LED FARMING FINAL REPORT

Introduction

Over 6 billion people will live in urbanized metropolitan areas in 2050. Food shortage and overpopulation will be inevitable. To solve this issue, LED farming or vertical farming is being introduced (IT, n.d.). LED farming is a technology that uses LED lights for plant growth. Among other lighting options such as High-Pressure Sodium (HPS) lights or compact fluorescent lights (CFL), LED is the best options for indoor light supply because it is more energy efficient with less waste heat (Conviron, n.d.). Since LED light is used instead of natural sunlight, plants can be grown in a small space or place with lack of sunlight. It is becoming increasingly popular as the future of modern agriculture and many large-scale indoor farming companies such as AeroFarms, Green Sense Farms, and BrightFarms are raising millions of dollars to expand their business (LeBlanc, 2018).

Different type of vegetables or herbs has different requirements in terms of light wavelength, light intensity, the spacing of the plants, etc. In this project, we will look into the effect of light intensity which is directly related to the position of the LED lighting on plant growth. We cannot be certain that shorter the distance between the light and the plant will maximize the growth. We will design an optimized plant pot so there is no light wasted. Also, at the end of this term, we will create an ultimate aesthetically pleasing and environmentally friendly LED plant pot. The position of the LED lighting will be decided from this research and to maximize productivity. Through this research, as a student, we will use the knowledge we gained during our undergraduate studies and gain practical experience by collaborating with different major students by doing multidisciplinary research.

Statistical Approach

There has been a number of innovations in agriculture since the human being has started farming. Conventional farming, which is the way we are most familiar with, contains many environmental, economic problems. As we continue on research other than our experiment, we came to have a solid belief that LED farming could replace conventional farming and solve the current problems at the same time.

The first problem we have noticed is the world-declining in arable land.

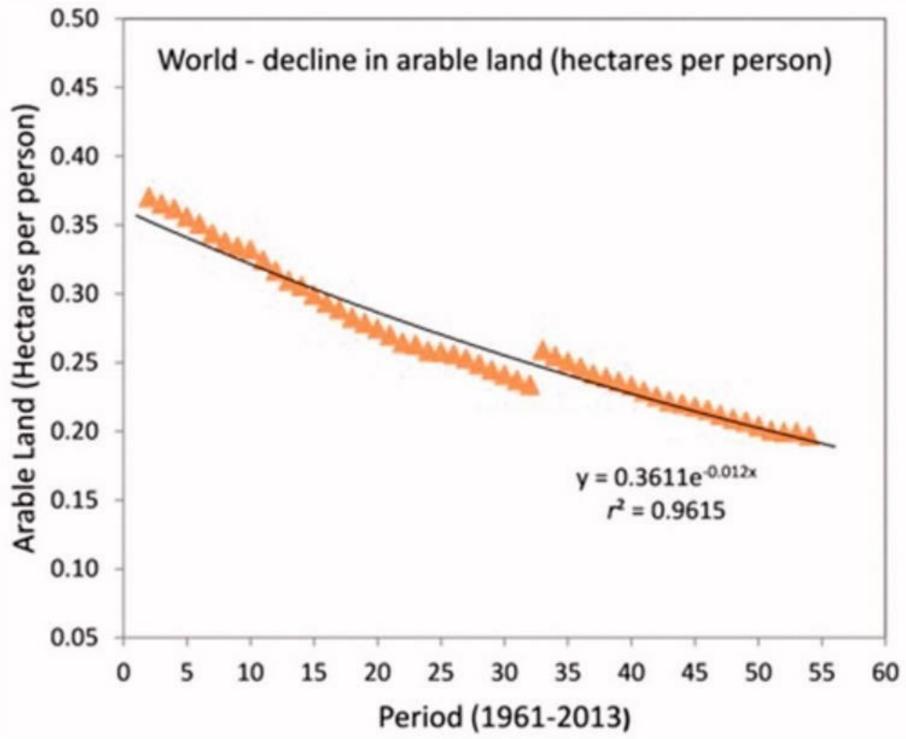


Figure 1: plot showing the decline in arable land

The graph above illustrates the decline of stocks of arable land in the world over the period 1961–2013. The trend line is calculated based on the data from the United Nations Food and Agriculture Organization ("Database on Arable Land," 2016). Note that there was a global recession in the early 1990s, which resulted in discontinuity coincides. The trend line has an R-squared value of 0.9615 as it is shown on the graph, which means the equation explains about 96.15% of the variance of the data. It is high R-squared value with high significance.

Considering that the arable land in the world has been continuously declining since the early 1960s, the importance of maintaining or even increasing the amount of crop harvested inland with limited space is growing. For this, LED farming could be an alternative to solving a fundamental problem. LED farming requires much less land compared to conventional farming. Another name for LED farming is known as 'vertical farming' in the meaning crops could be cultivated in vertical spacing as shown below.

Figure 2: The example of vertical farming (USDA)

Our experiment was dedicated to find the optimal light intensity for Basil growth. Refer to the result of the experiment, it is possible to cultivate crops in vertical positioning where is could satisfy the optimal light intensity. With controlled LED lights and vertical positioning, LED farming could be an innovation on agricultural land use if it is widely accepted in the world, solving the problem of declining arable land.

Secondly, we focused on environmental effect of conventional farming. Farmers apply nutrients on their fields in the form of chemical fertilizers or pesticides to provide crops with to promote faster growth and produce the food we eat. However, when these chemicals are not fully utilized by the growing plants, they can be lost from the farm fields and negatively impact air and downstream water quality. In casting light upon this problem, this report will focus on corn as a standard crop with three states; Illinois, Minnesota, and South Dakota. These three states are known as representative states producing corn as members of corn belt of the United States. Looking at the fertilizer used to produce corn from 1964 to 2016, the use of nitrogen, phosphate and potash fertilizer in Illinois, Minnesota, South Dakota and the US average is given as below.

