

COMPARISON OF AQUAPONICS AND TRADITIONAL CULTIVATION ON BASIL (*OCIMUM BASILICUM*)

A Report of a Senior Study


by

McCall Smallwood

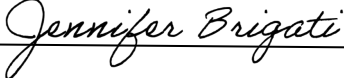
Major: Biology

Maryville College

Spring, 2021

Date approved April 23, 2021, by 

Faculty Supervisor

Date approved 5/5/2021, by 

Division Chair



## ABSTRACT

The increase in human population has necessitated exploration of alternative methods for agriculture production. Many of these methods include reducing the requirement for land and soil space. With the lack of research on comparison of the methodology of quality produce derived from aquaponics, it becomes clear that further investigation is pertinent to discovering solutions (Goddek 2015). Substrates are the fundamental component for soilless cultivation, besides performing the function of plant support, they act as a small reservoir of nutrients. An investigation was performed comparing the growth profiles in aquaponics and traditional soil farming over time, comparing yield from each plant set to determine the quantity of basil (*Ocimum basilicum*) growth and investigating correlation of the basil from each system as a measure of quality. Data analysis was conducted using SPSS software. Coconut coir was significantly similar to growth of plants in soil ( $p < 0.001$ ), in both stem height and number of leaves in a total of 6-weeks of growth. Strong significance was found among five out of six groups analyzed, in accordance with all the morphological values except the leaf density in the fourth week. This research has potential to open the door on further studies in soilless farming as a widespread practice, as well as the ability to have similar quality results.

## ACKNOWLEDGEMENTS

I would like to thank God and Yeshua for ensuring there is no such thing as coincidence in bringing me where I am at, He gets credit for it all. In addition, I also would like to thank Rocky Park Farm in Friendsville, TN for allowing me to complete research on site. I would also like to thank Dr. Andrew Crain for his advice and encouragement throughout the writing process, and guidance to perform and complete this project. Thank you to Dr. Jeff Bay for his assistance with statistical analysis. Thank you to all my family and friends for their continual love and support. Thank you to the koi fish for participating in the study (Hibachi, Teriyaki, Wasabi, Ramen, and Sushi).

## TABLE OF CONTENTS

	Page
List of Tables	iv
List of Figures	v
Chapter I: Introduction	1
Chapter II: Materials and Methods	13
Chapter III: Results	17
Chapter IV: Discussion	23
Works Cited	27

## LIST OF TABLES

Table	Page
1. Key Macronutrient concentration standards.	9
2. Antioxidant concentration of common dried herbs.	11
3. Measurements (mean $\pm$ standard error) of leaf number, stem height, and leaf density (leaf number/stem height).	18

## LIST OF FIGURES

Figure	Page
1. Nitrogen Closed Loop System.	3
2. (A) Soil, (B) Hydroponic, (C) Coconut Coir, (D) Aquaponic system layouts.	15
3. Comparison of mean ( $\pm$ SD) leaf count in each media system (aquaponic, hydroponic, coconut coir, soil).	19
4. Comparison of mean ( $\pm$ SD) apical meristem height in each media system(aquaponic, hydroponic, coconut coir, soil).	19
5. Comparison of mean ( $\pm$ SD) leaf density in each media system (aquaponic, hydroponic, coconut coir, soil).	20
6. Necrosis of leaves and new growth due to excess heat.	21
7. Unsolicited pruning.	21
5. Chlorosis in hydroponic specimens.	22

## CHAPTER I

### INTRODUCTION

The increase in human population has necessitated exploration of alternative methods for agriculture production (de Carvalho et al. 2015). This rise is also a challenge for commercial and pharmaceutical companies, which rely on the quality and consistency of produce grown to sustain needs (Woodcock 2004). Many of these methods include reducing the requirement for land and soil space. With the lack of research on comparison of the methodology of quality produce derived from aquaponics, it becomes clear that further investigation is pertinent to discovering solutions (Goddek 2015).

### *HISTORY OF AQUAPONICS*

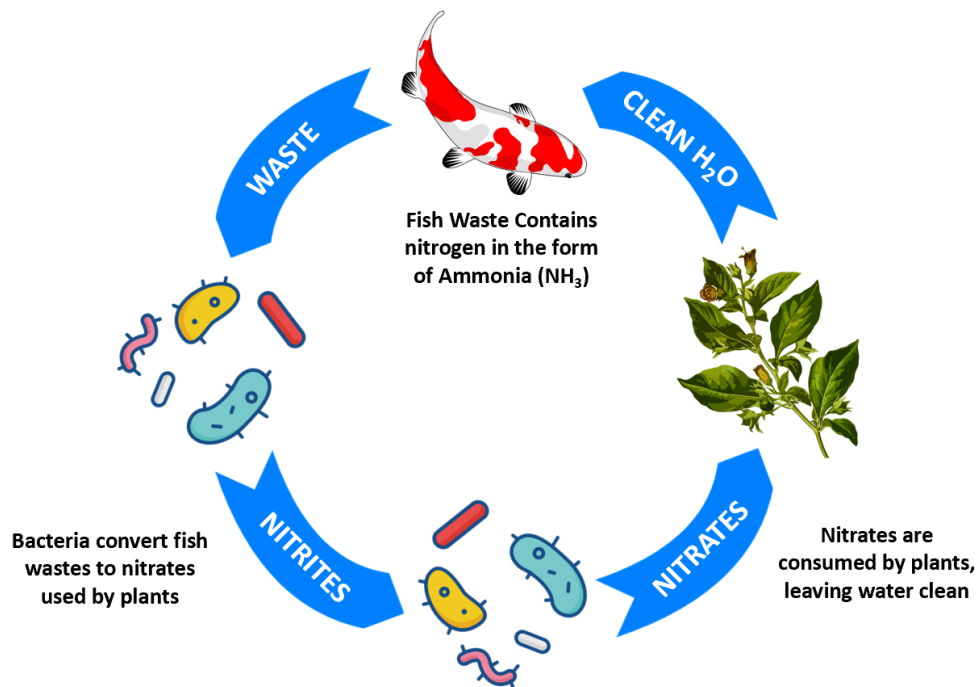
The concept of using fecal waste and excrements from fish to fertilize plants has existed for millennia, whereas the early civilizations in both Asia and South America applied this method. Modern aquaponic systems were first described in the early 1980s through the article published by Watten and Busch in 1984 (Connolly and Trebic, 2010). Prior to the technological advances of the 1980s, many of the attempts to apply hydroponics and aquaculture had limited success (Somerville et al. 2014). Aquaponics is an integrated multi trophic system that takes two elements of soilless farming into consideration. Aquaculture, being the breeding, rearing, and harvesting of fish, shellfish, algae, and other organisms in all types of water environments,

