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Hydroponics: Creating Food for Today and for Tomorrow

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Honors 401

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Hydroponics: Creating Food for Today and for Tomorrow

Abstract

In order to analyze how a plant growing technique, hydroponics is currently being utilized and to determine future possible implications for its usage exist I have examined research pertaining to this topic. From this research, I have selected information generated by several universities, a professor who is considered an authority on the subject, and the National Aeronautics and Space Administration (NASA). Despite there being a plethora of knowledge concerning hydroponics, this paper will cover information regarding the basics. For the survey of the literature, I focused on gathering information related to the history of hydroponics, to gain a better understanding of how it has been used in the past and how it could be used in the future. I also consider the various types of hydroponics. During the survey of the literature, there are three main questions that are considered: what are the various methods of growing vegetables with hydroponics as compared to traditional (soil), what is both the current and projected cost of hydroponics, and what is the public perception of hydroponics, if any, that would influence willingness to participate or support its usage. The results and findings of this paper are relevant for people in every country, and demonstrate that depending on the size of the operation, even people at home could create their own reliable source of food. As the human population is always increasing, it is the hope that this paper will elaborate on not only an effective, but viable option suitable to feeding people. Furthermore, it has implications as a potential avenue for growing food for space travel.

Introduction

Hydroponics is defined as “the cultivation of plants by placing the roots in liquid nutrient solutions rather than in soil” (Schlegel 2003). Depending on one’s knowledge regarding plant growing techniques, it may be startling to learn that plants do not need dirt to grow. After all, most would consider dirt, sunlight, and water as the trifecta required for plant growth. The technique of hydroponics turns this basic principle—one that has been around since our ancestors transitioned from hunter-gatherers to farmers—on its head. From this, it would seem that hydroponics is a product of modern technology, but the opposite is true. The first noted use of hydroponics was that of Babylon’s Hanging Gardens, though whether or not this fantastical account truly existed is up to individual interpretation. The Hanging Gardens, one of the Seven Wonders of the ancient world, were roof gardens irrigated by pumps (Halley 1965). Other ancient uses of hydroponics include the floating gardens of the Aztecs and Chinese (Resh 1989). In order to grow food on marshy land, the Aztecs engineered floating gardens made out of reed rafts, which were anchored to lake bottoms or strong trees. Indeed, Marco Polo observed similar floating gardens in China during his thirteenth century expeditions. A more modern use of hydroponics was by John Woodward, a seventeenth century scientist, who is considered to be “the first person to grow plants in water culture” (Hershey 1994). In 1699, Woodward discovered that it was substances in water, rather than water itself, that contributed to plant growth (Resh 1989). Although hydroponics has been around for centuries, it did not receive its name until the 1930s. It was W.F. Gericke of the University of California who first coined the term *hydroponics* (Resh 1989). The word is derived from two Greek terms: *hydro* (meaning “water”) and *ponos* (meaning “labor”). Thus, hydroponics literally means “water working.” W.F. Gericke himself notes the import role water plays in *The Meaning of Hydroponic*, stating that “[water’s] dynamics is the foundation on which the art and science of hydroponics is formulated” (Having

discussed the role of hydroponics in history, it becomes easier to see why modern botanists continue to utilize it.

Today, botanists use many different types of hydroponics, but this paper will consider the six major ones: nutrient film technique (NFT), aeroponics, aeration method, flood and drain method, trickle feed method, and tube culture (Sorenson & Relf 2009). Although each method will be examined more in-depth later, I will briefly introduce them here. NFT involves pumping a nutrient solution over the roots, which then drains back into the reservoir. Aeroponics involves misting exposed roots with nutrient solution every few minutes; therefore, in order to prevent the roots from drying out, misting must be continual. Aeration method utilizes an aquarium air pump to deliver oxygen to the roots; the roots themselves are suspended in nutrient solution and an inert material. Flood and drain involves intermittently immersing the roots in nutrient solution and then draining the solution back through a valve. Trickle feed method has a nutrient solution pumped through tubes to deliver the solution to each plant container. Tube culture is a variant of trickle feed where a vertical bag is filled with aggregate, holes are made for each plant and an irrigation tube is placed at the top. From this brief overview, it is evident that there are many different types of hydroponics. The merits and challenges of these six systems will be considered in the section surveying the literature.