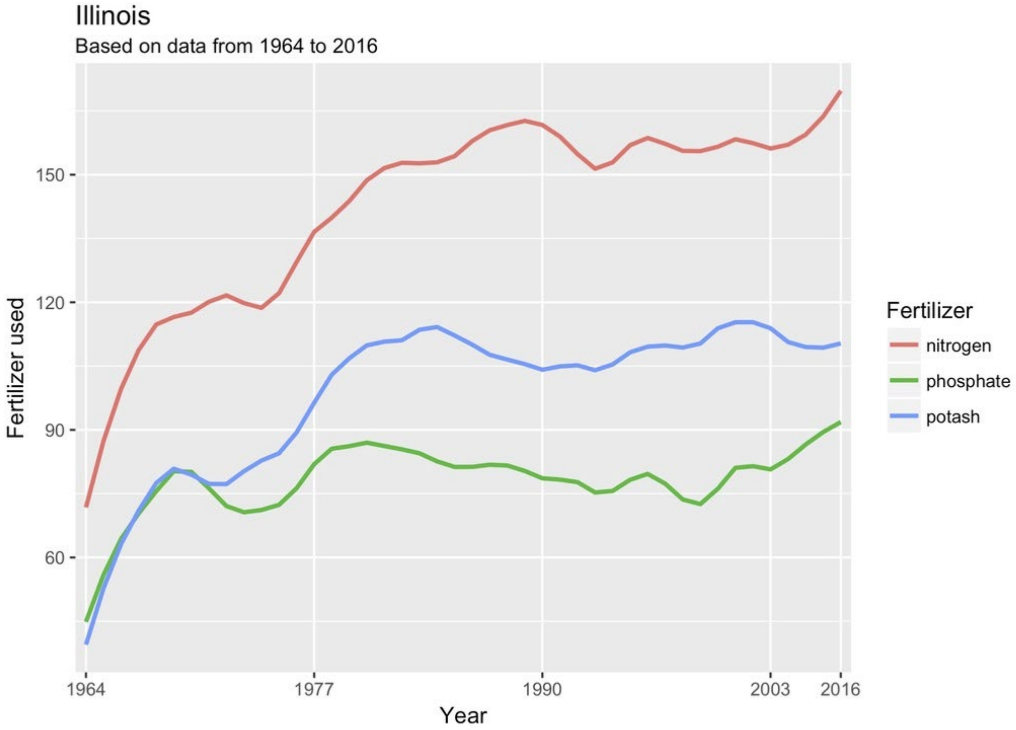


Figure 3: Fertilizer usage per year for Illinois

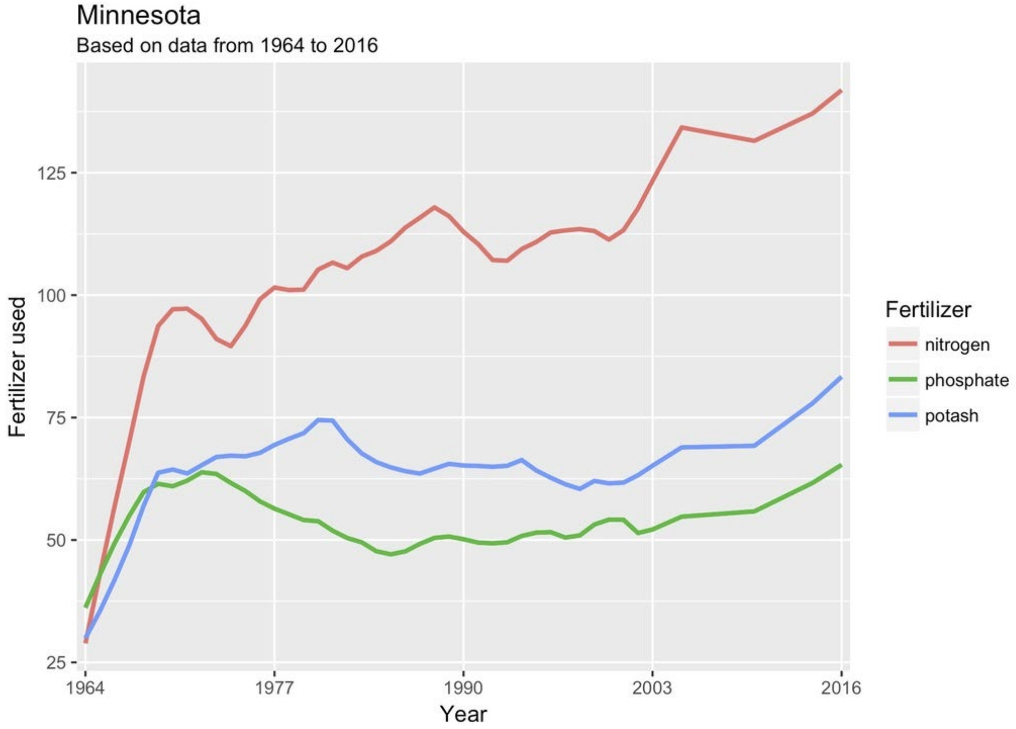


Figure 4: Fertilizer usage per year for Minnesota

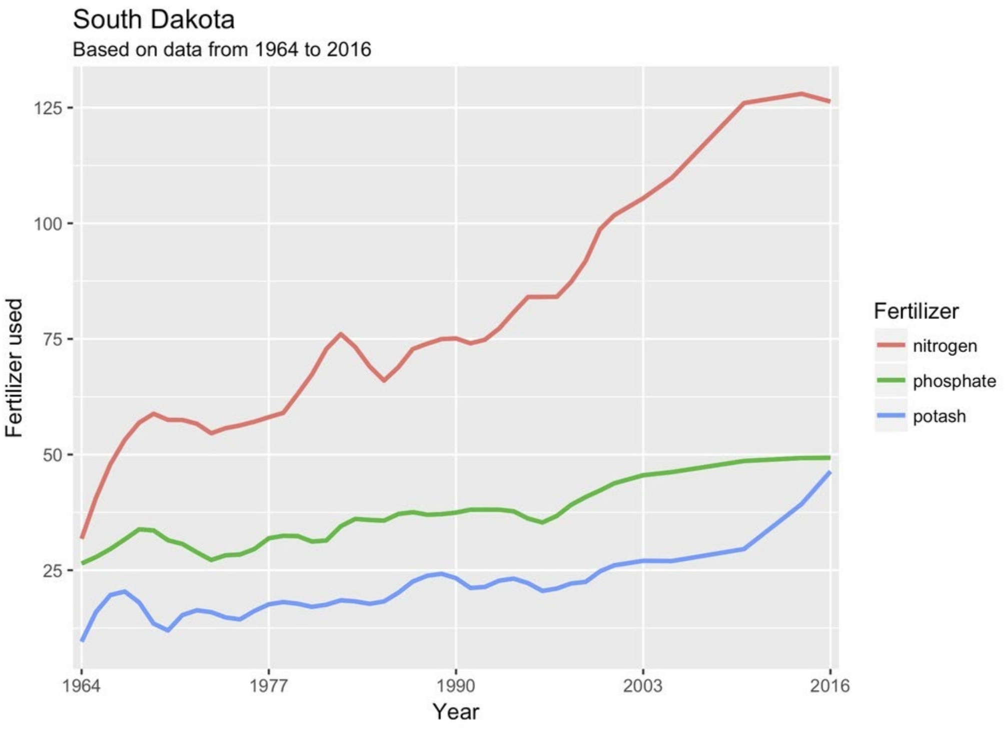


Figure 5: Fertilizer usage per year for South Dakota

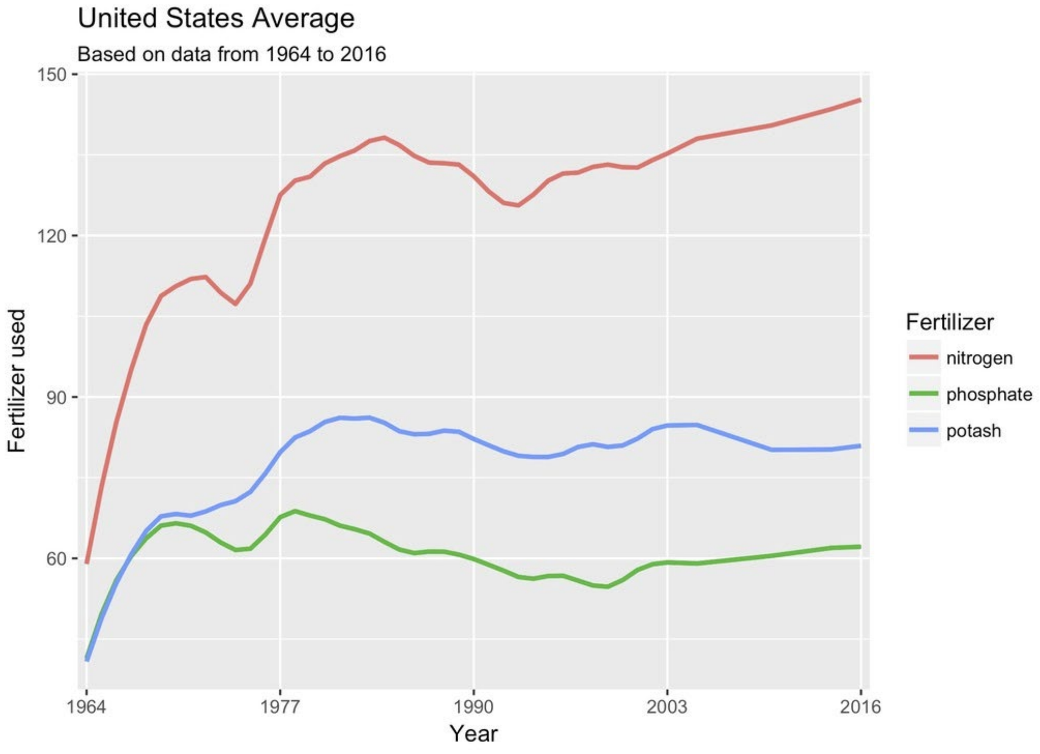


Figure 6: Fertilizer usage per year for the U.S average

The components of fertilizer could be categorized into three chemicals; the nitrogen, phosphate, and phosphorus. As we can see, the use of fertilizer has been increasing even though there is a difference in degree by chemicals. In the article "Nitrogen and phosphorus losses in surface runoff from agricultural land as influenced by the placement of broadcast fertilizer," Timmons explains that Nitrogen and Phosphorus losses form sediments and containing West-central area. However, in LED farming, this problem can be solved by applying the optimal amount of fertilizer and control agriculture effluent. This is the benefit from raise crop in controlled indoor setting using the exact amount of soil, fertilizer, and water needed for the crops.

The same explanation can be applied regarding the use of pesticide. The graph given below is the amount of pesticide used for corn in the three states this analysis is covering (Illinois, Minnesota, and South Dakota) and US average from 1960 to 2016.

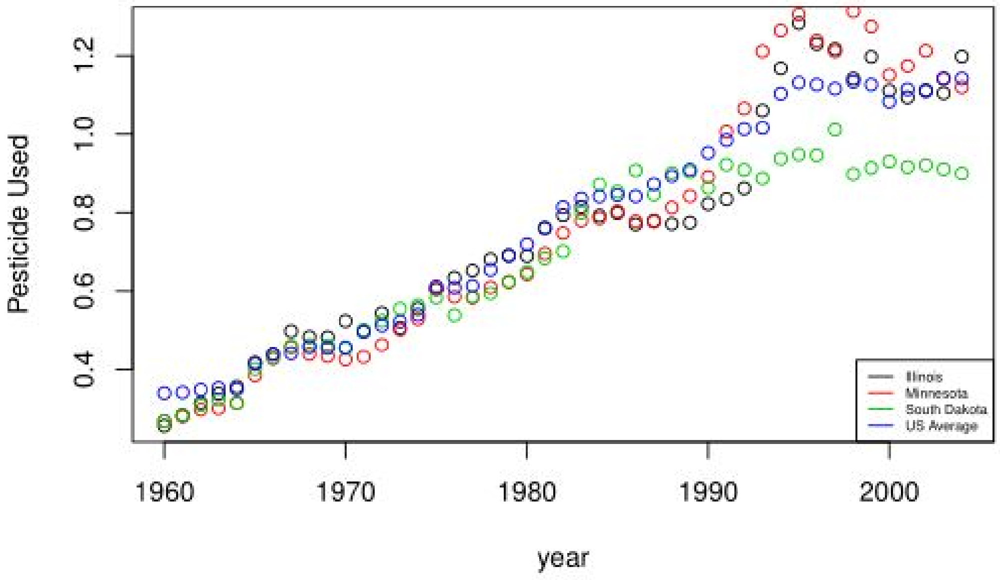


Figure 7: Pesticide usage per year for Illinois, Minnesota, South Dakota, and the U.S average

Since the three states area member of Corn Belt in the United States, they tend to use a larger amount of pesticide compared to the United States average. However, the tendency is clear that the usage of pesticide has been steadily increased since 1960. As crop raise is done in an indoor environment in LED farming, the usage of pesticide becomes unnecessary. Furthermore, Jaimin Patel, a plant pathologist at the Lighting Research Center of the Rensselaer Polytechnic Institute in New York, and his team discovered that LED light can reduce disease in plants, a discovery that could, ultimately, lead to the redundancy of expensive and unpopular pesticides.

