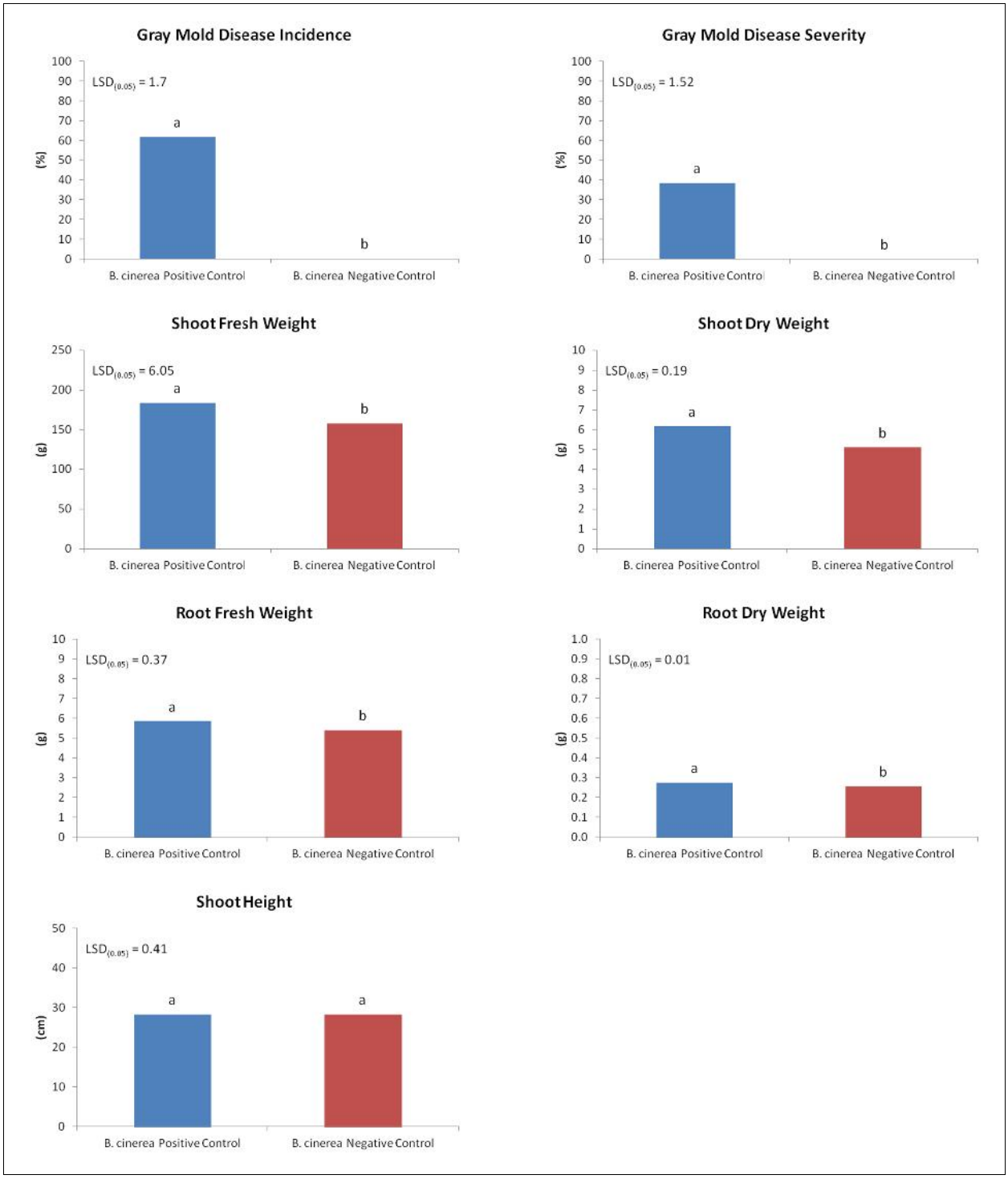
Significant effects between *B. cinerea* positive and negative control treatments were detected for gray mold disease incidence and severity, and lettuce growth response variables. Comparison of the treatment means showed gray mold disease incidence was 62% and 0% in the *B. cinerea* positive and negative control treatments, respectively. Gray mold disease severity was 38% and 0% in the positive and negative control treatments, respectively.

Disease assessments conducted at harvest determined 62% of the leaves assessed from plants treated with the *B. cinerea* positive control treatment were infected with gray mold disease where a corresponding 38% severity rating was determined for gray mold disease. Lettuce that received the *B. cinerea* negative control treatment did not display leaf symptomology of gray mold disease and thus, incidence and severity was determined to be 0%. In addition, the results indicate presence of gray mold disease did not extend beyond the application site of the positive control treatments for both compartments.

Significant effects were detected between *B. cinerea* control treatments for lettuce growth where both shoot and root, fresh and dry weight were significantly greater in the positive control treatment than that of the negative control treatment. The results indicate lettuce produced more biomass when infected with gray mold disease compared to where no gray mold disease was present. This effect is not entirely understood, as generally the presence of a plant disease results in a reduction of the hosts biomass. It is possible this effect is an artifact of trial design, as the location of some negative control treatment reservoirs were subjected to shading caused by the greenhouse structure and associated equipment. Previously conducted lettuce trials using similar production techniques determined lettuce located in areas of shading produced less biomass.

Shoot height was not significantly affected by positive and negative control treatments (Figure 14).

Figure 14: *B. cinerea* treatment effect on gray mold disease and lettuce growth.



