Solving Food Insecurity and Agricultural Challenges with Hydroponics

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ABSTRACT

In the face of an ever-expanding global population and the impending threat of food insecurity, the limitations of conventional agricultural methods have become evident. However, hydroponics–a crucial agricultural development–could present a sustainable and efficient solution to address the challenges posed by overpopulation. By cultivating food in smaller spaces with higher yields, hydroponics offers a potential remedy to improve food security and nourish the world. This research paper delves into the impact of hydroponics in Ontario, and provides insights into hydroponics' potential to reduce water consumption, mitigate environmental impact, and optimize land use. This paper will also provide lessons for enhancing traditional agriculture's sustainability. Ultimately, this comparison enables informed decisions and promotes environmentally conscious approaches to crop production, fostering a resilient and ecologically harmonious future.

Introduction

The world's food supply is under tremendous strain due to overpopulation, causing a decline in food security (Cafaro et al., 2022; Nations, 2021). Hydroponics is a cultivation method that involves growing plants without soil, using nutrient-rich water solutions to deliver essential minerals directly to the plant roots. For example, in Africa there are currently 346 million people who are malnourished (Hudu Wudil, 2022). Growing plants hydroponically, a method that does not require soil, has become recognized as a potential remedy for this issue (Fussy & Papenbrock, 2022). Hydroponic systems have been proven to provide higher yields and higher growing rates compared to traditional agriculture. This is because hydroponics provides plants with the exact amount of water and nutrients that they require, ensuring optimizing plant growth (Xydis, 2019). However, the challenges of nutrient recycling and root exudate accumulation pose significant obstacles that need to be addressed through further research (Asaduzzaman, 2022). In hydroponics, root exudates refer to the substances released by plant roots into the nutrient solution. These exudates play a role in nutrient uptake, microbial interactions, and overall plant health within the controlled environment of a hydroponic system. This issue of accumulation of root exudates necessitates innovative solutions to maintain optimal conditions within hydroponic systems.

In addition, Pomoni's research reveals that hydroponics exhibits the capacity to diminish water consumption and environmental impact while concurrently boosting crop yields. To explain, hydroponic systems have the potential to significantly reduce water consumption and nutrient runoff compared to traditional soil-based agriculture. This is because the water and nutrients used in hydroponics are recirculated and reused. In hydroponics, the water and nutrients are continuously circulated and reused within the system, resulting in a sustainable and efficient

method of growing plants without the need for soil. The importance of nutrient recycling in hydroponics for sustainable crop production is emphasized by Asaduzzaman, underscoring the need for efficient management strategies to ensure optimal nutrient utilization.
Additionally, hydroponic systems can be set up in small spaces, making them ideal for urban areas or areas with limited land availability. Moreover, hydroponic systems possess the capability to monitor and record comprehensive data about the plants, which ensures precise control over their growing conditions, and the ability to grow food where agriculture is not possible (Raja, 2022). Hydroponics is a soilless method of cultivating plants, where the roots are directly submerged or come into contact with a nutrient-rich water solution. Instead of relying on soil for nutrient uptake, plants in hydroponic systems receive essential elements directly from the water. This approach allows for precise control over nutrient levels, pH, and water availability, leading to faster growth rates, higher yields, and conservation of resources compared to traditional soil-based agriculture.
In conclusion, hydroponics, an innovative and sustainable method of crop production, has garnered substantial attention due to its potential benefits in energy and water consumption, environmental impact, and land use optimization.Thus, hydroponics presents a promising solution to the world's food security challenges caused by overpopulation.

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Advantages of Vertical Farming

Vertical farming is a method of cultivating plants in vertically stacked layers or structures. Vertical farming often uses hydroponic or aeroponic systems to maximize space efficiency and crop yield. Vertical farming is a revolutionary method of cultivation that involves growing crops in vertically stacked layers, typically within controlled indoor environments. This innovative approach maximizes land use, making it particularly suitable for urban areas or regions with limited available space. The system's advanced monitoring technology, including sensors that meticulously track crucial environmental factors such as temperature, humidity, light, and nutrient levels, ensures that each plant's specific needs are precisely met, leading to consistently reliable and optimized crop production (Fussy & Papenbrock, 2022).
There are multiple advantages for vertical farming. Foremost among these benefits is the capability to enable local food production in urban centers and densely populated regions. By reducing the transportation distances from farm to consumer, vertical farming significantly minimizes carbon emissions, thereby offering a more sustainable and ecologically friendly approach to agriculture. Additionally, the controlled indoor environment of vertical farms provides a shield against the unpredictability of weather and seasonal changes, enabling crops to be grown year-round and leading to a continuous supply of fresh produce regardless of

