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The Profitability of Growing Cannabis Under High Intensity Light

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ABSTRACT

The purpose of this study was to analyze the relationship between light intensity, cannabis yields, and profitability. We also look for evidence that spectrum differences across broad-spectrum, horticulture lights and general-purpose LEDs impact the relationship between yield and light intensity. Finally, we discuss the financial return of increasing light intensity in order to increase yields. We find that yields increase linearly with light intensity up to at least 1500 μmols/ $m^2 \cdot s$, which is at least twice the intensity that is most commonly used by cannabis growers. That relationship did not appear to be influenced by spectrum quality differences across the lamps included in the study. Finally, for all the intensity ranges that we considered, the value of the gain in yields from increasing light intensity far exceeded the cost of using more electricity.

Core Ideas

- Cannabis yields increase linearly with light intensity up to at least 1500 μmols/ $m^2 \cdot s$
- The relationship between irradiance and yields did not appear to be influenced by spectrum quality differences across the lamps included in the study.
- For all the light intensity ranges considered, the value of the gain in yields from increasing light intensity far exceeded the cost of using more electricity.

Introduction

Because cannabis only recently became legal in a few regions of the world, it is common to see cannabis growers, even large commercial growers, embracing production strategies that have not been validated through rigorous scientific experiments. Rather, many conventions have been transmitted across the industry by means like word-of-mouth and internet forums. Lighting is an important example. Most cannabis growers use double-ended, high-pressure sodium (HPS) light during the plant's flowering phase. Most of the LED alternatives are marketed as "HPS replacements." Specifically, they are designed to provide the same light intensity as an HPS light while consuming less electricity. A Canada regional sales manager for one of the world's largest sellers of both HPS and LED horticulture lights estimates that 90% of Canadian cannabis growers use HPS lights. A survey published in a leading cannabis trade journal reports that 62% of North American growers use HPS while 85% use lights that provide around the same or less light intensity as an HPS (CBT Staff, 2016). This suggests that the market has determined that the light intensity provided by HPS lights maximizes the profitability of cannabis production. Nonetheless, this hypothesis has never been tested by a peer-reviewed study.

This is not surprising since prohibition, which has only recently started to end, prevented the vast majority of researchers from considering such topics. Nonetheless, one result from the scant research that does exists suggests that cannabis growers may be under powering their plants, and thus reducing profitability. In particular, Chandra et al. (2008) analyze the photosynthetic response of 20 cannabis plants and find that for some varieties, under certain conditions, net photosynthesis increases at light intensities up to 2000 μmol/m$^{2}\cdot$ s. Although no survey data exists on the topic, any industry insider would agree that the most common lighting strategy for cannabis is placing a 1060W double ended high pressure sodium bulb (HPS) at least 76 cm above 1.48 m^2 of plants. At one meter from the canopy height, this strategy typically delivers around 400 μmol/m$^{2}\cdot$ s of light to the canopy (CREE, 2016). Our own field measurements show that that level can be significantly higher (up to 700 μmol/m$^{2}\cdot$ s) at certain locations in a grow room that receive substantial spill-over light from neighboring tables. Even so, the results of Chandra et al. (2008) imply cannabis growers could potentially significantly increase yields by increasing light intensity. Nonetheless, measurements of leaf photosynthetic rates alone are a poor predictor of final yields (Evans, 1997). Instead, the economic implications of lighting choices must consider the actual weight of the plant's dried flower, harvested at peak ripeness.

For this study, we grew hundreds of cannabis plants under several different LED and HPS lights. Though all the lights could be considered broad-spectrum, each had a different spectrum quality and light intensity. This variation allowed us to estimate the impact of light intensity on yields and to look for evidence that spectrum quality differences impact that relationship. Depending on the plant, previous research has shown that spectrum differences can impact yields. For instance, Kim *et al*. (2008) found that adding green light to an LED that otherwise only emits red and blue increased lettuce growth and biomass. Researchers have also shown that spectrum can change the chemical profile of some plants. However, in this study, we did not consider the impact of spectrum or light intensity on the plant's chemical profile.

