Comparisons of Three Hydroponic Growing Concepts to Develop an Effective Vegetable Production System

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Category – PST-Power, Structural, Technical Systems

Division 2 – Teams in grades 7-8

IMPORTANCE

At this time, the world is facing an ever-increasing population. According to World O Meter, it is estimated that today's population is 7,800.000,000 people. The population density is estimated at 52 P/Km², (P = # of people). It is estimated that 56% of these people live in city and urban areas. However, in the year 2050, the estimated world population will be 9,800,000,000 with a population density of 65 P/Km², with 65 % living in city and urban areas.

The main reason for this growing concern in population growth is the ability of the world to meet the nutrient needs of this population. We have been able to increase food production through the Green Revolution and modern technological advancements relating to hybrid plants, improved methods of crop production and use of biologicals for symbiotic benefits they provide to plants. However, today we are seeing an increase in the price of food to the consumer due to increases in the materials needed to production as well as rising costs associated with the logistics and infrastructure of it distribution to the population. With the increase of population, increase in population density and increase of people removed from rural areas, there is a need to empower the individual family to successfully grow and provide quality fresh vegetables to help supply their daily nutrient needs and prevent nutrient related diseases such a diabetes,

According to www.ers.usda.gov/data-products/food-access-research-atlas, our community of Ft. White, FL, a rural community, is considered a Food Desert and a community at risk in acquiring quality nutrients for a healthy life as it is also listed as a low, socioeconomic community. On the other hand, as cities grow larger, more people move into more densely packed urban areas, and there is a decline in quality food availability raising the possibility of a greater number of Food Deserts appearing within the city along with increases in diabetes and obesity. One way for the people of these areas to cope with this situation is to become more self-reliant on basic vegetable production. However, such a system should be simple to construct and use as well as be able to produce the vegetables efficiently and at a low cost to the consumer. It should be able to be conducted in a small area not requiring a lot of space to produce a significant amount of food.

Beginning in 1999, vertical hydroponic growing systems have expanded eliminating the need for large amounts of land for food production. The main advantage of vertical agriculture is that you'll produce a much higher crop yield than you would if you were growing in a horizontal fashion. For example, at our school, we are now able to grow twenty lettuce plants in 2 ft^2 were before it was 3 -4 plants in 2 ft^2. In addition, from our own personal experience, once these systems are set up, they are easier to manage and control the application of plant nutrients.

This research project's objective was to determine if such a low cost, high efficiency vertical hydroponic growing system can be successfully designed and implemented as a model for individual families who wish to improve the quality of food they consume as well as meet the needs of their family's nutrition. It is for this reason, that a test was conducted comparing a commercial vertical growing system to two hybrid vertical systems that were composed of recycled materials found around the house and community. The three systems tested were the Vertigro commercial vertical hydroponic growing system to a passive vertical wick system and a deep-water culture vertical system, both constructed of recycled materials. If successful, these recycled systems could help families meet their nutrition needs through affordability.

OTHERS WORK

When designing the vertical hydroponic systems in this research, the mechanics of various hydroponic systems were investigated for consideration to develop a prototype that would meet the goal of this experiment.

Flotation systems have been around for centuries. As described by Deep Water Culture Hydroponics 101 - Planet Organics the flotation, deep-water culture method does not use electricity to run therefore is considered to be passive. No pump or timer is needed. This method works simply by the plants being placed into a floating bed that floats on top of the nutrient solution held in a reservoir, allowing the roots to grow into the nutrient solution held in a reservoir. A reservoir/container is anything that holds water and can act as a nutrient solution holding tank on which the floating bed will rest when filled with the plant nutrient solution. Holes are usually cut into the lid so that a net type pot or cup can be placed the hole. The size and distance these holes are apart is dependent upon the type of plant being grown. One such system is the Floating, Deep -Water Culture Hydroponic System.

Floating, Deep - Water Hydroponic Culture System

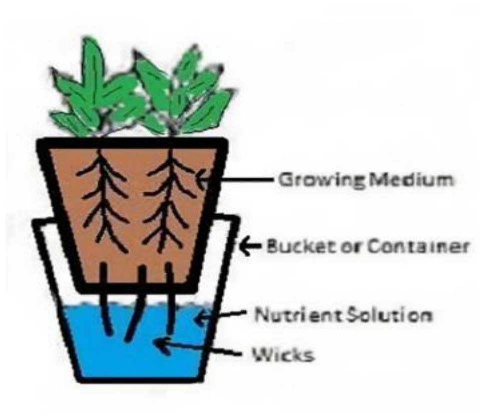
(https://www.bing.com/image)

Transplants are placed in the net pots maintaining the growing media in which they were germinated. The tip of the net pot is place into the hole of the floating bed so that the nutrient solution only touches the bottom of the transplants growing media. The above roots are exposed to the air. This allows plants to take up sufficient oxygen, water, and nutrients.

Over a period of time, as plants grow, the nutrient solution level will become lower in the reservoir with time. As the reservoir runs out of the water due to plant uptake, transpiration and evaporation, the reservoir may be recharged with water and nutrient solution which allows plants to continue its growth phase. In the research being done in this experiment, an air bubbler is being implemented to increase dissolved oxygen into the plant nutrient solution.

An offshoot of this system is the Hydroponic Wick System. As described by Wick System, smartgardenguide.com, the wick system hydroponics is the simplest type of the hydroponics system designs. The name refers to the fact that these systems take advantage of the action of wicking to feed a water-based nutrient solution to the roots of plants. Every hydroponic wick system is made up of four basic components: a growing container, a reservoir to hold the plant nutrient solution, a growing medium for roots to grow in and wicks to carry the plant nutrients up to the medium and roots of the plants. In a hydroponic wick system, capillary action is the process by which the plant nutrient solution moves up the wick to the plant medium. Capillary action, as described by Capillary Action and Water | U.S. Geological Survey, https://www.usgs.gov/.../capillary-action-and-water, is capillary action is important for moving water (and all of the things that are dissolved in it) around. It is defined as the movement of water within the spaces of a porous material due to the forces of adhesion, cohesion, and surface tension.

