The Effects of LED Lighting on Winter Greenhouse Grown Sugar Snap Peas

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Acknowledgements

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Background

As both a horticulture student interested in sustainable and progressive growing methods and the co-owner of a small but diverse farm, I have become convinced that for our business, achieving "sustainability" requires the adoption of the following principles: the creative and thrifty use of available resources and assets; experimentation and integration of both "old school" methods and new ideas; a management strategy that safeguards not only our environment and it inhabitants, but the health and well being of our family; and the adherence to economically viable methods of enterprise management. In keeping with these guiding principles, in 2010 we began a 2 year project on our farm through the support of Sustainable Agriculture Research and Education (SARE). The project focuses on creating a profitable year-round cropping system by utilizing our greenhouses, straw-bale culture and LED (Light emitting diode) lighting.

The main components of the SARE project were designed to meet the requirements of our guiding principles: The utilization of a bedding plant production greenhouse that is normally dormant for 7 months a year, for multiple seasons. The creation of a cropping schedule that minimizing non-renewable energy inputs and seasonal work stress. The recycling of farm by products such as straw-bales and compost. The employment of a promising new technology in conjunction with a flexible growing method. And finally, the creation of an additional revenue stream for our farm. Straw-bale culture was chosen to maximize farm by-products, maintain flexibility by growing above ground and limit weeding requirements. A number of potential crops have been be part of this experiment, along with various scheduling options and different LED lighting and heating inputs. This Masters Integrated Project is an extension of the SARE project and focused on the production of 'Sugar Snap' peas (*Pisum sativum*) during the winter months. The primary objective of this research is to establish a supplemental lighting protocol for the profitable production of 'Sugar snap' peas in a winter greenhouse. Due to their initial expense, determining the impact on yield of various LED lighting treatments is critical to this objective.

Abstract

The use of light emitting diodes (LEDs) as a supplemental grow light was studied at a small sustainably managed farm in Afton, Minnesota. Both their effectiveness as a supplemental light source and their economic viability as a grow light for winter edible pea pod production were evaluated. Two different lighting treatments were given to *Pisum sativum,* Sugar Snap Peas, grown in straw-bale culture from Jan 8 to May 4, 2011. The treatments were, 20 hours of supplemental 40 watt red light spectrum and 20 hours of supplemental 30 watt red, plus 8 watt full spectrum light. The control was no supplemental light. Treatments were randomized and replicated 4 times. Each treatment area covered a 9 sq ft block, containing 2.5 linear feet of peas. The greenhouse was maintained at a minimum night time temperature of 42° F. Time to first blossom(TFB), shoot length(SL), first harvest (FH), total yield (TY), total yield by treatment (TYT) and total yield by block (THB) were monitored and recorded. FH of the 8 blocks with LED lighting treatments averaged 17 days earlier than the 4 blocks with no supplemental lighting. Red, plus full spectrum LED produced the highest TY at 6.0 ounces/ linear

foot (lf). 100% red spectrum LED produced a TY of 5.3 ounces/lf, and no supplemental lighting produced a TY of 1.9 ounces/lf. All plants displayed leaf necrosis beginning about 21 days post transplant. The plants with no supplemental lighting had substantially more necrosis and SL averaged only 50% of the length of the two LED treatments. While the cause of the necrosis was not determined, it is likely that the reduced leaf surface caused a substantially reduced yield in some or all of the blocks. The 4 highest yielding blocks produced .5lb/lf of pea pods, resulting in a significant economic loss. A follow-up experiment with alteration to timing and protocol is suggested that could reduce expenses and increase yield. Based on the results of this experiment, it is believed that supplemental lighting with LEDs, both all red spectrum and red+ 20% full spectrum, significantly improve the yield of sugar snap peas when grown in a winter greenhouse. There was no statistically significant difference in the yields and harvest data between the two lighting treatments. The yield outcomes achieved during this experiment were not economically viable and would require significant cost reduction or alterations in protocol.

Introduction.

Finding products, that fill niche market, is often one of the strategies that small scale farms employ to boost economic viability. There is often an additional benefit to producing these unique, or high value crops, if there is also a 'first to market' seasonal advantage. Sugar snap peas have a number of attributes ,that if brought to market early or out of season, and economically, could potentially provide just such a crop for a small farm. Some of the positive attributes of sugar snap peas include: availability of string less pods, they can be eaten fresh, cooked or from frozen, if stored properly they have a good shelf life, they have a sweet flavor and they come 'pre-packaged' . They are a challenge, however, to harvest, and because they require cool temperatures are difficult to grow in successive plantings. These attributes limit them to a minor crop for many small growers, but increase their value in certain situations. According to Nick Walters, produce Manager for Mississippi Market in St. Paul, MN, there is only a reliable local source of sugar snap peas in Minnesota from mid- June to early July. Not only would they be willing to pay upwards of 2x the current price of $3.00/lb wholesale, for early or out of season locally grown sugar snap peas, but they would do so even if organic certification was not achieved (Walters, phone conversation, Jan 2011).

