INDOOR AGRICULTURAL TECHNOLOGIES: AN INTRODUCTION TO THE FUTURE OF SUSTAINABLE FARMING

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ABSTRACT: Indoor agriculture provides a framework to address the need for new, innovative solutions to feed the planet's exponentially growing population. This investigation assesses the advantages and future prospects of indoor agricultural technologies as a sustainable alternative to traditional farming. A hybrid approach of academic literature review and exploration of indoor farming culture is used to provide a comprehensive scope of indoor agriculture. Cost-benefit analysis is utilized to examine potential economic advantages of hydroponic gardening systems and Light Emitting Diodes (LEDs). Advancements in artificial lighting technologies, a dwindling global water supply, and unpredictable weather patterns prompted by climate change, signals a promising prospective future for indoor farming.

Introduction

The human population is expected to reach 9.6 billion by 2050, creating a desperate need for new forms of sustainable agriculture (World Resources Institute 2014). Industrial agriculture is one of the largest contributors to environmental degradation and greenhouse gas emissions (Blanco et al., 2014). Climate change and environmental pollution creates an unpredictable set of variables that are difficult to navigate with traditional agriculture. New adaptive techniques will be necessary to mitigate undesirable farming conditions and environmental degradation.

New specialty forms of produce will emerge on the market. Indoor, hydroponically grown produce will become a niche market for wealthy consumers. Filtered and recirculated water is going to be preferred by consumers over the polluted soils of traditional agriculture. The air intake will be scrubbed by carbon filters, removing many of the pollutants circulating the atmosphere. Hydro-organic nutrient inputs will flourish as a new form of plant fertilizer for small-scale and high-end hydroponics gardeners.

While lighting technology advances, indoor gardening will become progressively efficient. Instead of dedicating large plots of land to agriculture, indoor gardening can provide a stacked multi-level system that conserves acreage. This system could be used in multiple stories of a building, or vertical stacking systems with many layers of lights in a single room. Light emitting-diodes (LEDs) are quickly replacing traditional indoor high intensity discharge lamps used for indoor horticulture (Wojciechowskaa, Długosz-Grochowska, Kolton & Zupnik, 2015). LED lighting allows farmers to optimize their lighting intensities and spectrums to achieve maximum photosynthesis rates for various cultivars (Gerovac & Craver, 2016).

Indoor agriculture is emerging as a distinct subset of farming techniques, technology, and culture. Current indoor agriculture technology, techniques, and information has set the framework for the future of sustainable farming. Exploring contemporary indoor gardening solutions is a necessary step for securing a sustainable future in both urban and industrial agriculture.

The following components of indoor agriculture will be investigated:

- Market-driven knowledge versus academic research, as it pertains to indoor agriculture.
- Cost-benefit analysis of various agricultural lighting technologies.
- Advantages of recirculating hydroponics and aeroponics systems.
- Site visit of successful, functioning, indoor farm.
- Interview with successful Urban Farming Specialists at Microsoft.

Methods

Much of the information pertaining to indoor agricultural technology is market driven and resides outside of academia, which prompted a hybrid approach to literature analysis and research. This involved consulting both academic and community-based contributions. Many contributors are accomplished academics, though they tend to submit articles to informal publications, blogs, and magazines (Maximum Yield 2017). This paper takes an Environmental Studies approach to understanding the culture of indoor farming, how the industry has developed, and how it can be applied to improve large-scale agriculture.

Cost-benefit analysis was conducted to compare and contrast various lighting technologies, namely high pressure sodium (high intensity discharge) lamps and light-emitting diodes (LED). Calculations were made with consideration to cost of electricity, lumens per watt, spectrum efficiency, maintenance fees, and air-conditioning. Agricultural lighting efficiency is an essential component to profitability.

A site visit was conducted at Microsoft's Urban Farm in Redmond, WA. I was given a comprehensive, informational tour of two indoor farming facilities. This tour was conducted by two of their lead Urban Farming Specialists and was followed by an interview consisting of roughly nine questions with intermittent conversation and follow-up questions. The site visit and interview was a valuable method of gathering information from specialists with hands on experience designing, facilitating, and configuring a medium-large scale indoor farm.

Limitations

Academic sources are quite limited because many industry standard practices have yet to be investigated or have only very recently been researched. For example, hydrogen peroxide in hydroponics systems is very commonly used to prevent root rot but does not appear to have been formally studied in academia until 2016 (Bosmans, et al. 2016). This suggests that academic research pertaining to indoor gardening techniques is behind market driven and community-based contributions.