Materials and Methods

Research location

Our experiment took place inside an approximately 2,800 m^2 cannabis facility, Greenseal Cannabis Company, in Stratford, Ontario (Fig. 1). The company grows cannabis in an indoor vertical farm, using several types of lighting, including LED and HPS lighting. The growing environment is highly controlled by an automated building control system. At the time of the experiment, Greenseal did not have space dedicated to R&D, so the experiment was run inside a normal production room. Panda paper was used to prevent light from spilling over across treatments, and several small fans were added to compensate for the reduced airflow caused by the panda paper.

Light intensity and spectrum

For this experiment, we varied both spectrum and intensity by using six different commercially available models of LED lighting fixtures and a 1060W double ended high-pressure sodium fixture (HPS). We also included two general-purpose, broad-spectrum LEDs designed for outdoor flood lighting. Table 1 reports energy, light intensity, and spectrum characteristics for each lamp. We installed each lamp according to the manufacturer's recommendations. Then measured light intensity by taking the average of 100 PPFD measurements taken across the 1.22 m by 1.22 m table surface between 64 and 76 cm from the table surface, since we forecasted that the final canopy height would be in that range. Table 1 shows that each light is technical broad spectrum, though there is some variability across the broad-spectrum LEDs. Moreover, the HPS light's spectrum is predominately in the green and red range, while a "pink" LED's spectrum is primarily concentrated in the red range. Average PPFD varies between 490 to 1498 μmols/ $m^2 \cdot$ s.

Below we report results for three runs of the experiment. For each run, there were two replicates for each light treatment. Each light was placed over a 1.49 m^2 table. Each table contained 16 plants. The location of the replicates inside the room was randomly selected. The first run included 288 plants, the second run included 160 plants, and the third included 256 plants. The second run included fewer plants because an error during harvesting caused plants for 4 of the 9 treatments to be mixed together. Thus, we dropped those treatments from the analysis. Between the second and third run of the experiment one lamp stopped working, so we dropped that treatment from the analysis as well.

Each experiment started by placing Cannabis sativa L. cuttings of cultivar "Green Cush" into aeroponic cloning machines. The clones were grown under T8 fluorescent lights for approximately two weeks until roots were approximately 8 cm long. The light intensity during this period was measured using a Spectrometer (Asensetek Passport Pro). It was approximately 110 μmols/ $m^2 \cdot$ s along the canopy surface. The clones were then transplanted into 11-liter pots filled with a peat-based medium (PRO-MIX HP with MYCORRHIZAE). After the transplant, all plants continued to be grown under T8 fluorescent lights for 24 hours a day for an additional five days. The light intensity during this period was, on average, 250 μmols/ $m^2 \cdot$ s across the canopy surface.

All treatments were placed in the same flowering room, where lights were on for 12 hours a day. Lights-on temperature, relative humidity, and CO2 levels were kept constant at 25 ± 2% C, 50 ± 5%, and 1100 ± 25 ppm respectively. Lights-off temperature, relative humidity, and CO2 levels were kept constant at 18 ±

2% C, 50 ± 5%, and 1100 ± 25 ppm respectively. The plants were grown until the Master Grower deemed the flowers had reached peak ripeness, approximately 60 days, and then harvested. The harvested plant shoots were dried until flower samples registered a humidity level of 12%. Finally, the dried flower was weighed for each treatment and each run.

Statistical Analysis

To estimate the relationship between yields and irradiance we ran three OLS regressions using Excel, one for each run, where yield per 1.49 m^2 was regressed against PPFD. The data reported regarding plant morphology, except for plant height and node spacing, are qualitative observations made by the Master Grower.

RESULTS

Morphology observations

The plants grown under the most intense lighting (1498 µmols/ m2· s) had paler leaves that were much more often curled and burned towards the top of the plant (Fig. 2). The paling is indicative of a nitrogen deficiency, and a tissue analysis showed much lower nitrogen levels compared to plants grown under lower intensity lighting. These symptoms were obvious as early as the second week of the flowering stage, and we did not attempt to treat these symptoms by varying temperature, airflow, irrigation, or nutrients. At harvest, compared to the lower-powered LED and HPS treatments, these plants had more narrow internodes (3.91 vs 5.04 cm), and the shoots where noticeably stronger and an average of 5.2 cm shorter (data not shown). Evidently, lower light levels caused plants to stretch towards the light, an effect that has been observed for other container plants (Kim et al., 2008). Moreover, the Master Grower reported that the highest intensity LED treatments had flowers that were noticeably denser. These two morphological characteristics have important implications for profitability since narrow internodes and denser flowers are generally believed to increase the value of yields (e.g., Rauscher, 2017). Finally, all the LED treatments reached peak-ripeness 5 days sooner than the HPS treatment. The Master Grower determined peak ripeness by monitoring changes in the color of the flowers' stigmas and trichomes.

