Hydroponic Crop Cultivation as a Strategy for Reducing Food Insecurity
(Technical Paper)

Hydroponic Farming as a Sustainable Transition from Current Farming Practices
(STS Paper)

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By
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On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

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Introduction

Population growth, urbanization, and climate change are all factors that are creating stress on crop cultivation. Conventional farming methods are unsustainable under these conditions, and the result is a rise in food insecurity faced by many groups across the world. My Systems Engineering Capstone team is working to create a viable supplement, or even alternative, to current agricultural practices. Over the course of four years, Professor Garrick Louis has worked with previous Capstone groups to create an efficient hydroponic farming system. Hydroponics refers to the cultivation of plants through a nutrient rich solution without the need for soil. This year, our group will work to improve and build upon the current hydroponic crop system that has been modified and constructed over time. The goal of this project is to provide a humanitarian service of helping create sustainable food sources in areas with high risk of hurricanes and flood events. The main modification we are looking to make to the current design is enabling the system to float in the event of flooding or sea level rise, as we want to implement our design into coastal and island communities facing food insecurity.

The focus of my STS topic is very closely related to my Capstone, as it evaluates the potential of hydroponic farming to become the new widely used crop cultivation method. Hydroponic techniques have been around for thousands of years, the earliest examples dating back to Hanging Gardens of Babylon and the Floating Gardens of China (Espiritu, 2019). Today, hydroponic systems have evolved to grow plants faster, stronger, and healthier, and are used on limited commercial-scales as well as at-home food production by hobbyists. But why are hydroponics not more widely used or accepted? Though there have been efforts by companies and individuals to increase sustainable farming methods, more specifically, hydroponic growing systems, it just hasn't caught on yet. My STS will focus on where and why hydroponics have been successful and also where they fall short, and how perhaps in the future, society might transition to hydroponics as a more sustainable alternative to the current agricultural regime.

Technical Topic

Current traditional farming methods face pressure from climate and non-climate stressors such as population growth, demand for animal products, and availability of fertile soil. In the next century, climate change is projected to negatively impact the four pillars of food security – availability, access, utilization, and stability. These four pillars are under pressure from human-induced effects: increasing temperatures, changing precipitation patterns, and the increase in frequency, duration, and intensity of extreme weather events like floods, droughts, and hurricanes (Byrne, 2021). Small-scale farmers in Small Island Developing States (SIDS) are especially vulnerable to the impacts of climate change on food security. SIDS are located in the Caribbean, Pacific, Indian Ocean, and South China Sea and make up approximately 1% of the world's population. These populations face unique challenges due to their small land area, remote geography, and susceptibility to extreme climate events (United Nations).

Hydroponic farming alleviates the increasingly pressing issue of food scarcity because it is a self-contained system which does not rely on natural climate conditions to grow crops. My Systems Engineering Capstone team will work to improve and build upon the current hydroponic crop system that has been created over the course of four years by previous Capstone groups. Figure 1 displays a picture of the hydroponic system developed over the past four years. The most recent Capstone group modified the system to make it collapsable and transportable, so that hydroponic farmers could bring the system indoors in the event of a storm or hurricane. The previous group also added an agricultural fabric to the outside of the system to act as a shelter for the plants in an effort to protect against wind and pest invasions (Hoherchak, 2020). Like the year before, the goal of this project is to provide a humanitarian service of helping create sustainable food sources in areas with high risk of hurricanes and flood events. We are working to adjust our current hydroponic system to make it even more storm-resistant and create a hydroponic farm with the ability to float that will be able to maintain its integrity in areas with sea level rise or recurrent flooding in order to present more food security to these areas (such as SIDS). To make the system sturdier, we will use more durable materials rather than the PVC pipes currently being used. We plan to alter the structure of the system to make it more aero-dynamic and storm-resistant, and lastly we will give the system the unique ability to float. We hope to modify the current system in this way so that it can also be used to create resilient food systems in hurricane risk environments, urban food deserts, refugee camps, and even rooftop gardens. Our group is composed of both Civil and Systems engineers. The Civil engineers will focus mainly on the construction and physical alterations to the hydroponic system while the Systems engineers will analyze where our system can be best implemented and what factors make hydroponic farming feasible in various scenarios and settings. We will work hand in hand with the Civil engineers to design a hydroponic system that meets the needs of our users. A systems approach will be used to analyze and assess the optimality of our design given our constraints, as well as to gauge which communities would benefit most from the technology being created.