Cohesion may be termed the attraction of like molecules, such as the water, for each other which keeps water molecules close to each other. Adhesion is the attraction of water molecules to other materials. The surface tension acts to hold the surface intact. The process of capillary action occurs in the when the water molecules adhere to the wick. The water molecule then adheres to a higher-level part of the wick while, by capillary action, pulling up water molecules from the reservoir. The height to which capillary action will take water is limited by surface tension and, of course, gravity.



Hydroponic Wick System

(https://www.bing.com/images)

Although these two systems are very inexpensive and not difficult to construct, research conducted by Robert Hochmuth, University of Florida, IFAS, indicates that they are limited in growing larger plants due to weight and size restraints on the physical apparatus holding the nutrients and plants. In addition, there is the possibility of stagnant water in the reservoir. The reservoir should be a dark color or solid so that light does not pass through it making it beneficial in controlling algae growth in the reservoir. Flotation systems are basically “standing water” which also results in depleted oxygen and nutrient levels, varying pH levels, along with algae growth and fungal problems if the nutrient solution is not shielded from sunlight.

In these systems, nutrient dosing is normally managed on a batch volumetric level. Everything is mixed at one time, irrigated at one time, and when it runs out, mixed again to recharge. Hochmuth's research indicates that managing nutrient dosage, water acidity levels (pH), and oxygen mix is a complex process in-solution. Providing the consistent nutrient and Electroconductivity (EC) levels to hydroponic plants throughout this cycle is a challenge. According to Paul Fisher, a Professor and Extension Specialist in the Environmental Horticulture Department at the University of Florida, high electrical conductivity (EC) in the growing medium makes it harder for roots to take up nutrients and water–it is like trying to grow plants in sea water and can result in "salt burn" (damage to sensitive root tips) and toxicity symptoms in foliage.

However, Hochmuth's research does indicate these systems work well with short-season, shallow-rooted crops such as lettuce, basil, and watercress, which grow well under high-moisture conditions in the root zone. High-tech versions of this system can be expensive to build and operate, but low-tech versions have been tested and are in use on small farms and home production in Florida

Vertical hydroponic growing systems have been in wide use, enabling the growing of plants in small spaces. Vertical hydroponic systems produce crops in upright or vertical rows, a method that can significantly increase plant populations. Such a growing system may be as simple as a series of horizontal rooting pipes mounted on a frame, while others are a series of buckets/pots mounted on top of each other to form a tower. The plant nutrient solution is held in a reservoir from which nutrients are pumped to the vertical systems. Hochmuth suggests to help with the oxygenation of plant roots and maintain a heterogenous nutrient mixture, an air pump and air diffuser should always be used.

The Verti Gro hydroponic vertical growing system (trade name) is constructed by stacking square Styrofoam buckets set 90 degrees from each other, each corner of the bucket forming an opening for setting a plant. These open areas in the corners are for setting transplants.

Vertigro Vertical Hydroponic System

Hydroponic Vertical Farming Equipment VIC - VERTI GRO Phillip Island – Verti Gro Australia

As described by Vertical Growing: The Future of Gardening & Farming, hydrobuilder.com/learn/vertical-growing, the rooting medium can be either organic or inorganic with perlite and coconut fiber being the more commonly used since they have good water retaining and drainage properties as well as being light weight, an important factor when stacking a number of Styrofoam buckets on top of each other. This medium is primarily for stabilizing the plant and does not have any nutritional value. The nutrient solution is periodically applied at the top and middle of the tower buckets through irrigation tubes and allowed to flow down through the stack, providing needed water and plant nutrients for the rooted plants in the buckets below the irrigated buckets. To ensure water and plant nutrient efficiency, a drip irrigation system may be employed with a dripper placed at each plant station.

For ensuring sufficient nutrient solution distribution within the tower, the volume of nutrient solution applied is such to create an outflow at the base, the outflow being either discarded or collected for re-circulation. Nutrient solution application can be controlled resulting with little or no discharge from the base of the tower.

Although vertical growing systems have their advantages when dealing with limited space, Hochmuth's research also found that vertical growing systems have not proven to be financially viable for the commercial production of larger food products, but can be of value to the home gardener, who can construct his own vertical growing unit using items readily available or larger scale production of smaller varieties of vegetables or strawberries. Managing the growing system for option plant production can be a challenge, such as selection of the nutrient solution formulation and determining its use factors.

It is also important to take into consideration the plant's size. As a plant grows it increases its requirements for nutrition and water the time of pumping and time of delivery would need to be increased. As plants reach maturity, it is not uncommon for the nutrient delivery intervals to double or triple per 24-hour period. Because the optimal nutrient delivery requirements change throughout the life cycle of the plants, it is not uncommon for growers to have to experiment with various pump-on and pump-off durations for a few cycles until they find the ideal pump timing for their given system.

Vertical systems can benefit greatly from additional aeration in the reservoir. An air pump and air diffuser should always be used in the reservoir.

One thing that is common among all these systems is the need for a plant nutrient system that can readily be used within the system and yet deliver the nutrients that the plants require and maintaining an efficient dissolved oxygen level (6mg/L – 8mg/L). For example, if lettuce were to be grown in the systems, then these parameters for growing lettuce in hydroponic solutions should be standard.

