Autonomous Plant Harvester LED Technical Analysis

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1 Abstract

This technical analysis was done to aid in plant selection and to determine a LED light cycle for the selected plant. Three candidate plants were researched and analyzed for LED light cycle energy usage here. The candidate plants were tomatoes, lettuce, and apogee wheat.

2 Introduction

Varying the light intensities and wavelengths used can significantly affect the growth of the plant and can change the yield and nutritional properties of the crop. For our application, there are many factors to consider in choosing the right LED light cycles. Satisfactory plant growth is most important to us, followed by cost. We have a limited budget and want to focus on the robotics system. The energy usage, size and weight of the LEDs, and lifetime of the LEDs are also considerations that would be especially important in a space environment. This analysis focuses primarily on energy usage and plant growth. Specific qualities of plant growth are prioritized for this application. For example, in a space environment, it would be ideal to maximize nutrients while minimizing crop size, so that is a consideration in selecting LED light cycles.

3 Results and Analysis

The analysis is based on the usage of the Cree® XLamp® XP-E2 LEDs. They offer far more wavelengths than are analyzed here. In this analysis only red (630 nm), blue (475 nm), green (530 nm), white (400-700 nm), and far-red (730 nm) wavelengths are considered. These are similar to the wavelengths which are the ones used in the heritage NASA Advanced Plant Habitat project[1] so should be satisfactory for plant growth in a space environment. I developed my own software to develop LED light cycles and do the energy analysis. It is hosted on a web application found at https://ground-control.vercel.app/ so that different light formulas can be easily modified and compared. The calculations for the energy usage and light intensity are based on the variables from the Cree® XLamp® XP-E2 data sheet and the relation E = V*I*t as well as the directly proportional relationship between the applied voltage and light intensity

The first plant analyzed was the tomato. The tomato has two different stages that require different light cycles. The vegetative growth stage consists of the first two weeks after planting where the tomato is growing stems and foliage. During this stage the plant requires 16-18 hours of light per day. Following this stage is the flowering stage which may last for 4-10 weeks before crops are ready to be harvested. This stage requires less light at only 12 hours per day. During this stage increased red and far-red light has been shown to be capable of increasing the yield[2]. Far red and blue light has been shown to eliminate or minimize intumescence injury[3], which is a disorder associated with abnormal cell division and creates bumps on the leaves of the tomato plant. Based on this, the cycle for the vegetative stage in a tomato plant proposed has high intensity red, blue, and far-red wavelength for 16 hours a day as shown in Figure 1. This results in an energy usage of around 45 Whr/day. The proposed cycle for the flowering stage features high intensity red light, far-red light, and moderate white light and is on for 12 hours a day as shown in Figure 2. It uses 31 Whr/day of energy.