Cost-benefit analysis is subjective to local weather conditions, cost of electricity, scale of facility, room dimensions, and desired outcome. It is difficult to create an analysis that will hold true in any given scenario. An assumption is made that the facility in question is a medium to large scale farm of at least 20,000 watts of electricity.

Researching particular agricultural products and indoor gardening techniques was a particularly daunting task. Indoor gardening products often have extremely competitive niches that rapidly evolve. Due to these brisk changes, it is unrealistic to determine which products and techniques work best by consulting academic research. Indoor growers collectively decipher which techniques and products are most effective through anecdotal experience, monitoring tools, online message boards, and recently, social media. Aside from this approach not being academic research, a large portion of indoor gardeners are cannabis growers, effectively dominating the indoor agriculture market. Cannabis growers look for qualitative traits that food crop growers may not value, such as trichome production.

The limitations all suggest an increased need in indoor agricultural research, though this need is mainly necessitated by the advancements in market driven technologies and techniques. A great deal of academic research could be conducted in order to validate or invalidate commonly held beliefs in indoor agriculture culture.

Results

Light Emitting Diodes (LEDs) vs High Intensity Discharge Lamps (HIDs)

Utilizing LEDs instead of HID lighting systems is not only more energy efficient, but more economical as well. The most common industry standards in artificial greenhouse lighting are the HID lamps, High Pressure Sodium (HPS) and Metal Halide. HPS lamps last a maximum of 20,000 hours and Metal Halide 10,000 hours, whereas LEDs have a lifespan of 100,000 hours (Yeh, Naichia, and Jen-Ping Chung 2009). HPS and Metal Halide lamps gradually diminish in lumen output over time. To ensure HID lamps are running at optimal efficiency, bulbs must be replaced at least once per year butideally every 6 months. Assuming these were changed once a year, that would only give HID bulbs a shelf life of 6,570 hours, costing $50-100 USD per bulb. LEDs run much cooler than HPS lamps, putting out approximately half as much heat. This not only eliminates a costly need for air conditioning, it allows the lamps to be closer to the plant, enabling it to absorb a higher amount of lumens.

As far as general lighting systems go, HPS is fairly efficient at roughly 100 lumens per watt. LEDs have reached over 300 lumens per watt in lab settings (Cree 2016). Factoring luminous efficiency (lumens per watt) is somewhat important for considering which lighting systems to use. This is not, however, the deciding factor for determining efficiency of horticultural lighting systems. Plants do not heavily utilize a full light spectrum, allowing LEDs to enhance specific wavelengths for more efficient optimization (Darko et al., 2014).

HID lighting systems do outperform LEDs in one important department, and that is initial setup cost. A high end LED system, with equivalent output to a 1,000 watt HID system, would cost roughly $1700. A high end 1,000 watt HID system would cost roughly $500. Assuming the cost of power is $.10 per Kilowatt/Hour, which is roughly the cost of power in the Greater Seattle Area, an 18 hour day under HID would cost $1.80 per light. If there were 20 HID lamps running, it would cost $36 per day or $1,080 per month. An equivalent LED light would only require 60% of the power a HID system draws, saving $432 each month or $5,184 per year. It would also save an additional $1,500 per year in bulbs. If the LEDs were only used for 5 years or 32,850 hours, that would be a total savings of $33,420 [($5184+$1500)*5 years]. One of the hidden fees of indoor gardening is air conditioning. Depending on outdoor temperatures, the baseline for air conditioning per 1,000 watt bulbs is 4,000 BTUs (in some areas much higher).

$$1\text{W} = 3.412141633\text{BTU/hr.}$$
$$4{,}000\text{BTU} \div 3.412141633 = 1172.284280733 \text{ watts.}$$
$$1172.284280733 \times 20 = 23{,}445.68561466 \text{ watts.}$$

It is difficult to determine how long the air conditioner will run per day because it is subjective to weather, season, and room. Cooling a room running HIDs can be quite costly.

LEDs are more costly to set up initially, but in the long run they are less expensive, more energy efficient, and environmentally friendly than HID lights. This technology is projected to advance to further maximize these benefits, making LEDs a primary candidate for artificial grow lighting.

