Assessing the Feasibility of Microgrid Supported Open Hydroponics (MSOHCC) for A Resilient Fresh Food Supply in SIDS

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***Abstract* - Small island developing states (SIDS) are extremely susceptible to the damages brought upon by intensifying climate change such as hurricanes and typhoons whose intensities have been exacerbated by higher storm surges due to sea level rise and by more intense winds due to higher ocean surface temperatures in the tropics. Hurricanes can severely damage domestic food production on SIDS while simultaneously compromising the infrastructure for food imports. According to the Food and Agriculture Organization of the United Nations (2017), almost every SIDS imports over 60% of their food supply and over 50% of SIDS imports over 80%. In some SIDS, as much as 95% of the food consumed is imported (Food and Agriculture Organization, 2008).**

As such, SIDS present a case study of a region that is extremely vulnerable to food insecurity due to intensifying climate change, decreasing amounts of arable land, decreasing availability of freshwater resources, and increasing global population, which all threaten the global food system (supply, production, processing, distribution, and consumption) due to disruptions in conventional crop cultivation (CCC).

Our goal is to assess the potential for Microgrid Supported Open Hydroponic Crop Cultivation (MSOHCC) to be an effective complement to current food security initiatives in SIDS. As part of this overarching goal, we will start by determining how Hydroponic Crop Cultivation (HCC) can be utilized as an alternative to CCC in providing food security. We will then determine how MSOHCC can promote sustainable agriculture specifically in SIDS by providing climate resilience and energy efficient solutions. We will finally determine how MSOHCC can deliver economic opportunity to local SIDS economies by giving local residents the ability to produce locally grown food.

The project team will grow lettuce seeds in a prototype MSOHCC unit that is powered by a solar panel. The growing conditions will be akin to those of the conditions that may be encountered in SIDS. The results will be compared to those of common lettuce yields from CCC methods to see if MSOHCC can be used as an alternative and/or as a supplement to CCC. For the MSOHCC unit itself, the team will measure the amount of lettuce harvested (kg), water used (L), energy used (kW), and land area utilized (sq. m). These results will be compared to those of lettuce yields from CCC.

MOTIVATION

The Bahamas and other SIDS face unique environmental, economic, and social challenges that put pressure on conventional agricultural methods in guaranteeing a sufficient fresh food supply. Lying in areas of the Caribbean Sea and the Atlantic, Indian, and Pacific Oceans, SIDS are extremely susceptible to damage brought upon by extreme weather events such as hurricanes and typhoons whose intensities have been increasingly exacerbated by climate change. These weather events critically threaten domestic food production on SIDS while simultaneously compromising the infrastructure for food imports. Even when not suffering from natural disasters, SIDS struggle to produce enough food because of limited space for conventional farming and decreasing amounts of arable land. Hence, SIDS heavily rely on food imports which is unsustainable for already declining economies and increases vulnerability to food insecurity.

Compounded by the damages from hurricanes and arable land becoming more scarce, competition for freshwater resources in SIDS poses a significant challenge which is aggravated by increasing population density and intensifying climate change. 71% of SIDS are at risk of water scarcity while 73% of SIDS are at risk of groundwater pollution (United Nations Environment Programme, 2016). This presents a new challenge for equitable access to freshwater resources which further threatens the success of conventional agricultural methods in providing enough fresh produce.

A potential solution to these issues could be found in micro-grid supported open hydroponic crop cultivation (MSOHCC), which is a method of growing plants without soil by instead using a nutrient-rich solution. MSOHCC is one method to decrease the risk that SIDS face from hurricanes, as it produces crops using 90% less water and 75% less land space than CCC in soil (Savvas, 2003). MSOHCC allows for crops to be grown in areas with low soil fertility, limited farmland, and limited water resources which could give SIDS the ability to produce their own food in both times of natural disasters and throughout the calendar year. This could lead SIDS to become less reliant on external food imports, thereby stimulating their economies and reducing the threat of food insecurity. This team's successful harvest of a crop using MSOHCC unit will be used to argue that a local SIDS farmer can harness this technology just as easily to yield fresh produce. MSOHCC can provide livelihood for farmers and supplement food supplies in SIDS, especially in the aftermath of hurricanes and other natural disasters, which would strengthen food security and add resilience to the food supply in SIDS.