B. cinerea Positive Control n = 197, B. cinerea Negative Control n = 199.

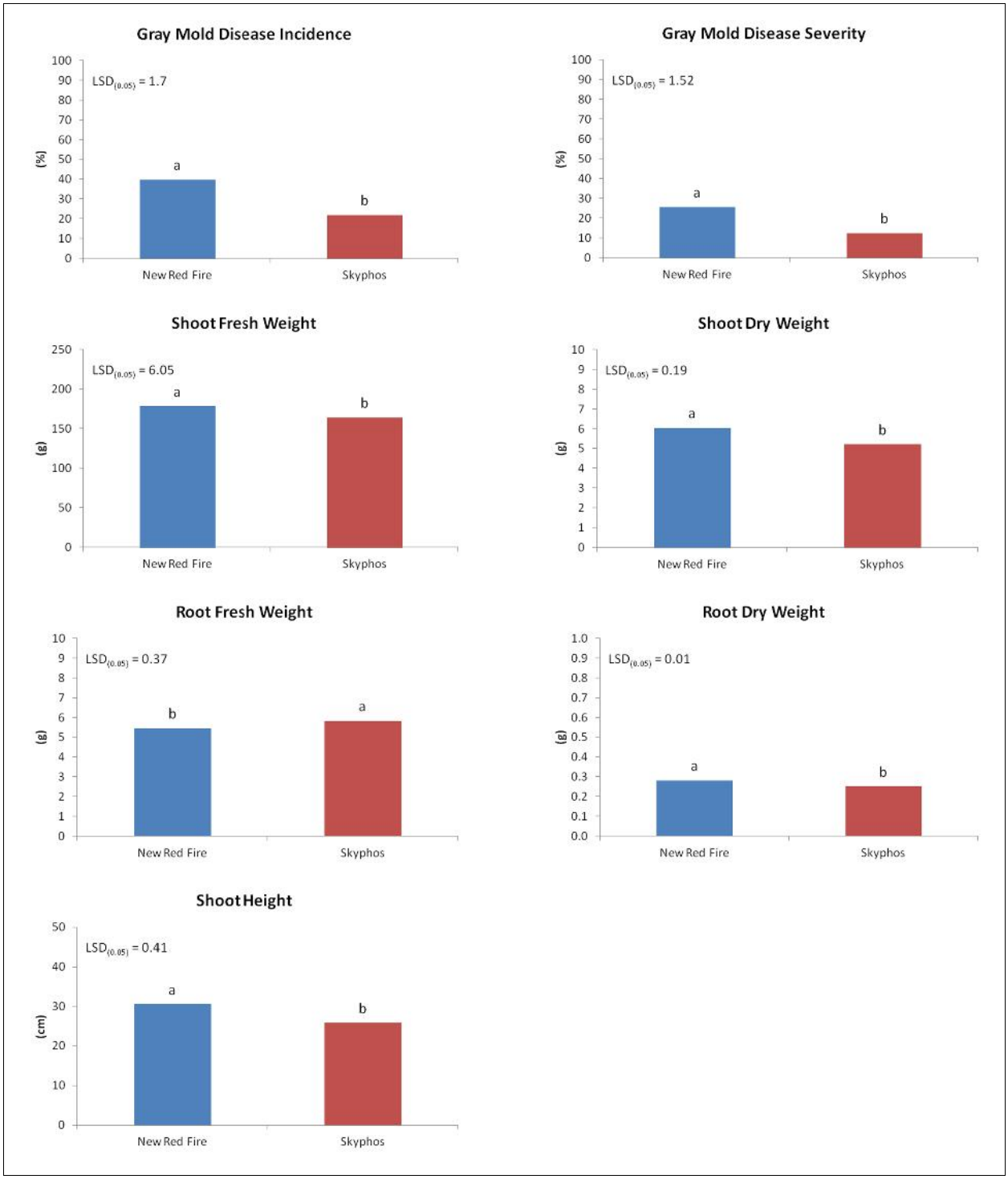
Lettuce Variety Effect on Gray Mold Disease and Lettuce Growth

The analysis of variance revealed that variety was highly significant for gray mold severity, shoot dry weight and shoot height ($P < 0.001$), significant for gray mold incidence and root fresh and dry weight ($P < 0.01$) and slightly significant for shoot fresh weight ($P < 0.05$) suggesting performance of lettuce was dependent on variety (Table 3).

Significant effects between varieties were detected for gray mold disease incidence and severity, and all lettuce growth response variables suggesting differences existed between lettuce varieties and their response to gray mold disease.

Comparison of lettuce variety means determined New Red Fire produced significantly greater shoot fresh and dry weight, and root dry weight than that of Skyphos. In addition, shoot height for New Red Fire was significantly greater than that of Skyphos. Root fresh weight for Skyphos was significantly greater when compared to New Red Fire. The results reveal growth of the two varieties differed in the trial (Figure 15).

Figure 15: Lettuce variety effect on gray mold disease and lettuce growth.



New Red Fire n = 198, Skyphos n = 198.

Compartment x Variety Effect on Gray Mold Disease and Lettuce Growth

Gray mold disease incidence was determined to be 33.4% in the CG compartment for both lettuce varieties indicating no difference existed for gray mold disease incidence between lettuce varieties. On the contrary, a 35.7% difference between varieties for gray mold disease incidence was determined in the LSC compartment, where Skyphos was affected less than New Red Fire suggesting an interaction between the LSC compartment and lettuce variety occurred. The results suggest Skyphos responded more favourably to the presence of gray mold disease in the LSC compartment when compared to New Red Fire.

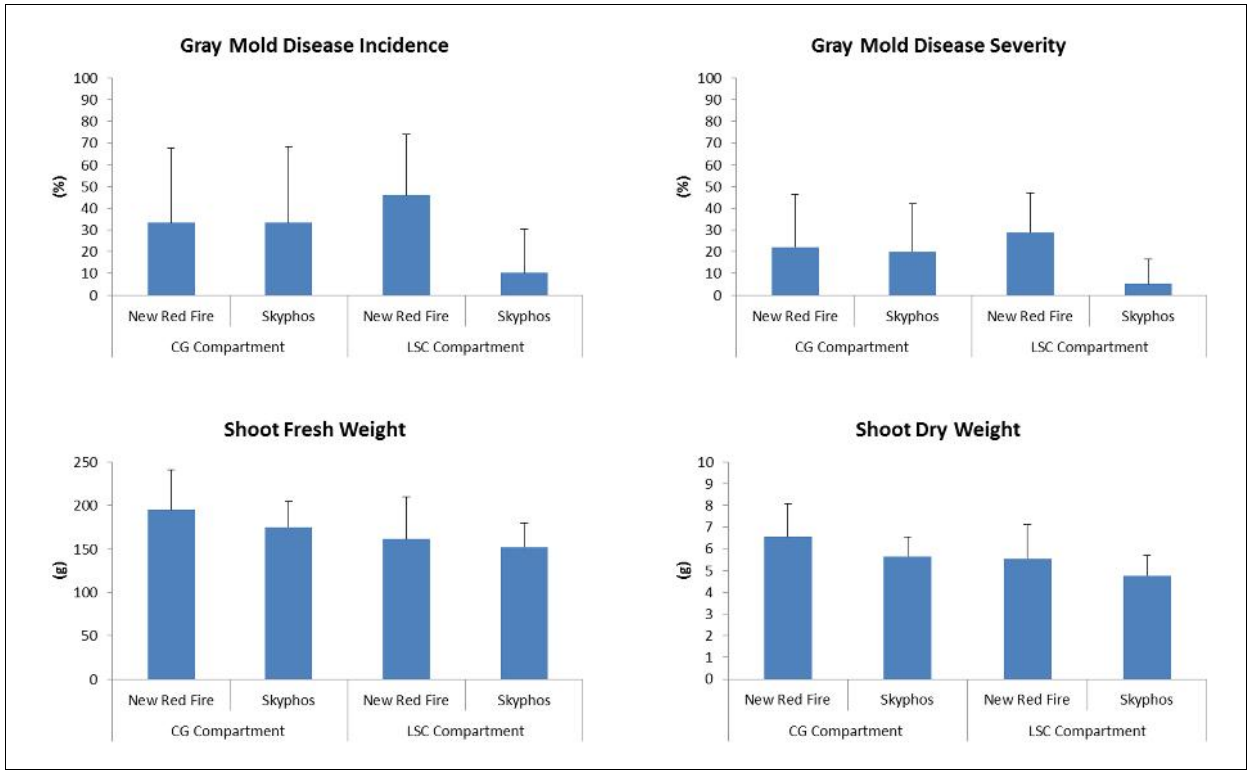
Similar to the difference detected for gray mold disease incidence between varieties in the LSC compartment, gray mold disease severity for Skyphos was 23.6% less when compared to that of New Red Fire in the LSC compartment. Gray mold disease severity was similar for both lettuce varieties in the CG compartment where Skyphos displayed 2.3% less disease severity than that of New Red Fire.