Nonetheless, for our experiment, we decided to harvest all plants when the master grower deemed the HPS plants ready, which always occurred at approximately day 60.

Yields

Average yields increased substantially between the first two runs and the third. The reason is that about 6 months of time separates the end of the second run and the start of the third, and the master grower made changes to his nutrient recipe and pruning technique over this period. Figure 3 plots final yields, measured in average grams of dried flower per table, against light intensity for each run. The results show a positive, seemingly linear relationship between yields and light intensity for the range that we considered. The strength of the relationship, measure by the R^2, is very strong for all runs (0.87 to 0.94). In other words, nearly all of the yield variability is explained by light intensity alone, suggesting spectrum tuning across broad-spectrum lights is not an important factor for yields if we hold intensity constant. It is possible that spectrum tuning could still be important for the chemical profile of the plant in a way that could increase the value of the flower. We did test the chemical profile and found variations, but we only had enough funds to test one sample per treatment, resulting in a sample size that was too small to justify reporting the results.

The financial return of using more electricity

We find that yields increase approximately linearly with light intensity up to about 1500 μmols/ $m^2\cdot$ s, but those high intensity lights used much more electricity than the lower intensity lights. So, we next asked if the additional light intensity and resulting yields justify spending more money on electricity. The regression coefficients allow us to estimate the net return of using additional electricity to generate an additional μmol/$m^2\cdot$ s increase in light intensity. The results are reported in Table 2. For instance, for the first run of the experiment, the estimated coefficient on PPFD is 0.51. Thus, if we increase μmol/$m^2\cdot$s by one, yields are forecasted to increase by 0.51 grams. Power and light measurements performed during our testing suggest that the LED lights produce, on average, around 1.3 μmol/$m^2\cdot$ s of PPFD using one watt of electricity, at their respective mounting heights. Light producers and some researchers have reported much higher efficiency levels. That level depends on the distance of the measuring device from the lights which is often not reported. Nonetheless, increasing the assumed efficiency level would only strengthen the results reported here.

Thus, it takes about 0.77 watts to produce one μmol/m^{2}· s. In the case of our experiment, plants were grown for 60 days and the lights were on 12 hours a day, or a total of 720 hours. So, the additional 0.77 watts would generate an additional 0.55 kWh of electricity. Assuming electricity is 0.11 USD per kWh, the additional watts required to produce an additional 2.68 USD of cannabis would cost about 0.06 USD. Table 2 reports that the estimated revenue generated from spending the additional 0.06 USD ranges from 1.58 to 3.08 USD.

Following this experiment, Greenseal Cannabis Company converted their two-level HPS-lighted flower rooms to 5 and 6 level high-intensity, LED lighted rooms (Fig. 4.). The combination of higher yields per plant and an increased number of plants per cubic meter, nearly tripled their production.

Conclusion

Our results show a positive, apparently linear relationship between intensity and yields continues to at least 1498 μmols/m^{2}· s, which is over twice the level provided by an HPS fixture in the grow configuration that is currently the industry standard. Moreover, holding light intensity constant, regarding yields, all the lamps spectrums appear to perform equally well. In other worlds, we find no evidence that the HPS lamp's spectrum or the various tuned spectrums offered by specialty horticulture LED lights increase yields compared to a general-purpose, broad-spectrum LED lamp. It may be the case that spectrum tuning impacts the chemical profile of the flower, but that question went beyond the scope of this study. Finally, the Master Grower judged that all the LED treatments for each run took about five fewer days to reach peak ripeness compared to the HPS treatments.