To many, the world of hydroponics—with its various systems and complexities—may seem confusing and foreign. One may question what is wrong with the traditional system of raising plants in soil. Although the soil-based system is fine, hydroponics can do the same job while providing additional benefits such as a year-round growing season, water conservation, and reducing the amount of pesticide used. These additional benefits can help increase plant yields, which in turn can help feed more people. With the world population at a staggering 7.3

billion, adaptation is necessary to meet the demands of a growing population, especially for areas where there is lack of farmable land and resources (United Nations). Urbanization reduces available land that would otherwise be devoted to farming. People living in the cities also have less access to fresh produce. Instead of waiting for seasonal farmers markets and community gardens, hydroponics seems to promise a year-round source of vegetables. In addition, hydroponics is advantageous because it helps conserve water. This may seem counter-intuitive at first; after all, hydroponics grows plants in water. However, hydroponics conserves water because it allows for the “precise water and nutrient application directly to the roots of each plant” (Sorenson & Relf 2009). Instead of watering an entire field, hydroponic growers can target the root of each plant, thus using less water. Furthermore, water is reused in these systems and there is less water waste through evaporation and run-off (Sorenson & Relf 2009). Another benefit of hydroponics is the lessened need for pesticides (Resh 1989). Although some pesticides are utilized in hydroponics, growing plants in water circumvents many of the reasons pesticides are used. For example, pesticides are traditionally used because of soil-based diseases, insects, and animals. In hydroponics, there is no soil for soil-based diseases and no exposure to insects or animals. The reduced need for pesticides, combined with a year-round growing season and water conservation, makes hydroponics an attractive option for growing plants amidst the challenges of an expanding population.

Although there are a number of advantages to using hydroponics, there are also major obstacles preventing its wide-spread use. One of the barriers that must be overcome is the cost of hydroponics. Foremost, there is a high initial capital cost to hydroponics (Resh 1989). Although hydroponic plants can be grown outside, they are often grown in greenhouses. Greenhouses are relatively expensive to build and maintain because of construction, labor, and

energy costs. Even after the greenhouse is constructed, there are ongoing expenses to maintain the controlled environment, ranging from heating to cooling to lighting. Since hydroponic plants are more expensive to grow, they are also more expensive for consumers to buy. Although savvy consumers may appreciate the ecological benefits of hydroponics, their wallets surely will not. Other difficulties associated with hydroponics include diseases that can spread through the system and complex nutritional problems (Resh 1989). Although hydroponics avoids soil-based diseases, diseases such as *Fusarium* and *Verticillium* can wreak havoc in a hydroponics system. Additionally, hydroponic growers must find a precise balance of minerals and elements or else plant growth will be stunted. These challenges, while sizeable, are not entirely insurmountable. Later in this paper, I will examine how (and if) these issues can be overcome to make hydroponics cost-effective on a commercial scale.

In summary, I will research hydroponics, including the various forms available, and elaborate on the feasibility of hydroponics as a commercial venture. This will be done by analyzing multiple sources published by universities and others with expertise in this field. There are three main questions that I shall consider during this survey:

1. What are the various methods of growing vegetables with hydroponics as compared to a traditional (soil) method?
2. What is both the current and projected cost of hydroponics?
3. What is the public perception of hydroponics, if any, that would influence willingness to participate or support its usage?

To investigate these questions, I will examine the extensive research authored by various universities, articles, and books published by authors with definitive knowledge on the subject.

My survey of the literature will include studies that elaborate on a variety of hydroponics systems along with their advantages and disadvantages.

Survey of the Literature

Introduction

By examining research related to hydroponics, I will explain how a plant growing technique, hydroponics, is currently being utilized, as well as future implications for its usage. To that extent, I will examine the six major systems of hydroponics used today: nutrient film technique (NFT), aeroponics, aeration method, flood and drain method, trickle feed method, and tube culture. Ultimately, the goal of this paper is to evaluate if hydroponics could be utilized at a community level, as a way to stimulate local economies and serve a reliable source of nutrition.

