Expanding Farming to a New Dimension

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Methods and Materials

In our experiment, we will seek to add to the knowledge in favor of the efficiency of growing crops in an environment like that in a vertical farm. To do so, we hope to disprove the main argument against these growing methods: that they are not energy efficient enough to be sustainable in an artificial growing environment. To disprove this point, we will test various light sources, then compare the energy input to the energy output. Currently, this is about a three to one ratio, meaning that for every three calories of energy we use to plow, transport, and fertilize our crops we only receive one calorie out in growth (Despommier, 2007). In this investigation we will test both commercial growing lights, like metal halide bulbs, and residential light sources, such as incandescent and fluorescent bulbs. We hope to find the lighting method with the lowest energy-in to energy-out ratio.

To test which light grows plants most efficiently indoor we collected a 50w metal halide, 60w incandescent, and 15w compact florescent bulbs. Separate housing for each light source was constructed, each from 5/8 inch plywood and painted with one coat of white primer, then two coats of black water-based paint (Exact measurements and layout are illustrated in Appendix A, with a brief description of circuitry.) Each box contained two enclosures with four 10 cm by 10 cm plastic planters of grass. Each planter was filled with 5 cm of loosely packed 1 cm tumbled lava rock and Grodan Rockwool (a chemically inert growing substrate for hydroponic experiments). Then, 5 grams of grass seed was evenly scattered in each planter on the surface of the soil. Each light was mounted in the center of their enclosure, 25 cm from the growing surface. The Rockwool was kept moist by the electric hydroponic system employing two levels of tubs (shown in appendix A). For the 28-day duration of the experiment, the lights were left on

Comment [SLG1]: For the second half of the paper, refer to the following rubric: http://www.mistergweb.com/Rubric_Final_Paper.pdf Notice how the Lit. Review stuff on this rubric has been condensed to a single line. The main focus of this paper is now on your project procedure, results, and interpretation of the findings. That said, though, you should have a revised Lit. Review that incorporates the changes and revisions from your first Lit. Review. Turning in the same, unrevised product of the Lit. Review for this assignment will be problematic. **For the purpose of this model, the Lit. Review was left out. Your final submission will include it.**

Comment [SLG2]: Notice how their project is connected to one of the main debates and controversies that was brought up in the Lit Review.

Comment [SLG3]: A clear and succinct statement of the purpose of their project.

Comment [SLG4]: Specificity is critical in your M&M section. Give manufacturer, part numbers, catalogue details, etc. Somebody should be able to peer review your results and findings by recreating exactly your experiment/project based on the outline and roadmap you leave for them here.

Comment [SG5]: Since the project is complete and this has already been done, this section is written in past tense.

Comment [SG6]: This is great use of the Appendix section to avoid cluttering the body of the paper.

Comment [SLG7]: A common problem in the M&M section, besides lack of specificity, is listing off steps and/or materials using bullet points or numbered lists. This section needs to be a NARRATIVE. By the way, it should match what your partners have, but it should be in your own words. You need to understand and coordinate this or you risk charges of plagiarism.

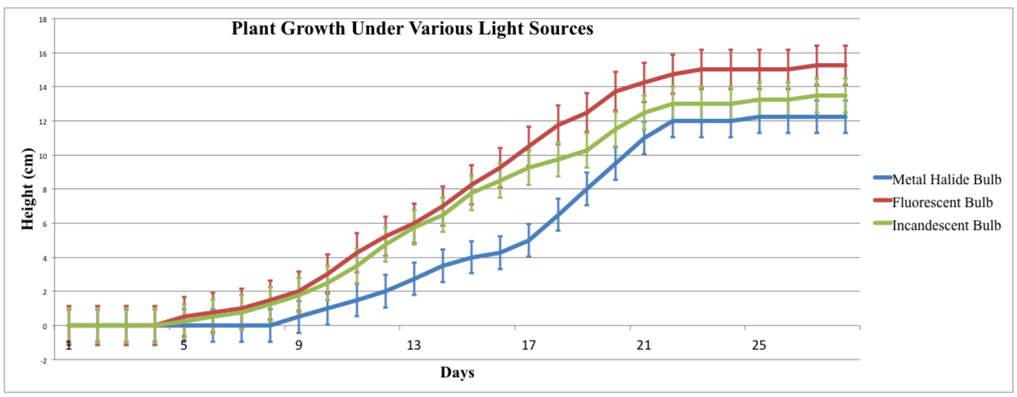
for twelve hours each day, from 7 a.m. to 7 p.m. The watering system ran continuously on low setting. Each day the average height of the grass in centimeters was measured as the lights were turned off, and each plot was photographed on a weekly basis. We plan analyze the results in a line graph that shows the results obtained for each bulb, as well as through a chi-squared analysis.