MATERIALS

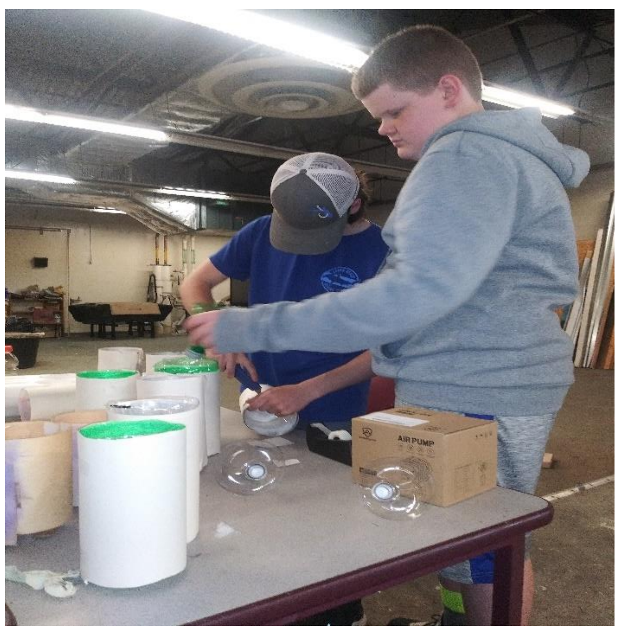
The materials used in this experiment included:

MATERIAL	DESCRIPTION
Weighing Scale	Triple Beam Balance
Vertigro Hydroponic tower	5 bucket system
Styrofoam pieces	Discarded sheets 1 inch thick
Soluble Blend Hydroponic Plant Nutrients	25 lb. bag of 5-10-22
Sharp Cutting Utensil	Exacto Knife
Plastic liter Soda Bottle	Disposed - 20 Bottles
Plant Medium	Coconut Fiber - 1 Block
Oxygen Meter	Measures temperature and dissolve oxygen
Old cotton T-shirt	Disposed
Hydroponic Solution Plant Nutrients	25 lbs. of 16- 0 - 0
Electroconductivity Meter	Measure electrical current conductivity
Discarded Plywood	3/4 inch sheets (discarded)
Air Stones	10
Air Line Tubing	1/8 " x 20 ft
Aerator	Multi lines
1 1/4-inch pvc pipe	7 ft (Disposed)
Transplant Materials	Lettuce seeds, transplant trays, potting mix
½ " x 8" Hex Head Bolt	5

METHOD

Needed materials were gathered to construct the wick and the flotation, deep -water culture, bubbler hydroponic systems. The Vertigro system was already in operation so no construction was necessary. To construct the other two hydroponic systems, twenty 2-liter bottles were cut to make the wick and flotation, deep water, bubble system containers (10 each). They were cut 20 cm from the bottom with an Exacto knife leaving the bottom and top (similar to a funnel) separate.

The bottoms of each of the cut twenty bottles were covered with construction paper using tape to secure the paper in order to block sunlight from entering the nutrient reservoir which would promote algae growth.



Preparation of bottles were similar for both the flotation, deep culture, bubbling and wick system. Both were constructed from the 2-liter plastic soda bottle as the cut bottom would act as a reservoir to hold plant the nutrient solution. For the wick system, the top of the bottle was inverted with a cotton wick running down through the opening of the bottle top, filled with coconut fiber and used to grow the plant

A hole punch was used to make the holes on the side of the bottles to allow the bottles to be secured to the tower with zip ties which was constructed from a 1 ¾ inch PVC pipe. We cut five circular pieces of plywood into circles with a radius of 10 inches and bore a 1 ¾ inch hole in the middle. These plywood pieces were used as the base on the pipe on which the bottles would set in a vertical fashion. These plywood bases were held on the pipe by drilling a 3/8-inch hole through the pipe at the same heights the five buckets of the Vertigro system were off the floor and passing a ½ "x 8" hex head bolt through each drilled hole in the PVC pipe. The circular base sets on this board and acts as the platform that the plastic bottle reservoirs will set. The tower was 7 foot tall so to be secured to a cable which ran above it and the Vertigro system.

The width of the bottle was measured and 10 Styrofoam circles were cut slightly smaller than the bottle width to give room for the Styrofoam to float in the solution when placed into the bottle. This produced a floating raft, deep-water, culture system. In the center of this Styrofoam circle, a hole was cut slightly smaller than the width of the top of a net cup so it would securely hold a net cup in which the plants would be placed and the hose from the aerator would run through down to the bottom of the bottle reservoir through which air would bubble in the plant nutrient solution to help oxygenate it.

Lengths for the air hoses were measured to sit in the bottles running from the air pump and then cut to the correct length so that the floatation, deep water culture bottles could be aerated while the bottles sat on the plywood platforms on the vertical system made with the PVC pipe.

T- junctions were placed on the hoses so that one delivery hose would go into two bottles at a time. A total of five junctions were used allowing for the aerator, which had five air outlets, to service 10 floating, deep-water culture, bubbler systems.

The Vertigro Tower System's plant nutrient solution (150 gallons) was prepared and mixed to an Electronegativity (EC) of 2.54. In order to provide all systems with identical plant nutrient concentration with an EC of 2.54, 600 ml of the Vertigro mixed hydroponic plant nutrient solution (EC of 2.54) was placed into the each reservoir of the wick and floatation, deep- water culture , bubbling system.

For the flotation, deep-water culture, bubbling system system, plastic line air hoses were placed through the net cups set in the Styrofoam rings. The net cup with the lettuce plant and air hose with an air stone on the end was placed into the net cup and lowered into the reservoir of the system with its roots extending down into the plant nutrient
solution as shown in the picture below.

For the wick system, the tops of the 2-liter bottles were used to hold coconut fiber and the plant. Before the coconut fiber was added to the top, a 13 cm x 3 cm cotton wick was cut from an old cotton T shirt and passed through the bottle top opening with the top of the wick even with the top cut part of the bottle top.

www.bing.com/images

With the bottle top upside down and holding the top of the wick in the so that it pulled up in the center. coconut fiber was then poured into the top surrounding the wick.