combined with hydroponics, which is the growing of plants in nutrient solutions with or without an inert medium (such as gravel) to provide mechanical support, allows a recirculating system that can be used to ultimately allow conditions for growth (NOAA 2019). The methods of aquaponics are based on processes occurring in the natural world, originating in lakes, ponds, and rivers. Aquatic animals excrete waste, bacteria convert the waste into nutrients, plants remove the nutrients and improve the water quality (Love 2014). In this symbiosis the fish provide much of the plants' required nutrients and bio-filtering plants clean the water for fish. This repurposes the wastes excreted by fish, such as urine and ammonia, to be converted by denitrifying bacteria in the hydroponic grow bed into forms readily absorbed by plants for energy and growth (Diver, 2006; Considine, 2007; Nelson, 2008).

### *CLOSED LOOP SYSTEM*

As a sustainable agriculture production system, aquaponics fulfills all part of the definition "satisfy human food and fiber needs; enhance environmental quality and the natural resource base upon which the agricultural economy depends; make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls; sustain the economic viability of farm operations; and enhance the quality of life for farmers and society as a whole" (FACTA 1990).

Aquaponics has features that are adapted not only to urban environments, or areas where land is scarce or polluted, but in rural areas as well (McClinton 2013). To date, only a few aquaponic systems are being used for purely commercial production (Buehler 2016). The process used in aquaponics is the closed-loop system (See Figure 1), whereas the only input required for an aquaponics farm is the food that sustains the fish.



**Figure 1:** Nitrogen Closed Loop System

### *NITROGEN CLOSED LOOP CYCLING*

The most important biological process in aquaponics is the nitrification process, which is an essential component of the overall nitrogen cycle seen in nature. Nitrogen (N) is the most important inorganic nutrient for all plants, as it is necessary for healthy plants which often contain 3 to 4 percent nitrogen in their above-ground tissues, a much higher concentration than compared to other nutrients. It is so vital to plant life because it is a major component of chlorophyll, the compound by which plants use sunlight energy to produce sugars from water and carbon dioxide. Much of the plant-available nitrogen is in the inorganic forms NH<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup> (sometimes called mineral nitrogen). As microorganisms continuously grow, they remove H<sub>4</sub><sup>+</sup> and NO<sub>3</sub><sup>-</sup> from the soil's inorganic, available nitrogen pool, converting it to organic nitrogen

in a process called immobilization. Because plants require very large quantities of nitrogen, an extensive root system is essential to allowing unrestricted uptake. Plants with roots restricted by compaction may show signs of nitrogen deficiency even when adequate nitrogen is present in the soil, which is cause for substrate specificity (Torgny 2009).

Water quality must be consistently maintained in a recirculating fish tank to achieve optimal growth conditions and sustaining health of the fish. Regularly testing water quality is key and can be performed using water quality testing kits obtained from aquaculture supply companies. The fish diets are to be well balanced in terms of amino acids, proteins, fats, vitamins, minerals, and carbohydrates (Surnar 2015). The food provides the stimulant for the plant growth, the fish excrete their waste into the water, including ammonia “ $\text{NH}_3$ ” that is toxic to the fish at high levels, while also containing nitrogen that is a beneficial input to plant growth. In the settling tank, the solid waste sinks to the bottom while the  $\text{NH}_3$ , which is dissolved in the water, is broken down by microorganisms. Nitrifying bacteria are an essential component of the nitrification process that converts plant and animal waste into accessible nutrients for plants to live in diverse environments such as soil, sand, water, and air. Nitrosomonas bacteria convert the  $\text{NH}_3$  into nitrite (“ $\text{NO}_2$ ”) and then nitrobacter bacteria convert the  $\text{NO}_2$  into nitrate (“ $\text{NO}_3$ ”), which plants can easily absorb (Tomlinson 2015). The bacteria are cultivated and maintained by cycling the system with ammonia, which can be introduced through the waste from the fish. Bacterial colonies can live on any material, such as plant roots, on fish tank walls and inside grow pipes. Total available area available for these bacteria will predict how much ammonia they have the capacity to metabolize. Depending on the fish biomass and system design, the plant roots and tank walls can provide adequate area.

To produce vegetables, traditional hydroponics systems rely only on fertilizers to meet the needs of plants that grow in water. Green vegetables are recommended for aquaponics because they tolerate higher levels of water in their roots and the significant variations and changes in the levels of nutrients that are dissolved in the nutrient solution without symptoms of nutritional deficiency (Effendi et al., 2016). There are system layouts where plants are removed from the substrate once roots emerge, which are suspended directly into the aqueous solutions, while in others the seedlings might be kept in the substrate with various methods of delivering nutrients (Schafer 2014). These methods may include systematically spraying or washing the roots with an aqueous solution or irrigating the solution through porous substrate (Roosta and Afsharipour 2012; Schafer 2014).