Experiments

Experimental Objectives (Woo)

Experiments will be performed to figure out the appropriate light intensity for LED farm. By growing proper crops from 8 separated pots with different light intensities, the relationship between light intensity and the growth of the plants will be visualized. Once specific LED light is selected, the equation for the light intensity changes depending on the distance difference will be built based on the data collected from the sensors. Height value can be optimized by analyzing the above experimental values and the equation. The optimized height value will be provided to design the final LED farm product.

Assumptions and Procedures

Assumptions:

1. Temperature is assumed to be consistent
2. LED light doesn't generate heat

3. Air is moderately circulated
4. 3.5:1 ratio of light combination is appropriate to grow sweet basil

Procedures

1. Two different test-beds are prepared with four flowerpots each.
    a. First test-bed: 1 foot high
    b. Second test-bed: 2 feet high
2. Basil seeds soaked in water
3. 3~4 basil seeds are planted in each pot with plenty of soil
4. Each flowerpot is placed on the different number of stacks to make 50 cm height variance to each sample
5. LED light is set to be 20000 lux at the surface of the third sample
6. 50 mL of fertilizer-mixed water is released to each pot when humidity level of the soil goes under 1.5
7. Size of the leaf from each pair (from stem to the end of the leaf) is measured on Monday and Thursday
8. Average of the size of the leaves from the same pot is recorded
9. After a month of measurement, the power of LED light from the second test-bed increases to its maximum
10. Same procedure to measure the leaf size is repeated for another month
11. Weight of all leaves from each pot is measured after two months of leaf-size measurements

Test Crop Selection (SM)

Conditions:

1. Growth Efficiency – the crop needs to be able to grow a significant amount in a relatively short time in order to investigate its growth rate during the research period.
2. Sensitivity – the crop should be easily affected by environmental factors, specifically light intensity, in order to be able to notice a difference when such factors are altered for experiment.
3. Aesthetics – ideally, the crop should be pleasing to the eye when displayed in exhibition

Considered Candidates:

1. Strawberry:

The first candidate considered was the strawberry. Strawberries are one of the most common garden crops grown, as they are relatively easy to grow, aesthetically pleasing, and even edible. However, this plant was rejected for this research due to its tendency to grow well in most conditions, which would make determining the effect of light intensity on the growth rate of the plant. Moreover, designing a test model for strawberries would be inefficient because of the large area needed for their growth.

2. Lettuce (Loose Leaf):

The second candidate considered was lettuce, a common garden crop known for its low difficulty of cultivating. However, this crop was rejected for this research due to its tendency to grow well in most conditions. Lettuce would be too unaffected by environmental factors for showing the effect change in light intensity on the crop's growth rate.

3. Lavender:

Typically, herbs are more sensitive to environmental factors unlike normal garden crops.

The third candidate considered was lavender, an herb used for cooking and medicine. When grown indoors, it is cherished for its calming fragrance and vibrant purple color. However, this herbal plant was rejected for the purposes of this research because of its sensitivity to water supply. The effect of change in light intensity on the crop's growth rate cannot be clearly shown through the growth of lavender.

4. Lemon Balm:

The fourth candidate considered was Lemon Balm, a type of herb commonly used in cooking. This crop was rejected for research because of its tendency to grow well in most conditions. In particular, its insensitivity to light intensity was concluded to be inappropriate for investigating the effect of changing light intensity on the propagation of a crop.

5. Pansy:

Figure 8: Pansy Flower Germination Test

The fifth candidate considered was the Pansy, a type of garden flower. As shown in Figure #, the pansy was the first plant to be tested. Two pansy seeds were planted in cups. Contrary to our expectations, the pansy seeds did not germinate at all. Through further research, the test seeds did not germinate because pansy seeds need a dark environment for germination. Also, the optimal conditions for pansies keep changing throughout its growth. Such divergent conditions of the Pansy flower lead to the conclusion that the Pansy is inappropriate for investigating the effect of changing one growth factor (light intensity) on the propagation of the crop.

https://pss.uvm.edu/ppp/articles/pansies.html

6. Basil:

Figure 9: Germination of Basil Seeds

Figure 10: Test Plant of Germinated Basil Seeds

The sixth candidate considered was Basil, a popular garden and culinary herb. There are many varieties of Basil including the Sweet Basil, Thai Basil, and Lemon Basil. For this research, the Sweet Basil or the Genovese Basil was selected as its foliage size is larger than the other varieties. It was predicted that the larger the foliage size, the easier it would be to determine change in plant growth. As shown in Figure #, initial germination of Basil seeds succeeded, and sprouts were transplanted to four different test pots. After a few weeks, growth in the Basil sprouts were determined as shown in Figure #, showing a highly efficient growth rate.

Final Selection: Basil (Genovese); *Ocimum Basilicum*

https://www.growing-basil.org/artificial-lighting-for-growing-basil/

http://extension.illinois.edu/herbs/basil.cfm

Test Bed Design Changes (Woo)

- Initial Design Concept

Figure 11: Commercial LED farm sample design

Initial objective of plant design is to have multiple functions as shown in Figure #. The final LED farm design is considered to be exhibited in the public area. Therefore, aesthetically pleasing design is recommended unless the system affects to the growth of the plants. LED light that is used to grow the plant can also have a function of lighting the surroundings. Above commercial LED farm product is a design sample to be referred.

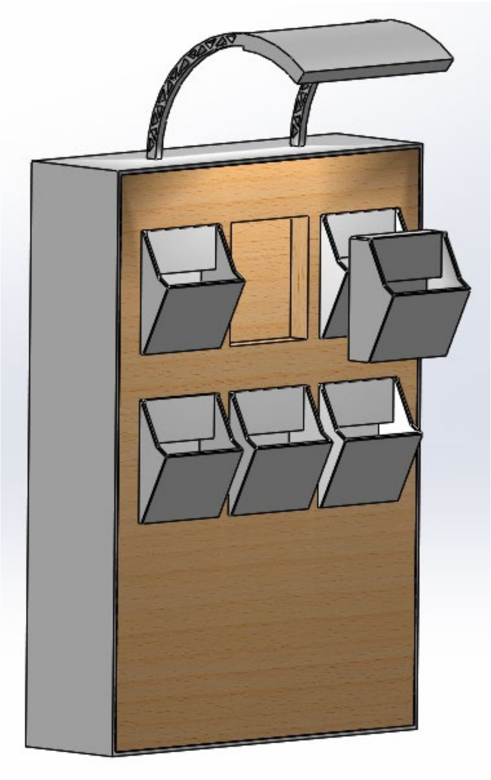


Figure 12: CAD design for the commercial sample design

Unique point of the above design is the angle of the light and the separated plants from the body frame. Since light intensity is one of the major influential factors to the growth of the plant, test bed for testing the light intensity depending on the angular and planar position change of LED light is designed.