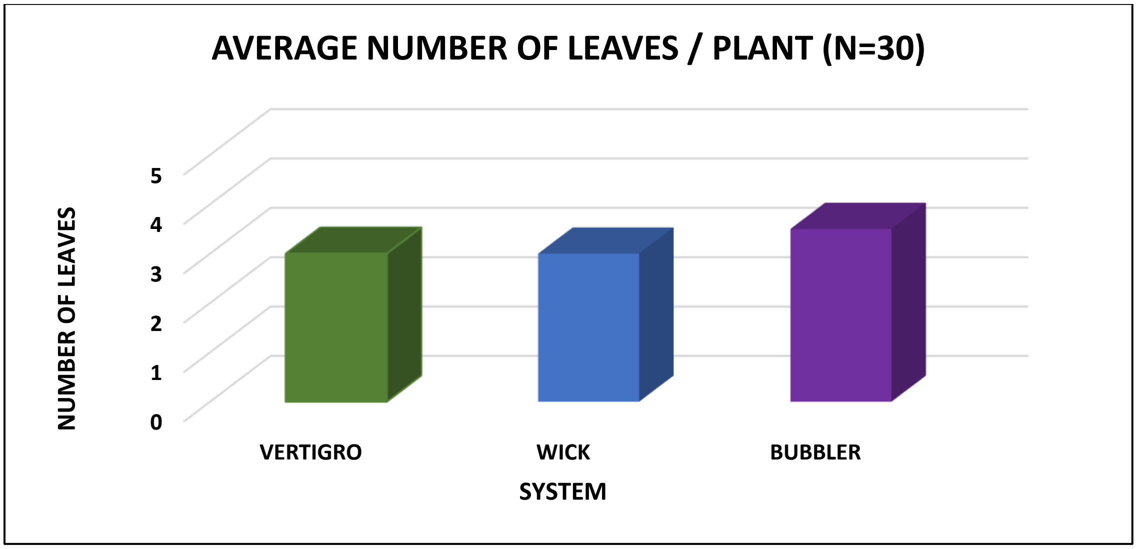
The coconut fiber was prepped by pouring water on it till it leaked from the wick extending down through the mouth of the bottle. The top was placed on top of the reservoir so that the wick extended down into the plant nutrient solution. The nutrient solution, through capillary action, moved up the wick into the coconut fiber and the plant roots. The plant was planted next to the wick in the coconut fiber and the system was placed on the plywood base tower.

The Vertigro, flotation, deep water culture, bubbler system and wick system were set side by side on vertical towers as shown in the picture above. Plants were allowed to grow for 14 days after transplant and then were removed from the system for analysis and measurements. A total of 30 plants were grown and measured for number of leaves produced, surface area of leaves, root length, fresh harvest weight of lettuce, and root weight. The electroconductivity of the plant nutrient solution in each system was monitored over those 14 days. Data was analyzed. Data was compared by averages, mean values were graphed and statistical difference was determined by running a T-test ($p < 0.05$).

HYPOTHESIS

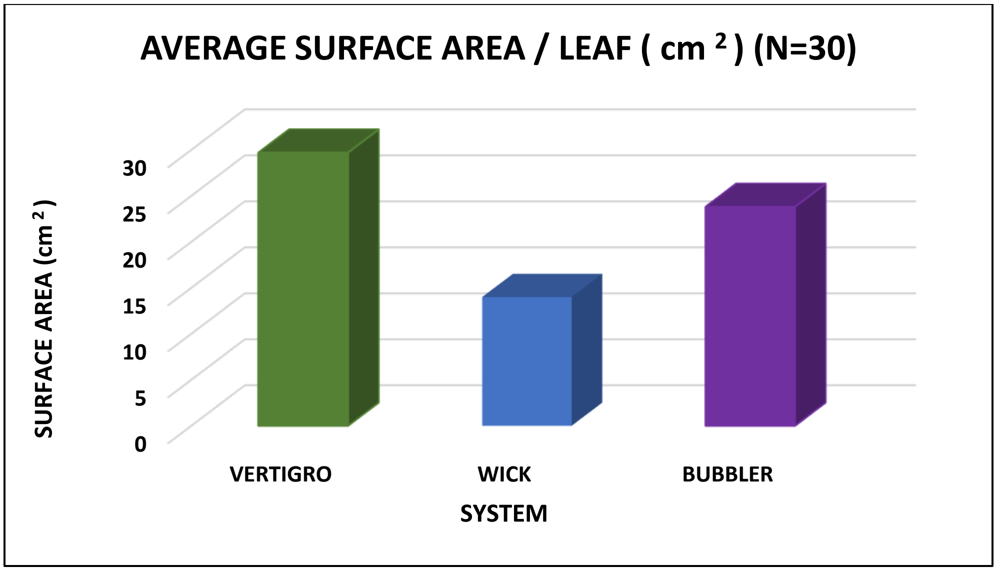
A null hypothesis was formed that stated there would be no difference in leaf surface area, leaf weight, root length, root weight, number of leaves on a lettuce plant between lettuce plants grown in a commercial Vertigro hydroponic system, a floating, deep-water culture, bubbler hydroponic system, and a wick hydroponic system