### *Essential Oils*

The quality of essential oils has had an increasing interest in considering the use of natural substances, and some questions concerning the safety of synthetic compounds have encouraged more detailed studies of plant resources. According to the International Standard Organization (ISO), essential oils are products obtained from parts of plants, generally through steam distillation, as well as by expression of pericarps of citrus fruits (Danuta 2003). Essential oils are odorous and volatile products of plant secondary metabolism. China, India, and the Middle East were who began using herbs and oils in cooking, cosmetics, medicine and in religious rituals. These substances are associated with several functions necessary for their survival, such as the defense against microorganisms, predators, and attraction of pollinators. Due to the numerous properties associated with them, such as analgesic, expectorant, antimicrobial, antiseptic, insecticidal, fungicidal, and bactericidal qualities interest have

continued to increase. Certain properties have piqued the interest of many researchers in different parts of the world, who are seeking alternative products to replace synthetic insecticides and fungicides due to the risks posed to health and ecosystems (Peters 2016).

The biosynthesis of the essential oils can be affected by several factors, mainly including genetic and environmental ones. These potential variations in their chemical composition can occur and have been the subject of many researchers. Many of the most commercially important species are perennial species, their harvest time and cultivation conditions can be upgraded through better knowledge of the variations in the phenology in order to improve yields and quality of their essential oil. In addition to sensorial characteristics, carried through by specialists, quality control of essential oils involves the determination of previously physical properties (specific gravity, optical rotation, refractive index, residue on evaporation, freezing-point, solubility in alcohol); determination of chemical properties (determination of acids, esters, alcohols, aldehydes, ketones, phenols), and the instrumental techniques cited (chromatographic and spectroscopic techniques) (Sousa 2012).

Each individual essential oil has specific criteria for the maintenance of its quality. This criterion constitutes quality norms that vary in accordance with their use (medicines, foods, flavors, and fragrances). The norms and specifications are elaborated by national and international authorities for normalization, pharmacopoeia, alimentary codices, etc., and published by organizations such as the International Standards Organization (ISO) (Sousa 2012)

## *DIVERSITY IN SUBSTRATE*

Of these selected standards, one question arises from the use of aquaponics regarding the lack of soils. Soils are observed to have a complex structure, with unique biological, chemical, and physical characteristics. They can support plants, the primary producers, and supply them with moisture and nutrients, thus providing all other terrestrial ecosystems with the basis of the food chain. There are many decisions about land use made without consideration of the underlying soils and for any serious proposals for sustainable use of the land, soil properties and functions should be recognized.

Substrates are the fundamental component for soilless cultivation, besides performing the function of plant support, they act as a small reservoir of nutrients (Table 1). Hence, the use of inadequate substrates may create adverse conditions for plant cultivation, causing reduction in the production parameters of the crops (Salam et al., 2014). There have been several studies on the quality differences between the variety of natural and man-made substrates available in agriculture today. One that stands out in beneficial attributes is coconut-fiber as a stand-alone substrate, which may be attributed to greater height, leaf length and width, and stem thickness (Camposeco-Montejo, 2018).

Coco coir is a byproduct of coconut fiber and an inert growing substance, with a pH level near neutral. It is essentially a 'blank slate' for anything put into it while this suits some plants, not all will thrive unless this balance is altered slightly. It was first used in gardening in the West in the 19th century but fell out of favor because the low-quality coco available at the time degraded when used for short-term growing. Toward the end of the 20th century, it was rediscovered as an organic, environmentally sustainable substrate when new production methods made it possible to create hardier products. Coco fibers are stringy bundles that allow oxygen to

easily penetrate a plant's root system and boasts antifungal properties, which keeps the roots healthy. It can repel some pests and when used for drain-to-waste growing, coco coir gives excellent results. With the right coco coir nutrients plants spend less energy searching for food and more time growing (Camposeco-Montejo 2018).

Table 1: Key Macronutrient concentration standards found in soil in comparison to aquaponics.

Nutrient	Concentration		Purpose	References
	Optimum Soil Range	Aquaponic Standard (mean ± standard error) mg/l		
P	20-30ppm	6.6±1.0	Promotes early plant growth and root formation through its role in the division and organization of cells	Marx, 1999 Bittsanszky et al., 2016 University of Missouri, 2020 Jaquetti et al., 2016
Total N	10-20ppm	10.6±2.1	Integral part of chlorophyll and is a component of amino acids, nucleic acids, and coenzymes.	Marx, 1999 Bittsanszky et al., 2016 University of Missouri, 2020 Jaquetti et al., 2016
K <sup>+</sup>	100-150ppm	50.8±11.9	Necessary to plants for translocation of sugars and for starch formation.	Marx, 1999 Bittsanszky et al., 2016 University of Missouri, 2020 Jaquetti et al., 2016
Ca <sup>2+</sup>	1000-2000 ppm	129.6±18.5	Promotes plant vigor and rigidity and is important to proper root and stem growth.	Marx, 1999 Bittsanszky et al., 2016 University of Missouri, 2020 Jaquetti et al., 2016
Mg <sup>2+</sup>	50-70ppm	20.9±1.1	Component of the chlorophyll molecule and is therefore essential for photosynthesis.	Marx, 1999 Bittsanszky et al., 2016 University of Missouri, 2020 Jaquetti et al., 2016
SO <sub>4</sub> <sup>2-</sup>	>10ppm	8.3±12.2	Constituent of three amino acids (cystine, methionine and cysteine) that play an essential role in protein synthesis.	Marx, 1999 Bittsanszky et al., 2016 University of Missouri, 2020 Jaquetti et al., 2016