Figure 1

STS Topic

Global population is projected to reach 9.8 billion people and 68% of the population is projected to live in urban areas by 2050 (Boylan, 2020). The amount of fertile and arable land is expected to decrease significantly by that time. Rising global temperatures, changes in precipitation patterns, an increased frequency in droughts and heatwaves, sea-level rise, melting of sea ice and a higher risk of more intense natural disasters are all effects of climate change that will worsen with time (Porter). My STS focus will document various cases where hydroponic farming has already been implemented and other studies involving hydroponics, and through these case studies I will analyze the viability of hydroponics as an alternative or augmentation to the current agricultural regime.

Sustainability transitions can be defined as "long-term, multi-dimensional, and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption" (Markard, 2012). Using the sustainability transitions framework, this paper will assess why hydroponics have not been widely adopted by society, why they have worked within certain local settings and scenarios, and how, based on this information, hydroponic systems must change to become a potential large-scale alternative to current agricultural farming practices. In a related piece, Aravind Kundurpi notes that local governments "often are disengaged from encouraging [small and medium sized enterprises] to take on sustainability-oriented initiatives." He notes that the critical importance of intermediaries other than government entities is to "fill knowledge and resource gaps, and act as boundary spanners in an increasingly complex web of actors, actions, and sustainability driven goals" (Kundurpi, 2020). With this framework in mind, I will take lessons from small-scale hydroponic enterprises to try to find factors that will translate into successful larger-scale hydroponic farming and potentially initiate a transition to more sustainable agricultural modes of production and distribution infrastructure.

The current regime of agricultural practices is not sustainable. The negative effects of unsustainable farming methods include, but are not limited to, wasteful water consumption, soil erosion and degradation, pollution, excess nutrients, climate change, genetic erosion, and land conversion (Verma, 2017). Many of the big market players in hydroponics, including AeroFarms, Argus, and Emirates Farms, to name a few, are creating efficient top-of-the-line hydroponic systems integrating the most high-tech components (Wood, 2021). As a result of the high costs that come with this advanced technology, the current market is tailored to well-off consumers and stakeholders, effectively halting the expansion of hydroponics into lower-income communities with limited resources. Despite this, smaller-scale efforts have been made to meet the needs of these less-fortunate consumers.

Hydroponics, in some cases, have been used in urban settings to relieve food insecurity, especially in areas considered food deserts. Food deserts are defined by areas where people have limited access to a variety of healthy and affordable food. Common characteristics associated with these areas include lower income and vehicle availability, as well as limited access to public transportation (Dutko, 2012). As an example, Blue Sea Development Corporation created an affordable housing complex in the South Bronx, New York called Arbor House, which features a hydroponic rooftop farm. The building provides housing for residents earning sixty percent or less of the area median income, and the rooftop will produce enough fresh crops to meet the needs of up to four-hundred and fifty people a year, all at affordable prices (Zeman, 2012). The hydroponic roof is irrigated by the property's own rainwater collection. Blue Sea Development was able to purchase the land from the New York City Housing Authority (NYCHA) at a below-market price in return for allocating units for underserved community members (Serlin, 2013). This hydroponic integration into affordable housing is only possible because of the partnership between the New York City Housing Authority and Blue Sea Development. More partnerships like these, which effectively reduce the cost of scarce resources, could lead to the successful development of hydroponics. The potential synergy of reducing food insecurity while promoting social goals of government or non-government organizations can make a meaningful difference.