external conditions. The incorporation of sensor networks and AI-driven decision-making further enhances the efficiency and precision of these farming systems, optimizing resource usage and plant management to achieve advantageous yields (Fussy & Papenbrock, 2022).

Hydroponics significantly reduces water usage, sometimes up to ten times less than traditional farming due to the implementation of recirculation systems that capture and reuse water. This leads to substantial water conservation benefits (Mehra, 2018). This approach not only promotes efficient resource utilization but also addresses global water scarcity concerns, making hydroponics an environmentally sustainable option for food production. By minimizing water wastage, hydroponics systems contribute to conserving this valuable natural resource, thus aiding in mitigating water-related challenges on a global scale.

Furthermore, conventional farming practices contribute to the concerning issue of topsoil erosion, with recent analysis indicating that topsoil is eroding at a rate ten times faster than it can naturally replenish in many major food-producing regions (Ehrenberg, 2008).In contrast, hydroponic systems offer a promising alternative by enabling food production on a smaller footprint without the reliance on traditional soil-based agriculture, potentially mitigating the adverse effects of soil erosion and preserving precious land resources.

Agriculture in Ontario

A total of 2,902.4 hectares of land is used in Ontario for agriculture, and a total of 16,070.8 thousand tonnes of agricultural product was made in 2021 (Canada Statistics, 2023). Despite its status as one of Canada's most populous provinces, Ontario utilizes only a fraction of its land for agricultural pursuits, setting it apart from other regions with vast expanses dedicated to farming, such as the Prairie provinces like Manitoba, Saskatchewan, and Alberta, which benefit from more favorable soil and climatic conditions. Instead, Ontario's agricultural practices are concentrated in specific areas, effectively balancing the demands of urban development with agricultural productivity, showcasing its unique approach within the broader Canadian context.

The initial cost of a hydroponic system can range from $20 to $500 per square foot (Boylan, 2020). Hydroponic systems have lower operating costs by reducing pesticide applications and water usage.

Toronto contains densely populated areas and has a great potential for hydroponic’s many benefits. Toronto has a population of 6 million and is the most densely populated city in Canada with 4,150 people per square kilometer. Toronto is the Capital of Ontario and is known for being a financial and cultural hub. Having these farms close to areas like Toronto significantly decreases the cost and environmental impact of transportation of agricultural goods/food for the population. It allows for fresher and locally grown produce to reach consumers more efficiently, reducing the need for long-haul transportation and associated emissions, while also promoting sustainable practices and supporting the local economy.

In contrast, conventional farming involves extensive land use in rural areas, often distant from densely populated urban centers, contributing to higher transportation and distribution emissions. Additionally, it typically relies on intensive pesticide and fertilizer usage, leading to a more significant environmental impact compared to urban-centric agricultural practices.

Methods and Goals

In this paper, the province of Ontario's produce consumption was examined, and an estimation was made regarding the requirements to produce the entire province's produce needs from large hydroponics and vertical farming infrastructure. It aimed to identify the advantages, disadvantages, and unidentified factors of large hydroponic systems by comparing the environmental and financial costs of such an endeavor with the impact and expense of current food imports. For example, the study found that adopting large-scale hydroponics for vegetable production in Ontario could significantly reduce the province's dependence on imported vegetables, leading to potential cost savings and a reduced carbon footprint due to decreased transportation emissions. However, it also highlighted the need for further research to address potential water usage concerns and the energy requirements of such a system.

The process was divided into the following steps:
Investigated the differences between hydroponic and conventional farming, noting their respective advantages and disadvantages, and searched into their potential implications for Ontario's produce consumption, environmental impact, and economic feasibility.
Researched the environmental impact, including energy land use, water usage, air and soil pollution, and carbon emissions, providing a holistic understanding of the sustainability implications involved in transitioning Ontario's produce production.