### *BASIL: Health Properties*

Essential oils of basil are usually extracted from the leaves and flowering tops of basil plants. In most of the century's basil was cultivated for culinary and medicinal purposes, which created a great diversity of species within the *Ocimum* genus (Singh 2019). *Ocimum basilicum* has been used for many years in the Indian Ayurvedic and Unani medicine for cough treatment, inflammations, dyspepsia, aches, and pains (Hili et al., 1997). It is also used in food as a food spice and mentioned leaves of *O. basilicum* are suitable for treatment of pain and cough. Basil, the essential oil from *O. basilicum* L., is shown to have an inhibitory effect on *Aspergillus ochraceus* and antimicrobial activity (Hili et al., 1997). The aromatic nature of basil is due to the composition of essential oils. These essential oils are elicited as a stress response and serve as antimicrobial and antifungal agents (Wilson et al. 2017). The essential oil obtained by steam distillation from air dried basil leaves showed antibacterial activity against resistant clinical isolates from the genera *Staphylococcus*, *Enterococcus* and *Pseudomonas*. An ethanol extract of *Ocimum sanctum* was found to be active against *Staphylococcus aureus*, *Bacillus subtilis*, *Bacillus cereus*, *Bacillus thuringiensis*, *Salmonella typhi* at a minimum bactericidal concentration of 5 to 10 mg /mL (Hili et al., 1997). In previous studies, flavonoids, orientin and vicenin, that were isolated from the leaf extract of *O. sanctum*, were found to protect mice against radiation injury (Devi et al. 2000). Preclinical studies have also shown that some of its phytochemical's eugenol, Rosmarinus acid, apigenin, myrtenol, luteolin,  $\beta$ -sitosterol, and carnosic acid prevented chemical-induced skin, liver, oral, and lung cancers and to mediate these effects by increasing the antioxidant activity (Table 2), altering the gene expressions, inducing apoptosis, and inhibiting angiogenesis and metastasis (Baliga 2012). Some of the highest

concentration essential oils in basil also include eugenol, camphor, linalool, thymol, and methyl chavicol (Wilson et al. 2017).

Table 2: Antioxidant concentration of common dried herbs (Tapsell 2006)

Common Name	Botanical Name	Antioxidant Activity
Clove	<i>Syzygium aromaticum</i>	465.3 mmol/100 g
Oregano	<i>Origanum vulgare</i>	137.5 mmol/100 g
Cinnamon	<i>Cinnamomum zeylanicum</i>	98.4 mmol/100 g
Peppermint	<i>Mentha piperita</i>	78.5 mmol/100 g
Thyme	<i>Thymus vulgaris L.</i>	74.6 mmol/100 g
Rosemary	<i>Rosmarinus officinalis L.</i>	66.9 mmol/100 g
Marjoram (sweet)	<i>Origanum majorana</i>	55.8 mmol/100 g
Basil	<i>Ocimum basilicum L.</i>	30.9 mmol/100 g
Ginger	<i>Zingiber officinale</i>	22.5 mmol/100 g
Dill	<i>Anethum graveolens</i>	15.9 mmol/100 g
Curry	<i>Murraya koenigii L.</i>	13.0 mmol/100 g
Chives	<i>Allium schoenoprasum</i>	7.1 mmol/100 g
Parsley	<i>Petroselinum crispum</i>	3.6 mmol/100 g
Coriander	<i>Coriandrum sativum L.</i>	3.3 mmol/100 g
Vanilla Seeds	<i>Vanilla planifolia</i>	2.6 mmol/100 g
Garlic	<i>Allium sativum L.</i>	2.1 mmol/100 g

#### *Essential Oil: Substrate Factor*

Formation of bioactive constituents of plants depends on the actual environmental and on growing factors. Controlled environment technology ensures the application of specific stresses that can optimize the production of secondary plant metabolites by inducing natural biochemical changes in plants (Manukyan 2011). Studies have shown that aquaponics provided a more

constant supply of nutrients to plants when compared to hydroponics and a significant difference in leaf number and plant height. This affects the essential oil composition, which is shown to be different in basil grown in hydroponic and aquaponic systems. An essential oil analysis suggested that the quality of basil is different in hydroponic and aquaponics systems, and in the hydroponic system had higher concentrations of the identified essential oils (Wilson et al. 2017).

The goals in this project are to: (1) compare the growth profiles in aquaponics and traditional soil farming over time, (2) compare yield from each plant set to determine the quantity of basil growth and (3) investigate correlation of the basil from each system as a measure of quality.

## CHAPTER II

### MATERIALS AND METHODS

This study was conducted at Rocky Park Farm located in Friendsville, Tennessee. The farm hosted an established aquaponic system and multiple greenhouse units. The system used for growth was set apart from the main use grid, they were maintained under the same conditions. The pH was kept at a safe level for the koi fish ( $7.0 \pm 0.2$  (up to 7.8 if no plants)), while maintaining the needs for plant growth. The aquaponic table was a single sheet, composed of a grow bed with media above a fish tank with an oxygen bubbler and pump. The water from below was pumped directly back into the media so that all the root systems within the grow tray were well saturated. A similar system of hydroponics was placed in the main tilapia-supplemented flow, water was pumped in descension from a two-tiered table into a basin at the end of the unit. In PVC grow tubes, coconut coir reservoirs provided a linear bed that was supplied with similar nutrient rich water flow to the hydroponic system, with a gravity fed flow originating from the pumped reservoir.

#### *Aquaponic System*

Sunleaves Rocks (Sunleaves Garden Products, Bloomington, IN) were used filling 75% of the depth of the grow bed. The aquaponic system was constructed following Malcolm and Arcaro (2011; pgs. 21-25). The water was previously cycled with the fish already in a healthy and established system. Koi were obtained from Perennial Ponds in Maryville, TN.

### *Experimental Design*

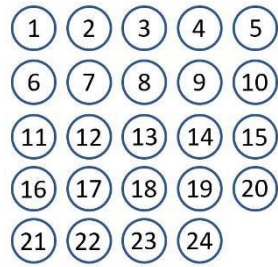
Basil (*Ocimum basilicum*) plants were propagated in 5x10 unit trays and divided by random selection into four mediums. Plants transplanted to mediums were moved at the two-week period of growth. Plants were inserted into coconut coir medium tubes in a row of 24 across. Basil was also placed in 4-inch standard pots with soil from the greenhouse garden plots, directly from the ground, and set up in a numbered grid layout of 5x5 rows.