Before delving into my research questions, I will provide a more detailed history of hydroponics. Howard M. Resh Ph.D. in his book *Hydroponic Food Production* gives a succinct review of the history of hydroponics. The name hydroponics means cultivation of plants in water. Dr. Resh states “Since many hydroponic methods employ some type of medium it is often termed “soilless culture,” while water culture alone would be true hydroponics.” However it is known from scientific studies that plants need more than water to grow. As early as 1699 John Woodward concluded from experiments with plants grown in water with different amounts of soil that plant growth was a result of certain substances in the water, which came from the soil, rather than simply the water itself. With the advancement in research techniques and chemistry in 1804 De Saussure theorized that plants are composed of chemical elements obtained from water, soil, and air. This was verified later in 1851 by Boussingault, a French chemist. His experiments involved growing plants in sand, quartz and charcoal. He then added solutions with known chemicals. Boussingault discovered that the hydrogen from water and that from the air

the plant dry matter consisted of hydrogen, carbon and oxygen. He also found that plants contain nitrogen and other mineral elements. Now that it was known that plants could be grown in an inert medium moistened by a water solution that contained minerals needed for plant growth it was a small step to eliminate the medium and just grow plants in a water solution. Between 1860-1861 Sachs and Knop, two German scientists accomplished this very thing. Their accomplishment was the beginning of the science of “nutriculture”. The research at that time revealed that for normal plant growth to occur a solution containing salts of nitrogen, phosphorus, sulfur, potassium, calcium, and magnesium are need. These elements are defined as the macroelements or macronutrients because they are required in relatively large amounts. With further research and refinement of research techniques seven additional elements were found to be necessary for plant growth. These elements are iron, chlorine, manganese, boron, zinc, copper, and molybdenum. They are known as microelements or trace elements since they are required in relatively small amounts. Research continued and many different formulas were developed by scientist such as Arnon, Hoagland, Robbins, Shive, Tollens, Tottingham, and Trelease. Many of their formulas are still in use today in laboratory research on plant nutrition and physiology.

However, it wasn't until the 1920's that an interest in the practical application of nutriculture developed. The greenhouse industry in 1925 become interested in nutriculture as an answer to some of the problems they were experiencing. The soil in greenhouses had to be replaced frequently due to problems with soil structure, fertility and pests. Growing plants without soil could be the answer to their problems. The years between 1925 and 1935 were replete with developments in laboratory techniques that would make the leap from scientific research applications in a lab to those applicable to commercial growers. W.F. Gericke of

University of California was one scientist who was able to do this successfully. (M.J.M 1949).

He grew tomatoes, beets, radishes, carrots, cereal crops, fruits, and flowers using water culture in large tanks. The tomatoes he grew were so tall they had to be harvested on a ladder. The press made much of this and called it the discovery of the century. Like all new technologies it's potential applications appeared unlimited which led to some unscrupulous business dealings involving selling of useless equipment. Despite this, research continued and hydroponics became established as a sound scientific study in horticulture. Also of interest is the fact that Gericke's application of hydroponics was utilized by the U.S. military in 1940's to provide food for troops stationed on nonarable islands in the Pacific. After WWII the military established a 22–hectare hydroponic plant in Japan. According to Dr. Frank Thone, as a result of this hydroponic plant, “with [the tomatoes] have been produced lettuce, cucumbers, green peppers, onions and radishes enough to run the season's total up to about 3,180,000 pounds” (“Hydroponic Harvest”). This enormous number demonstrates the utility provided by hydroponic systems. In the 1950's commercial use of hydroponics spread to countries like Italy, Spain, France, England, German, Sweden, USSR and Israel. The next large step forward for hydroponics was the development of plastics. Plastics helped reduce the costs involved in building concrete beds and tanks used prior to the introduction of plastic. The development of pumps, timers, plastic plumbing, solenoid valves and other necessary equipment has allowed the hydroponic system to be as automated as desired. This helps to reduce both capital and operational cost. Hydroponic installations are now in almost every state in the United States and throughout the world. Canada also has a large hydroponic greenhouse industry. Areas with limited fresh water resources like Mexico and the Middle East, benefit from hydroponic plants that use desalinated water obtained from sea water. Even though hydroponics is a still a young science and has only been used on a commercial basis

for less than sixty years there are still many exciting possibilities for its use. From the depth of the oceans in atomic submarines to the Mir space station, hydroponics has been able provide fresh food that would otherwise not be available (NASA 2007). From this, it is evident that the future of hydroponics extends beyond the scope of feeding people solely on earth.

What are the methods of growing vegetables with hydroponics as compared to traditional?