- Structural Design for Initial Concept

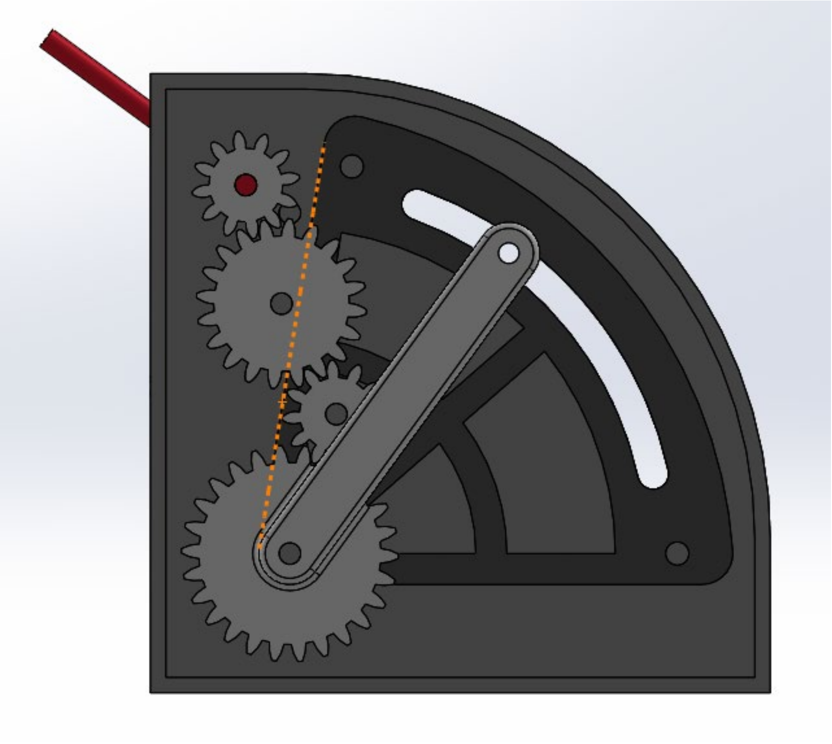


Figure 13: First test bed design for varying the angular position of LED light

Angular position change is considered first to design the test bed as shown in Figure #. Four different gears are meshed to rotate the fourth gear which has the largest pitch diameter and the connecting bar to LED light. To enhance the stability of the light, frame is added on the structure. By using smaller gear to the lever connected part compared to other gears in the same train, it will be able to control the angular position of LED light more sensitively. However, this design causes huge frictions between each gear and requires larger forces than expectation to rotate the lever. To minimize the unexpected bumps on the surfaces of the gear teeth that might result in excessive frictions, gears with smaller module are also tested. However, as laser cutter that is used to generate the gear has huge tolerance and inappropriate power settings, boundary of the gear teeth is molten down. The manipulated boundary of gear teeth results in the failure of being meshed to each other.

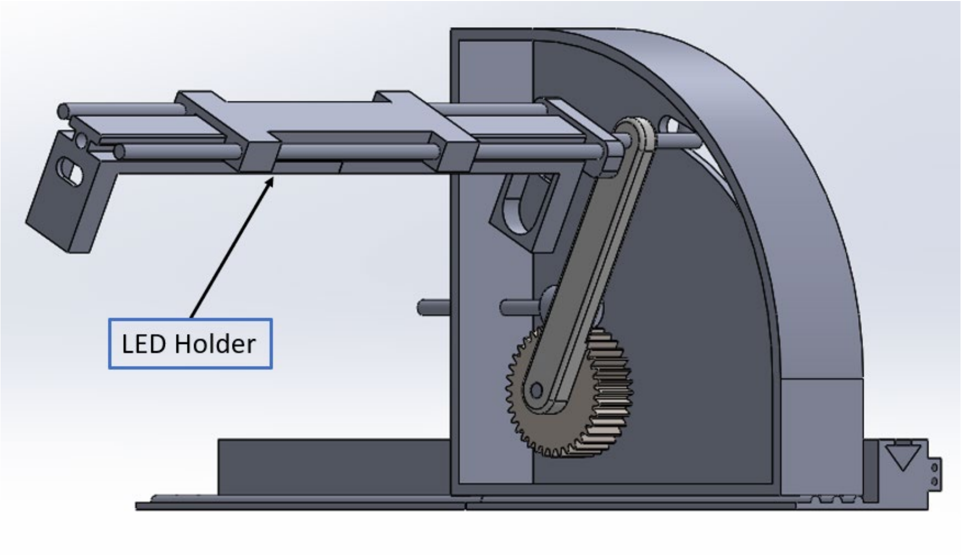


Figure 14: Second test bed design for varying the angular position of LED light

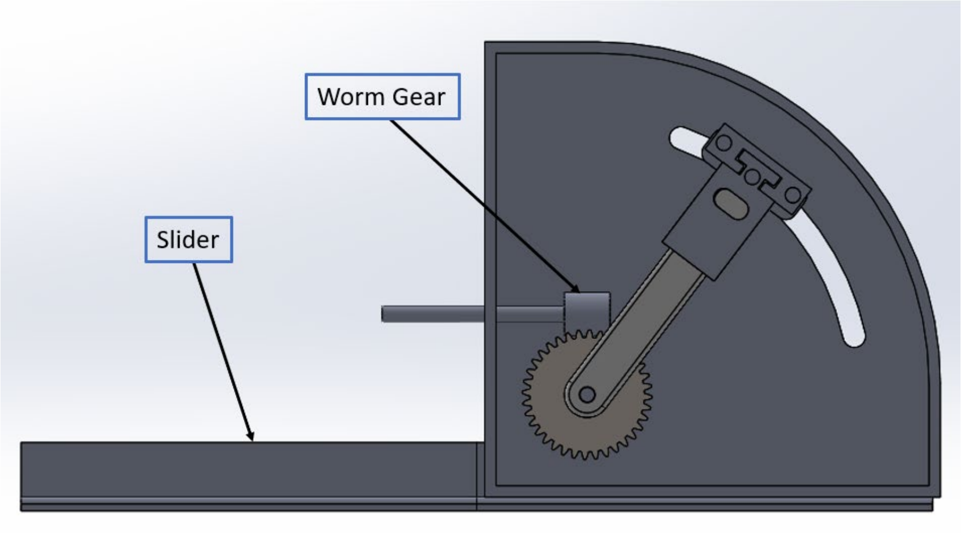


Figure 15: Side view of the second test bed design

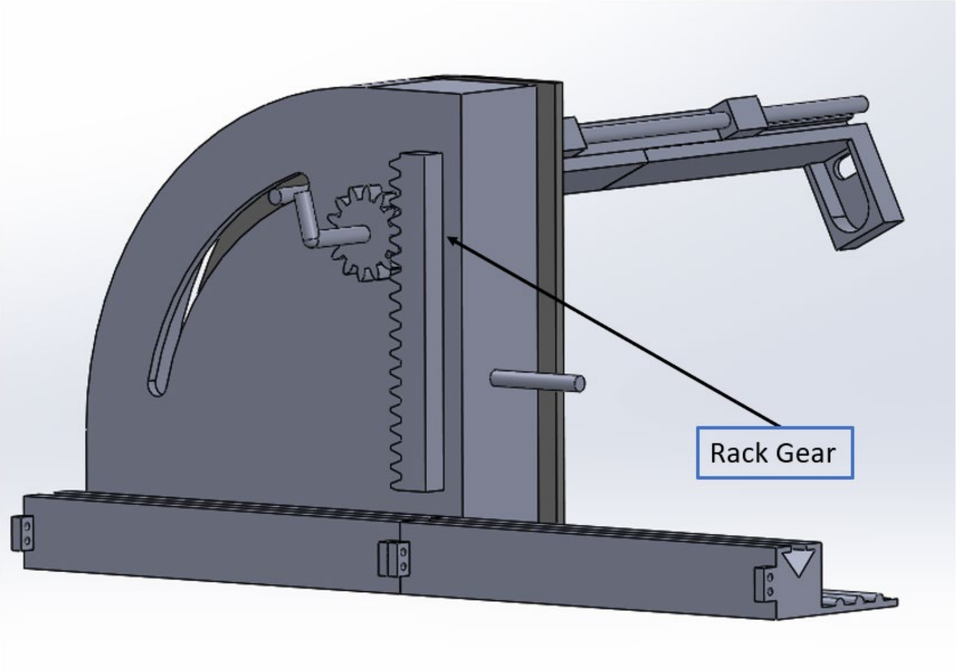


Figure 16: System for translation on the opposite side of the system

Figure # indicates the simpler design to control the angular position of LED light. Instead of gear train mechanism, worm gear is used to minimize the friction and move the gear by applying perpendicular force. LED holder is added on the design to check the stability of the system. This version of design includes the mechanical system for the planar position change of LED light by sliding whole body and rotating the lever. Slider and rack gear mechanism are used to make changes of planar position as indicated in Figure 15.

- Second Design Concept

In theoretical approach, the growth of the plant will not be affected by the angular position of LED light since light intensity measured on the surface of the soil doesn’t change. There should be differences as the area exposed to the light might be differed depending on the angular position of LED light, but it doesn’t meet the objective of this project. For this reason, LED light is decided to be fixed on the top of the structure and the height of the plants is varied instead.