RESULTS



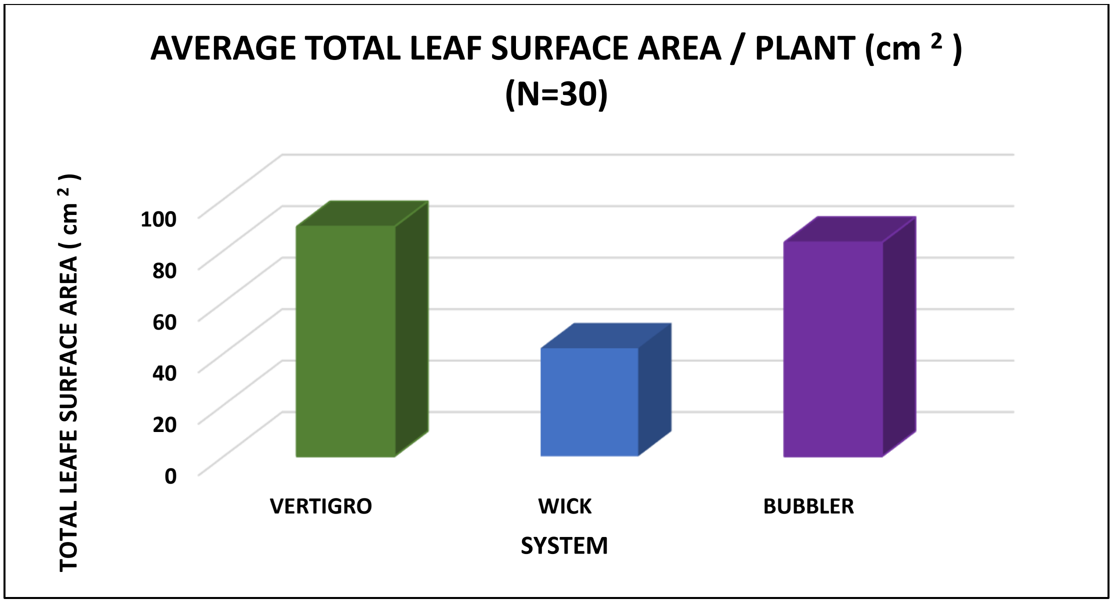
AVERAGE NUMBER OF LEAVES / PLANT (N=30) SYSTEM		
VERTIGRO	WICK	BUBBLER
3	3	3.5

When comparing the average number of leaves per plant, the floating, deep-water culture, bubbler system produced plants which had 1.16 time more leaves per plant than either the Vertigro and wick systems. The average number of leaves per plant for both the Vertigro and the wick systems were similar (no difference). When determining the significant difference of number of leaves per plant between the floating, deep-water culture, bubbler and the other two systems, the floating, deep-water culture, bubbler system was found not to be significantly different ($p < 0.066987$) than the other two systems.



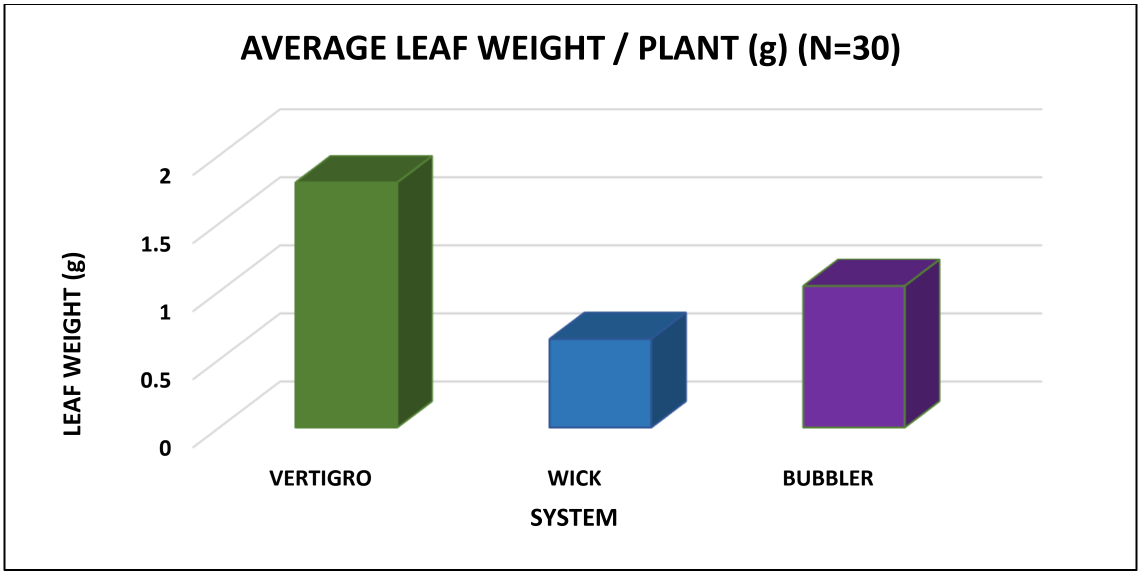
AVERAGE SURFACE AREA / LEAF (cm ^{2}) (N=30) SYSTEM		
VERTIGRO	WICK	BUBBLER
29.7	14	23.8

When comparing the average surface area of a leaf, the Vertigro system produced lettuce with the greater leaf surface area/leaf, followed by the floating, deep-water culture, bubbler. The wick system produced lettuce plants with the least surface area/plant. The average surface area/leaf of lettuce grown in the Vertigro system was 1.24 times greater than the average surface area/leaf of lettuce grown inf the floating, deep-water, culture system. The average surface area/leaf of lettuce grown in the Vertigro system was 2.12 times greater than the average surface area/leaf of lettuce grown inf the wick system. The average surface area/leaf of lettuce grown in the floating, deep-water culture; bubbler was 1.7 times greater than the average surface area/leaf of lettuce grown inf the wick system. The average surface area/leaf of lettuce grown in the Vertigro system was not significantly different (p< 0.0.095731) from the average surface area/leaf of lettuce grown inf the floating, deep-water, culture system or was not significantly different (p< 0.053131) from the average surface area/leaf of lettuce grown in the wick system. The average surface area/leaf of lettuce grown in the floating, deep-water culture; bubbler was not significantly different (p< 0.28761) from the average surface area/leaf of lettuce grown in the wick system.



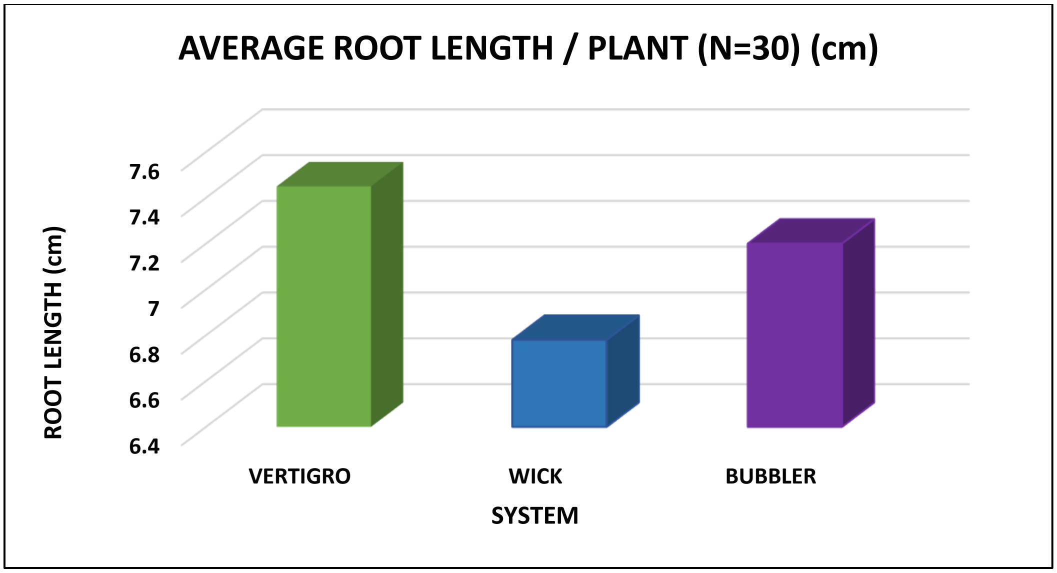
AVERAGE TOTAL LEAF SURFACE AREA/PLANT (cm ^{2}) (N=30) SYSTEM		
VERTIGRO	WICK	BUBBLER
89.2	42	83.1