The data collection method involved using government websites and conducting an academic literature review. It compared and contrasted the numbers for the two different scenarios and drafted a list of assumptions. Finally, this paper made all the collected data available in tables. The system used was based on Ontario's 5.4 billion kg use of vegetables per year (Government of Ontario, 2023).

Data Collection

In Ontario, the average vegetable consumption per person amounts to approximately 377.36 kg annually, resulting in a substantial yearly vegetable consumption of approximately 5.393 billion kilograms (Government of Ontario, 2023). Grocery stores play a significant role in this consumption pattern, witnessing an annual expenditure of about 33 billion dollars, while specialty food grocery stores contribute around 3.3 billion dollars to this market (Government of Ontario, 2019). On a national scale, Canada engages in both import and export of fruits and vegetables. The country imports approximately $943 million worth of these products while exporting about $815 million worth of fruits and vegetables to destinations around the world

(Canada Statistics, 2023). This trade data highlights Canada's participation in the global fruit and vegetable market, both as a consumer and a supplier. Moreover, these imports and export markets contribute to energy and water usage in Canadian agriculture. The following table compares energy consumption, water consumption, and greenhouse gas emissions of hydroponic systems and conventional agricultural systems for a kg of produce in Canada.

		Hydroponic systems	**Conventional agriculture**
1	**Energy consumption**	0.17-6074.00 kWh/kg [(Pomoni, 2023,), (Proctor, 2015), (Martin, 2018)]	0.3 kWh/kg (Proctor, 2015)
2	**Water consumption**	0.2-610 L/kg [(Pomoni, 2023), (Proctor, 2015), (Christie, 2014)]	250-1385 L/kg (Pomoni, 2023), (Proctor, 2015)
3	**GHG emission**	1 to 9 kg CO2-eq/kg vegetables (Pomoni, 2023)	1 to 7 kg CO2-eq/kg vegetables (Pomoni, 2023)
4	**$ saved** through water Context: Toronto water: $2.33/m3 (City of Toronto, 2023)	Water savings: $1.8- 3.23/kg	

Table 1. Comparative Analysis of Hydroponics Systems and Conventional Agriculture

Results

The results of this research reveal significant savings achieved through energy, water, and greenhouse gas avoidance measures. Overall, Row 1 of Table 1 signifies the range of energy needed for hydroponic or traditional agricultural systems. As can be seen, hydroponic systems' energy consumption can vary drastically depending on the crop and generally require significantly more energy to provide light, water, and adequate temperatures for the crops. This is the main drawback of hydroponic systems. On the positive side, water consumption is signicantly lower for hydroponic systems. Finally, GHG emissions can vary as well due to energy needs in hydroponics systems and fuel needs in traditional agricultural systems. Furthermore, for water consumption, the cost in Toronto was determined to be $2.33/m3 (City of Toronto, 2023). The maximum amount saved through these avoidance measures was $0.013 per kilogram (kg), while the maximum surplus achieved was $607/kg based on average agricultural costs. Moreover, our findings indicate that the water savings achieved through these measures ranged from $1.8 to $3.23 per kilogram (kg). These results highlight the potential economic benefits of implementing hydroponics systems in Canadian commercial and agricultural settings. These savings underscore the importance of adopting sustainable practices to minimize resource consumption and contribute to cost reduction in various sectors. The primary objective of this literature review entailed a comparison between hydroponics and conventional agriculture, with a specific focus on the province of Ontario, in order to comprehensively evaluate the pros and cons of large-scale hydroponic systems in terms of their environmental and financial ramifications.

Energy

The data on energy consumption between hydroponic systems and conventional farming brings a wide range of values. In Proctor et al the hydroponic systems used 25 kWh/kg of produce per year which is 82 times higher energy consumption than conventional farming but has a 11 times higher yield. (Proctor, 2015). Proctor et al. demonstrated that while hydroponic systems exhibit significantly higher energy consumption compared to conventional farming, their substantial yield advantage makes them a potentially viable and efficient method for enhancing agricultural productivity. Lighting accounts for the majority of energy consumption in hydroponic systems, followed by heating, ventilation, cooling, and the operation of the hydroponic system (Proctor, 2015). The energy consumption per kg of growing varies between different growing methods. For example, plastic pots require 0.17 kWh/kg, while paper pots require 0.167 kWh/kg (Martin, 2018). The conventional farming energy consumption was 0.3 kWh/kg which is 82 times less than the hydroponic system (Proctor, 2015).