To set up the experiment, basil plants were divided into four groups (n = 24 for each) based on system type (aquaponics, hydroponics, coconut coir and soil; determined by random selection; see Figure 2). The basil plants were assigned numbers as when placed into their respective systems for identification. Each basil plant was measured for stem length and number of leaves after being planted in the system. Stem length was measured after a period of two weeks as distance between the shoot apical meristem and the top of the media bed.

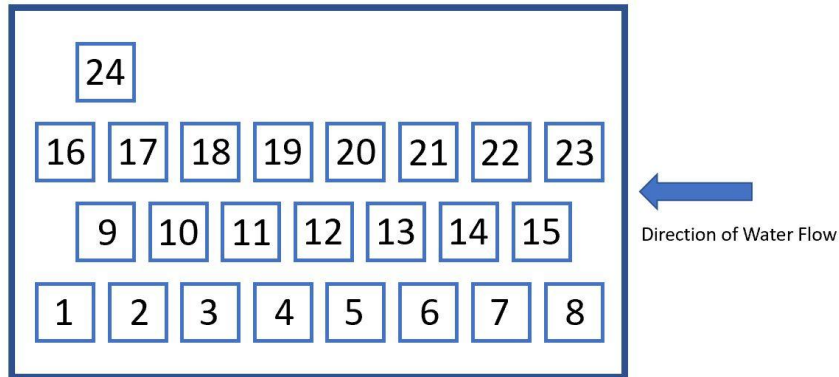
### *Statistical Analysis*

The morphometric values for each individual specimen were calculated by use of descriptive statistics to determine the meaningful differences between media. Stem height (cm), leaf number, and leaf density (number of leaves/stem height). SPSS software was used to statistically analyze the data. One-way ANOVA and Tukey HSD Post Hoc were used to analyze. A t-test assuming equal variance (with  $\alpha = 0.05$ ) through SPSS Univariate Analysis of Variance was used to compare the differences between pairing of media values.

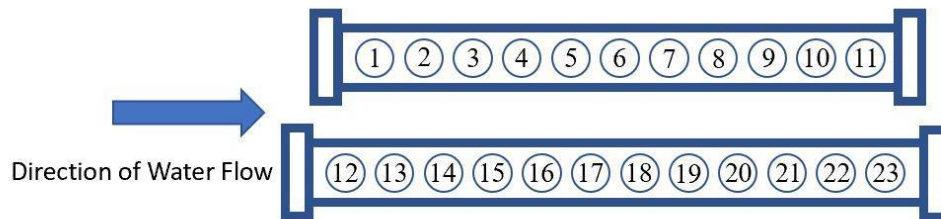
A.



B.



C.



D.

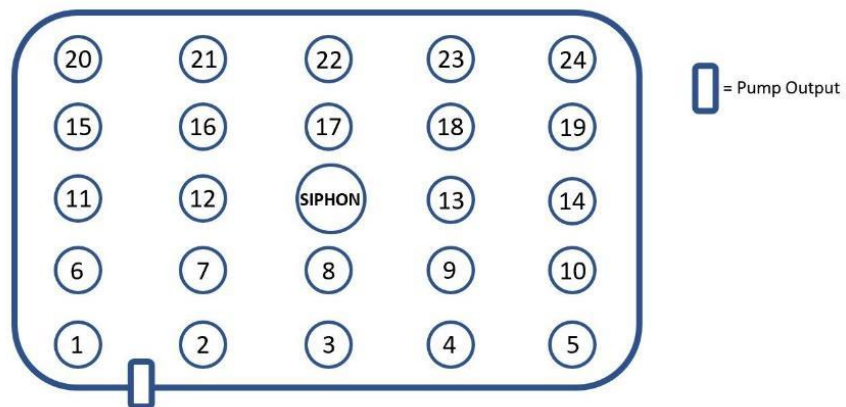


Figure 2: (A) Soil, (B) Hydroponic, (C) Coconut Coir, (D) Aquaponic system layouts. Direction of water flow indicated. Plant ID assigned by number.

Aquaponic and hydroponic systems were located in the same greenhouse, while the PVC coconut coir tubes and soil occupied the neighboring greenhouse maintained under the same conditions. The plants were grown for a total of four weeks, adding to the initial two-week propagation period.

## CHAPTER III

### RESULTS

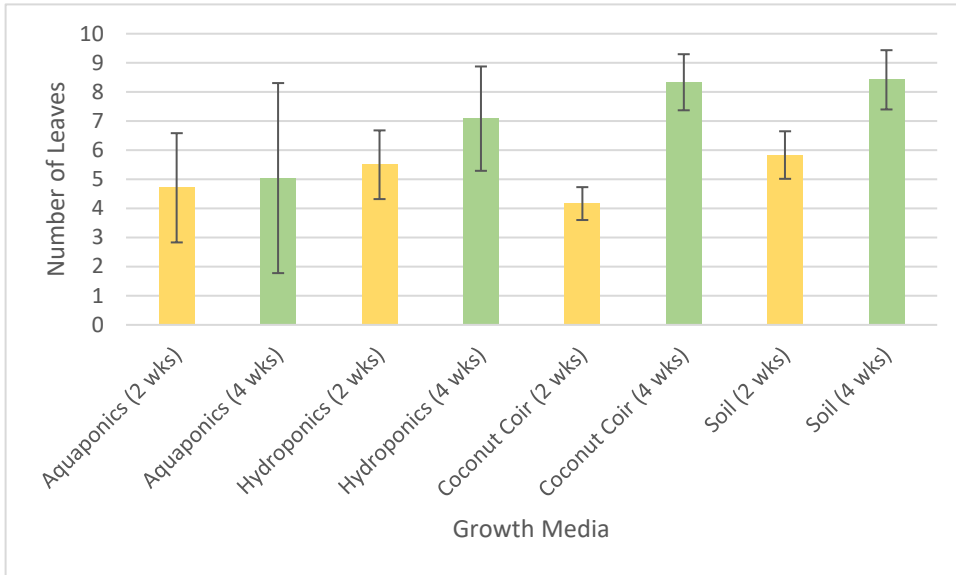
#### SECOND LINE OF CHAPTER TITLE IF NEEDED