When comparing the average total leaf surface area/plant, the Vertigro system produced lettuce that was 1.07 times larger than the average total leaf surface area than the floating, deep-water culture, bubbler system and 2.02 times more than the average total leaf surface area than the wick system. The floating, deep-water culture produced lettuce with 1.9 times more than the average total leaf surface area/plant than the wick system. The Vertigro system produced lettuce with an average total leaf surface area/plant that was significantly ($p< 0.011128$) greater than the average total leaf surface area/plant of the floating, deep-water culture, bubbler system and was significantly larger ($p< 0.000282$) times more than the average total leaf surface area/plant than the wick system. The floating, deep-water culture produced lettuce with an average total leaf surface area/plant that was not significantly ($p< 0.065825$) greater than the average total leaf surface area/plant than the wick system.



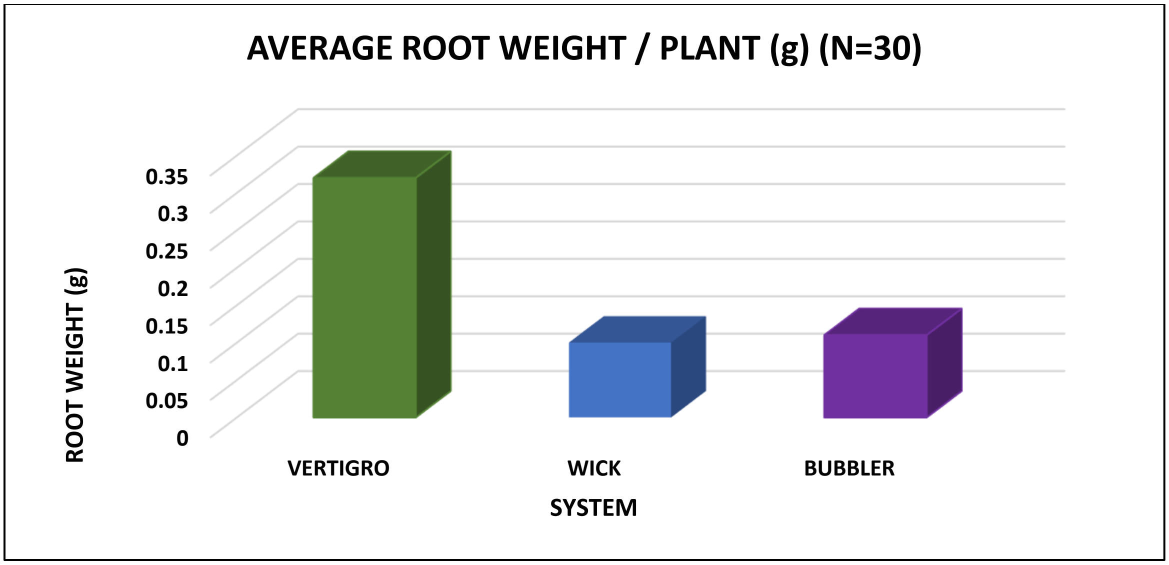
AVERAGE LEAF WEIGHT / PLANT (g) (N=30) SYSTEM		
VERTIGRO	WICK	BUBBLER
1.8	0.65	1.04

The Vertigro system produced 1.73 times greater average leaf weight than the floating, deep-water culture, bubbler system and 2.76 times greater average leaf weight than the wick system. The floating, deep-water culture, bubbler system produced 1.6 times greater average leaf weight than the wick system. Significant difference calculation found that the lettuce grown in the Vertigro system did not significantly ($p < 0.05396$) produce greater leaf average leaf weight than the deep-water culture, bubbler system. The Vertigro system significantly ($p < 0.009302$)) produce greater leaf average leaf weight than the wick system. The deep-water culture, bubbler system did not significantly ($p < 0.060764$) produce greater leaf average leaf weight than the wick system.



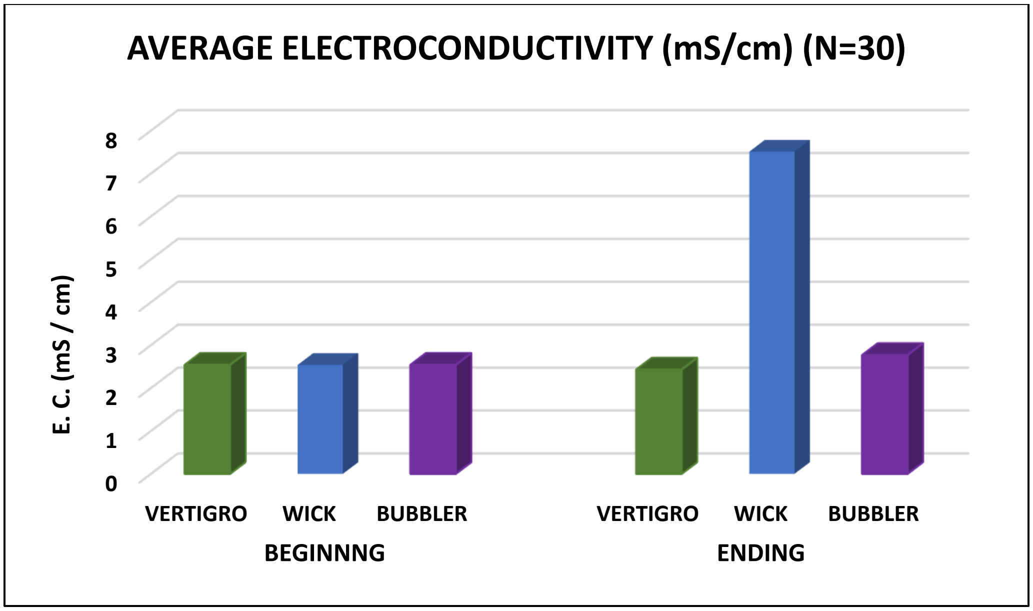
AVERAGE ROOT LENGTH/PLANT (N=30) (cm) SYSTEM		
VERTIGRO	WICK	BUBBLER
7.45	6.78	7.2