Comment [SG8]: Another common error in the M&M section is leaving out basic information about the unit of measurement and the type of graphical representation and statistical analysis you plan to do with the results.

Results

In the first week of data collection, the seeds were germinating. Although the grass grown under the metal halide bulb did not exhibit significant growth until day 9, the grass grown under

Comment [SLG9]: The use of graphs and/or tables in your Results section is, for the most part, a matter of style. If you decide to use them, YOU MUST ALSO include a narrative description of your results BEFORE the graphic. If you don't use them here, they belong in the Appendix.



the fluorescent and incandescent bulbs took an early lead as growth was observed by day 4. At the conclusion of the experiment, the grass grown under the fluorescent bulb reached 15.25 cm in average height, whereas the grass grown under the metal halide had only grown to an average height of 12.25 cm. The incandescent is clearly shown to have a remained at an in-between value, reaching a height of 13.5 at the conclusion of the experiment (Refer to Appendix B for full set of experimental data points).

Comment [SG10]: If you include graphical representations of data in your results, be careful to label both the X and Y axis. Include a title and legend, as well.

Comment [SG11]: The Results section will be/should be the shortest section of your paper. It's simply an objective statement of results and qualitative observations. There should be NO interpretation of data. Save that for the Discussion.

In addition to our experiment of growing grass under various light sources, we thoroughly amassed data that shows the carbon emissions involved in the modernized farming that the majority of US farms practice. We found that approximately 1178.64 metric tons of carbon dioxide emissions are produced annually through the production of various components of fertilizers (refer to Appendix C), and an even larger expenditure of fossils fuels is involved in the production and implementation of pesticides, including 4,702.38 metric tons for the production of herbicides. Furthermore, it was found that an average farm that produces corn or wheat releases 135.98 kg of CO_2 annually as involved irrigation, readying fields, and harvesting. In addition, the average distance produce must travel within the United States before it reaches its market was calculated. Further examination of the carbon emissions involved in the tillage of major crops can be found in Appendix D.

Comment [SG12]: Good use of the subscript feature in Word to drop the "2" below the O.

Discussion

Our hypothesis was not supported. We believed that the most commonly used growing light, the metal halide, would be best in growing grass artificially. However, the plot grown under the fluorescent light was taller at the end of the testing period than the plot grown under the metal halide bulb. However, it was discovered through our chi-squared analysis that this difference is not significant.

Comment [SG13]: Per the rubric, in the first part of the Discussion you explain/interpret your results and state whether or not your hypothesis was supported and/or problem solved, depending on the type of project you tackled.

Comment [SG14]: Notice how the interpretation of the results and conclusions of "success" are tied to the statistical model they previously identified.

However, there were flaws in the experiment that could have skewed results; for example, the differing wattages of each respective light bulb. However, it is hypothesized that the different wattages would not affect the data significantly, because the luminous intensity of each light is relatively close. This means that the amount of light produced is about the same, and the difference in power usage can be explained by how efficiently each bulb transforms electrical energy into light. In the case of the incandescent and metal halide, only about 8% of the electrical energy becomes light and the rest is lost as heat. This lack of efficiency in heat and light sources as a challenging factor in successfully implementing vertical farms was similarly noted in Despommier's studies from 2009 and 2010. Another variable that could have affected the outcome of our experiment was the relative times it took for each light to "warm up" and exhibit their maximum production of light. Both fluorescent lights and the metal halide bulbs require a certain amount of time to reach their typical light production rate. However, it was not found that this factor significantly affected growth in any way because this "warm up" time was found to be only 22 seconds for the fluorescent and on average three minutes and 28 seconds for the metal halide, and the lights were left on for twelve hours.

Furthermore, another flaw in the experiment is that the particular plant species used in the experiment is not completely reliant on light for growth. Although all plants, including grass, need essential nutrients to grow, as provided through the hydroponics system, it was not scientifically determined whether grass is completely reliant on light for growth. Therefore, the experiment may have been able to run even without the various types of lights as long as the essential nutrients were present. However, the different types of lights were able to show how plant growth, even in grass, is helped by different types of lights in varying degrees.