Due to the short growing season in Minnesota, creating unique, locally grown 'first to market' products often requires some type of protection or covered structure. These could include: row covers, cold frames, greenhouses or even multiple coverings. Extensive research by Eliot Coleman has established that a number of crops can be grow in winter months with minimal energy inputs, in climates similar to ours here in the Twin Cities (Coleman, 2010). Low winter temperatures are limiting, but not necessarily prohibitive, for crops such as: maché, spinach and arugula. Growing these crops in winter, does however, require them to be grown in-ground, with multiple coverings. They must also be established in early fall and, are more accurately described as being "held" rather than grown in winter months. The need for a supplemental heat source is also likely here in the Twin Cities to ensure crop survival in winter. But to successfully grow a non-"greens" type crop would require a different approach.

Sugar Snap peas, because of their growth habit and temperature requirements, could be well suited for greenhouse production in winter. Sugar snap peas are successfully grown in greenhouses in countries such as Australia and Ethiopia and, because they are self pollinating, there is no need to bring in a pollinator. The economic viability of *winter* greenhouse grown sugar snap peas is in large part a function of the energy inputs required to overcome the cold, short-day months of February, March and April. Previous research as to the viability of growing sugar snap peas, in a cold climate, during winter months , could not be found. However, there is documented information that provides some clues as to their temperature requirements. Pea seeds will germinate at temperatures between 39° and57° and prefer that temperatures stay below 80° (Drost, 2010) While optimum temperature levels for the vegetative and reproductive periods of peas are reported to be 69° and 60°F, and 60° and 50°F (day and night) respectively (Duke, J.A. 1981), peas can tolerate temperatures as low as 28°F without damage (Slinkard *et al*. 1994). A 2003 Oregon State Commercial Vegetable Guide for Edible Pea-

Pods directly links 'heat units' to harvest times, stating that in cool regions, "In general, April plantings will require about 70 days to harvest, May plantings about 60 days and June plantings about 55 days."

While published research on day-length/light requirement could not be found, there is some evidence that along with temperature, day-length/light has a role in edible pea pod growth. For example, a production manual produced by University of California Cooperative Extension, notes that although grown year-round in various moderate climate areas, there are seasonal differences in harvest times for edible pea pods. They *do not* however, attribute those differences specifically to day-length/light (Gaskell, 1997). Miles and Sonde claim that *edible pea shoots,* grown in winter, do benefit from supplemental lighting November thru March (Miles and Sonde, 2003), but do not detail the specifics. Because pea shoots never produce blooms or pods, the benefits of supplemental lighting may be different than for that of edible pea pods. Although likely a growth factor, it is unclear as to what the specific day-length/light requirements would be for sugar snap peas grow in a winter greenhouse.

Documented greenhouse lighting studies, specifically dealing with edible pea pods, could not be found, but numerous greenhouse lighting studies have been published. Studies with lettuce and other green leafy vegetables have shown that high pressure sodium (HPS) or low pressure sodium (LPS) lamps increased plant yield (Koontz *et al.* 1987; Cathey and Campbell 1979). A research report by Michigan Agricultural Experiment Station in 1965 showed that "supplemental light increased lettuce yields up to 150%, and the time required for growing a crop could be reduced by as much as one-third" (Wittwer ,1965 in Miles and Sonde, 2003). But what about the effects of the much more energy efficient light-emitting diodes (LEDs)?

The history of using LEDs for plant growth began in 1990 with research done at the University of Wisconsin (Morrow, 2008). Their advantage as a grow light, over traditional horticultural lighting, include: efficiency of energy use, durability, long lifetime, cool temperature and specific wavelength options (Massa, 2001). Much of the early research was conducted by researchers affiliated with NASA ,with the goal of developing plant based life support systems for future Moon and Mars bases (Morrow, 2001). Early trials were limited to the use of red LED arrays, because the technology was not advanced enough to supply sufficient blue irradiance (Morrow, 2001). Subsequent research has established that the addition of anywhere from 1% to 20% blue light can improve seed development and yield in various plant species (Yorio, 1998)when LEDs are the ***sole*** light source. But, when LEDs are used as a ***supplemental*** light source, it is unclear if the blue light in the available natural day-light, is sufficient to fulfill that requirement. While there is a solid body of evidence that LEDs can have effects comparable to other grow lights when used as the sole light source, their use as supplemental lighting has many variables that are not yet well documented.

A recent $4.8 million grant, partially funded by the USDA, was awarded to a collaborative project between 4 universities called “Developing LED Lighting Technology and Practices for Sustainable Specialty-Crop Production” (GPN, 2010). This funding suggests that LEDs have the potential to become a much more widely adapted greenhouse grow light . Research in other countries; such as the Netherlands (Ouzounis , 2011), are seeking to prove their effectiveness as an energy saving option over traditional greenhouse lighting. It is their perceived improvement as a 'green' technology, that make them appealing to those interested in sustainability, and their capability of providing specific light spectrums that makes them unique as a grow light. LEDs have been shown to require 70-80% less energy that traditional greenhouse lighting. Paired with their 50,000 to 100,000 hour lifetime (Morrow, 2008) if effective as a supplemental light source, they become a promising option for greenhouse production.