In order to begin a comparison between hydroponic and traditional methods of farming, it is necessary to discuss the differences between them. I will discuss the difference relating to nutrition, plant spacing, weed control and cultivation, diseases and soil inhabitants, water, fruit quality, fertilizer, land usage and yields. *Hydroponic Food Production* by Dr. Resh describes in detail the differences between soil and soilless methods. When growing plants in soil the nutrition of the soil is highly variable and can be unavailable to plants due to poor soil structure, pH. Also the soil can be difficult to sample, test, and adjust. Plants grown in soilless conditions the nutrition available to the plant is completely controlled, stable, available in sufficient quantities for all plants, pH can be tested, sampled and adjusted easily. Plant spacing in soil is limited by soil nutrition and available light. In soilless the plant spacing is limited only by light so plants can be planted closer together and vertically. In regards to weed control and cultivation plants grown in soil need to be weeded and the soil needs cultivated at regular times. In soilless there are no weeds or soil to till. There are many soil borne diseases, nematodes, insects and animals with attack the crops. Since there is no soil used in soilless farming these problems are avoided. The use of water is significantly different. In soil farming the plants are subject to water stress, water is not as readily available due to poor soil-water relations soil structure and low water holding capacity. Also water is not used efficiently in the soil because of surface evaporation and water seeping below the level of the plant roots. In soilless conditions there is

no water stress to the plants. Water is available to every plant and there is a dramatic decrease in amount of water necessary to sustain plant life. The quality of the fruit of the plant grown in soil can be poorer due to deficiencies of calcium and potassium. When grown in soilless conditions the fruit is firm with longer shelf life. This allows growers to pick vine ripened fruit and be able to transport it further distances. Studies have also shown that the nutrition value of hydroponically grown fruits and vegetables are as high as or higher than those grown in soil. A big difference between soil and soilless farming is land usage. For example in 1 acre of soil 7000 pounds of cucumbers can be grown however in the same 1 acre of soilless 28,000 pounds can be grown. Additionally, studies observing hydroponic systems have noted an additional benefit. In a study by J.C. Ojala and W.M. Jarrell, it was concluded that hydroponics “have been very useful in plant mineral nutrition studies and are easily adapted to studies of the essentiality and toxicity of elements, solution salinity, and pH” (“Hydroponic Sand Culture Systems for Mycorrhizal Research”). Therefore, hydroponic systems use extends even beyond providing food

There is a wide assortment of available types of hydroponic systems as mentioned earlier. According to Ruth Sorenson (2009), these types can be divided into water culture systems and aggregate systems. For both types Dr. Resh advises that for successful operation there are several plant requirements that must be met, first is root aeration, second is root darkness, and third is plant support. For root aeration there are two ways to accomplish this. First, a pump or compressor is used to bubble air into the nutrient solution by means of a perforated pipe placed at the bottom of the bed or the container. Second option is to circulate the nutrient solution through the beds and back to a reservoir by means of a pump. Best results can be achieved via the second option whereby the roots are in constant contact with the aerated solution. The second plant requirement is root darkness. Although, plants can function normally

with their roots exposed to light during the daytime it would require 100% relative humidity. The only problem with this is algae growth. The algae then compete with the plants for nutrients and oxygen, produce smells, reduce acidity of solution and produce toxic products. All of which are detrimental to plant growth. It is best to build beds with or cover the containers with opaque materials. The last plant requirement is plant support which is accomplished by means of a litter tray. This tray then sits above the nutrient solution as part of the bed. The litter tray used to be a wooden framework 2 to 4 inches deep with a wire mesh across the bottom to support the porous material. Currently the trays are plastic screens or styrofoam sheets. The porous material is dependent upon the nature of the plant root system. Various products have been used such as straw, wood shaving, coarse sawdust, chaff, peat or sphagnum moss, rice hulls or dried hay.

Among the types of water culture systems are nutrient film, aeroponics, and aeration method. Simply described, the nutrient film technique operates by suspending the plants in a trough that is sloped. Because the trough is sloped, gravity moves the thin film of nutrient solution toward the nutrient reservoir. Aeroponics involves misting the plants with a solution as opposed to sitting them directly in the solution. A vaporizer is typically used to create the mist. Aeration involves an aquarium air pump to bubble oxygen to the roots of plants that are placed 1-in above the solution. This type requires the use of inert material, such as gravel, clay pebbles, or vermiculite, to both stabilize and provide a way for the roots to grow into the solution. Aggregate systems, similar to aeration, use inert material as a root support system. The types of hydroponic systems included in this system include the flood and drain method, trickle feed, and tube culture. The flood and drain method works by flooding a container of plants and aggregate and submerging the plants with the nutrient solution between twenty to thirty minutes at a time.