In the near future we would like to conduct further research concerning emerging lighting technology, such as organic light emitting diodes (OLEDs) in an attempt to reduce carbon emissions and increase the efficiency of vertical farming methods. These non-commercially sold lights are constructed of organic materials and used in computer monitors; television screens; and small, portable system screens used in devices such as mobile phones; PDAs; and watches. Specifically, blue OLEDs are very efficient, as they produce no light and consume no power when inactive, have a long lifespan, and require little energy for the amount of light that they emit. However, the lights themselves are a relatively new technology, and are expensive. Therefore, they wouldn't help in one of the major issues that hinders the implementation of a

Comment [SG15]: One of the most common missteps in the Discussion section is NOT connecting your findings to the previous body of work and studies that you covered in your Lit. Review. If you're unable to make this sort of a synthesis connection, then you need to dive back into the research and find one. It doesn't, by the way, have to be a similar finding. It could be contrasting, which would be just fine. It could be both if you make multiple connections. Do this at least once. More would be better in this case.

Comment [SG16]: Don't hide from the problems you encountered along the way. If you embrace them, they will teach you. Besides that, a thorough analysis of them is required on the rubric. Be fearless in this section of the paper. Consider all sorts of different aspects of your project in which your methodology could've been more finely tuned and/or was problematic.

Comment [SG17]: There are two parts of the Discussion and Conclusion section in which you address future plans. The first is dealing with the relatively, immediate short term future project steps you plan to take as it relates to your project findings. It doesn't haven't to be as grand as this one is. It could be as simple as adding more trials and manipulated variables. *See below for the other place you'll discuss the future.*

vertical farm in the near future: lowering the initial costs of implementing the structure in an urban environment. However, OLEDs could be useful in lowering the overall costs of implementing a vertical farm in the long run. Besides exhibiting extremely high frequencies of up to six times that of an incandescent light bulb (Chen, C., et al. 2006), OLEDs can theoretically be modified to produce specific light frequencies, so that excess frequencies that plants are unable to utilize are not produced as a waste product. An added benefit is that they are very thin and mechanically flexible; OLEDs can be manufactured to be 0.5 mm or thinner.

Conclusion

The results of our experiment help to demonstrate ways in which vertical farming could help reduce carbon emissions linked to various agricultural practices in the United States and other parts of the world. However, it is unlikely that vertical farms will be implemented on a larger scale until higher efficiency lights such as OLEDs are able to be manufactured cheaply. Appendix E contains a brief analysis of a vertical farm's energy usage (Cox, 2010).

Although our research suggests that vertical farming is currently inapplicable on a large scale, application of its sustainable practices can be applied on a smaller scale to gradually lessen dependence on inorganic fertilizers and pesticides that dump many tons of carbon emissions into the atmosphere annually. Hydroponic and aeroponic systems can be implemented in greenhouses or local gardens in practicing sustainable agriculture. In the long term, we also plan to implement our findings by creating a movement advocating local food production using sustainable and economically feasible technology, such as hydroponics, instead of investing in overly ambitious "silver bullet" ideas that are based upon large corporations. It isn't agriculture itself that needs to be fixed, but its harmful products and wasteful practices. By altering the ideas of vertical farming to a small scale, we are able to reduce the threat of the impending food and energy crisis.

Comment [SG18]: The second place where you address the future is in the Conclusion. Here's where you think big and laterally, looking for "big picture" connections and plans for future works that have broader, systemic implications.

Ultimately, vertical farms themselves will not stop global climate change. However, its sustainable concepts, including growing crops hydroponically and aeroponically, are realistically and economically applicable on a small scale. Simple hydroponic systems are fairly easy to set up, as experienced in our experiment of grass under various light sources. Furthermore, growing plants using these practices has its benefits: plants are not as susceptible to factors such as disease and parasites and can be grown year-round under controlled environmental conditions. Growing plants indoors hydroponically or aeroponically also eliminates the need for pesticides, and helps to reduce carbon emissions in producing and transporting the pesticides

References

Comment [SG19]: Again, the reference are on a separate page (use the page break feature to ensure this: Ctrl + Enter), it's alphabetized, double spaced, and uses hanging indentation. It's a collection of ONLY the sources you cited in your paper/lit. review.

Bawaba, A. (2010, September 12). Vertical farming can help shape up food security. *Khaleej Times*. Retrieved October 4, 2010, from ProQuest Newsstand.