Interestingly, New Red Fire gray mold disease incidence and severity was shown to be greater in the LSC compartment when compared to the CG compartment inferring this variety responded differently between compartments to gray mold disease.

Shoot fresh weight between varieties differed by 20g in the CG compartment where greater biomass was produced by New Red Fire than that of Skyphos. Whereas, a 9g difference in weight was determined in the LSC compartment between varieties inferring less variation between varieties existed in the LSC compartment. However, shoot dry weight differences between varieties were 0.9g and 0.8g in CG and LSC compartments, respectively, suggesting lettuce response was similar between compartments based on dry weight determinations for shoot biomass.

Similar responses between lettuce varieties were obtained for both compartments where New Red Fire was shown to produce more shoot biomass than Skyphos (Figure 16).

Figure 16: Compartment x variety effect on gray mold disease and lettuce growth.



CG Compartment New Red Fire n = 100, Skyphos n = 99; LSC Compartment New Red Fire n =98, Skyphos n = 99.

Compartment x Treatment x Variety Effect on Gray Mold Disease and Lettuce Growth

Gray mold disease incidence was determined to be 66.7% and 67.4% for New Red Fire and Skyphos lettuce, respectively, for the *B. cinerea* positive control treatment in the CG compartment. The results indicate no difference to the CG compartment and treatment existed between varieties. Whereas, gray mold disease incidence was determined to be 61.8% and 40.9% for New Red Fire and Skyphos, respectively, for the *B. cinerea* positive control treatment in the LSC compartment. The results indicate varieties responded differently to the LSC compartment and treatment. Skyphos displayed 21% less disease incidence when compared to New Red Fire in the LSC compartment indicating Skyphos lettuce responded more favourably to the presence of gray mold disease when compared to New Red Fire.

Similar to the difference detected for gray mold disease incidence between varieties in the LSC compartment, gray mold disease severity for Skyphos was 18% lower when compared to that of New Red Fire in the LSC compartment. Gray mold disease severity was similar for both lettuce varieties in the CG compartment, where Skyphos displayed 4.1% less disease severity than that of New Red Fire.

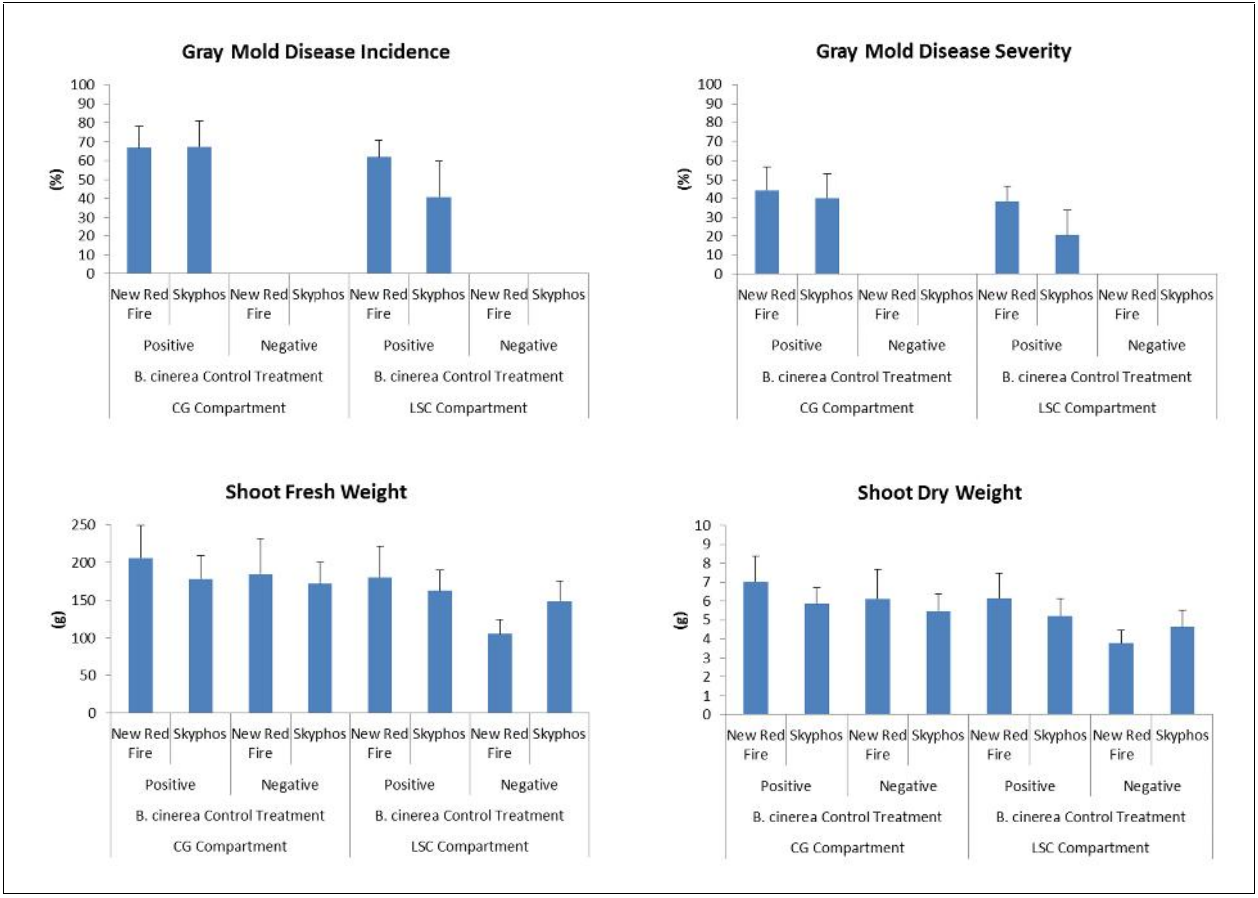
In the CG compartment, shoot fresh weight between varieties and between *B. cinerea* positive control treatments differed by 27.4g, where greater shoot fresh weight was produced by New Red Fire when compared to Skyphos. In the LSC compartment, shoot fresh weight between varieties and between *B. cinerea* positive control treatments differed by 17.5g, where greater shoot fresh weight was produced by New Red Fire when compared to Skyphos. Differences in fresh shoot weight detected between