KEY STAKEHOLDERS AND THEIR ROLES

The primary stakeholders for the MSOHCC project are as follows: Babylon Micro-Farms (BMF), Small Island Developing States, the Bahamas Ministry of Agriculture (BMA), and Bahamian residents.

In partnership with the project team, BMF is a local start-up that is headquartered in Richmond, VA that is a commercial vendor of hydroponic crop cultivation units (HCC). In their commercial research of HCC, BMF reports that consumers can grow crops with 95% less water, 95% food waste, 94% less fertilizer, 99.9% less transportation, and 71% less carbon emissions. BMF's played a heavy role in early-stage design and implementation of the MSOHCC unit.

SIDS, such as the members of the Caribbean Community (CARICOM), are key stakeholders because they are at the highest risk of being devastated by hurricanes. As climate change intensifies, the frequency and magnitude of these hurricanes will consequently increase. Tourism, agriculture, animal husbandry, fishing, and forestry are the predominant sectors of CARICOM's GDP—all of which are very vulnerable to the damages from natural disasters. Investing in climate resiliency for these nations is imperative to protecting these nations' infrastructures and economies. Investigating the efficacy of MSOHCC in SIDS can play a significant role in bolstering their agricultural infrastructures to be more climate resilient.

Specifically for this project, the Bahamas serves as a test case for the team's MSOHCC units. In partnership with the BMA, the team's MSOHCCa units will be implemented in the Bahamas's national food emergency plan. The BMA will also integrate MSOHCC as common practice in their agricultural sector. Crop yields from the MSOHCC units will then be distributed to areas that are in need of food supplies such as emergency shelters. The implementation of MSOHCC will have transformative potential in revolutionizing agriculture in the Bahamas, restoring the agricultural output in the Bahamas, and providing much needed climate resilient technology to the nation, and the CARICOM region as a whole.

Bahamian residents will benefit from utilizing MSOHCC as it will provide a form of consistent year-round crop yield that will withstand the effects of hurricanes: heavy rain, strong winds, disturbed supply of freshwater resources, and unpredictable connectivity to the power grid. As disruptions to CCC are inevitable after hurricanes, MSOHCC provides an opportunity for smallholder farmers to mitigate disruptions to their agricultural output. MSOHCC can also increase the productivity of smallholder farmers (unit mass of yield per unit area) thereby increasing the profit potential of each farmer. Finally, the user experience of the MSOHCC units by the Bahamian residents will inform the project team of any changes that must be made to create an easier user interface to use.

GOALS AND OBJECTIVES

The main objective of the project is to design a prototype MSOHCC unit. The goal for this prototype is to introduce HCC methods to SIDS in order to assist the provision of consistent food supply for the populations of these nations—especially in the aftermath of natural disasters.

There are several guiding objectives for our research that support the design of the MSOHCC prototype. First, it is imperative that we create a system that can be feasibly constructed and maintained by the rural farmer population that has access to a very different set of resources than our team has. In order to achieve accessibility, the team has continually used materials that mirror what is available local in SIDS. This also ensures that shipping costs can be kept down when the prototype is ultimately shipped, as local materials can be used for system components. The second objective for the MSOHCC project is to create a framework for monitoring the system after construction.

Our third objective is to make the argument for hydroponics, showing that hydroponics can be a viable and sustainable technology and farming solution for SIDs, and even on a larger scale. This is particularly important as we are working to prove that MSOHCC is an especially appropriate solution for creating sustainable and plentiful food sources even in the aftermath of large tropical storms.