Bouquet, T. (2010, January 9). The world of work is set to change; This is Denise Nurse, a lawyer. She has more than 200 clients, yet has never set foot inside a solicitor's office. Welcome to the 21st-century workplace [Eire Region]. *The Times*, *50*. Retrieved October 17, 2010, from ProQuest Newsstand.

Cox, S., & Tassel, D.V. (2010). Vertical farming doesn't stack up. *Synthesis/Regeneration*. Retrieved October 6, 2010, from Gale Opposing Viewpoints.

Chen, C., Chen, C. H., Chen, J., Chen, S. & Chu, T. (2006). "Highly efficient and stable inverted bottom-emission organic light emitting devices". *Applied Physics Letters*, *89*: 053503.

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Ehrenberg, R. (2008, October). Let's get vertical. *Science News*, *174*(8), 16, 18-20. Retrieved October 7, 2010, from JuniorQuest Magazines.

Marland, Gregg. (2001). A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States. *Agricultural Ecosystems and Environment*, *2*(91), 217-225.

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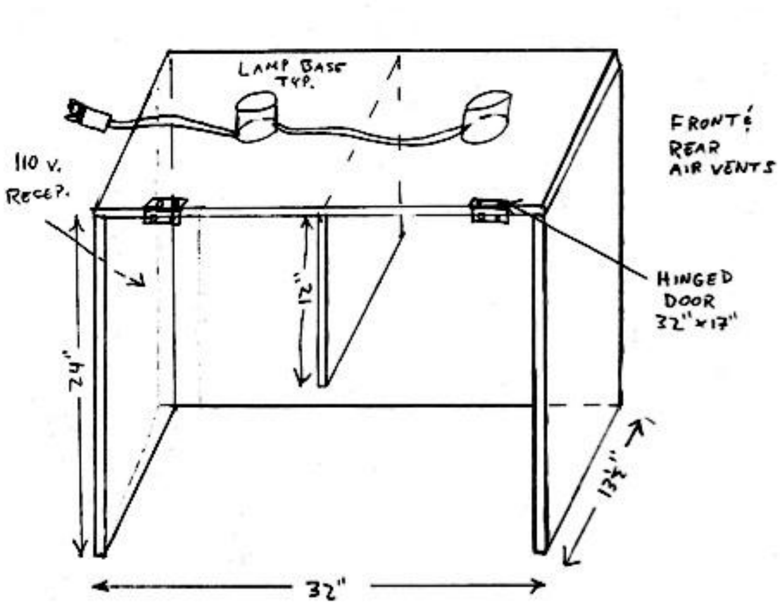
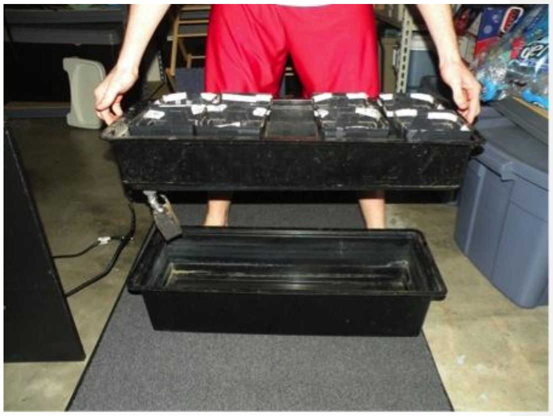
Appendix A





The tubs are slid under the divider and plugged into the outlet mounted on the side. The lights are plugged into the outlet through an *Intermatic* automatic timer. The outlet is wired so it can be plugged into any 110volt wall outlet.

Comment [SG20]: This group made extensive use of the Appendix section, including multiple appendices. While we typically expect to see only one Appendix, feel free to use more if you feel it's justified.

Comment [SG21]: This is the last section of your paper. Notice how it's still a part of the document and the Running Head and page numbering are intact. Remember to use the page break feature to create this break.