varieties across compartments where less difference between varieties was determined for the LSC compartment infer less variation in fresh shoot weight between varieties existed in the LSC compartment when compared to the CG compartment.

Shoot fresh weight was greater in *B. cinerea* positive control treatments when compared to *B. cinerea* negative control treatments in both compartments with the exception where New Red Fire was cultivated in the LSC compartment, where shoot fresh weight was less in the positive control treatment.

Similar responses were detected for shoot dry weight (Figure 17).

Figure 17: Compartment x treatment x variety effect on gray mold disease and lettuce growth.



CG Compartment B. cinerea Positive Control Treatment New Red Fire n = 50; CG Compartment B. cinerea Positive Control Treatment Skyphos n = 50; CG Compartment B. cinerea Negative Control Treatment New Red Fire n = 50; CG Compartment B. cinerea Negative Control Treatment Skyphos n = 49; LSC Compartment B. cinerea Positive Control Treatment New Red Fire n = 25; LSC Compartment B. cinerea Positive Control Treatment Skyphos n = 74; LSC Compartment B. cinerea Negative Control Treatment New Red Fire n = 73; LSC Compartment B. cinerea Negative Control Treatment Skyphos n = 25.

Lettuce Bolting

Difficulties were encountered regarding achieving adequate disease infection levels while simultaneously avoiding the occurrence of lettuce bolting, as evidence of *B. cinerea* infection was first observed eight days prior to trial harvest while bolting was first observed three days before trial harvest was initiated. As the objective of the trial was to successfully inoculate lettuce with *B. cinerea*, preference was given to achieving adequate infection levels to ensure collection of incidence and severity data however, bolting of lettuce was present at harvest in both compartments.

When determining presence or absence of bolting at harvest, bolting was considered to be slight regarding the degree of stem elongation.

Based on observations conducted at harvest, incidence of bolting was less for both lettuce varieties in the LSC compartment when compared to the CG compartment (Table 4).

Table 4: Bolting of lettuce in compartments at harvest.

Compartment	Bolting (%)	
	New Red Fire	Skyphos
CG	67	63
LSC	46	49

CG Compartment = 200, LSC Compartment n = 200.

It is unclear why bolting was found to be less in the LSC compartment however, it is possible that exposure to warm temperatures and amount of cumulative light received [17] contributed to the differences observed between compartments. As previously described, CG compartment heating control equipment failure at trial onset resulted in air and reservoir nutrient solution temperatures to be warmer than in the LSC compartment for a period of six days. Refer to the Appendix for more information.

Lettuce Leaf Tissue Nutrient Analyses

Leaf tissue was analysed to determine nutrient content in order to investigate whether differences exist between lettuce variety and *B. cinerea* control treatment. Dry shoot biomass of lettuce was collected from *B. cinerea* positive and negative control treatment plants of each variety in both compartments and submitted to a laboratory (Exova Canada Inc., Surrey, BC) for analysis. Analyte detection values were provided for each nutrient and in addition, target range classifications for analytes except sulfur, molybdenum and sodium were also provided by the laboratory. Target ranges provided by the laboratory relate to plants in general (pers. com. With laboratory) and thus, an additional reference [18] for analyte target ranges specific for butterhead lettuce is provided (Tables 5 and Table 6). Optimal range classifications of analytes provided by the laboratory are presented in the appendix of the report.

Analysis of New Red Fire and Skyphos leaf tissue revealed nitrogen, phosphorous, potassium, sulfur, manganese and molybdenum were present in levels greater than their respective target ranges in both

compartments. In addition, results for the Skyphos *B. cinerea* positive treatment in the CG compartment treatment was found to contain excess boron. None of the samples were found deficient in analytes.

Values of analytes found above reference ranges are highlighted in yellow and values that differ remarkably in *B. cinerea* positive and negative control treatments are highlighted in green. No interpretation is available at this time to provide an explanation for anomalous values detected zinc and iron in control treatments and varieties. However, as additional copper was supplied in the trial it is possible that the affected reservoir received a double rate.

Table 5: New Red Fire lettuce leaf tissue nutrient analyses.

Analyte	Units	Target Range	*B. cinerea* Control Treatment			
			Positive		Negative	
			CG	LSC	CG	LSC
Total nitrogen	%	4.7 – 5.5 (4.2 – 5.6)	6.12	6.49	5.76	5.70
Phosphorous	%	0.5 – 1.0 (0.62 – 0.77)	1.66	1.73	1.98	2.05
Potassium	%	7.5 – 9.0 (7.82 – 13.68)	14.9	14.7	14.7	15.2
Sulfur	%	* (0.26 – 0.32)	0.324	0.352	0.351	0.359
Calcium	%	2.0 – 3.0 (0.80 – 1.20)	1.30	1.26	1.10	1.08
Magnesium	%	0.50 – 0.80 (0.24 – 0.73)	0.43	0.45	0.41	0.43
Zinc	ug/g	25 – 150 (33 – 196)	74.5	74.9	49.1	45.1
Boron	ug/g	23 – 50 (32 – 43)	37.2	36.0	38.7	36.6
Manganese	ug/g	15 – 200 (55 – 110)	333	302	201	145
Copper	ug/g	8 – 25 (6 – 16)	9.9	11.1	8.59	10.3
Iron	ug/g	50 – 100 (168 – 223)	77	75	75	74
Molybdenum	ug/g	* (0.29 – 0.58)	1.3	1.2	1.5	1.5
Sodium	%	*	0.13	0.13	0.13	0.14

** - no target range interpretation was provided by the laboratory for the detected value. Target range values in parentheses are the average tissue analysis range from healthy greenhouse butterhead lettuce* [19].