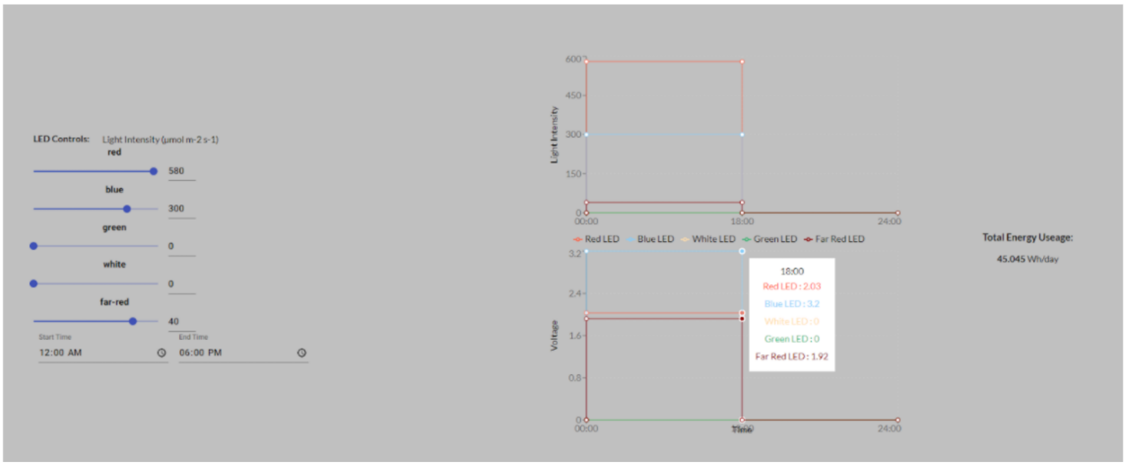

Figure 1: Tomato light cycle for vegetative stage

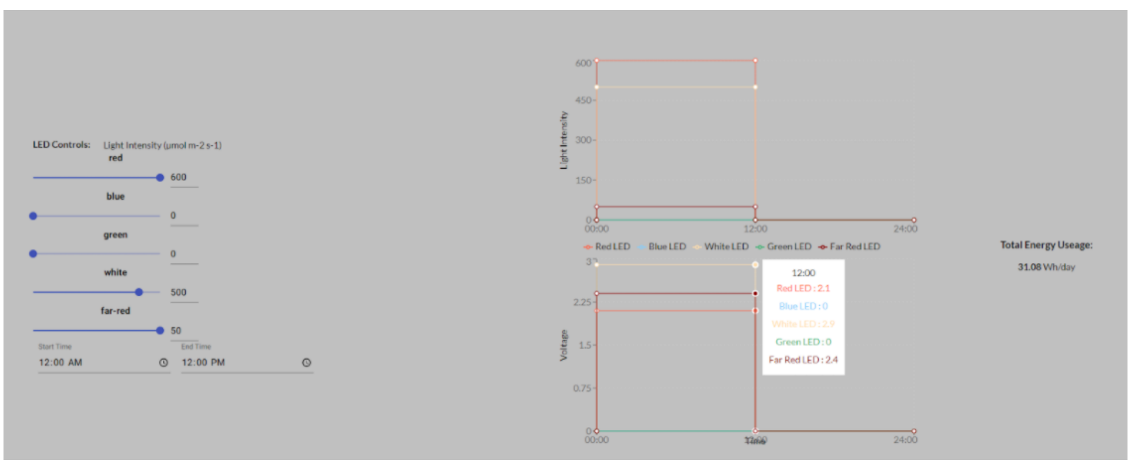

Figure 2: Tomato light cycle for flowering stage

The next plant considered is lettuce. Lettuce takes 6-8 weeks to harvest and does not require different lighting stages. Lettuce can grow under red light alone but higher light intensity and different wavelengths can cause more growth[4]. Adding small amounts of blue light to red light has been shown to improve biomass yield[4] and using white light alone has been shown to positively enhance the nutritional value of the yield[5]. In a space environment, the enhanced nutritional content would be more important than increased biomass. Therefore two suitable light cycle for lettuce are presented here based on this. The first uses high-intensity red, blue, and far-red light for 16 hours a day and is shown in Figure 3. This formula uses 44.8 Whr/day of energy and would be suitable for lettuce growth and improving biomass. The second uses high-intensity red and moderate blue and white light for 16 hours a day and is shown in Figure 4. This cycle would be more ideal in a space environment as it would be more likely to improve nutritional yield, however it uses more energy at 45.9 Whr/day.