LED vs the Sun

LEDs may not be able to compete with the sun in regards to energy efficiency but growing with the sun alone is not necessarily more economically efficient. A study conducted on multiple Mentha species showed up to four times higher essential oil production with LED lighting in comparison to field and greenhouse conditions (Sabzalian et al., 2014). The same study showed higher growth and flower production rate in lentil and basil plants compared greenhouse conditions. These plants also finished more quickly than those in greenhouse conditions.

Implementing LEDs can also be much more space efficient than traditional agriculture. This is especially important in regards to urban farming. An indoor farming operation called Mirai in Japan was able to achieve an increased spatial efficiency of roughly 100 times that of traditional agriculture (Kellner, 2014). Utilizing indoor spaces as opposed to sun exposure opens up new opportunities for urban agriculture, reducing food miles (transportation of food), and increased land use efficiency.

Recirculating Irrigation Systems

As the population increases, an ever increasing amount of water is needed to divert to agricultural irrigation, a sector that accounts for 69% of global water withdrawal (FAO, 2012). This will inevitably result in a conflict between environmental processes and access to water resources. Recirculating irrigation systems like hydroponics and aeroponics can drastically reduce water use for irrigation in addition to improved crops yields. In a study conducted in Yuma, Arizona, hydroponically grown lettuce yielded 11 ± 1.7 times more produce than conventional agriculture andthe amount of water used was over five times less L/kg/y (yield to water use ratio) (Barbosa et al., 2015). Other benefits include reduction of soil degradation, eutrophication, and improved waterway preservation. Integrating recirculating irrigation systems reduces water consumption, environmental degradation, and is more economically efficient than traditional agriculture.

Site Visit

I visited two indoor agriculture facilities at Microsoft in Redmond, WA and met with the two Urban Farming Specialists (UFS1 and UFS2) that worked on the projects. As I sat down with them, the UFS2 asked me what the one thing I would like to take away from the visit would be. I responded by indicating that aside from a short interview, I would like advice as to which lighting technology is the most efficient. They both seemed to think the answer was subjective to the plant being grown. Suggesting that leafy greens would do better with LED lights and plasma lights would be better for fruiting plants. They did not like their particular plasma lighting system, however. We commenced to the tour of urban farms.

The first site they took me to was an aeroponic lettuce garden. It was a pyramid style aeroponics system under plasma lighting in a public setting. When they took me into their reservoir room I was surprised to find that they used a hydro-organic base nutrient, Pure Blend Pro by Botanicare. Microsoft reports the garden uses “up to 90 percent less water than a standard field-grown lettuce crop” (Microsoft 2015). This garden may not have been energy efficient, but it was an effective conceptual demonstration of hydroponic water efficiency.After visiting the lettuce garden, I was taken to a different building where their microgreens were grown. The room had 15 types of microgreens in an automated watering system with 100% organic nutrient inputs. The water pooled into each tray of microgreens, slowly being absorbed by the roots and medium. Most of the water in the tray was being absorbed by the microgreens, but they also had an overflow drainage system. Because of the standing water they occasionally had issues with root rot. Since the microgreens life cycle is only 20 days, they did not find treating root rot to be necessary, especially since it wasn’t a widespread issue. The room was arranged with multiple levels/stacks of T5 lighting systems. Most of the lighting was T5 fluorescent panels with occasional LED replacements. UFS1 mentioned that LEDs are much more cost efficient to replace in T5 panels as opposed to simply purchasing an LED system. They did not need fans in the room because of the powerful HVAC and high level of ambient co2. The microgreens facility was an excellent demonstration of a space efficient urban farm with organic inputs.

After visiting the microgreens room they took me into their sanitation room. This was a room they washed out all their trays and gardening materials, similar to a dishwashing station in a kitchen. Sanitation was stressed as incredibly important to the entire process.

After the tour of the site, I did a sit down interview with UFS1 and UFS2. The inspiration was for this garden was Mark Freeman, the Director of Global Dining at Microsoft,wanting an "ingredient revolution." His interest in indoor growing was sparked by going to gardening conventions. The garden was meant to represent innovation, the future of food, and was partly a marketing strategy. Aesthetics and conceptual appeal was meant to lure stakeholder buy in, andwithout these appeals the garden would not have been implemented. Both interviewees suggested that it wasn't important what's actually going on, more what they think is going on. 80% is stakeholder managed. Making things look perfect is a priority. UFS1 mentioned that things that happen in permaculture could not happen in public spaces because they need to look presentable.