Table 6: Skyphos lettuce leaf tissue nutrient analyses.

Analyte	Units	Target Range	*B. cinerea* Control Treatment			
			Positive		Negative	
			CG	LSC	CG	LSC
Total nitrogen	%	4.7 – 5.5 (4.2 – 5.6)	6.33	6.66	6.43	6.91
Phosphorous	%	0.5 – 1.0 (0.62 – 0.77)	1.93	2.45	2.24	2.34
Potassium	%	7.5 – 9.0 (7.82 – 13.68)	16.8	14.1	13.8	14.0
Sulfur	%	* (0.26 – 0.32)	0.332	0.272	0.281	0.273
Calcium	%	2.0 – 3.0 (0.8 – 1.20)	2.50	1.75	1.90	1.82
Magnesium	%	0.50 – 0.80 (0.24 – 0.73)	0.70	0.57	0.57	0.56
Zinc	ug/g	25 – 150 (33 – 196)	86.6	65.4	74.5	62.5
Boron	ug/g	23 – 50 (32 – 43)	51.8	39.5	41.1	40.5
Manganese	ug/g	15 – 200 (55 – 110)	268	187	201	204
Copper	ug/g	8 – 25 (6 – 16)	18.1	9.48	10.0	8.81
Iron	ug/g	50 – 100 (168 – 223)	91	70	221	71
Molybdenum	ug/g	* (0.29 – 0.58)	1.0	0.8	0.9	0.7
Sodium	%	*	0.16	0.14	0.14	0.14

** - no target range interpretation was provided by the laboratory for the detected value. Target range values in parentheses are the average tissue analysis range from healthy greenhouse butterhead lettuce* [19].

Conclusions

The results demonstrated that luminescent solar collector panels provided a significant reduction of gray mold disease for lettuce varieties used in the trial. Reduction of disease incidence and severity achieved by lettuce cultivated under luminescent solar collector panels was indicated to be dependent on lettuce variety, as lettuce varieties displayed a varying response to the disease.

As both lettuce varieties displayed a significant reduction for gray mold disease when cultivated under luminescent concentrator panels, it can be concluded luminescent solar collector panels provide a positive influence for lettuce varieties infected with *B. cinerea*, as gray mold disease was neither as prevalent nor as severe for both varieties when compared to their cultivation under clear glass panels.

Review of lettuce growth response data revealed significant interactions between compartments and variables occurred where shoot biomass was less for lettuce when cultivated under luminescent solar collector panels. Shoot height for both varieties were shown not to differ significantly between greenhouse compartments.

Although shoot fresh weight was reduced for both lettuce varieties cultivated under luminescent solar collector panels, biomass achieved should be considered commercially acceptable, as average yields attained for both varieties were within the commercially acceptable target range for fresh weight of lettuce.

Previous research demonstrated plant resistance to *B. cinerea* infection can be influenced by altering genetic and environmental factors that affect the physiological status of the host tissue, as treatments that advance senescence of host tissue make it more susceptible to *B. cinerea* infection, whereas those that delay senescence have the opposite effect.[20]. Based on the results obtained from this trial, it is possible to postulate the effects displayed by both lettuce varieties in this trial are the result of lettuce growth displaying delayed senescence through exposure to conditions within the luminescent solar collector panel environment compared to that of the clear glass greenhouse environment.

As demonstrated in the trial, lettuce susceptibility to gray mold disease was reduced where lettuce was produced under luminescent solar collector panels and as no varieties of lettuce are known to be resistant [21] to *B. cinerea*, utilizing a greenhouse fitted with luminescent solar collector panels would be beneficial to the greenhouse producer in complimenting current greenhouse sanitation and management efforts for reducing incidence and severity of gray mold disease.

Until gray mold disease resistant varieties of lettuce are available to greenhouse lettuce producers, cultivating lettuce while influenced by luminescent solar collector panels appears to provide an immediate solution in providing a defensive action for gray mold disease control.

Further research efforts should be undertaken involving further *B. cinerea* resistance screening using additional lettuce varieties and other greenhouse crops in order to provide more information to greenhouse producers.

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Appendix

New Red Fire lettuce. CG compartment *B. cinerea* negative control treatment leaf tissue analyses.

Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High	Method Reference
Plant Tissue Results									
Total Nitrogen	%	5.76	4.70 - 5.50						AOAC-990.03
Calcium	%	1.10	2.00 - 3.00						AOAC-985.01
Phosphorus	%	1.98	0.50 - 1.00						AOAC-985.01
Potassium	%	14.7	7.50 - 9.00						AOAC-985.01
Magnesium	%	0.41	0.50 - 0.80						AOAC-985.01
Sodium	%	0.13		No Interpretation					AOAC-985.01
Sulfur	%	0.351		No Interpretation					
Zinc	ug/g	49.1	25.0 - 150.0						AOAC-985.01
Boron	ug/g	38.7	23.0 - 50.0						AOAC-985.01
Manganese	ug/g	201	15.0 - 200.0						AOAC-985.01
Copper	ug/g	8.59	8.0 - 25.0						AOAC-985.01
Iron	ug/g	75	50.0 - 100.0						AOAC-985.01
Molybdenum	ug/g	1.5		No Interpretation					AOAC-985.01

New Red Fire lettuce. LSC compartment *B. cinerea* negative control treatment leaf tissue analyses.

Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High	Method Reference
Plant Tissue Results									
Total Nitrogen	%	5.70	4.70 - 5.50						AOAC-990.03
Calcium	%	1.08	2.00 - 3.00						AOAC-985.01
Phosphorus	%	2.05	0.50 - 1.00						AOAC-985.01
Potassium	%	15.2	7.50 - 9.00						AOAC-985.01
Magnesium	%	0.43	0.50 - 0.80						AOAC-985.01
Sodium	%	0.14		No Interpretation					AOAC-985.01
Sulfur	%	0.359		No Interpretation					
Zinc	ug/g	45.1	25.0 - 150.0						AOAC-985.01
Boron	ug/g	36.6	23.0 - 50.0						AOAC-985.01
Manganese	ug/g	145	15.0 - 200.0						AOAC-985.01
Copper	ug/g	10.3	8.0 - 25.0						AOAC-985.01
Iron	ug/g	74	50.0 - 100.0						AOAC-985.01
Molybdenum	ug/g	1.5		No Interpretation					AOAC-985.01

New Red Fire lettuce. CG compartment *B. cinerea* positive control treatment leaf tissue analyses.

Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High	Method Reference
Plant Tissue Results									
Total Nitrogen	%	6.12	4.70 - 5.50						AOAC-990.03
Calcium	%	1.30	2.00 - 3.00						AOAC-985.01
Phosphorus	%	1.66	0.50 - 1.00						AOAC-985.01
Potassium	%	14.9	7.50 - 9.00						AOAC-985.01
Magnesium	%	0.43	0.50 - 0.80						AOAC-985.01
Sodium	%	0.13		No Interpretation					AOAC-985.01
Sulfur	%	0.324		No Interpretation					
Zinc	ug/g	74.5	25.0 - 150.0						AOAC-985.01
Boron	ug/g	37.2	23.0 - 50.0						AOAC-985.01
Manganese	ug/g	333	15.0 - 200.0						AOAC-985.01
Copper	ug/g	9.90	8.0 - 25.0						AOAC-985.01
Iron	ug/g	77	50.0 - 100.0						AOAC-985.01
Molybdenum	ug/g	1.3		No Interpretation					AOAC-985.01

New Red Fire lettuce. LSC compartment *B. cinerea* positive control treatment leaf tissue analyses.

Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High	Method Reference
Plant Tissue Results									
Total Nitrogen	%	6.49	4.70 - 5.50						AOAC-990.03
Calcium	%	1.26	2.00 - 3.00						AOAC-985.01
Phosphorus	%	1.73	0.50 - 1.00						AOAC-985.01
Potassium	%	14.7	7.50 - 9.00						AOAC-985.01
Magnesium	%	0.45	0.50 - 0.80						AOAC-985.01
Sodium	%	0.13		No Interpretation					AOAC-985.01
Sulfur	%	0.352		No Interpretation					
Zinc	ug/g	74.9	25.0 - 150.0						AOAC-985.01
Boron	ug/g	36.0	23.0 - 50.0						AOAC-985.01
Manganese	ug/g	302	15.0 - 200.0						AOAC-985.01
Copper	ug/g	11.1	8.0 - 25.0						AOAC-985.01
Iron	ug/g	75	50.0 - 100.0						AOAC-985.01
Molybdenum	ug/g	1.2		No Interpretation					AOAC-985.01

Skyphos lettuce. CG compartment *B. cinerea* negative control treatment leaf tissue analyses.

Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High	Method Reference
Plant Tissue Results									
Total Nitrogen	%	6.43	4.70 - 5.50						AOAC-990.03
Calcium	%	1.90	2.00 - 3.00						AOAC-985.01
Phosphorus	%	2.24	0.50 - 1.00						AOAC-985.01
Potassium	%	13.8	7.50 - 9.00						AOAC-985.01
Magnesium	%	0.57	0.50 - 0.80						AOAC-985.01
Sodium	%	0.14		No Interpretation					AOAC-985.01
Sulfur	%	0.281		No Interpretation					
Zinc	ug/g	74.5	25.0 - 150.0						AOAC-985.01
Boron	ug/g	41.1	23.0 - 50.0						AOAC-985.01
Manganese	ug/g	201	15.0 - 200.0						AOAC-985.01
Copper	ug/g	10.0	8.0 - 25.0						AOAC-985.01
Iron	ug/g	221	50.0 - 100.0						AOAC-985.01
Molybdenum	ug/g	0.9		No Interpretation					AOAC-985.01

Skyphos lettuce. LSC compartment *B. cinerea* negative control treatment leaf tissue analyses.

Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High	Method Reference
Plant Tissue Results									
Total Nitrogen	%	6.91	4.70 - 5.50						AOAC-990.03
Calcium	%	1.82	2.00 - 3.00						AOAC-985.01
Phosphorus	%	2.34	0.50 - 1.00						AOAC-985.01
Potassium	%	14.0	7.50 - 9.00						AOAC-985.01
Magnesium	%	0.56	0.50 - 0.80						AOAC-985.01
Sodium	%	0.14		No Interpretation					AOAC-985.01
Sulfur	%	0.273		No Interpretation					
Zinc	ug/g	62.5	25.0 - 150.0						AOAC-985.01
Boron	ug/g	40.5	23.0 - 50.0						AOAC-985.01
Manganese	ug/g	204	15.0 - 200.0						AOAC-985.01
Copper	ug/g	8.81	8.0 - 25.0						AOAC-985.01
Iron	ug/g	71	50.0 - 100.0						AOAC-985.01
Molybdenum	ug/g	0.7		No Interpretation					AOAC-985.01

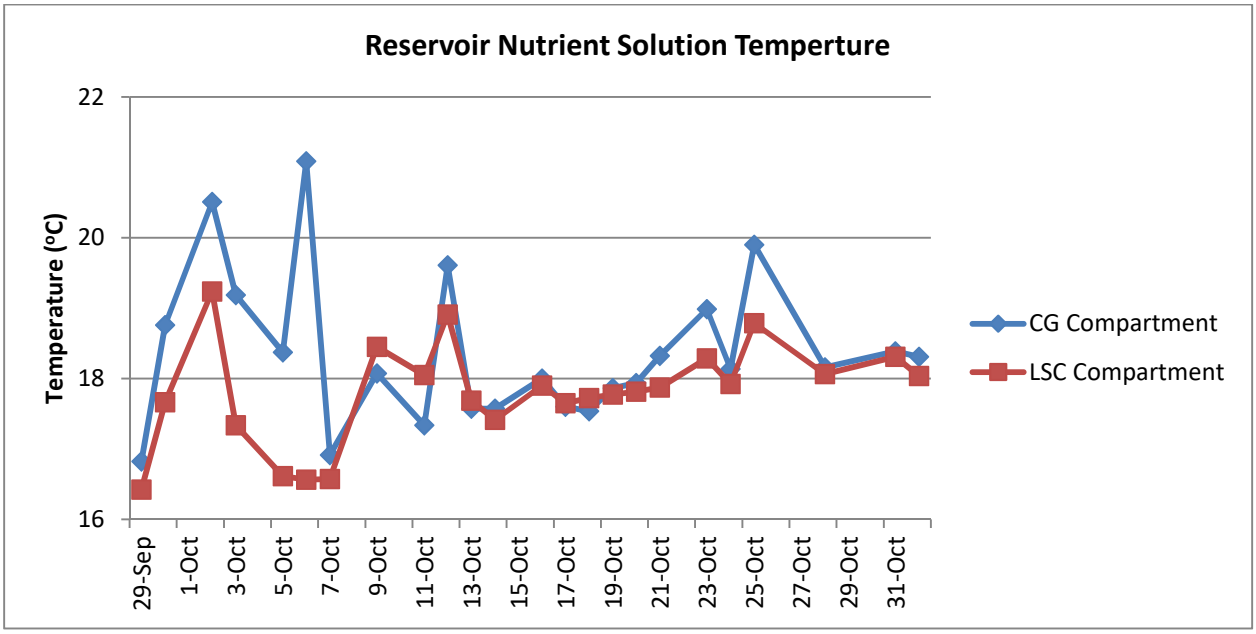
Skyphos lettuce. CG compartment *B. cinerea* positive control treatment leaf tissue analyses.