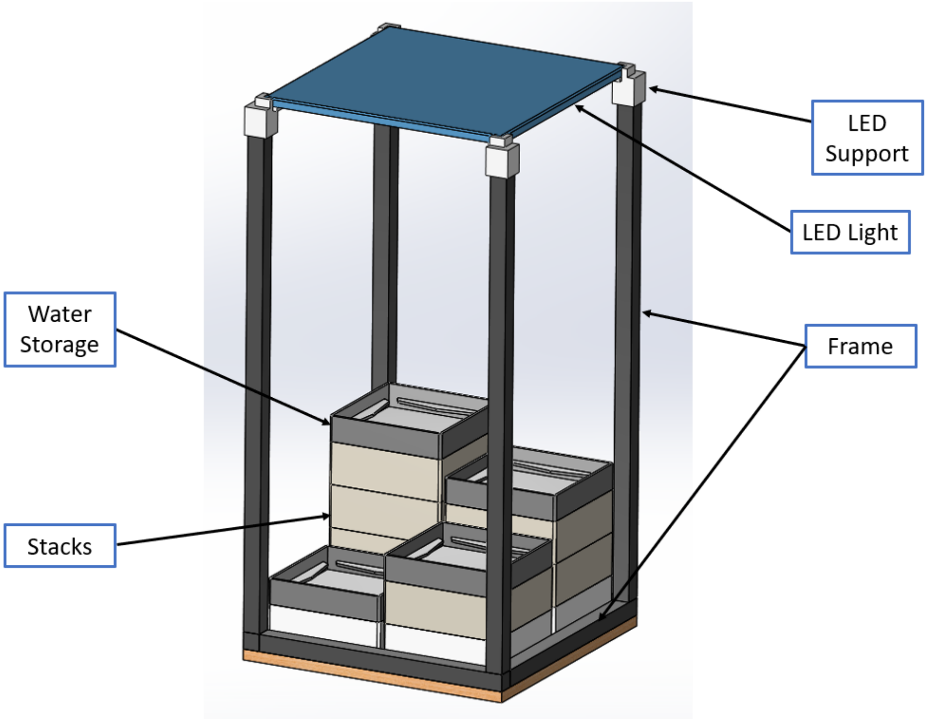


Figure 17: LED farm design for the experimental purpose

As this structure is designed to be only used for the experimental purposes, aesthetical points are not considered at all. To minimize the waste of materials and time by avoiding excessive use of 3D-printer, frames are bought from Mcmaster. Stacks and water storage that are 3D-printed to differ the light intensity from the surface of the flowerpots. Four flowerpots will be placed on the water storage each so that we will be able to dispose the water conveniently and make the pots stable on the stacks as well. Each stack is 50 cm height and the distance from the light to plants can be controlled by the number of the stacks. Additionally, four LED supports are used for each frame to position the LED on the top of the structure.

Design considerations:

1. The maximum local stress on LED support needs to be greater than one-fourth of LED weight.
2. Enough space for 3~4 plants is required for each flowerpot.
3. Stacks can be connected to each other but they should be easily detached.
4. Water storage needs separated space to store the wasted water and hold the flowerpot.

Figure 18: Temporary structure for LED lighting system

Temporary structure for LED farm is constructed by recycling LED frames and flowerpots that are initially designed. As there are many variables to be considered in the process of performing the experiments, experiments need to be repeated several times. To repeat the experiments as many times as possible under limited time, temporary LED farm is constructed. Flowerpots from the initial design are used as stacks and half-cut of the raw wood piece is used as frames of the structure. Initially designed LED support is connected to the wood pieces by using the wooden shafts.

Figure 19: Test bed for LED farm experiments

Above Figure # is a picture of the final test bed assembly for the experiments. The frames are simply connected to each other by using L-brackets. Each frame has 20 mm thickness. Frame for the bottom square is 1 foot each and the height of the test bed is 2 feet. LED stays on the top of the test bed by using the holders that are equipped at the top-four sides of the frame. The height of the flowerpots is varied by the number of the stacks that are 50 cm each as shown in Figure 19.

Design considerations:

1. LED holders are designed to be fit to each frame to make LED stable.
2. Enough surface area of LED holders is required to prevent LED from falling off from the top of the test bed and to endure the weight of LED.
3. 50 cm height of each stack is appropriate to vary the intensity of the light by using the minimum number of the stacks.