The leftover solution drains back into the reservoir by means of valve at the bottom of the container.

The trickle feed method is another common aggregate system. The nutrient solution is continuously moved by means of irrigation tubing which branches into smaller tubing that goes to the containers. The nutrient reservoir then receives the excess solution. A variation of the trickle feed method is call the tube culture. In this method a 4-6 inch plastic tube or bag contains light weight aggregate. The plants are placed in holes made on all sides of the container. The tube is then suspended vertically. Irrigation tubing is placed in the top of the container and the nutrient solution runs down through the tube. The solution is sometimes recycled when it leaves the container at the bottom.

What is both the current and projected cost of hydroponics?

Although plants can be grown outside in a hydroponic installation, it is easier to control their environment inside a greenhouse. With this advantage, it seems like greenhouses would be the obvious choice for hydroponic growers. However, greenhouses can be expensive to build and maintain. In the article “Financial Considerations—Florida Greenhouse Vegetable Production,” the authors make this observation outright: “One of the most important points a new grower needs to know is that greenhouse vegetable production is very costly” (Hochmuth, Thomas, Sweat, & Hochmuth 2015). The authors attribute this costliness to several factors, including the establishment of the greenhouse facility, crop production, harvesting, and shipping. The price of a greenhouse can vary dramatically depending on size and materials, but a typical 4000 square-foot greenhouse will set a grower back by \$30,000 to \$50,000 (Hochmuth, Thomas, Sweat, & Hochmuth 2015). Once the greenhouse is built, there are still sizeable costs associated with crop production. When supplies, fuel, overhead, packing, shipping, and labor are factored

in, the total cost of production ranges from \$5,000 to \$10,000 (Hochmuth, Thomas, Sweat, & Hochmuth 2015). Therefore, a grower must invest anywhere from \$35,000 to \$60,000 before the first crop even arrives. It will likely take several years for a grower to realize a return on this initial investment. Let's return to the 4000 square-foot greenhouse and assume the grower plants tomato crops. Each tomato plant is capable of producing between 25 and 30 pounds of fruit (Hochmuth, Thomas, Sweat, & Hochmuth 2015). In a greenhouse of this size, the grower could house approximately 1200 plants. Since tomatoes can be sold at \$1.00 per pound, that means a grower could earn from \$25,000 to \$30,000. At this price, the grower will not recoup his investment within a single year. However, even this is perhaps too rosy of an outlook. Indeed, only the most experienced growers can achieve a yield of 25 pounds of fruit per plant. The average yield is closer to 15 pounds per plant. Therefore, it takes patience, luck, and capital to succeed in the greenhouse business.

More specifically speaking, there are also costs associated with the different hydroponic systems. The price varies greatly with the size of the operation, and depends on whether it is for home or commercial purposes. For the home grower, hydroponics can be an affordable option, with some sets costing less than \$100 (Hydroponics.com 2015). Of course, these sets are intended more for recreational purposes. On a commercial scale, soilless growing carries a more substantial price tag. First, consider the price of the nutrient film technique (NFT). A complete system for lettuce crops costs approximately \$45,000 for a 3960 square-foot greenhouse (AmHydro 2015). That may seem expensive, but it is relatively affordable compared to an aeroponic system. In today's market, a commercial aeroponic system costs nearly \$150,000 for a 3000 square-foot greenhouse (AgriHouse 2015). Depending on the system, there can be a high upfront cost to hydroponics.

Although the financial aspect of hydroponics is an important consideration, there are other costs associated with raising crops. These include environmental costs involving the land, water, and pesticides. First of all, hydroponic farming uses less land than traditional farming because of higher yields per plant. For example, beans grown in soil yield 5 tons per acre; beans grown in soilless cultures yield 21 tons per acre (Resh 1989, 29). The difference is even greater for potatoes: 8 tons per acre in soil compared to 70 tons per acre in soilless culture (Resh 1989, 29). Returning to tomatoes, a farmer can expect a yield of 5 – 10 tons per acre in soil, but a yield of 60 – 300 tons per acre in soilless cultures (Resh 1989, 29). These greater yields translate into less land required. In Canada, the population consumes roughly 400 million pounds of tomatoes each year (Resh 1989). With traditional farming methods in soil, it would take 25,000 acres of land to grow this quantity of tomatoes. However, it would only take 1,300 acres to grow the tomatoes hydroponically. Another environmental cost associated with farming is water usage. Although it seems counter-intuitive, hydroponics actually uses less water than traditional farming. Researchers from the University of Arizona state that “Hydroponic greenhouses use about 10 times less water than a field crop” (Merrill 2011). The main reason for this is a targeted approach to watering. In traditional farming, the entire field is sprayed with water, with the water eventually seeping into the roots. However, in hydroponics, less water can be used because it goes directly to the roots. The Massachusetts Institute of Technology explains, “Hydroponics, with its various forms of drip and flow style irrigation limits the threat of water waste via over- or poorly-timed irrigation” (2015). Therefore, at least in terms of environmental costs, soilless farming is less costly than traditional farming.