LED's most undesirable feature, as with many 'green energy' technologies, may be their expensive *initial* cost. That cost however, has been declining, as evidenced by the 20% decrease in price in the past year alone for the light purchased for this experiment. Despite this reduction, finding a means of subsidizing their initial cost through grants, wholesale pricing or other incentives is certainly desirable . Without subsidies of some kind, 'green' energy in general , would be utilized to a much lesser degree by individuals and small businesses. Determining how much light, for how long and of what spectrum are the primary variables that directly affect their *long-term* economic expense and viability. This study hypothesizes that the addition of supplemental lighting does improve growth of sugar snap peas when grown during winter months in Minnesota and focuses on comparing 2 different LED light spectrums.   Additionally, an evaluation of their economic viability is presented.

Materials and Methods

To measure the effects of different light spectrums of LEDs on the growth of sugar snap peas, a two part experiment was conducted in a 224' space, of a 14' by 36' greenhouse, at Little Foot Farm in Afton, Minnesota.

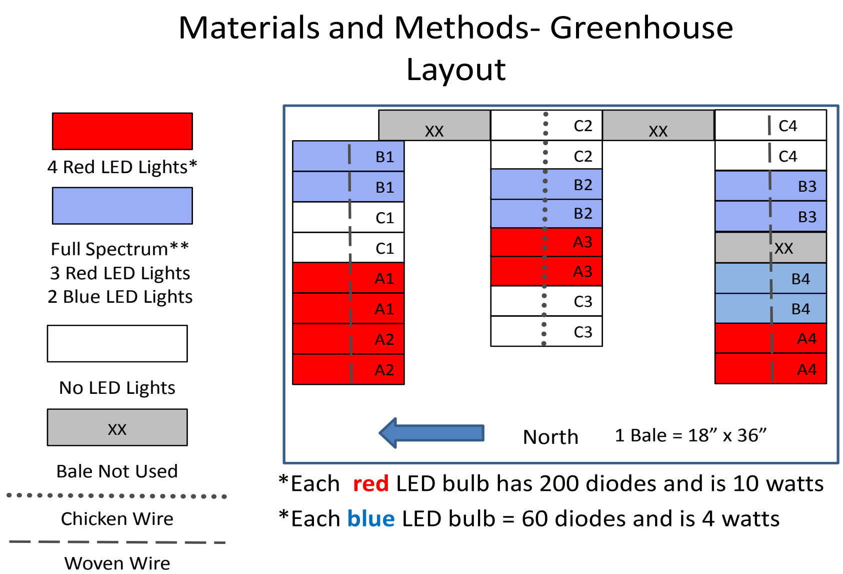

Figure 1. Greenhouse Layout - Sugar Snap Pea LED Lighting Evaluation - Jan. 8, 2011- May 4, 2011

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A ***preliminary*** experiment was conducted from October 15, 2010 to December 30, 2010, to determine some of the basic requirements for winter greenhouse grown sugar snap peas, specific to Little Foot Farm. The snap pea variety 'Cascadia' was grown on straw-bales, with either organic potting mix and Suståne organic fertilizer, or compost from the farm along with worm castings. One half of the peas were direct seeded, and the other half were transplanted.   All of the peas were given supplemental lighting for 6 hours with either 100% red spectrum LEDs or 80% red spectrum and 20% full spectrum LEDs.   The lighting treatments were given from 3:00 pm to 9:00 pm to extend the day-length to approximately 13-14 hours. The nighttime temperature was maintained at 40° F . No pea pods were actually harvested, but based on the growth results of this ***preliminary*** experiment, a protocol was established for the ***primary*** experiment.

For the primary experiment, straw-bales were prepared with a top-dressing of 2-3 inches of Sunshine Organic potting mix. The shorter cultivar 'Cascadia', despite its easier management requirements, was replaced by taller, but higher yielding, Johnny's 'Super' Sugar Snap Peas. It was determined that the use of transplants was more energy efficient and also provided the best germination results. The peas were seeded indoors, in 601 packs, and transplanted as 11 day old seedlings. To extend the harvest times, two separate plantings were done. The first group of peas was seeded on January 8, 2011 and were transplanted on January 19, 2011. The second group was seeded on January 19, 2011 and transplanted on February 2, 2011. Transplanted seedlings were spaced 2" apart in two rows, one on each side of a 48" wire trellis, for a total of 24 plants per treatment. Each row of peas were then side-dressed with Suståne at a rate of 8 oz. per 36".   The minimum night-time temperature was held at 42° F.

In an effort to maximize the lighting treatment effects, two LED lighting treatments were given for 20 hours per day. Treatment A consisted of four, 10 watt red spectrum lights for each 2.5 lf (2 bales) of pea seedlings. Treatment B, consisted of three, 10 watt Red spectrum plus two, 4 watt full spectrum lights for each 2.5 lf of pea seedlings. According to Mark Fleck, Founder of *Grow with LEDS,* the two, 4 watt full spectrum lights provided approximately 8% blue spectrum light out of the total wattage(meeting, 12/14/2010). Lights were clamped onto the woven wire at approximately 12" above the seedlings. As the pea plants grew the lights were raised to maintain the lighting coverage area and lighting intensity as much as possible. Treatment C was a control of no supplemental lighting. Due to budget constraints, sample sizes were limited to 4 replications of each treatment randomly located. Bales were checked routinely and watered as needed. First blossom times (TFB) were recorded along with average shoot lengths (ASL) at 30 days and 60 days post transplant. Pods were harvested by block and weighed with a digital scale, 2 times a week ,starting on April 8. Harvest data collected included; time to first harvest (TFH), length of harvest (LH) total yield by block (TYB) and total yield by treatment (TYT)

Results

The first data point recorded was TFB. There was no difference in TFB between Treatment A and B ; both at 67 days post transplant. Treatment C's TFB was 4 day later at 71 days post transplant. ASL was recorded at 30 and 60 days post transplant (Figure 2). The ASL for Treatment A was 27" and 53.2",Treatment B was 27.8"and 55" and Treatment C 14.2" and 26.2".