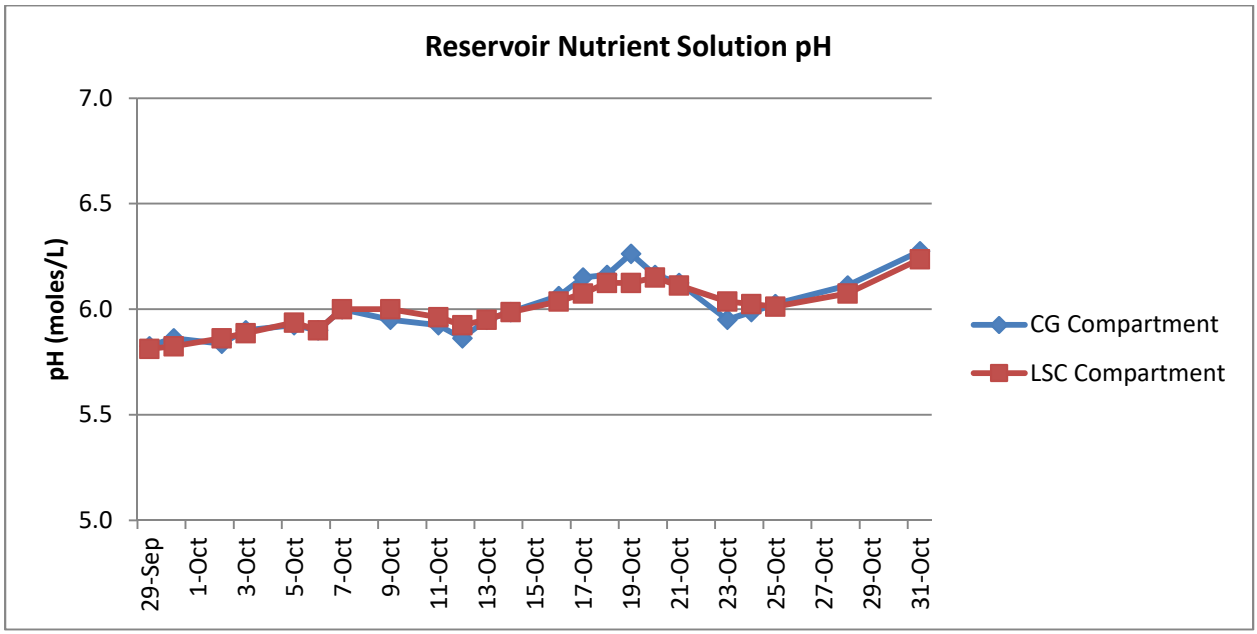
Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High	Method Reference
Plant Tissue Results									
Total Nitrogen	%	6.33	4.70 - 5.50						AOAC-990.03
Calcium	%	2.50	2.00 - 3.00						AOAC-985.01
Phosphorus	%	1.93	0.50 - 1.00						AOAC-985.01
Potassium	%	16.8	7.50 - 9.00						AOAC-985.01
Magnesium	%	0.70	0.50 - 0.80						AOAC-985.01
Sodium	%	0.16		No Interpretation					AOAC-985.01
Sulfur	%	0.332		No Interpretation					
Zinc	ug/g	86.6	25.0 - 150.0						AOAC-985.01
Boron	ug/g	51.8	23.0 - 50.0						AOAC-985.01
Manganese	ug/g	268	15.0 - 200.0						AOAC-985.01
Copper	ug/g	18.1	8.0 - 25.0						AOAC-985.01
Iron	ug/g	91	50.0 - 100.0						AOAC-985.01
Molybdenum	ug/g	1.0		No Interpretation					AOAC-985.01

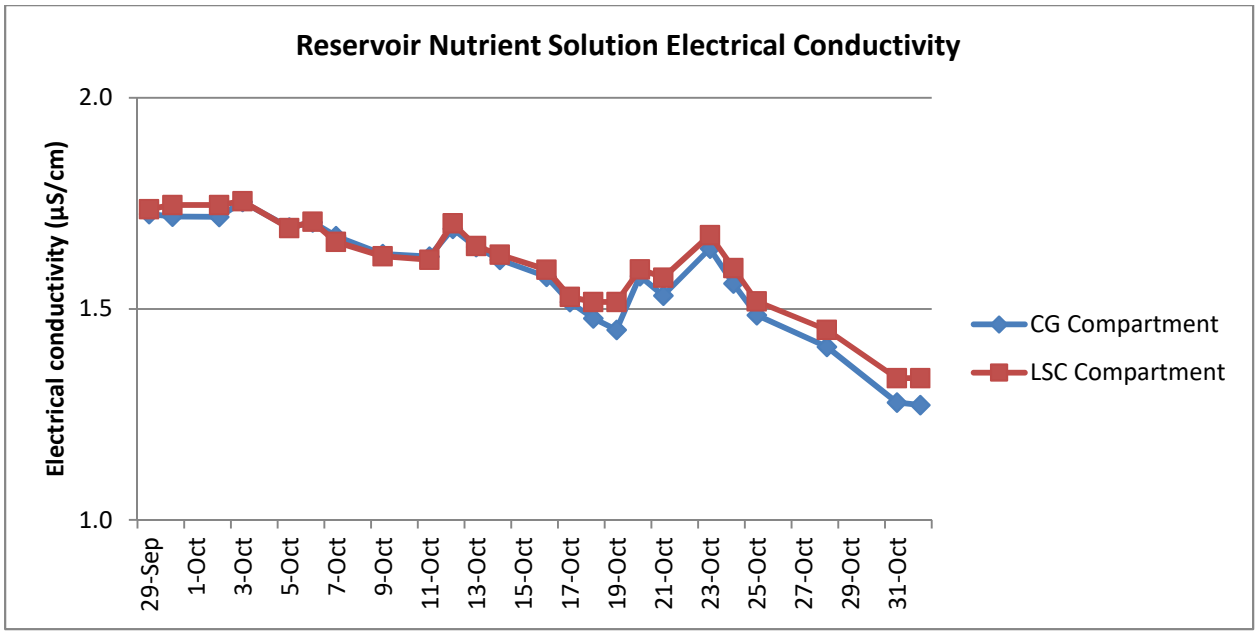
Skyphos lettuce. LSC compartment *B. cinerea* positive control treatment leaf tissue analyses.