Plants grown in the Vertigro system demonstrated roots that were 1.03 times longer than roots of plants grown in the floating, deep-water culture, bubbler system and 1.09 time longer than the roots grown in the wick system. The roots of plants grown in the floating, deep-water culture; bubbler system were 1.06 times longer than roots of plants grown in the wick system. Plants grown in the Vertigro system demonstrated roots that were not significantly ($p< 0.346461$) longer than the plants grown in the floating, deep-water culture; bubbler system and were not significantly ($p< 0.259331$) different from plants grown in the wick system. Roots of plants grown in the floating, deep-water culture; bubbler system were not significantly ($p< 0.312492$) different from plants grown in the wick system.



AVERAGE ROOT WEIGHT/PLANT (g) (N=30) SYSTEM		
VERTIGRO	WICK	BUBBLER
0.32	0.10	0.11

Average root weight of roots from plants grown in the Vertigrao system were 2.90 times heavier than roots grown in the floating, deep-water culture, bubbler system and 3.2 time heavier than roots of plants grown in the wick system. Average root weight of roots from plants grown in the floating, deep-water culture, bubbler system was 1.1 time heavier than roots of plants grown in the wick system. Average root weight of roots from plants grown in the Vertigrao system were significantly ($p< 0.011684$) heavier than roots grown in the floating, deep-water culture, bubbler system and were significantly ($p< 0.010476$) heavier than roots from plants grown in the wick system. Average root weight of roots from plants grown in the floating, deep-water culture, bubbler system was not significantly ($p< 0.418429$) heavier than roots from plants grown in the wick system.



AVERAGE ELECTROCONDUCTIVITY (mS/cm) (N=30)						
BEGINNING				ENDING		
VERTIGRO	WICK	BUBBLER		VERTIGRO	WICK	BUBBLER
2.54	2.54	2.54		2.43	7.51	2.77

The average electroconductivity (EC) of the plant nutrient solutions for all systems tested began at 2.54 mS/cm. After 14 days of growing the lettuce plants in the systems, the Vertigro and floating, deep-water culture, bubble system were similar EC readings of 2.54mS/cm and 2.77 mS/cm. The wick systems average EC was found to be 3.09 times greater than the average EC of the Vertigro system and was 2.71 times greater than the average EC of the floating, deep-water culture, bubble system. The average EC of the wick system was significantly ($p< 0.0001$) greater than the Vertigro system and was significantly ($p< 0.0001$) greater than the floating, deep-water culture, bubble system.

DISCUSSION

The results of this research indicate that the more effective system at this time is the commercial Vertigro system. It was noted that the floating, deep-water culture, bubbler lettuce plants produced more leaves (3.5 – 3) than the other systems but found not to be significantly different from them. It was also noted in the research that as the plant nutrient in the reservoir in the floating, deep-water culture, bubbler system became lower, the plant was also lower into the reservoir. With the paper on the side of the reservoir to block out sunlight to prevent algae, it also blocked light from the lettuce.

The Vertigro system lettuce demonstrated 1.24 times greater average surface area/leaf than lettuce grown in the floating, deep-water, culture system, 2.12 times greater average surface area/leaf than plants grown inf the wick system. The Vertigro system produced lettuce with an average total leaf surface area/plant that was significantly ($p < 0.011128$) greater than the average total leaf surface area/plant of the floating, deep-water culture, bubbler system and was significantly greater ($p < 0.000282$) than the average total leaf surface area/plant than the wick system.

When comparing the average total leaf surface area/plant, the Vertigro system produced lettuce that was 1.07 times larger than the average total leaf surface area than the floating, deep-water culture, bubbler system and 2.02 times more than the average total leaf surface area than the wick system. The floating, deep-water culture produced lettuce with 1.9 times more than the average total leaf surface area/plant than the wick system. The Vertigro system produced lettuce with an average total leaf surface area/plant that was significantly ($p < 0.011128$) greater than the average total leaf surface area/plant of the floating, deep-water culture, bubbler system and was significantly larger ($p < 0.000282$) times more than the average total leaf surface area/plant than the wick system. The floating, deep-water culture produced lettuce with an average total leaf surface area/plant that was not significantly ($p< 0.065825$) greater than the average total leaf surface area/plant than the wick system.

The Vertigro system produced 1.73 times greater average leaf weight than the floating, deep-water culture, bubbler system and 2.76 times greater average leaf weight than the wick system. The floating, deep-water culture, bubbler system produced 1.6 times greater average leaf weight than the wick system. Significant difference calculation found that the lettuce grown in the Vertigro system did not significantly ($p< 0.05396$) produce greater leaf average leaf weight than the deep-water culture, bubbler system. The Vertigro system significantly ($p< 0.009302$)) produce greater leaf average leaf weight than the wick system. The deep-water culture, bubbler system did not significantly ($p< 0.060764$) produce greater leaf average leaf weight than the wick system.

Plants grown in the Vertigro system demonstrated roots that were 1.03 times longer than roots of plants grown in the floating, deep-water culture, bubbler system and 1.09 time longer than the roots grown in the wick system. The roots of plants grown in the floating, deep-water culture; bubbler system were 1.06 times longer than roots of plants grown in the wick system. Plants grown in the Vertigro system demonstrated roots that were not significantly ($p< 0.346461$) longer than the plants grown in the floating, deep-water culture; bubbler system and were not significantly ($p< 0.259331$) different from plants grown in the wick system. Roots of plants grown in the floating, deep-water culture; bubbler system were not significantly ($p< 0.312492$) different from plants grown in the wick system. Average root weight of roots from plants grown in the Vertigrao system were significantly ($p< 0.011684$) heavier than roots grown in the floating, deep-water culture, bubbler system and were significantly ($p< 0.010476$) heavier than roots from plants grown in the wick system.