Food insecurity is especially a problem in places with limited fertile soil and arable land. In small island communities with deficient farming land, consumers pay a hefty premium for produce due to shipping and markups, as many of their grocery products must be imported. This only adds onto the economical stress of poverty-stricken small island communities. An example like this can be observed in Cape Eleuthera, Bahamas where the expense of imported products and a higher unemployment rate relative to the rest of the Bahamas causes economic unavailability of food on the island. In her research study, Alexandra Becraft makes the argument that small-scale hydroponic farms and hydroponic backyard gardens are a potential solution to providing local, fresh produce that would otherwise be unaffordable for most households. To conduct the study, Becraft estimated start-up costs for the at-home hydroponic system and modeled a home-made unit for its low cost, material accessibility, and ease of construction. However, the author does note obstacles that will need to be overcome including gauging interest from the local community, identifying availability of materials/resources, and assessing the affordability of maintaining the system for years to come (Becraft, 2017). In this study, the author mainly focuses on the cost considerations of the hydroponic system. Because most households in Cape Eleuthera cannot afford high-tech hydroponic growing systems as an at-home garden, hydroponic unit prototypes must be designed with the financial needs of the locals in mind. This same approach can be applied to many other regions globally.

Not only does hydroponics offer a remedy to food insecurity, but it also provides other advantages to society including mental health and educational benefits. For example, the John E. Polk Correctional Facility in Seminole County, Florida, has introduced hydroponic farming as a tool to boost self-confidence, increase morale, and prompt interest in learning among inmates. The Bureau of Justice found that 83% of state prisoners were arrested at least once within nine years following their release, so providing educational training using hydroponics is a method used to try to reduce recidivism. The greenhouse sells $9,000 in produce annually to the facility's cafeteria which greatly increases the amount of fresh produce being served to both inmates and deputies (Wooten, 2020). Another institution using hydroponics as an educational tool are schools. For example, a school in Brooklyn, New York is using hydroponics to combat food injustice and close the gap for healthy food. Many students at the Brownsville Collaborative Middle School are pre-diabetic due to the lack of fresh produce available in the low-income neighborhood. The principal of the school reported that he counted more than 20 fast-food restaurants in the area, noting a pattern that grocery stores tend to settle in wealthier areas. The fruits and vegetables grown are used in the school cafeteria and are also sold at a discount from market rates to community members. Studies have shown that students exposed to hands-on learning, including cooking and gardening activities, “ate triple the amount of fruits and vegetables as students did in schools with less of this kind of learning” (Lloyd, 2019). Several non-profit organizations have been involved in building other hydroponic greenhouses meant for schools, including schools in New York, New Jersey, Minneapolis, and more (Lloyd, 2019). Implementing hydroponics into communities in creative ways can help start a dialogue around hydroponic growing. By introducing hydroponics to school children, this can create a cultural change where familiarity and comfort with this process becomes widespread. It is in these small community settings where the full potential of hydroponics can be uncovered and grown.

Next Steps

The next steps for my technical capstone work is to begin running simulations testing against wind force and rain. Afterwards, we can begin building a new prototype of the more durable, storm-resistant system. From a systems perspective, we must work on finding what island regions we plan to implement our design in. Furthermore, we have to learn what types of locally grown crops from these places can be grown hydroponically, and then understand what the nutrient needs are depending on the crop being grown. The next steps for my STS focus involves finding a pattern between the different case studies under analysis. I have to uncover the underlying root problem as to why our socio-technical system has not adopted hydroponics as the “norm” of agriculture. Finding more scenarios where hydroponic technology has either succeeded or failed will help me achieve this. Lastly, I have to use my findings and analysis to give a recommendation for how hydroponic systems must change to meet the needs of all levels of society.

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