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Figures

Fig. 1. The experimental setup at Greenseal Cannabis Company in Stratford, Ontario, Canada.

Fig. 2. Common upper leaf appearance 6 weeks into the flowering phase for the 1498 $\mu mols/m^2 \cdot s$ lighting treatment. Upper leaves commonly show characteristics ranging from curling and paling to leaf tip necrosis.

Fig. 3. Estimated relationship between light intensity (μmols/m²· s) and yields (g/1.49 m²) for three runs of the experiment. For all three regressions, the coefficient on light intensity was significant at the 1% level.

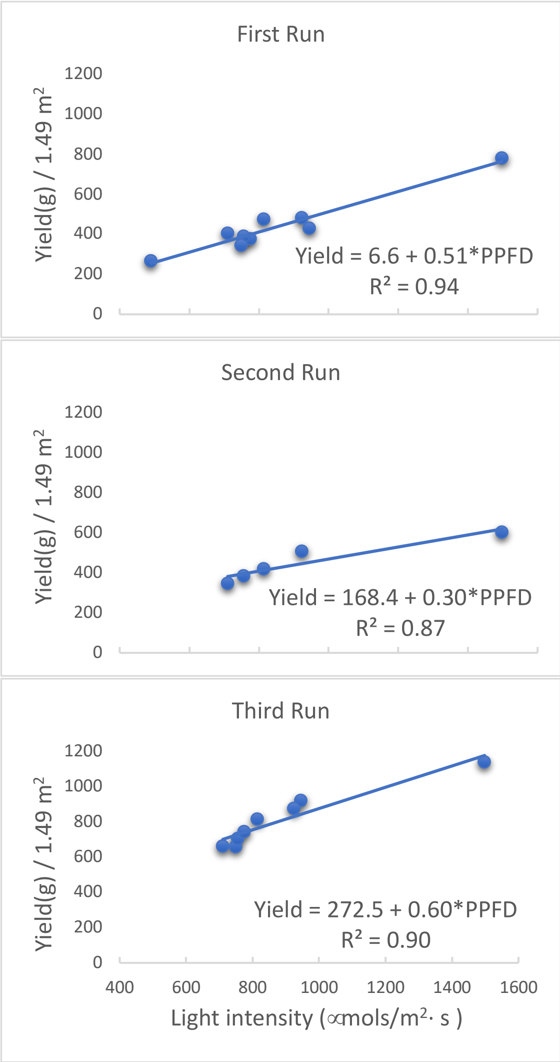

Fig. 4. Following this experiment, Greenseal Cannabis converted their two-level HPS lighted flower rooms to 5 and 6 level high-intensity, LED lighted rooms.

Tables

Table 1. Average irradiance at the canopy level during the flowering period.

	Watts / 1.49 m^2	PPFD	% 400-500 nm	% 500-600 nm	% 600-700 nm
Horticulture LED 1	440	490	13%	24%	63%
HPS	1100	710	20%	40%	40%
Horticulture LED 2	640	750	4%	38%	58%
Horticulture LED 3	660	756	19%	31%	50%
Horticulture LED 4	640	775	24%	26%	50%
General Purpose LED 1	640	815	8%	7%	85%
Horticulture LED 6	640	945	10%	42%	48%
Horticulture LED 7	660	1024	11%	43%	45%

The lamps were illuminated 12 hours per day. The table also reports the percentage of light falling in the 400-500, 500-600, and 600-700 nm wavelength ranges.

Table 2. The electricity cost of increasing light intensity.

(A) Electricity cost (USD/kWh)	0.11
(B) Light Efficiency (μmol/m^2·joule)	1.30
(C) Total hours lights illuminated	720.00
(D) Watts required to generate 1 μmol/m^2	0.76 = *C*(1/B)/1000)*
(E) Cost of generating an additional μmol/m^2	0.08 = A*D
(F) Average retail value of cannabis (USD/gram)	5.25
Value (USD) of forecasted yield increase from an additional μmol	
Run 1 (regression coefficient = 0.51)	2.68 = F*0.51
Run 2 (regression coefficient = 0.30)	1.58 = F*0.30
Run 3 (regression coefficient = 0.60)	3.08 = F*0.60