METHODOLOGY

Design

The structure was designed to perform as a storm and pesticide resistant unit in which plants can grow safely. In addition to being able to resist these threats, the unit must also be able to provide a consistent water and nutrient supply to all of the growing plants

The design of the MSOHCC unit includes three attachable pipes that connect to form a "S" shape (Fig 1). The pipes have holes on top in which cups will be placed that the plants will grow. The connected pipes must lie flat on a stable and level surface to ensure that water levels remain even throughout all of the unit, so that all of the plants receive a constant amount of water. On one end of the pipe system is a rain barrel that houses the water enriched with the appropriate nutrients as well as a solar powered water pump.

Fig 1. Pipe Arrangement of MSOHCC unit

In order to address other farming problems, including strong winds and pest intrusion, the unit will be placed inside of a "hoop house" that serves as a shelter for the plants (Fig 2). The hoop house allows for appropriate airflow while protecting the plants from pests and rainwater by acting as a physical barrier. The hoop house also contributes in regulating the temperature for the MSOHCC unit. Controlling rainwater is an important aspect in open hydroponic farming, which is focused on providing plants with the optimal quantity of specific nutrients and water.

Fig 2. The MSOHCC unit housed in the Hoop House

Abundant Water Supply

The water supply for the unit can come from a variety of sources. In normal conditions, the user can fill the nutrient barrel with water from their house connection, a well, or another clean water source. If there is a disruption to the site, such a pollutant or pathogen in the water supply, or saltwater intrusion, the user can connect the nutrient barrel to a rainwater collection system and use rainwater to water their plants. It is important that the water supply is clean in order to produce safe, healthy crops.

Utilizing Solar Power

Hurricanes have often compromised the electricity supply grid in SIDS, which means that the systems can be off for periods of weeks or months at a time. Therefore, it is important that the MSOHCC unit is able to function without grid electricity. Two previous project groups concluded that solar energy would work well in this environment. The output of the solar energy system would need to produce energy to power the water pump and other essential items within the system.

Optimal Crops

The team concluded that lettuce was the optimal crop to be grown in the unit in Charlottesville, VA as it had the necessary properties that allowed it to be grown in late winter and early spring (Fig 3). Additionally, leafy green vegetables are oftentimes used for hydroponics systems as this growing method supports more rapid growth and higher yields for this class of crops (Touilatos et. al 2016).

Fig 3. Lettuce that have Sprouted in the MSOHCC unit

CONCLUSION AND FUTURE WORK

MSOHCC is not at a stage where it can supplement the demand for CCC; however, it presents a strong case for being a complement to CCC especially in the domain of SIDS. Because of the limited varieties of crop species that can be successfully grown by means of HCC, the role of MSOHCC will most likely be complementary to CCC. Aside from SIDS, MSOHCC has the opportunity to be utilized in areas in that are not conducive to CCC such as urban centers—allowing for the possibility of being integrated in a vertical sense, increasing the potential of agricultural output per unit area—and areas of land that do not have fertile soil.

There will be a follow up study that will be conducted after the conclusion of this iteration of the MSOHCC project that compares the yields from the MSOHCC unit to that of lettuce grown by CCC methods. Specifically, the follow-up study will compare the amount of lettuce harvested (kg), water used (L), energy used (kW), and land area utilized (sq. m), and costs (USD) of lettuce grown in the MSOHCC unit to lettuce grown by CCC methods.

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REFERENCES

Food and Agriculture Organization of the United Nations (2017). Global Action Programme on Food Security and Nutrition in Small Island Developing States.

Food and Agriculture Organization of the United Nations (2008). Excessive food imports threaten SIDS economies.

Savvas, D. (2003). Hydroponics: A modern technology supporting the application of integrated crop management in greenhouse.

Touliatos, D., Dodd, I. C., & McAinsh, M. (2016). Vertical farming increases lettuce yield per unit area compared to conventional horizontal hydroponics. *Food and Energy Security*, *5*(3), 184–191.

United Nations Environment Programme. (2016). "Transboundary Aquifers and Groundwater Systems of Small Island Developing States".

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