Results and Discussions

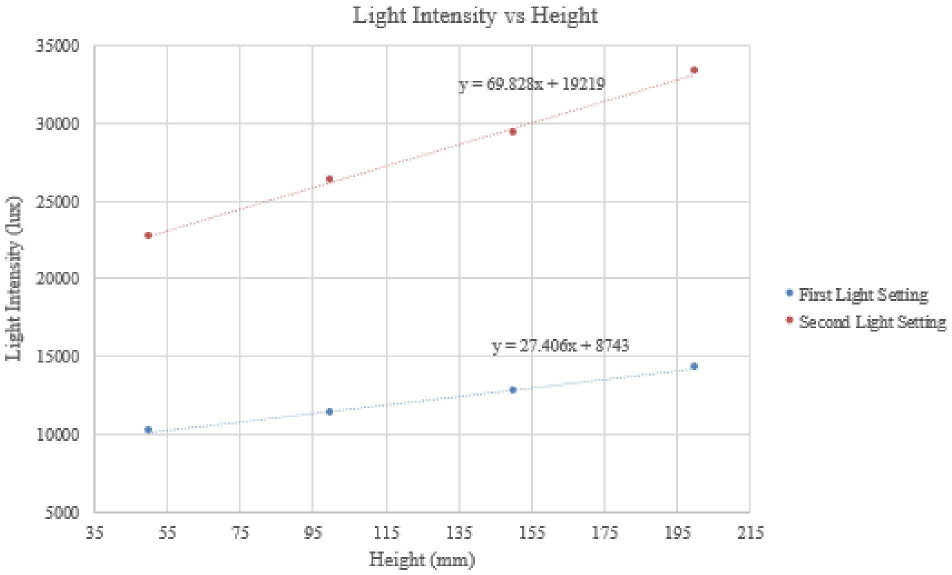


Figure 20: Light intensity depending on the height change of the sample

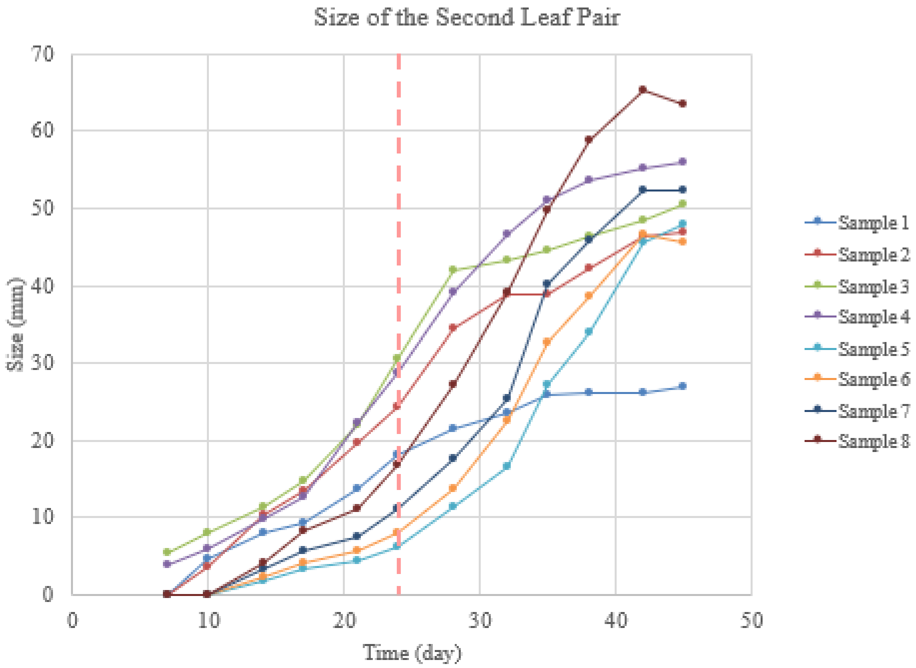


Figure 21: Size of the second leaf pair of each sample

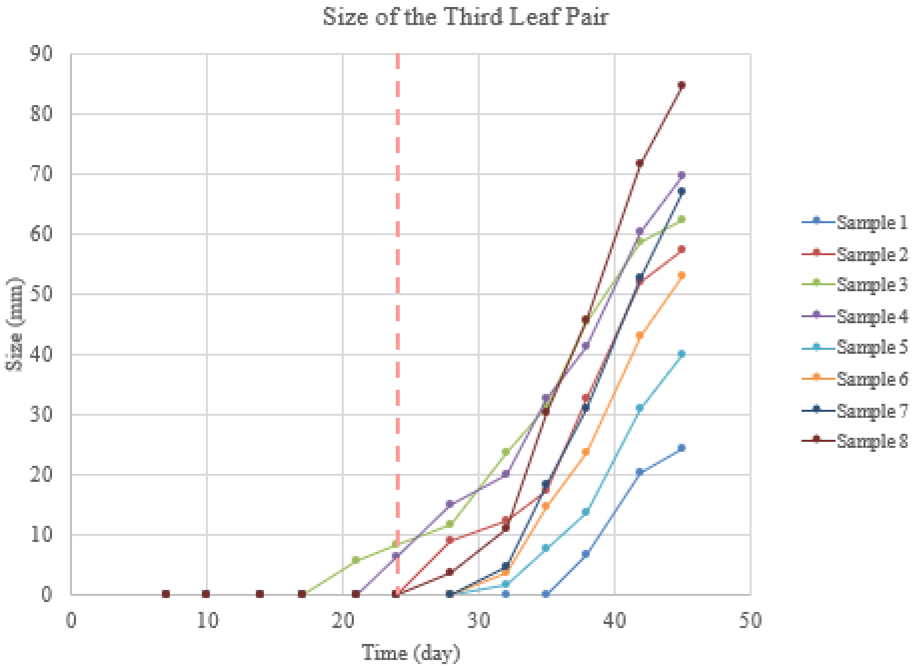


Figure 22: Size of the third leaf pair of each sample

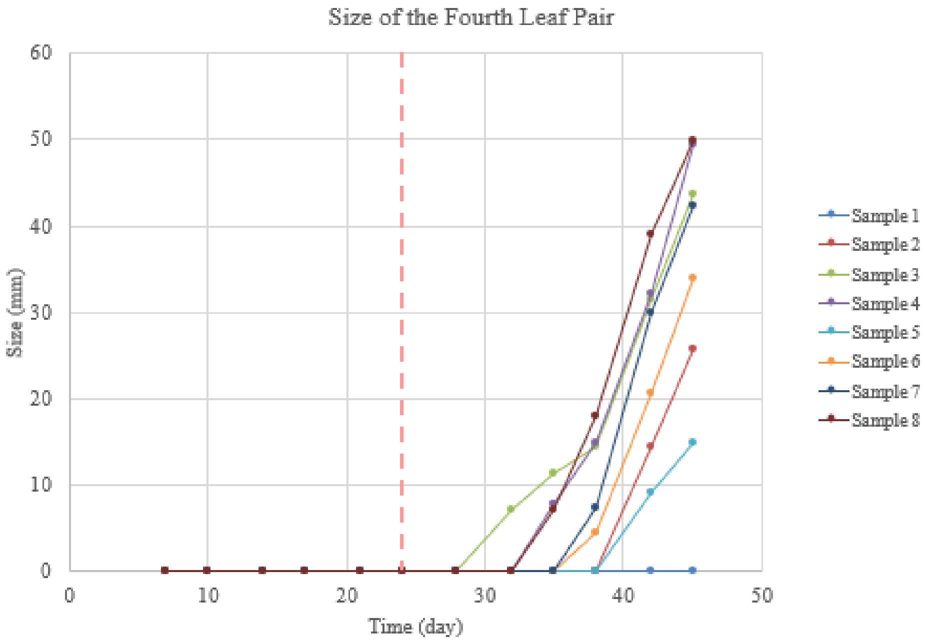


Figure 23: Size of the fourth leaf pair of each sample

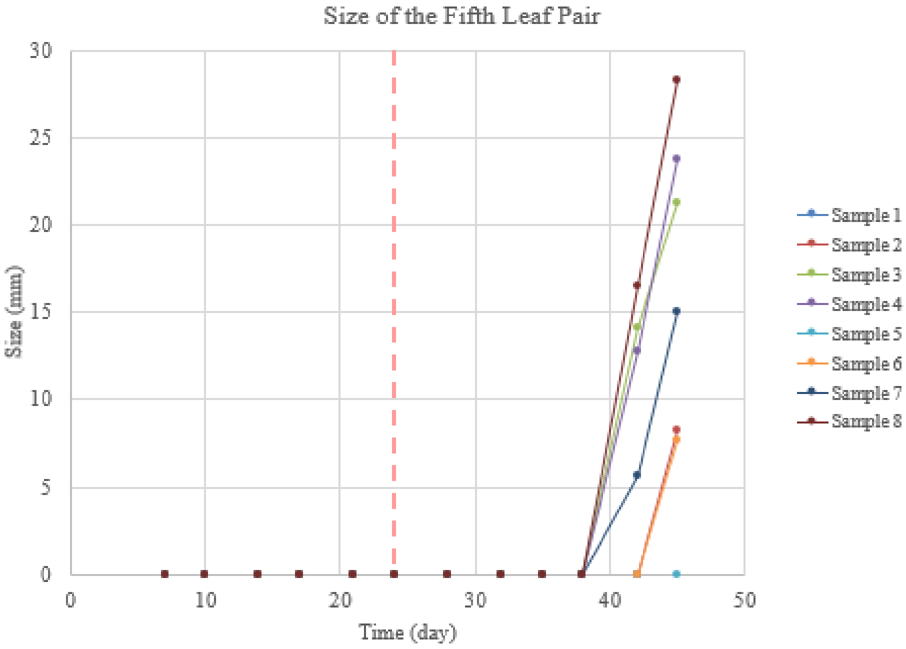


Figure 24: Size of the fifth leaf pair of each sample

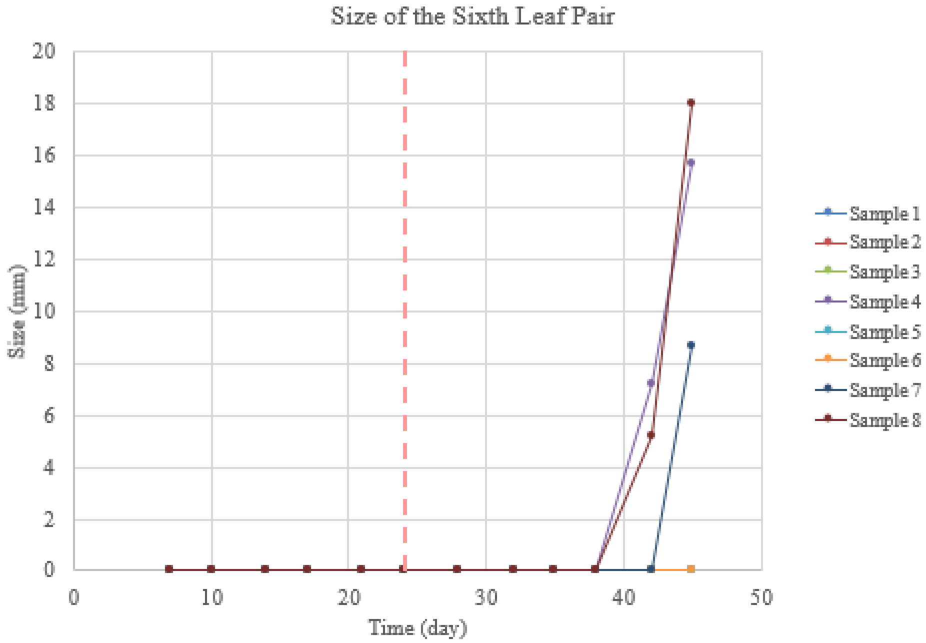


Figure 25: Size of the sixth leaf pair of each sample

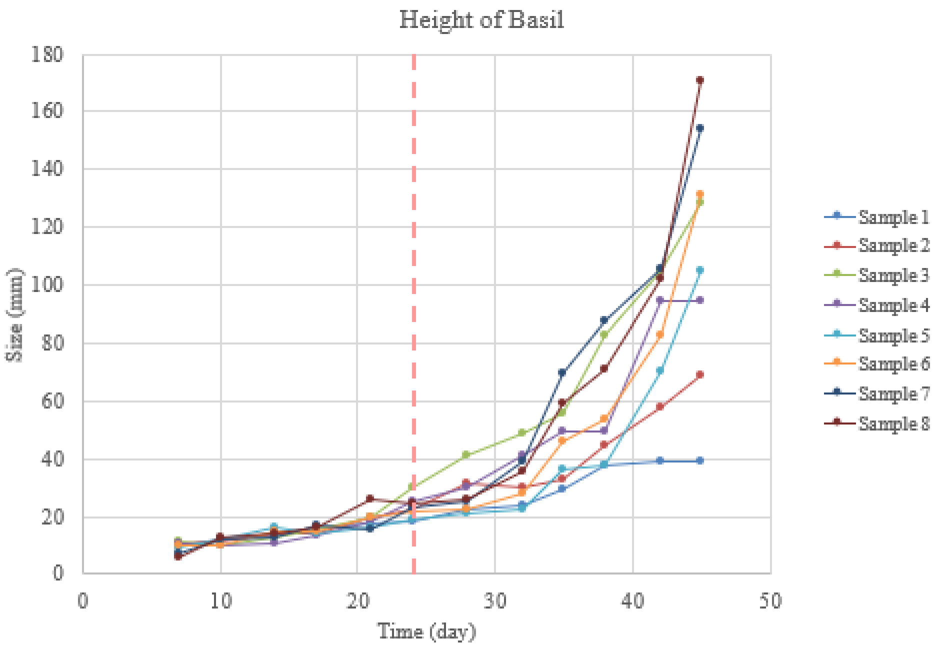
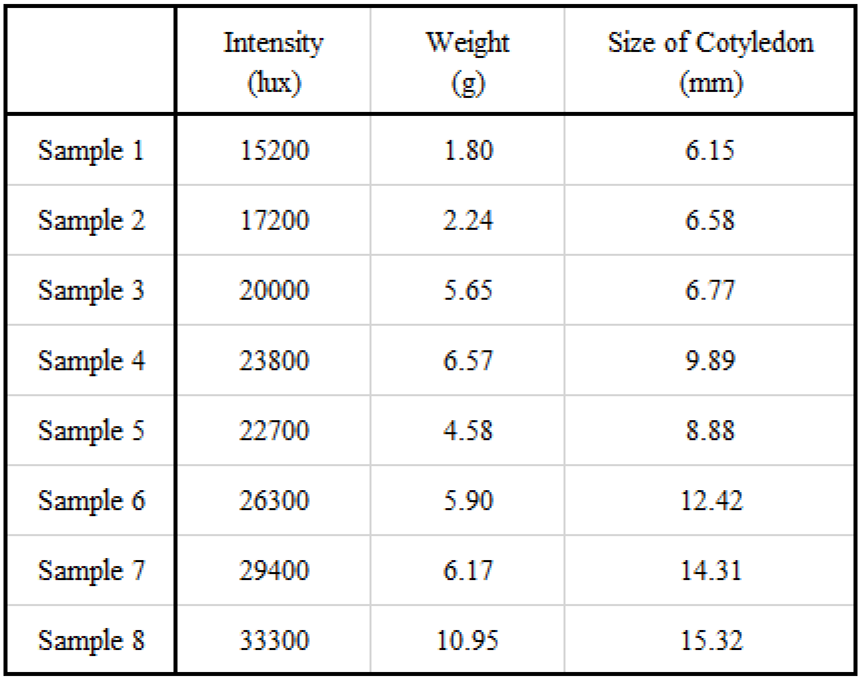
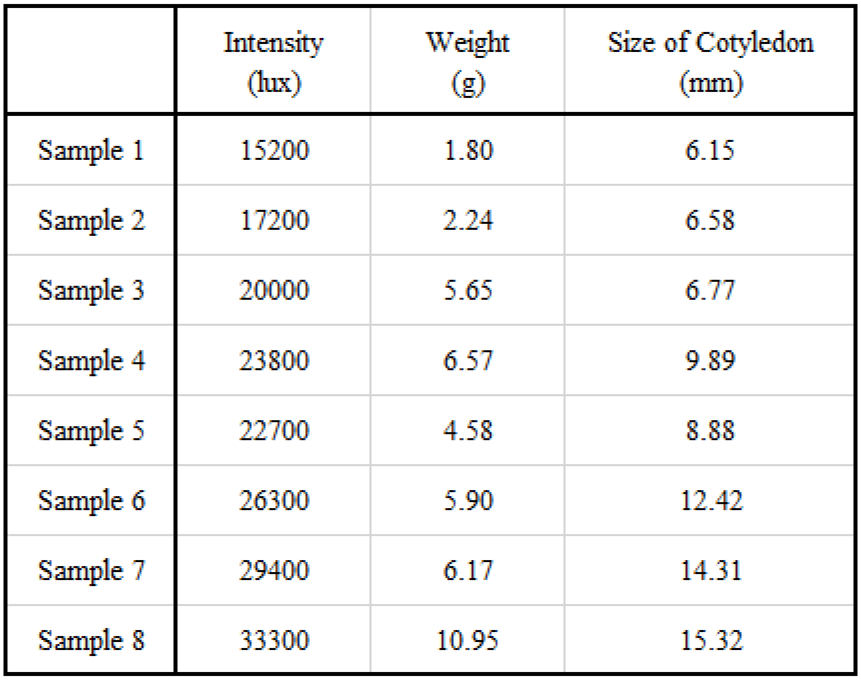