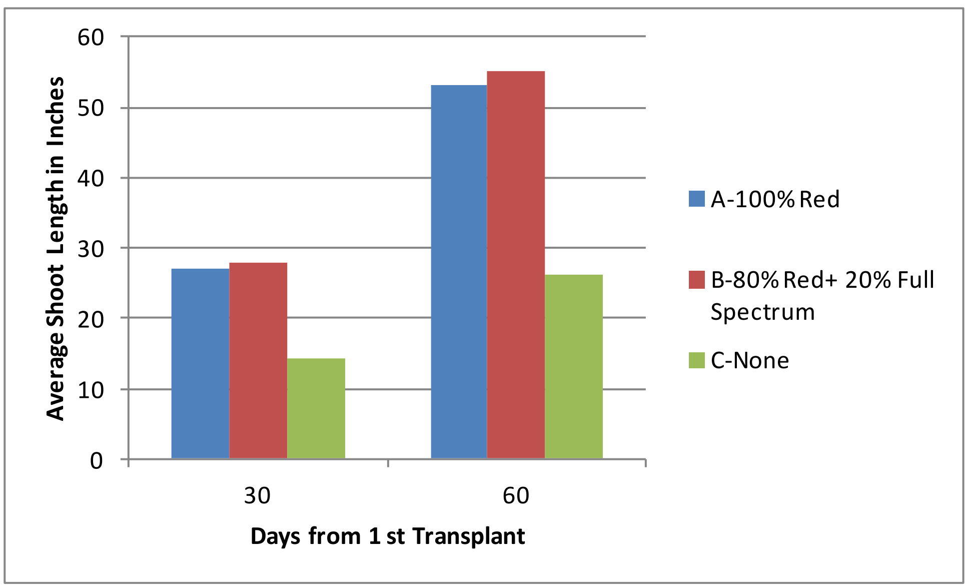

Figure 2. Average shoot length (ASL) (inches) at day 30 and day 60 of LED lighting experiment on Sugar Snap peas

Harvest dates are represented in Figure 3. Both TFH and LH were the same for Treatment A and B. TFH for Treatments A and B was 81 days post transplant and 92 days post seeding. TFH for Treatment C was 88 days post transplant and 99 days post seeding. LH for Treatment A and B took place over a 27 day period. Treatment A averaged 24.5 days per individual block and Treatment B averaged 23.25 days. LH for Treatment C took place over a 20 day period, but individual blocks only averaged 13 days.

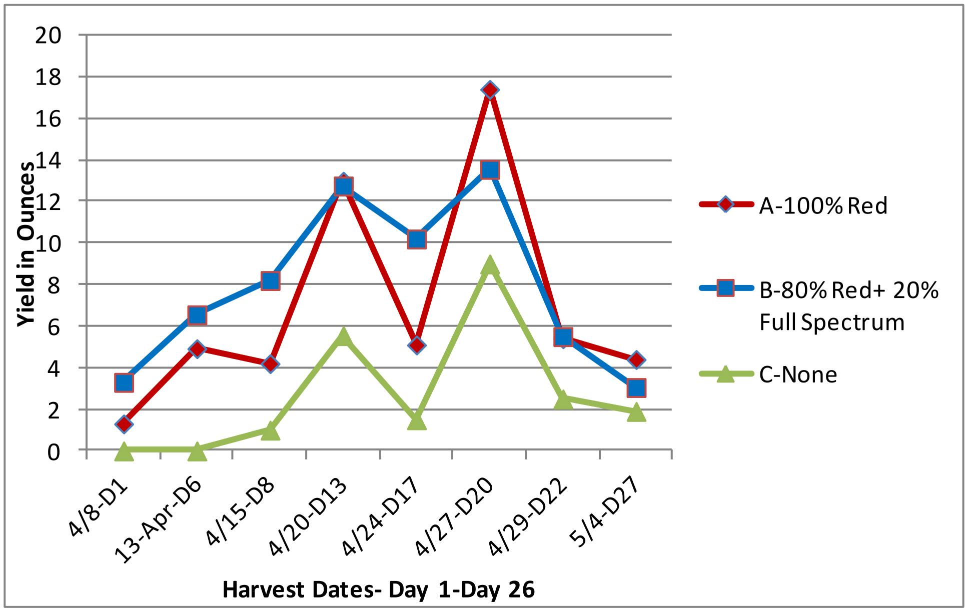

Figure3. Yield in Ounces by Harvest Date for 'Super' Sugar Snap Peas grown using LED Lighting

Yield totals are represented in Figure 4 and Figure 5. The highest and lowest TYB of the lighted blocks were both from Treatment A at 20.87 and 7.95 oz respectively. TYT for Treatments A and B and C were 57.57 oz and 63.10 oz, and 21.45 oz. respectively.