What is the public perception of hydroponics, if any, that would influence willingness to participate or support its usage?

Among the general public, hydroponics seems to possess a certain novelty. One example of this is the Chia pet, a ceramic animal that grows a “fur coat” when watered. Chia pets involve the seed *Salvia hispanica*, which is a member of the mint family (Hershey 1994). The seedlings cling to the unglazed ceramic, which causes “fur” to magically grow when the planter is watered. Another example of society’s fascination with hydroponics can be found at Walt Disney World. Although perhaps not as magnificent as the Hanging Gardens of Babylon, the hydroponic gardens at Epcot have their own charms. One such marvel is Mickey Mouse shaped fruits and vegetables, such as cucumbers, melons, tomatoes, and pumpkins (“Hydroponics at Disney World” 2009). The article explains that “This feat of farming is accomplished by fitting mouse-shaped plastic enclosures around fruits as they begin to form. As they grow, they fill out the shape, turning into Mickey Mouse himself.” In addition to providing entertainment, the gardens at Walt Disney World are also educational. They expose people of all ages to the idea and benefits of hydroponics. Educating young minds about hydroponics is the focus of the article “Solution Culture Hydroponics: History & Inexpensive Equipment” by David R. Hershey. Hershey explores several inexpensive science experiments students can perform to learn more about hydroponics. Among them are systems constructed out of 2-liter soda bottles and film canisters. Although not practicable on a commercial scale, these simple experiments get students thinking about the real-world applications of hydroponics. If nothing else, Hershey’s experiments, Chia Pets, and the gardens at Walt Disney World show society’s fascination with hydroponics. One misconception regarding hydroponics is that it is used by drug dealers to grow marijuana-which unfortunately does occur. The same reasons hydroponics is good for growing vegetables, fruits, and flowers makes it good for growing marijuana- it produces a bigger, better

and higher quality plant. Like other technologies humanity finds a way to use it for illegal and destructive purposes.

The field of hydroponics also holds real-world (or, more aptly put, out-of-this-world) applications at NASA. On earth, the value of hydroponics is already felt in deserts and other areas with poor soil. NASA has been researching the potential of hydroponics in outer space, where there is no soil at all. As NASA's space missions have become increasingly lengthy, scientists have been researching "bioregenerative life support systems" to help feed the astronauts ("Farming for the Future"). Hydroponics is an attractive option for astronauts because, "They could grow crops that would not only supplement a healthy diet, but also remove toxic carbon dioxide from the air inside the spacecraft and create life-sustaining oxygen" ("Farming for the Future"). If scientists succeed in growing crops in space, it could help NASA colonize the moon or Mars with long-term colonies. Of course, there are unique challenges facing hydroponics in space. Scientists are still figuring out how the different light, temperature, carbon dioxide levels, and atmospheric pressure affect plant growth in space. Although NASA's researchers have simulated space conditions on earth, it is difficult to accurately predict how hydroponics will fare in space. Still, they seem to be on the right track. Earlier this year, astronauts ate a salad made out of red romaine lettuce, which was grown hydroponically aboard the International Space Station (Yugas 2015). Although seemingly futuristic, hydroponics could help astronauts survive on distant planets.

While NASA researchers learn how to feed hungry astronauts, other scientists are trying to figure out how to feed the starving people on earth. According to the World Food Programme, "Some 795 million people in the world do not have enough food to lead a healthy active life. That's about one in nine people on earth" (2015). Although hunger is a complex

issue, hydroponics may be part of the solution. In an experiment conducted by the Food and Agriculture Organization (FAO) of the United Nations, hydroponic micro-gardens were constructed in Senegal. Senegal is one of the world's most food-insecure countries, with 17.2% of its population being underweight from the years 2008 to 2012 (UNICEF 2013). To help combat hunger in Senegal, the FAO taught families how to set up roof-top hydroponic gardens. The plants were "supported by an aggregate of gravel and groundnut shells or [grew] through holes punched in sheets of Styrofoam, which float[ed] on the water in the tray" ("Can roof-top gardens help feed hungry cities?" 2002). Despite the simple construction, each one-meter-square box provided up to one hundred pounds of tomatoes each year. The micro-gardens helped supplement the families' regular diets, while also providing income (the extra produce could be sold at market). With an initial cost of only \$7, these micro-gardens were also relatively affordable. Although the experiment was conducted on a small scale, its results look promising in reducing hunger in developing nations.