Analyte	Units	Results	Target Range	Very Low	Low	Medium	High	Very High	Method Reference
Plant Tissue Results									
Total Nitrogen	%	6.66	4.70 - 5.50						AOAC-990.03
Calcium	%	1.75	2.00 - 3.00						AOAC-985.01
Phosphorus	%	2.45	0.50 - 1.00						AOAC-985.01
Potassium	%	14.1	7.50 - 9.00						AOAC-985.01
Magnesium	%	0.57	0.50 - 0.80						AOAC-985.01
Sodium	%	0.14		No Interpretation					AOAC-985.01
Sulfur	%	0.272		No Interpretation					
Zinc	ug/g	65.4	25.0 - 150.0						AOAC-985.01
Boron	ug/g	39.5	23.0 - 50.0						AOAC-985.01
Manganese	ug/g	187	15.0 - 200.0						AOAC-985.01
Copper	ug/g	9.48	8.0 - 25.0						AOAC-985.01
Iron	ug/g	70	50.0 - 100.0						AOAC-985.01
Molybdenum	ug/g	0.8		No Interpretation					AOAC-985.01

Additional Data and Information



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Electrical conductivity (µS/cm)
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1.5
1.0
29-Sep
1-Oct
3-Oct
5-Oct
7-Oct
9-Oct
11-Oct
13-Oct
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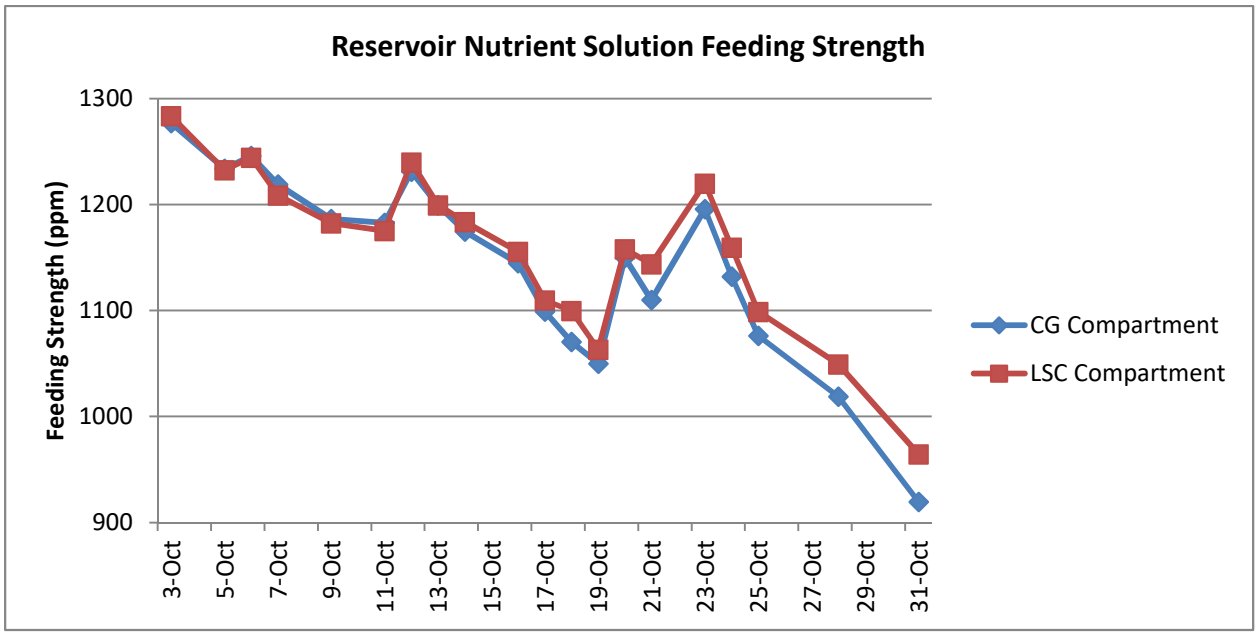
23-Oct
25-Oct
27-Oct
29-Oct
31-Oct
CG Compartment
LSC Compartment


Reservoir Nutrient Solution Feeding Strength
Feeding Strength (ppm)
1300
1200
1100
1000
900
3-Oct
5-Oct
7-Oct
9-Oct
11-Oct
13-Oct
15-Oct
17-Oct
19-Oct
21-Oct
23-Oct
25-Oct
27-Oct
29-Oct
31-Oct
CG Compartment
LSC Compartment

Unknown Effect to Lettuce

Observations conducted five days prior to trial harvest revealed leaf damage to Skyphos lettuce with tissue symptomology considered not to be associated with gray mold. To investigate the origin of the damage, leaf tissue samples from Skyphos were collected and evaluated, and diagnostic tests revealed the presence of bacteria and fungi. In addition, a review of reservoir solution temperature data showed two events where a temperature increase ranging from approximately 0.5 to 2.0°C occurred during the final week before trial harvest.

When first observed, leaf damage appeared constrained to Skyphos, however at trial harvest, both lettuce varieties exhibited damage attributed to this unknown effect. Assessments were conducted by counting the number of affected leaves per plant and providing a severity rating of leaf injury where ratings indicated both varieties were affected (data not presented). At time of writing this report, it remains unclear whether the source of the damage was biotic or abiotic or both.

Further research is currently underway in efforts to identify the cause of the damage.

Skyphos lettuce not displaying damage (October 24, 2016). The same lettuce reservoir is presented in the following two photographs.

Skyphos lettuce not displaying damage (October 26, 2016).

Skyphos lettuce displaying damage. Red circles indicate areas containing damaged tissue (November 1, 2016).

Skyphos lettuce displaying leaf damage at harvest. Red circles indicate locations of damage.