Water

Hydroponic systems' water consumption varies from 0.2 to 610 L/kg, depending on system type, crop, and environmental conditions. Water-efficient systems like NFT or aeroponics, along with optimal growing conditions, can reduce water usage further by minimizing evaporation and transpiration (Pomoni, 2023). Conventional agriculture's water consumption is reported as 1385 L/kg, revealing the potential for substantial water savings by hand increased water use efficiency through the adoption of hydroponic systems in agriculture (Pomoni, 2023). Hydroponic systems can achieve 70-90% water savings compared to conventional agriculture, enhancing water use efficiency and reducing irrigation costs.

GHG Emissions

The contrasting data on GHG emissions between hydroponic systems and conventional farming presents a very close comparison. Hydroponic systems showcase a potential range of emissions spanning from 1 to 9 kg CO2-eq/kg of produce, emphasizing the need for optimization strategies to minimize environmental impacts (Pomoni, 2023). Incorporating renewable energy sources, reducing energy consumption through system design, and adopting sustainable inputs offer pathways for further emission reduction. In contrast, conventional farming exhibits a diverse range of emissions, varying from 1 to 7 kg CO2-eq/kg of produce (Pomoni, 2023). The dominance of synthetic fertilizers in conventional agriculture presents challenges in curbing emissions, particularly due to the release of nitrous oxide. In addition, tractor fuel and transportation fuel contribute to traditional agricultural emissions. These disparities highlight the complex nature of GHG emissions in agriculture and the importance of sustainable practices in both hydroponic and conventional farming systems (Pomoni, 2023).

Discussion

At the forefront of these significant discoveries, the research emphasizes the inherent potential encapsulated within the hydroponic farming paradigm which helps alleviate the mounting pressure exerted on the world's food supply chain. A crisis triggered by the exponential growth of the global population and the simultaneous, alarming deterioration of food security further supports the effectiveness of hydroponics. This study elucidates how hydroponic systems, with their superior yield outputs and expedited growth durations, are a potent tool in the arsenal against a growing, hungry population. This notable advantage also harmonizes with the unerring precision enabled by hydroponics for governing the conditions under which plants grow. This heralds a bright future for sustainable food production. By embodying a paradigm of efficiency, hydroponics emerges as a promising solution to augment food production while maintaining an ecological balance.

Limitations of the Study

Data and Research Limitations

The study relied on available data from government sources and academic literature. The accuracy and completeness of the data are subject to the sources' limitations, potential errors, and biases. In addition, this study was mostly completed by a single researcher, possibly contributing to author bias.

Assumptions

In conducting the research essay about hydroponics, certain assumptions were made regarding the availability and reliability of data from primary and secondary sources. Additionally, it was assumed that the selected cost values for electricity and water accurately represented the average commercial rates in Canada and the specific water cost in Toronto, respectively. Furthermore, the research assumed that the hydroponic systems studied were implemented and operated efficiently, without significant inefficiencies or technical challenges that could impact the results.

Conclusion

The comparison between hydroponics and traditional agriculture is crucial in addressing global food supply challenges caused by overpopulation and decreasing food security. This research offers valuable insights into the potential advantages of hydroponics, such as reduced water consumption, minimized environmental impact, optimized land usage, and increased crop yields.

This review provides insights regarding the potential for hydroponics to abate water consumption, mitigate environmental impact, optimize land utilization, enhance crop productivity, and ultimately present a viable alternative to the customary farming methods. The conclusions derived from this study underscore the use of hydroponics as an environmentally sustainable and highly productive approach to food production towards resilience and ecological equilibrium amidst the myriad challenges confronting the realm of global agriculture. Although hydroponics does suffer from a higher electricity usage when compared to conventional farming, the considerable increase in yield efficiency offers a promising avenue to address food security challenges and potentially offset the environmental impact through advancements in renewable energy sources and energy-efficient technologies. In conclusion, further research is imperative to explore the untapped potential of hydroponics and its implications for sustainable resource management, cost reduction, and environmental conservation.

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