Conclusion

As this paper has revealed, hydroponics is a complex field of study with a rich history and promising future. There are many aspects associated with soilless growing, but this paper focused on three major questions. First, what are the various methods of growing vegetables with hydroponics as compared to a traditional (soil) method? Next, what is both the current and projected cost of hydroponics? Finally, what is the public perception of hydroponics, if any, that would influence willingness to participate or support its usage? I answered these questions with a survey of scholarly literature from various journals and government websites. The results are briefly summarized below.

Today, there are various methods used to grow plants hydroponically. They include the water culture systems of nutrient film, aeroponics, and aeration method. Also included are the aggregate methods of flood and drain method, trickle feed, and tube culture. Nutrient film functions by essentially covering the plants' roots in a film of nutrient solution so that the plants receive a steady supply of nutrients. Aeroponics uses mist powered by a vaporizer to supply nutrients as opposed to directly placing the plants in the nutrient solution. Aeration method requires the use of an aquarium pump to create bubbles; it also uses inert material to stabilize the plants as they develop. Flood and drain submerges the plants for between twenty to thirty minutes in nutrient solution, and then the solution drains away. Trickle feed supplies nutrients to the plants via branching tubes. Tube culture, a variation on trickle feed suspends the plants vertically in a bag and the plants receive nutrients via a tube running the length.

Although growing plants hydroponically can be costly, it is a worthwhile investment in our future. The major cost associated with hydroponics is building and maintaining a controlled environment, typically in the form of a greenhouse. Building a greenhouse is a major investment and easily costs tens of thousands of dollars. Once the greenhouse is built, there are additional costs to provide heating, cooling, energy, and lighting. It can take years to make a profit, which makes it a somewhat risky venture. However, growing plants hydroponically has the potential to solve several large-scale issues. First of all, soilless farming has less of an environmental footprint. Since hydroponic plants produce higher yields, it takes less land to grow them. Returning to a previously cited example, Canadians consume roughly 400 million tomatoes each year. With traditional farming methods in soil, it would take 25,000 acres of land to grow this quantity of tomatoes. However, it would only take 1,300 acres to grow the tomatoes hydroponically. Another benefit of hydroponics is water conservation. As opposed to traditional

farming, hydroponics delivers water directly to the roots. This eliminates the wastage associated with watering an entire field. Furthermore, soilless farming reduces the amounts of pesticides used. In traditional farming, growers spray plants with pesticides in order to kill disease, insects, and animals. Since most soilless growing occurs inside greenhouses, many of these hazards are eliminated, thus reducing the need for pesticides. Although hydroponics on a commercial scale is expensive, the benefits are also immense. As a society, we must decide if the benefits outweigh the costs.

Indeed, it appears that society has already taken an interest in hydroponics. Hydroponics possesses a certain novelty for the general public, as several companies have discovered. For example, children have been fascinated with Chia Pets for years. Hydroponics—not magic—is responsible for the “fur coat” that grows on the ceramic animals. Walt Disney World has also tapped into the hydroponics market. At Epcot, visitors can see hydroponic fruits and vegetables in the shape of their favorite cartoon characters. Aside from the entertainment value, the hydroponic gardens at Walt Disney World also educate the public about soilless farming. These gardens may seem impractical, but companies like NASA believe in their potential. As space missions become increasingly lengthy, hydroponic plants may hold the key to colonizing Mars or the moon. In fact, astronauts have already enjoyed romaine-lettuce salads grown on the International Space Station. Another application of hydroponics is providing food in urban areas, particularly in developing nations. Families in Senegal can grow fresh fruits and vegetables on their roof-tops to supplement their diets and incomes. Although commercial hydroponics can be expensive, a small roof-top garden can cost as little as \$7. Thus, hydroponics has the potential to help alleviate food-insecurity. Despite its novelty, hydroponics has many real-world applications.

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