##### *Basil Morphometrics*

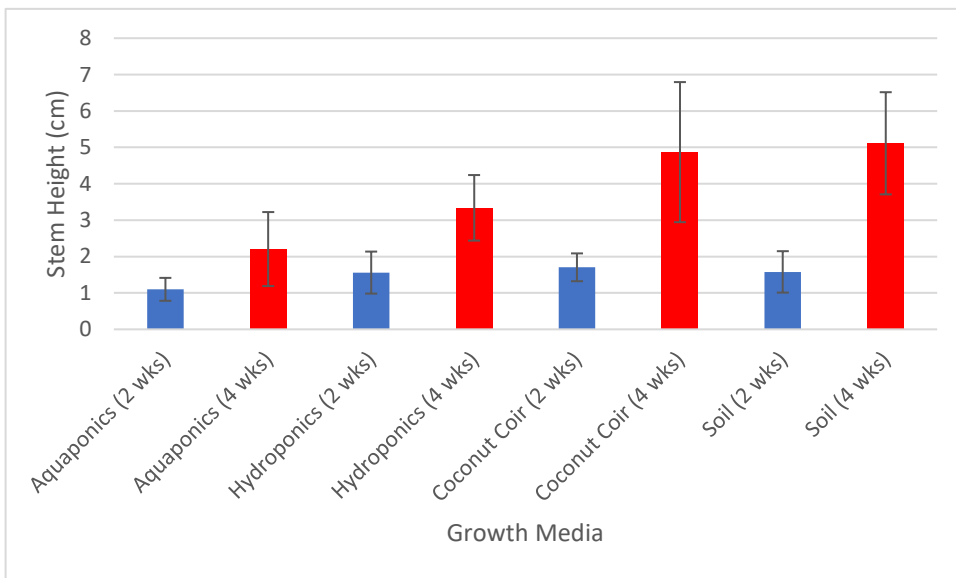
Table 3 presents 30 comparisons made between each of the media and time groups on measurements in the systems, with 20 that were found to be significantly different.. At the 2-week mark, there is a significant difference between the number of leaves on coconut coir plants and hydroponic plants. As well as a significant difference between the number of leaves on those grown in soil and in the Aquaponic systems. Also, there is a significant difference in between the values of soil and coconut coir. At the 4-week, there are significant differences between aquaponics and hydroponics, aquaponics and coconut coir, and aquaponics and soil. Between the first few weeks of height growth there is significance in the same way, with aquaponics standing alone in difference. In the 4-week data set there is a significant difference between aquaponics and hydroponics. There is also significance between the height of hydroponics and coconut coir and soil. There is also significance between aquaponics and soil. The 2-week density measurements have significant values with coconut coir compared to the other three media.

**Table 3:** Measurements (mean  $\pm$  standard error) of leaf number, stem height, and leaf density (leaf number/stem height) for basil plants grown in aquaponic (n = 24 for each age group), hydroponic (n = 24 for each age group), coconut coir (n = 24 for each age group), or soil (n = 24 for each age group) systems and media. Placed were transplanted at 2 weeks old. Measurements were taken after 2 weeks and 4 weeks of growth in the system. Bolded values are significant. Different letters in the same column indicate significant statistical differences ( $p < 0.05$ , Tukey's test).

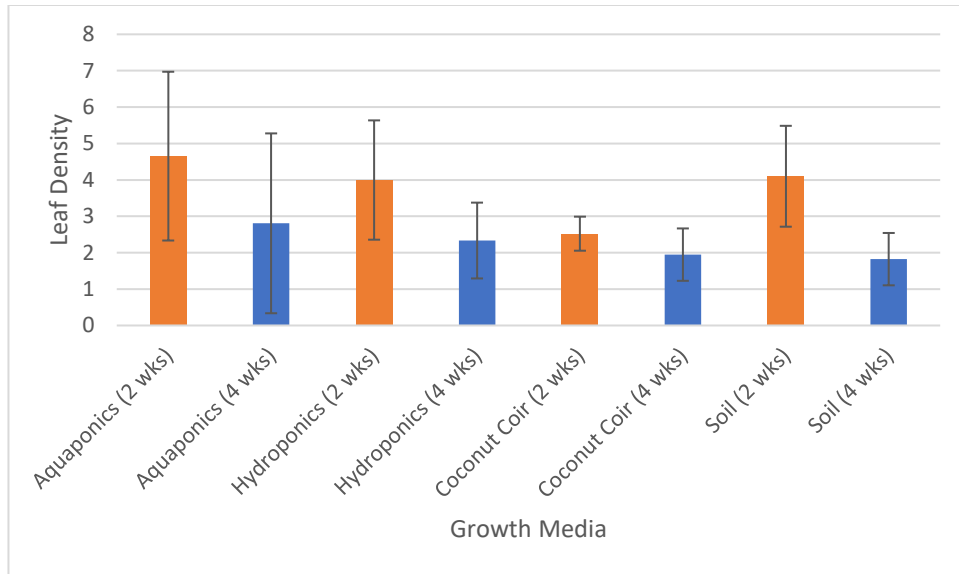
Leaf Number	2 weeks	4 weeks
Aquaponics	4.71 $\pm$ 0.39 <sup>ab</sup>	5.04 $\pm$ 0.70 <sup>a</sup>
Hydroponics	5.50 $\pm$ 0.24 <sup>bc</sup>	7.08 $\pm$ 0.37 <sup>b</sup>
Coconut Coir	4.17 $\pm$ 0.12 <sup>a</sup>	8.33 $\pm$ 0.20 <sup>b</sup>
Soil	5.83 $\pm$ 0.17 <sup>c</sup>	8.41 $\pm$ 0.21 <sup>b</sup>
<i>p</i> -value	<b>0.00002</b>	<b>4.84e-08</b>
Tukey HSD	$\alpha = 0.05$	$\alpha = 0.05$
Stem Height (cm)	2 weeks	4 weeks
Aquaponics	1.09 $\pm$ 0.06 <sup>a</sup>	2.21 $\pm$ 0.21 <sup>a</sup>
Hydroponics	1.56 $\pm$ 0.12 <sup>b</sup>	3.34 $\pm$ 0.18 <sup>b</sup>
Coconut Coir	1.70 $\pm$ 0.08 <sup>b</sup>	4.87 $\pm$ 0.39 <sup>c</sup>
Soil	1.58 $\pm$ 0.12 <sup>b</sup>	5.11 $\pm$ 0.29 <sup>c</sup>
<i>p</i> -value	<b>0.00015</b>	<b>3.08e-11</b>
Tukey HSD	$\alpha = 0.05$	$\alpha = 0.05$
Leaf Density	2 weeks	4 weeks
Aquaponics	4.65 $\pm$ 0.49 <sup>b</sup>	2.81 $\pm$ 0.52 <sup>a</sup>
Hydroponics	4.00 $\pm$ 0.33 <sup>b</sup>	2.33 $\pm$ 0.21 <sup>a</sup>
Coconut Coir	2.52 $\pm$ 0.10 <sup>a</sup>	1.95 $\pm$ 0.15 <sup>a</sup>
Soil	4.10 $\pm$ 0.28 <sup>b</sup>	1.82 $\pm$ 0.15 <sup>a</sup>
<i>p</i> -value	<b>0.00011</b>	0.05730
Tukey HSD	$\alpha = 0.05$	$\alpha = 0.05$