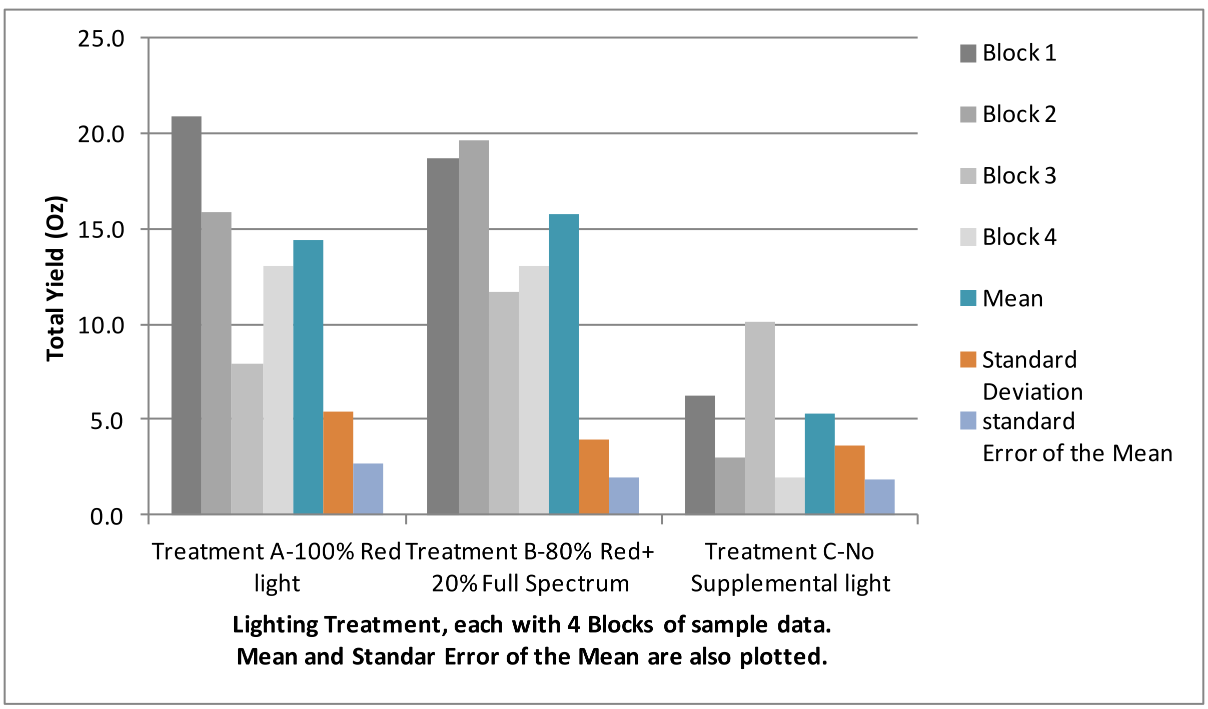

Figure 4.- Total Yield (ounces) Per Block- TYB for Sugar Snap peas grown using LED Lighting

The mean, standard deviation and standard of error are also represented in Figure 4. The standard of error is greater than the difference in mean between Treatment A and B, but is less than between Treatment C and treatments A and B.

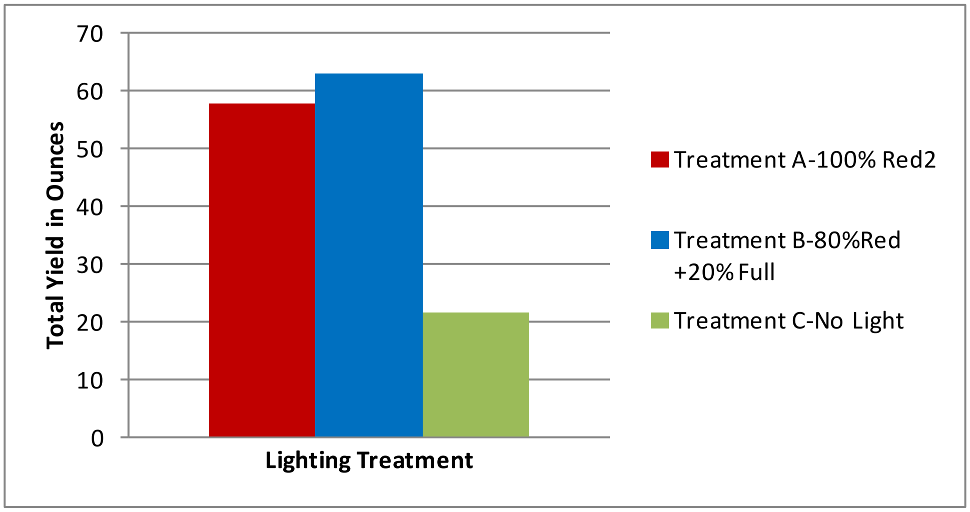

Figure 5. Total Yield (Ounces) Per Treatment-TYT for Sugar Snap peas grown with LED lighting