Figure 26: Height of the plant depending on light intensity

Table 1: Weight of leaves and the size of cotyledon of each sample



	Intensity (lux)	Weight (g)	Size of Cotyledon (mm)
Sample 1	15200	1.80	6.15
Sample 2	17200	2.24	6.58
Sample 3	20000	5.65	6.77
Sample 4	23800	6.57	9.89
Sample 5	22700	4.58	8.88
Sample 6	26300	5.90	12.42
Sample 7	29400	6.17	14.31
Sample 8	33300	10.95	15.32



	Intensity (lux)	Weight (g)	Size of Cotyledon (mm)
Sample 1	15200	1.80	6.15
Sample 2	17200	2.24	6.58
Sample 3	20000	5.65	6.77
Sample 4	23800	6.57	9.89
Sample 5	22700	4.58	8.88
Sample 6	26300	5.90	12.42
Sample 7	29400	6.17	14.31
Sample 8	33300	10.95	15.32

Product Design

Product Design Objective

Final model of this project should be designed to maximize the efficiency of LED farm with aesthetically pleasing look. The final model consists of two different parts, a product that includes flowerpots and watering system, and the outer structure that includes the frames and lighting system. As the final model is going to be exhibited at the cafeteria in Bevier Hall for the purpose of education, the product design is determined to be the coffee related products. Two different product designs are going to be suggested. The outer structure design will also be provided to hold the position of the product and enhance the aesthetical level by covering the raw materials. Final models are all designed based on the control values and the results of the experiments described in the previous section of this report.

Design Procedures

All the structures and products for this project are designed by CAD. Solidworks and Creo Parametrics are used to design the structures and products. Basic designs are done by both Solidworks and Creo Parametrics, and simple simulations are done by Solidworks. Stress analysis are simulated to simply confirm the stability of the models.

List of the uses of CAD:

1. Design of the initial test bed structures
2. Outer structure design of the final LED farm model
3. Two different design concepts for the final products
4. Full assembly of the final LED farm model

5. Stress analysis of each product design (supporting plate for flowerpots)
6. Stress analysis of outer structure (four-top corners)

Design of initial test bed is described in the previous experiment section since the test bed is designed to be used to perform the experiments. Appropriate colors are used to present the design.

Outer Structure Design

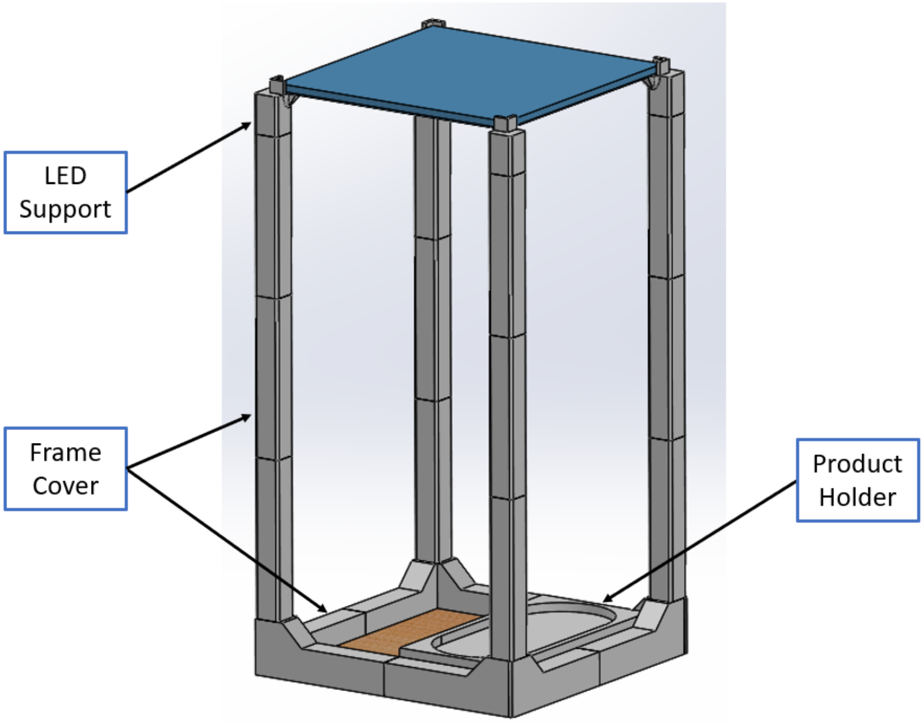


Figure 27: CAD design for the outer structure of the final LED farm model

The above figure shows the outer structure design for LED farm model. All frames that are used to build the model are perfectly covered by the printed parts. There is a product holder on the bottom plate so that the designed products can be placed at the proper position. Similar design of LED holders which are used for the test bed before is applied to this structure again.

Design considerations:

1. Slight change on LED holder design should distribute the stress so that the local structure at the four-top corner of the model becomes more stable.
2. Assembly of each frame cover should perfectly cover the frames for the aesthetical purposes.
3. Frame covers that are used to cover the bottom frames should have proper incline to cover the L-brackets that are used to connect the frames at the corners.
4. Product holder should fit to the bottom frame considering tolerances so that the holder can stay its position with the minimum stresses on the structure.