Average root weight of roots from plants grown in the Vertigrao system were 2.90 times heavier than roots grown in the floating, deep-water culture, bubbler system and 3.2 time heavier than roots of plants grown in the wick system. Average root weight of roots from plants grown in the floating, deep-water culture, bubbler system was 1.1 time heavier than roots of plants grown in the wick system. Average root weight of roots from plants grown in the Vertigrao system were significantly ($p< 0.011684$) heavier than roots grown in the floating, deep-water culture, bubbler system and were significantly ($p< 0.010476$) heavier than roots from plants grown in the wick system. Average root weight of roots from plants grown in the floating, deep-water culture, bubbler system was not significantly ($p< 0.418429$) heavier than roots from plants grown in the wick system.

In addition, the Vertigro system demonstrated a more consistent EC reading only varying 0.11 mS/cm over a 14-day period while the floating, deep-water culture, bubbler system varied only 0.17 mS/cm over the 14-day period. However, the wick system varied 4.97 mS/cm over the 14-day period. It was noted that the water levels in the wick systems were lower than those in the floating, deep-water culture, bubbler systems. This could be due to rapid movement of water from the plant nutrient solution in the reservoir up the wick or evaporation. This would result with the remaining plant nutrients in less water, making the solution more concentrated affecting the root growth of the lettuce when taken up the wick. As stated in the literature research, Paul Fisher, a Professor and Extension Specialist in the Environmental Horticulture Department at the University of Florida, found similar results in his work. The Vertigro system maintained a periodic and consistent delivery of plant nutrient solution to the plants maintaining the desired EC level of the plant nutrient solution.

The results of this research indicates that there is more testing to be done to determine the draw backs and flaws in the floating, deep-water culture and wick systems used in this research. Although these two systems were inexpensive and easy to make, their performance was not as effective as the Vertigro. These same issues were found by Dr. Bob Hochmuth, University of Florida, IFAS in his research. The research determined that these systems are basically "standing water" which results in depleted oxygen in the wick system and varying plant nutrient levels depending on water usage by plants and evaporation which can damage plant roots (Bill Argro, 2009) as occurred in both the wick system. Availability of sunlight to the plant was also an issue due to paper around the bottle in the floating, deep-water culture, bubbler system. These are basic things that do not apply to the Vertigro system as it delivers a plant nutrient source through a drip method that is fresh and trickles through the levels of medium in the buckets of the vertical system, mixing with oxygen as it travels with the ability to expose plants to sunlight.

CONCLUSION

The null hypothesis was not supported by the data. Data significantly supported the Vertigo hydroponic system as the most effective of the three tested hydroponic systems in relationship to leaf surface area, leaf weight, root length, root weight, number of leaves on a lettuce plant between lettuce plants. Deficiencies of the floating, deep-water culture and wick systems were noted and need to be evaluated for improvement and retesting. The areas of concern are to prevent stagnation and evaporation of water in bottle reservoirs, maintaining a constant water level in bottle reservoirs to prevent lowering of plants into the revisor resulting in blocked light to the plant and prevent an increase in plant nutrient concentration (EC) as found in the wick systems.

SUMMARY

At this time, the world is facing an ever-increasing population and with it a growing concern about population growth and the ability of the world to meet the nutrient needs of this population. One approach to this world challenge is the implementation of vertical hydroponic growing systems which have expanded eliminating the need for large amounts of land for food production. This research project's objective was to determine if a low cost, high efficiency vertical hydroponic growing system could be successfully designed and implemented as a model for individual families who wish to improve the quality of food they consume as well as meet the needs of their family's nutrition such as in a Food Desert like our home town. It is for this reason, that a test was conducted comparing a commercial vertical growing system to two vertical systems that were constructed of recycled materials found around the house and community. The three systems tested were the Vertigro commercial vertical hydroponic growing system to a passive vertical wick system and a floating, deep-water culture, bubbler vertical system, both constructed of recycled materials. It was the goal of this research to determine if these recycled systems could help families meet their nutrition needs simply and cheaply by growing their own vegetables such as lettuce as compared to the Vertigro system.

The importance of this study is not only to meet the needs of an increasing world population huger, but we also have many areas in our country and community with a different hunger in that they do not get quality food such as fresh vegetables on a daily basis. They are either socioeconomic challenged or live in Food Deserts. The results is a higher incidence of diabetes and heart disease in these areas than in areas with adequate supplies of fresh vegetables. In addition, with the decrease of supply ability in the world and increasing food prices, such system as tested in this research project could provide financial relief to those families that use them.

Data supported the Vertigro commercial hydroponic system as the most effective in growing lettuce than the 2-liter plastic soda floating, deep-water culture, bubbler system and 2-liter plastic soda wick system tested systems as compared to the other two systems which demonstrated they were inferior. Although the Vertigro system is used in commercial agriculture already on a large basis, it is a costly system. The estimated cost for a six-tower system is $ 1,500 while the other two tested systems, made from household and recycled materials, would be around $ 100 - $ $ 120 for six towers if a plant nutrient pump and timer were included. It is the goal of the researchers to continue testing ways to improve and make a hybrid of the floating, deep-water culture, bubbler and wick systems to provide a simpler and affordable system that the common person can construct and implement at their home to become more sustainable. Such a system may need to incorporate a plant nutrient solution delivery system similia to the Vertigro system to eliminate the problems of stagnation and increase in plant nutrient concentration.

ACKNOWLDGEMENTS

Mrs. Tammy McWherter, Teacher, for helping with supplying materials, helping record data, staying late after school, and transportation

Mr. Wayne Oelfke, Agriculture Teacher/FFA Advisor for mentoring us in this project, providing direction and encouragement and providing the facilities to conduct this project.

Teachers of Ft. White High School for providing the 2-liter plastic soda bottles used in this experiment.

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