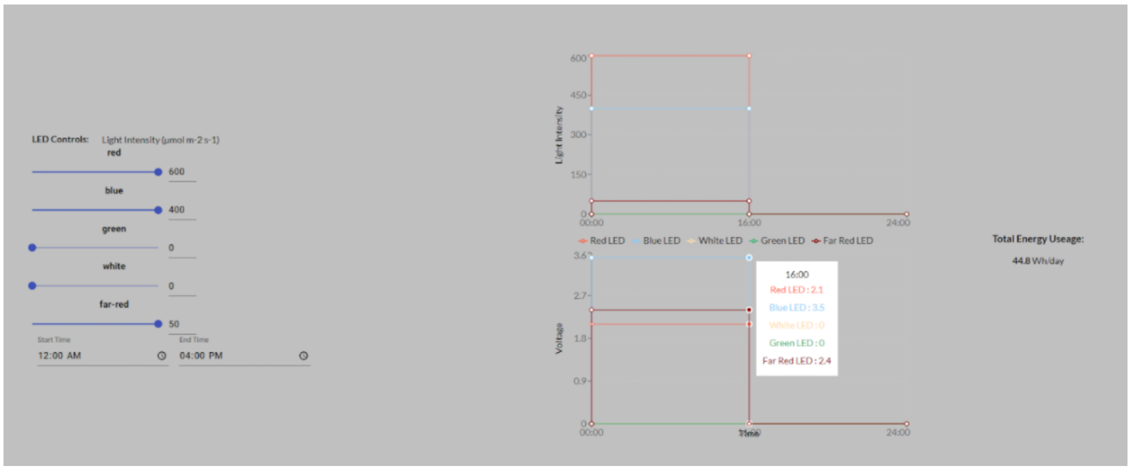

Figure 3: First lettuce light cycle

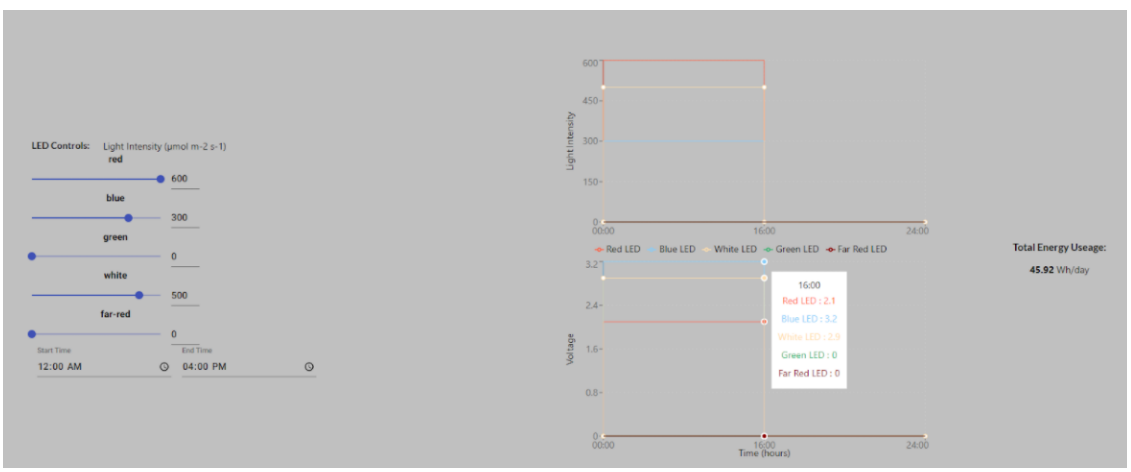

Figure 4: Second lettuce light cycle

Apogee wheat, similarly to lettuce, can grow under red light alone but adding blue light may improve biomass[6]. Apogee wheat typically takes the longest time to harvest of the three considered plants at 12 weeks. Apogee wheat also requires the most light at 22 hours a day, but researchers who have used red and far-red LED light have reduced time to flowering by as much as 50%, which, if reproducible, would make apogee wheat a more suitable choice for our project[7]. Based on this research, a light cycle has been proposed for apogee wheat in Figure 5. The cycle uses high-intensity red, far-red, and moderate blue light and runs for 22 hours a day. It has the highest daily energy use of any formula at 59.3 Whr/day.

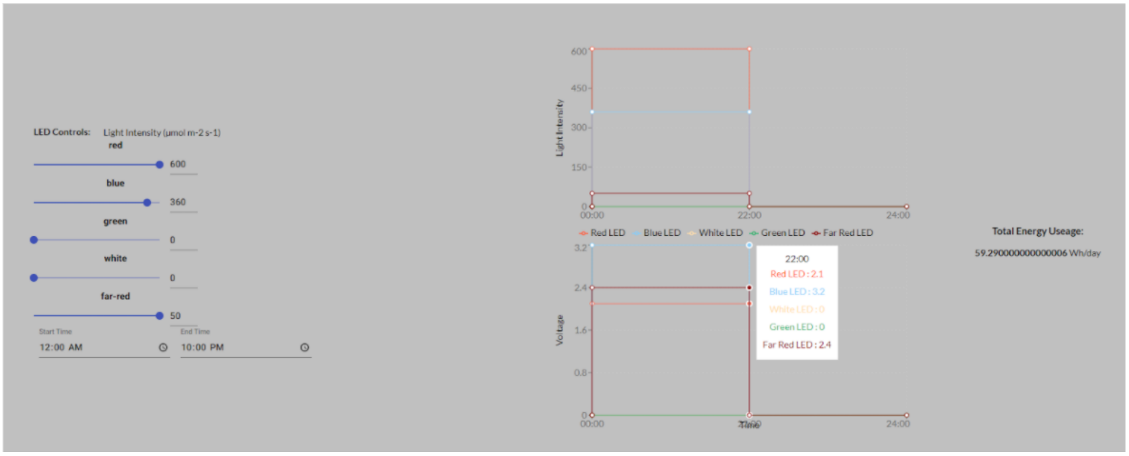

Figure 5: Apogee wheat light cycle

Light Cycle		Vegetative Stage	Flowering Stage	Total energy use
Tomato	Min	630.8 Whr	1261.5 Whr	1.892 kWhr / cycle
	Max	630.8 Whr	3153.8 Whr	3.785 kWhr / cycle
Lettuce #1	Min	1881.6 Whr	~	1.882 kWhr / cycle
	Max	2508.8 Whr	~	2.509 kWhr / cycle
Lettuce #2	Min	1928.6 Whr	~	1.929 kWhr / cycle
	Max	2571.5 Whr	~	2.572 kWhr / cycle
Apogee Wheat	Min	2490.2 Whr	~	2.490 kWhr / cycle
	Max	4980.4 Whr	~	4.980 kWhr / cycle

Figure 6: LED light cycles compared

4 Conclusion

Figure 6 condenses the results of the energy usage analysis over a whole cycle into a single chart. From this chart it is clear that from an energy standpoint, tomato or lettuce would be the best choice of plant to grow. Of these two, lettuce is the simplest to grow because it does not require two separate stages of light formulas for growth. Lettuce also has a smaller time and energy usage difference between the minimum and maximum cycle lengths. Both however are close and the formula could be modified to use less energy if necessary. In the future, the light cycles will likely have to be modified based on the needs of the selected plant and more analysis of different light cycles should be done. Analysis should also be done between different LED grow lights so that the cost and lifetime of the LED lighting systems may be compared and analyzed.

5 References

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