**Figure 3:** Comparison of mean ( $\pm$ SD) leaf count in each media system (aquaponic, hydroponic, coconut coir, soil). 2-week and 4-week (n=24).



**Figure 4** Comparison of mean ( $\pm$ SD) apical meristem height in each media system (aquaponic, hydroponic, coconut coir, soil). 2-week and 4-week (n=24).



**Figure 5** : Comparison of mean ( $\pm$ SD) leaf density in each media system (aquaponic, hydroponic, coconut coir, soil). 2-week and 4-week (n=24).

#### *Difference of Instances*

In Figures 3 and 4, out of the four media systems, soil and coconut coir had the higher end recorded values of stem height and leaf count. Figure 5 shows the change in density following the 2-week difference in growth, whereas the aquaponic system is ahead. In weeks 2 and 3 the hydroponic system basil plants were showing signs of chlorosis starting around the apical meristem and affecting the topmost leaves, recorded in Figure 8. Additionally, the aquaponics basil had a few heat related necrotic instances, causing irreversible leaf damage, shown in Figure 7. Due to the nature of the location of the research, unsolicited pruning occurred on a small number of plants in soil and hydroponics, during week 4 prior to data retrieval.



Figure 6: Necrosis of leaves and new growth due to excess heat.

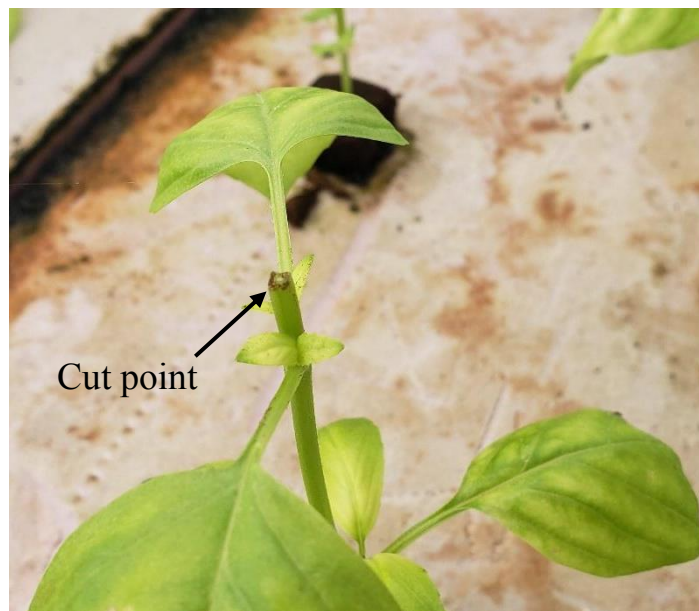


Figure 7: Unsolicited pruning.



Figure 8: Chlorosis in hydroponic specimens.

## CHAPTER IV

### DISCUSSION

The results of this research show there is a significant difference between traditional cultivation techniques and aquaponics, coconut coir and hydroponics. In the study, we show that (1) coconut coir and soil growth provide a significant rise in yield, (2) the morphometric basis of leaf number and meristem height had significant difference between media types of cultivation, (3) the density of basil for each specimen exhibits quality similarities despite growth differences.

#### *Leaf Number*

Comparisons during two weeks show there is a significant difference between the number of leaves on coconut coir plants and hydroponic plants, as well as a significant difference between the number of leaves on those grown in soil and in the aquaponic systems. Also, there is a significant difference in between the values of soil and coconut coir. At 4-weeks, there are significant differences between aquaponics and hydroponics, aquaponics and coconut coir, and aquaponics and soil. While the soil had the highest mean of leaves, the coconut coir was less than 0.1 in count behind. Hydroponics and aquaponic specimens had a closer relationship of similarity within the first 2-weeks of growth. coconut coir was also similar to aquaponic growth. Success in yield for leaf number was present in each.