Appendix B

Day of Test	Height (cm)		
	Metal Halide	Fluorescent	Incandescent
1	0	0	0
2	0	0	0
3	0	0	0
4	0	0	0
5	0	0.5	0.25
6	0	0.75	0.5
7	0	1	0.75
8	0	1.5	1.25
9	0.5	2	1.75
10	1	3	2.5
11	1.5	4.25	3.5
12	2	5.25	4.75
13	2.75	6	5.75
14	3.5	7	6.5
15	4	8.25	7.75
16	4.25	9.25	8.5
17	5	10.5	9.25
18	6.5	11.75	9.5
19	8	12.5	10.25
20	9.5	13.75	11.5
21	11	14.25	12.5
22	12	14.75	13
23	12	15	13
24	12	15	13
25	12.25	15	13.25
26	12.25	15	13.25
27	12.25	15.25	13.5
28	12.25	15.25	13.5

Appendix C

Carbon emissions (metric tons) released in the production of fertilizer:

Nitrogen - 857.54
Phosphorus pentoxide (P_2O_5) - 165.09
Potassium oxide (K_2O) - 120.28
Calcium carbonate ($CaCO_3$) - 35.73

Carbon emissions (metric tons) released in the production of pesticides:

Herbicides- 4702.38
Insecticide- 4931.93
Fungicide- 5177.52

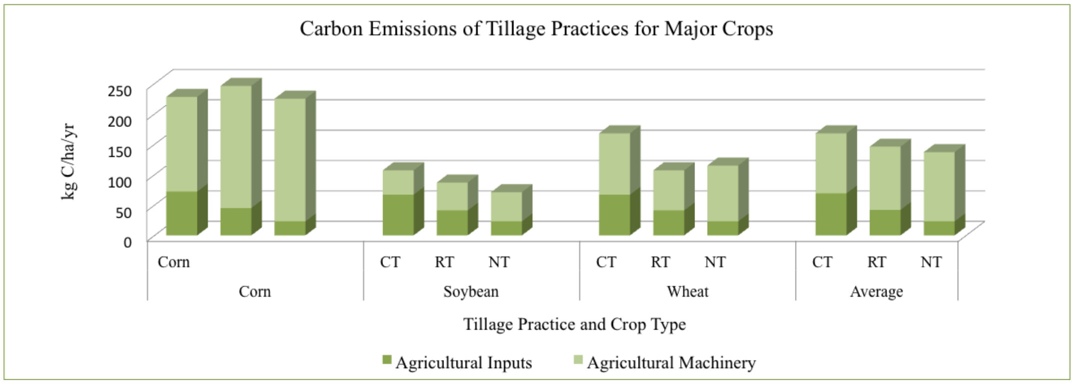
Carbon emissions released in irrigation (average per farm):

525.10 kg
Seed production (in kilograms of carbon emissions per kilogram of seed): 0.766 kg

Carbon emissions released in the average farm operation for the harvesting of:

Corn: 140.55 kg
Soybean/wheat: 131.41 kg

Appendix D



		Agricultural Inputs	Agricultural Machinery
		72	156
Corn	Corn	45	201
		23	202
	CT	67	40
Soybean	RT	41	46
	NT	23	48
	CT	67	101
Wheat	RT	41	66
	NT	23	92
	CT	69	99
Average	RT	42	104
	NT	23	114

Appendix E

“The following is a very rough estimate of the amount of power needed just for lighting. Note this is under ideal conditions for nutrients, temperature, and other productivity factors. Under excellent conditions, wheat has radiation use efficiency of 2.8 grams of biomass produced per [10.sup.6] joule of photosynthetically active radiation (PAR). So to produce one metric ton 1[0.sup.6]g) of wheat biomass requires [1[0.sup.6] g / (2.8 g/1[0.sup.6]J)] = 3.6 x 1[0.sup.11] joules of PAR over a season under ideal conditions.

Suppose an excellent 50% harvest index (ratio of grain mass to total biomass), so that a metric ton of wheat grain requires 7.1 x 1[0.sup.11] joules (actually more because the protein and oil in the grain require extra energy to produce, but ignore that.) The US produced 60 million metric tons of wheat grain in 2009, so that required 6 x 1[0.sup.7] times 7.2 x 1[0.sup.11], or 4.3 x 1[0.sup.19] joules of intercepted light energy to produce.

A metal halide greenhouse light (which provides light rich in the wavelengths needed for photosynthesis) requires 2.9 joules of electricity input to produce one joule of photosynthetically active radiation, so to produce 4.3 x 1[0.sup.19] joules of PAR would require 1.2 x 1[0.sup.20] joules of electricity at the socket. One kilowatt-hour is 3.6 x 1[0.sup.6] joules, so 3.4 x 1[0.sup.13] kWh of electricity would be required to run those lights.

Total delivered U.S. electricity supply from all sources in 2007 was 4.2 x 1[0.sup.12] kWh. So the entire U.S. electricity supply would have to be increased eightfold just to substitute for the solar radiation converted to biomass by the annual wheat crop.”