Product Design

Figure 28: Reference for the first product design

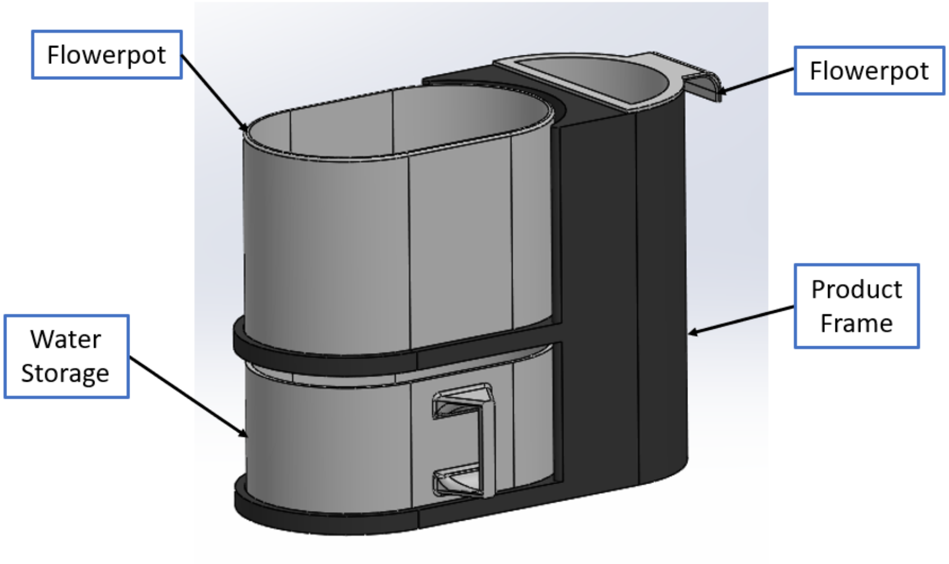


Figure 29: Isometric view of the first product design

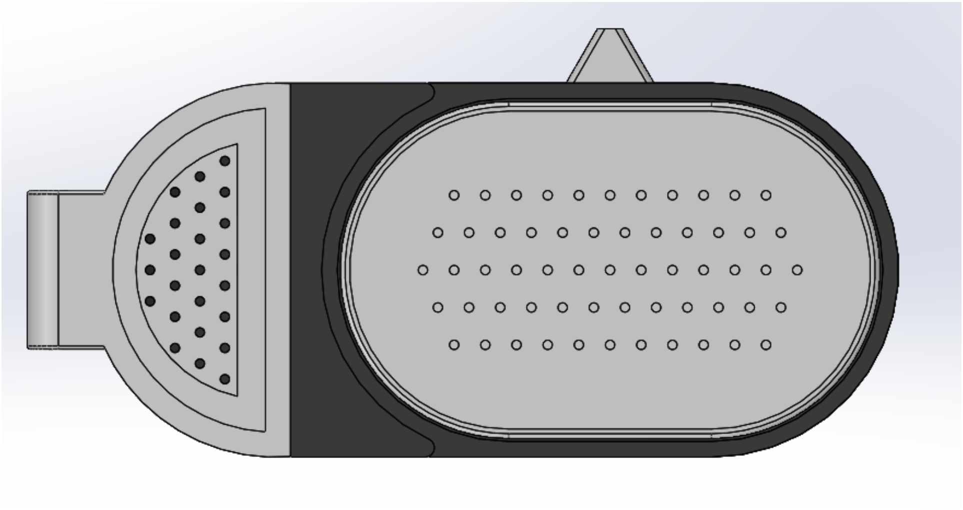


Figure 30: Top view of the first product design

The first design of the product is shown in Figure 29. This design is referred to the coffee maker in Figure 28. There are two flowerpots and they share one water storage. Referring to Figure 30, there are holes on the bottom of each flowerpot to release the water.

Design considerations:

1. Everyone can easily notice that the design is referred to coffee maker shown in Figure 28.
2. The height of the product should be determined based on the experimental results to provide the proper amount of light on the surface of the soil.
3. The size of the product should be big enough to store the appropriate amount of soil for at least 10 plants, but shouldn’t be larger than the half of the LED farm model.
4. Additional designs on the side of the water storage and small flowerpot are necessary to take the storage out from the product or put it back into the product conveniently.
5. Slight bump on the boundary of each floor of the product might be useful to make the flowerpot and water storage stay at their positions.
6. The holes that are at the bottom of the flowerpots should be evenly distributed for the water to be naturally released.
7. There should be space between the product body and each component to minimize the effects of tolerances and possible interferences.

Concept #2

Figure 31: Reference for Second Design

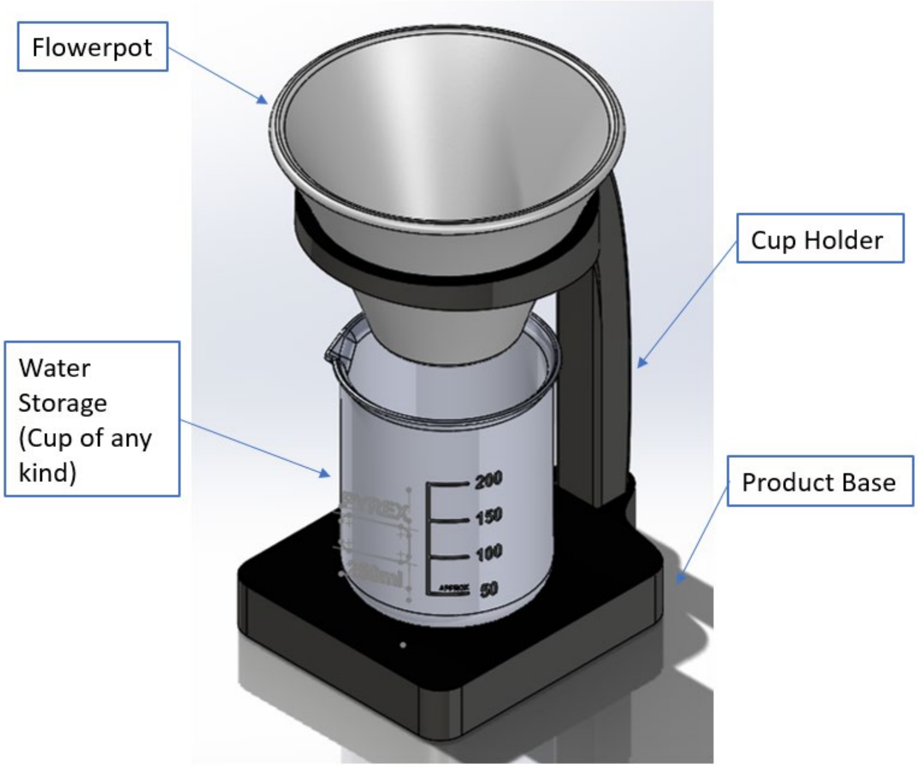


Figure 32: Isometric View of the Second Product Design

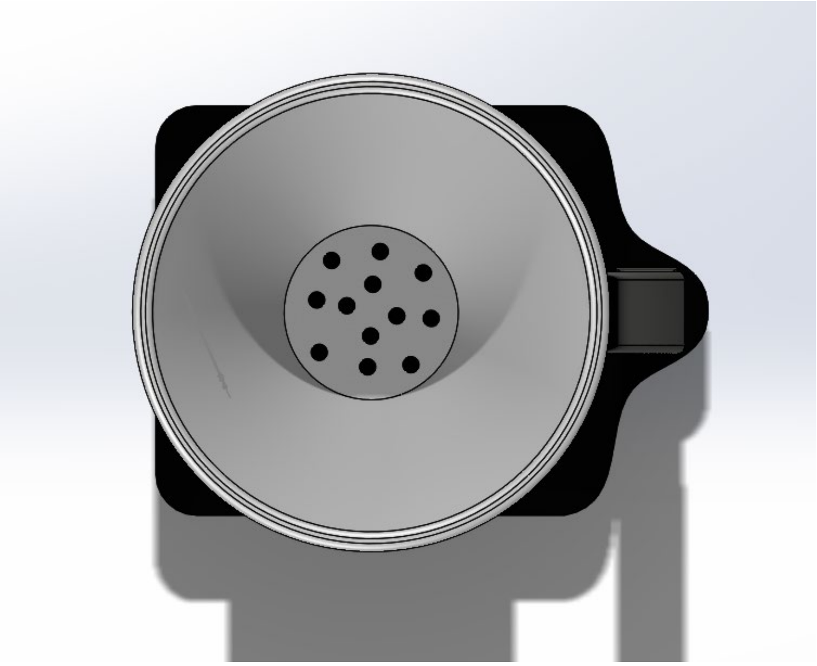


Figure 33: Top View of the Second Product Design

The second design of the final product is shown in Figure 32. This concept design was based on a drip coffee maker such as Figure 31. Holes exist on the bottom of the flowerpot part so that water can gradually flow straight down to the water storage. The water storage part can be placed and taken out freely to empty the water out of the storage part.

Design Considerations

1. Must be aesthetically pleasing and similar to a real drip coffee maker such as Figure #.
2. The height of the product should be determined based on experimental results to provide the proper amount of light on the surface of the soil.
3. The size of the product shouldn’t be larger than the half of the LED farm model.
4. The water storage component should be able to be removed and placed easily.
5. The holes on the bottom of the flowerpot should be evenly positioned for consistent outflow of water.

6. Some space should exist between connecting parts of components to accommodate for the effect of tolerance when 3-D printing the final product.

Conclusions

Figure 34: The final product and the poster in the Bevier hall of UIUC.

Figure 35: Photo of my project team with the final product in Bevier Hall

References:

Conviron. (n.d.). LED Lighting in Plant Growth Research. Retrieved from https://www.conviron.com/led-lighting-in-plant-growth-research

Infineon Technologies(IT). (n.d.). LEDs in Urban Farming. Retrieved from https://www.infineon.com/cms/en/discoveries/LEDs-in-Urban-Farming/

LeBlanc, R. (2018, April). Grow Light Options for Indoor and Vertical Farming. Retrieved from https://www.thebalancesmb.com/grow-light-options-for-indoor-and-vertical-farming-4147429

Timmons, D. R., R. E. Burwell, and R. F. Holt. "Nitrogen and phosphorus losses in surface runoff from agricultural land as influenced by placement of broadcast fertilizer." *Water Resources Research* 9.3 (1973): 658-667.