Discussion

The two most important findings from a grower's standpoint would most likely be that both TYT and TFH were significantly improved by the addition of both supplemental LED lighting treatments. There was an 8% greater yield in the red + full spectrum LED treatment , but that difference may be difficult to attributed solely to light spectrum variance. Location in the greenhouse and effects from disease could also be responsible for the difference. It is however, noteworthy, that the greater yield was attained with a slightly lower total wattage. It would also be an advantage that the yields by harvest date were much more consistent in the red +full spectrum lighting treatments. Although sample sizes were small, it can be seen from looking at the mean and difference in the mean, that supplemental LED lighting treatments did have a statistically significant benefit on yields. There is no statistically significant difference in yield between treatment A and B based on a sample of only 4 replications. The standard deviation was quite large for Treatment A and suggests that in addition to a larger sample size, controlling for other variables would improve the veracity of this research.

There were a number of factors other than lighting treatments that may have had an impact on the results. The most significant of those may have been the development of a disease. Considerable leaf necrosis began developing about 21 days after the first transplant. A number of diseases can effect peas, including: Fusarium wilt, powdery mildew, several viruses and root rot. Unfortunately, tissue analysis was not performed, so assigning a biotic pathogen is not possible. There may have been an abiotic cause as well. Based on a minimum temperature reading of 22°F in the greenhouse during the week of February 7, it is likely that a temporary power outage occurred and could have caused or contributed to the necrosis. Figures 6 and 7 below show some of the diseased plant tissue.

Figure 6.-Sugar Snap Pea Block B2-Feb 28

Figure 7. Sugar Snap Peas Block C2- Feb 28

Another factor that may have influenced the results of this experiment, was the difficulty in raising the lighting as the plants grew. Due to their narrow light arc of approx 60°, at a height of 12", LEDs will only direct primary light in a 1 sq ft area. As a result, it was difficult to maintain the intensity and coverage within desired parameters. It is not believed to have been a significant factor influencing the yield, but it was a labor intensive process. And finally, the blocks that were laid out on the edges of the greenhouse where the sidewalls were lower, were more difficult to trellis, light and harvest, then the blocks in the middle of the greenhouse. Again, this did not necessarily have a major impact on yield, but those blocks did required more management.

Economic Analysis

A budget for this crop including cost of bales, soil, seeds, fertilizer, labor, electricity and natural gas is summarized in Table 1. This report assumes the retail price for LEDs purchased, even though they were funded through a research grant for this experiment.

Expense Item	Number of Units	Cost /unit	Total Cost	Cost/Crop	Cost/Sq Ft/Crop
Bales	24	$ 2.50	$ 60.00	$ 30.00	$ 0.13
Soil	(6)2.8 cu ft bags	$ 11.00	$ 66.00	$ 49.50	$ 0.21
Seeds	1/2 lb/1000 sds	$ 6.50	$ 3.25	$ 3.25	$ 0.01
Fertilizer	6 lbs	$ 1.20	$ 7.20	$ 7.20	$ 0.03
Electricity	468 kWh	$ 0.10	$ 49.00	$ 49.00	$ 0.20
Nat. Gas	180 therms	$ 0.71	$ 127.80	$ 127.80	$ 0.53
LED 60 diode Full Spectrum	8	$ 24.00	$ 192.00	$ 6.00	$ 0.03
LED 200 diode Red Spectrum	28	$ 68.00	$ 1,904.00	$ 60.00	$ 0.25
Labor	16 hrs	$ 8.00	$ 128.00	$ 128.00	$ 0.53
			Total	**$ 460.75**	**$ 1.91**
Income					
Sugar Snap Peas Harvested-Spring 2011	9lbs	$ 6.00	$ 54.00	**$ 54.00**	**$ 0.23**
Net Profit (Loss)				**$ (406.75)**	**$ (1.68)**

Table 1. Expense Report- Winter Grown Sugar Snap Peas 2011- 224 sq Ft Greenhouse Space

The total electricity used totaled 6.04 kilowatts a day for 77 days for a total of 468 kWh. Based on a price of $.10439/ kWh, the cost for electricity during this experiment was $48.87. The cost for electricity accounted for 10% of the expense. The amortized cost of the LEDs based on 77 days of lighting for 20 hrs and a lifetime of 50,000 hrs. comes to $66.00. This would allow for the lighting of over 32 crops. The natural gas usage required to heat the 224 sq ft required for this experiment was approximately $130.00. slightly more than the total cost of the lighting. Figure 8. highlights the expense breakdown.