Growing microgreens was estimated to be half the cost of simply purchasing them. Microgreens are high value and don't store well, making them more practical to grow. Lettuce was a different story. Most of Microsoft's lettuce is purchased and is much cheaper to buy from farms. The plasma grow acts as an art installation, but produces 30 pounds of lettuce per pyramid. The main purpose of the plasma grow is stakeholder buy in and sparking conversation.

I asked them about plasma lighting as it compared to other lighting technologies. UFS2 remarked that plasma lighting is "cool" but the technology is underdeveloped. Bulb performance was also problematic. They replaced bulbs the day of the interview and one already went out. They theorized that plasma has better potential for fruiting crops and LEDs would be better for leafy greens. Plasma bulbs were meant to last for a full year but on that particular day there was an instance of six hour bulb life. The bulbs are made of quartz and have a lower amount of safer mercury than HPS bulbs. The systems they were using had recurring bulb outages, which are likely a symptom of poor manufacturing, coupled with new technology. The interviewees stated that Plasma and LED lights have different applications. LEDs can be closer to plants, whereas plasma lights are too light intense for close proximity. LED is better for stacks of leafy greens. Plasma is better for fruiting crops. Plasma has UV that helps promote the growth of certain resins. They thought that LED technology was more developed than Light-emitting Plasma and likely more practical to utilize. The following LED systems were recommended:

ILLUMITEX - NEOSOL DS - 520 WATTS:
$1,829.73 shipped

This system is equivalent to a 1,000 watt HPS system. It is dimmable down to 10% of it's full output, which may be useful for smaller plants. It also keeps its light intensity fairly consistent when raised, whereas many systems lose a considerable amount of lumens as they increase in distance from the plants. This is a generally well reviewed system and this brand was also recommended by UFS1.

Fluence SPYDRx Plus 685W LED Grow Light: $1500.00 (Or best offer)

This is another popular choice for high end LED systems. It focuses more on providing a full spectrum output of light. It pays respects to important photoreceptors outside 700 and 400 nanometers, as opposed to primarily boosting Chlorophyll A and B absorption ranges. Recommended to be used six inches from plant canopy. The wavelengths are designed for specific photomorphogenic responses, photoperiodic signals, chlorophyll A and B absorption, xanthophyll carotenoid pigments, and anthocyanin accumulation. Projected lifetime of 100,000 hours.

Some final thoughts and points made by the interviewees:

- Some plants may need low amounts of the light spectrum outside red and blue kelvins, necessitating full spectrum lighting.
- Before accepting advice or hiring consultant, look at their previous or current work to make sure they've worked with large-scale operations.
- It is more difficult to design systems that work for long periods of time.
- Experience is everything. There are a lot of people who say they know what they're doing but simply lack hands on or large-scale experience.
- Smaller designs are not always scalable.

Discussion

The technology and techniques of indoor farming have already been developed and utilized, they simply aren't present in mainstream agriculture. Cost-weight analysis of indoor agriculture versus traditional industrial agriculture is complicated to analyze, making it difficult for farmers to see the advantages of indoor agriculture. Creating artificial environments may also be more complicated and intricate than industrial agriculture, adding an element of risk to pursuing an indoor farming endeavor. One of the primary issues of indoor agriculture, as it relates to developing countries and sustainability, is that these facilities are quite costly to set up when compared to traditional agriculture. Technology is currently available to implement sustainable indoor agriculture on a large scale, but initial setup fees are much higher than current industrial agricultural models.

Conclusion

Traditional agriculture is one the primary contributors to environmental degradation, greatly necessitating new approaches to farming techniques. Investing in indoor agriculture is not merely an economic investment that will pay off over time,it is also an investment in the future of sustainable farming that can provide a cutting edge model for other establishments to follow. As this technology becomes more sophisticated, artificial lighting and recirculating irrigation systems will become progressively feasible.

LED lightings and recirculating irrigation systems are powerful steps towards implementing a futuristic model of indoor, urban agriculture. LED technologies have shown to provide clear advantages over HID systems regarding energy efficiency, space efficiency, heat output, and light spectrum optimization. Recirculating irrigation systems can drastically improve yield while simultaneously reducing water consumption. If LED lighting systems and recirculating irrigation systems enter mainstream agriculture it would reduce various aspects environmental degradation, creating a more sustainable future for the exponentially growing human population.

Projected population growth cannot be sustained by traditional agriculture. New farming techniques need to be explored and utilized to meet the future global carrying capacity of humans. Current indoor garden culture has provided a powerful framework for implementing the future of sustainable farming.

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