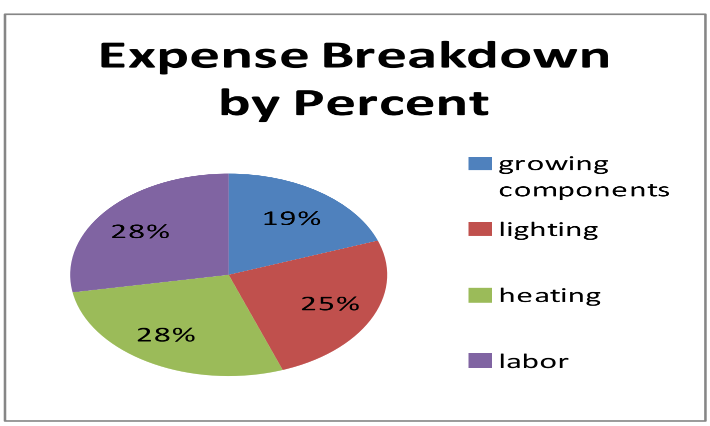

Figure 8. Expense breakdown for Sugar snap peas produced with supplemental LED lighting during January-April of 2011

Estimates on expected yield of sugar snap peas vary widely depending on source. According to Utah State University Cooperative Extension our resulting total yield of 9 lb for 30 lf of peas was in-line with the expected yield of 30 lbs /100 lf for garden grown peas with a spacing of 1-2"(Drost, 2010). Based on University of California Cooperative Extension statistics, yield for field grown edible pea pods were 4000-6000 lbs/acre in 1995-7(Gaskell, 2010). With an average of 25, 000 plants per acre, this calculates to a yield of .2lb per plant, much higher than Utah State's estimates. If a yield of .2lb/plant had been achieved, the TY in this 30 lf of space would have been 57 lbs. Income based on $6.00/lb would have been $345.00. This yield would still not have been enough to produce a profit in this high management environment based on the income /expense report. These numbers suggest that more than just an increase in yield/lf must be achieved to show a profit. A decrease in expenses would also be required.

While the results of this experiment do demonstrate that the growing of sugar snap peas in a winter greenhouse benefit from the addition of supplemental LED lighting, the economic benefit of growing this crop is much harder to establish. Based on total costs and a total harvest of 9 lbs of sugar snap pea pods, at first glance the growing of sugar snap peas during the winter month in Minnesota does not seem remotely viable. These result raise a number of questions and suggest that several alterations would be required to achieve economic viability. Possible follow-up questions to consider might include: What is the minimum time and wattage of LED lighting required to achieve the best possible yield? What effect would the supplemental LEDs have on this crop if grown during early spring or early fall instead of late winter? Could the lighting be effective if permanently hung ,therefore, reducing labor during set-up and growing? What is the ideal minimum temperature to achieve the best economic success? What alterations in spacing could improve yield/LF.

Future Work

A follow up experiment is recommended that would include; alterations in environmental controls, planting dates, greenhouse set-up and plant spacing. Some possible changes that effect energy inputs might include: the delay of planting to March 1 when heating and lighting requirements would be significantly reduced, time to harvest may be shortened and first to market could still be achieved; planting in September, thereby heating and lighting on the backside of crop time- reducing heating cost and maximizing lighting efficiency (while this timing would not provide a 'first to market' advantage, it would provide an out of season advantage); reducing the hours of lighting per day and/or increasing the coverage area by raising the initial lighting set-up; and finally, altering the minimum night time temperature to reduce heating cost or reduce the crop time.

In conjunction with the above possible changes, yields may be influenced by ; taking proactive measure to limit the risk of disease, monitoring for micro nutrient deficiencies and/or by altering planting density to maximize space, especially if horizontal airflow fans (HAF) are used. Based on an average of the 4 highest yielding blocks, .5 lbs./ lf was achieved with high disease pressure. If bales were run lengthwise and plants were not spaced to separate blocks, it is conceivable that the same greenhouse space could support 60 lf rather than 30 lf. For this layout, there would be 720 total plants and 30 total lights equaling 260 watts. In this scenario, the same space yielding .5lb/lf, could have yielded a total of 30 lbs. of edible pea pods. At $6.00/lb, a loss of $114 would have occurred. Table 2. and Figure 9. both reflect hypothetical expenses based on; current (Dec 5, 2011) LED cost per light, a 2 ft light spacing, a 70 day growing period requiring approximately 30 days of supplemental light and heat, 10 hours of supplemental lighting, 60 lf of planting and .5 lb/lf yield. These alterations reduce the heating and lighting inputs to just over one third of total expenses. If disease pressure was managed and yields of**.2lb/plant** were achieved, a yield of 144 lb and a profit of $570.00 could be realized. While strictly speculative, it is believed that these scenarios do offer enough incentive to warrant additional cropping attempts.

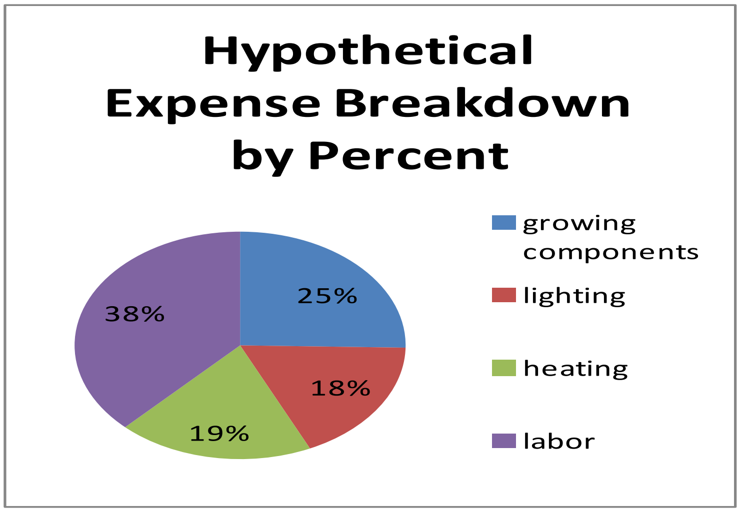

Figure 9. Hypothetical Expense breakdown for Sugar snap pea production from September-November

Expense Item	Number of Units	Cost / ur	Total Cost	Cost Per Cr	Cost/Sq Ft/Crop
Bales	24	$ 2.50	$ 60.00	$ 30.00	$ 0.13
Seeds	1/2 lb/1000 sds	$ 6.50	$ 4.87	$ 4.87	$ 0.02
Soil + Compost	(6)2.8 cu ft bags	$ 11.00	$ 66.00	$ 33.00	$ 0.14
Fertilizer	6 lbs	$ 1.20	$ 7.20	$ 7.20	$ 0.03
Electricity	116 kWh	$ 0.10	$ 12.06	$ 12.06	$ 0.05
Nat. Gas	80 therms	$ 0.71	$ 56.80	$ 56.80	$ 0.24
LED 90 diode Full Spectrum-**2011**	10	$ 20.00	$ 200.00	$ 6.25	$ 0.03
LED 200 diode Red Spectrum-**2011**	20	$ 54.00	$ 1,080.00	$ 33.75	$ 0.14
Labor	14 hrs	$ 8.00	$ 112.00	$ 112.00	$ 0.47
			Total	**$ 295.93**	**$ 1.24**
Income					
Sugar Snap Peas Harvested-Scenario #1	.5lb/ft =30lbs	$ 6.00	$ 180.00	$ 180.00	$ 0.75
Net Profit /Loss				**$ (114.31)**	**$ (0.49)**
Sugar Snap Peas Harvested-Scenario #2	.2lb/plant=144lbs	$ 6.00	$ 864.00	$ 864.99	$3.60
Net Profit /Loss				**$570.68**	**$2.36**

Table 2. Hypothetical Expense Report- Fall Grown Sugar Snap Peas 2012- 224 sq. ft Greenhouse

Conclusion

This research led to the following key observations and conclusions: Based on the influx of research dollars, the use of energy efficient LED lighting is gaining traction as a more sustainable option for greenhouse lighting. The improvements in spectrum availability, and improving price also bode well for their adaptation across a number of greenhouse applications. Both their initial cost and cost of use, necessitates that their application be in 'high value' crop situations, especially when utilized in a high management environment such as winter grow sugar snap peas. Their effectiveness as a supplemental lighting component of winter grown sugar snap peas was demonstrated through this experiment. The addition of 38-40 watts per 2.5 lf of peas increased yield by 200% and reduced time to harvest by 15-20%. LEDs with 8% blue spectrum did produce slightly better yields and more consistent harvest results than 100% red spectrum when used during February, March and early April in Minnesota, but the increase was not statistically significant. The economic viability of using LEDs as a supplemental light source, for this crop, remains in question and requires further evaluation.

Literature Cited

Cathey, H. M., and L. E. Campbell. 1979. Relative Efficiency of high- and low-pressure sodium and incandescent filament lamps used to supplement natural winter light in greenhouses. J. Amer. Soc. Hort. Sci. 104(6):812–825.

Coleman, Eliot. 1998. The Winter Harvest Manual: Farming the Back Side of the Calendar. Four Seasons Farm, Harborside ME. pg. 1-2.

Drost, Dan. 2010. Peas in the Garden. Utah State University Cooperative Extension.

Duke, J.A. 1981. Handbook of Legumes of World Economic Importance. Plenum Press, New York. p. 199- 265

Gaskell, Mark. 1997. Edible Pea-Pod Production in California. Vegetable Research and Information Center. University of California Cooperative Extension.

Greenhouse Product News . Purdue Receives Grant to Study LED Lighting November 1, 2010

Koontz, H. V., R. P. Prince, and R. F. Koontz. 1987. Comparison of fluorescent and high pressure sodium lamps on growth of leaf lettuce. Hort. Sci. 22:424–425.

Massa, Gioa G., H.H. Kim, R.M. Wheeler, and C.A. Mitchell. 2008. Plant Productivity in Response to LED Lighting. Hort. Science 43:1951-1955.

Miles, C.A. and M. Sonde, 2003. Pea Shoots. PNW567 A Pacific Northwest Cooperative Extension Publication. Washington State University. pg. 5.

Morrow, Robert C. 2008. LED Lighting in Horticulture. Hort Science 43:1947-1950.

Morrow, Robert C., R. J. Bulb, and T.J. Tibbits. 2001. Light Emitting Diodes as an Irradiance Source for Plants. ASGSB Bulletin vol 3.

Slinkard, A. E., G. Bascur, and G. Hernandez-Bravo. 1994. Biotic and Abiotic Stresses of Cool Season Food Legumes in the Western Hemisphere. 195-203. In: Muehlbauer F. J. and Kaiser W. J. (Eds.) Expanding the production and use of cool season food legumes. Kluwer Academic Publishers. Dordrecht, The Netherlands.

Yorioi, N. C., R. M. Wheeler, G.D. Goins, and G.W. Stutttie. 1998. Blue Light Requirements for Crop Plants in Bioregenerative Life Support Systems. Life Support Bioseph. Science. 5:119-128.

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