### *Height*

Between the first few weeks of height growth there is significance in the same way, with aquaponics standing alone in difference. In the 4-week data set there is a significant difference between aquaponics and hydroponics. There is also significance between the height of hydroponics and coconut coir and soil and between aquaponics and soil. This leads to soil and coconut coir to lead again in growth yield, during the 4-week set. Overall, the height of the water-based growth media was shorter than those in more substantial substrates.

### *Density*

Results from the leaf density test show that aquaponic media growth had higher density. However, that could be attributed to the overall shortest height growth between all factors in both time points. The significance for those values is 4 out of the 10 tested for significance in the first 2-weeks and do not have significance in the 4-week period. The shorter the plant can be anticipated to have more leaves in the given space on the stem. The 2-week density measurements have significant values with coconut coir compared to the other three media.

### *Chlorosis*

The lightening of the apical meristem and surrounding young leaves was an alarming sign for the hydroponic media. A treatment of AquaIron (Wheat Ridge, CO.) is one of the few additives that most aquaponics professionals agree needs to be regularly added to most aquaponics and hydroponics systems for the treatment and prevention of yellow leaf (Chlorosis). The condition improved some with the addition, yet with the short growth period, the effects are unknown to have affected growth (Roosta 2014).

### *External Influence*

A factor that influenced the result of height morphometrically was the unsolicited pruning that occurred. This variable, while unexpected, did not affect all specimens. The removed part of what could have been up to an inch of vegetation, had the possibility of changing the levels of hydroponic and soil means in height and density. Pests were not detected to be affecting the plants; thus, leaf dexterity was maintained for most of the study. Another factor that had an effect on data is the necrosis in the aquaponic system. Necrosis can be caused from many subjects, however, based on the starting location, it can be pointed to excess heat on the young growth of the basil. Shade cloths were used to cut radiation and direct light once discovered. Leaves and stem height were affected in a handful of individuals. Future research may have stronger values where all specimens are grown in the same greenhouse unit.

### *Hardening Off*

To improve the survivability of plants, exposing them to outdoor temperatures, wind, and conditions that are more challenging helps thicken their cuticles. Transplant shock is a variable that may be attributed to the received values. Poor growth, death from sudden change, temperature and light exposure fluctuations and other functions that change during transplant can be limited with a length of time added. (Ianotti 2021). Future research should survey with hardier plants that were transitioned using hardening off.

### *Conclusion*

The side-by-side observations of four growth media types in a controlled greenhouse setting allowed for a study of basil production that identifies the differences between alternative

farming and cultivation techniques. The results support the hypothesis of there being a significant quality difference in the basil that is grown for consumption, based on the growth yield. The use of coconut coir as a substrate media material is supported by the levels of morphometric success in comparison to the traditional soil technique. Additionally, with a study that lasts the entire growing season, or using a different species of plant could provide a more in-depth analysis on long-term effects.

## WORKS CITED

- Bittsánszky A, Uzinger N, Gyulai G, Mathis A, Junge R, Villarroel M, Kotzen B, Kőmíves T. 2016. Nutrient supply of plants in aquaponic systems. *Ecocycles* 2.
- Bridges E, & Baren, JV. 1997. SOIL: An Overlooked, Undervalued and Vital Part of the Human Environment. *Environmentalist*, 17:15-20.
- Buehler D, Junge R. 2016. Global Trends and Current Status of Commercial Urban Rooftop Farming. *Sustainability* 8:1108.
- Camp NL. 2015. Indoor Aquaponics in Abandoned Buildings: A Potential Solution to Food Deserts. *The Nurse Practitioner* 40:32–36.
- Camposeco-Montejo N, Robledo-Torres V, Ramírez-Godina F, Mendoza-Villarreal R, Pérez-Rodríguez MÁ, Cabrera-de la Fuente M. 2018. Response of Bell Pepper to Rootstock and Greenhouse Cultivation in Coconut Fiber or Soil. *Agronomy*, 8(7), 111. [10.3390/agronomy8070111](https://doi.org/10.3390/agronomy8070111)
- de Carvalho RO, Weymar Jr LCN, Zanovello CB, da Luz MLG, Gadotti GI, da Luz CAS, Gomes MC. 2015 Hydroponic lettuce production and minimally processed lettuce. *Agric. Eng. Int. CIGR J.*:290–294.
- Connolly K, Trebic T. 2010. Optimization of a Backyard Aquaponic Food Production System.

- Considine ML. 2007. Plant crops to clean up aquaculture waste. *Ecos*, 138:34.
- Diver S. 2006. ATTRA: National sustainable agriculture information service. *Choice Reviews Online* 43.
- Effendi H, Wahyuningsih S, Wardiatno Y. 2016. The use of Nile tilapia (*Oreochromis niloticus*) cultivation wastewater for the production of romaine lettuce (*Lactuca sativa* L. var. *longifolia*) in water recirculation system. *Applied Water Science* 7:3055–3063.
- Goddek S, Delaide B, Mankasingh U, Ragnarsdottir K, Jijakli H, Thorarinsdottir R. 2015. Challenges of Sustainable and Commercial Aquaponics. *Sustainability* 7:4199–4224.
- Iannotti M. 2021. *How to Harden Off Plants for Transplanting*. The Spruce.
- Jaquetti RK, Gonçalves JFC, Ferraz JBS, Ferreira MJ, dos Santos Junior UM. 2016. Ecofunctional Traits and Biomass Production in Leguminous Tree Species under Fertilization Treatments during Forest Restoration in Amazonia. *Forests*, 7(4), 76. 10.3390/f7040076
- Kalemba D, Kunicka A. 2003. Antibacterial and Antifungal Properties of Essential Oils. *Current Medicinal Chemistry* 10:813–829.
- Love DC, Fry JP, Genello L, Hill ES, Frederick JA, Li X, Semmens K. 2014. An International Survey of Aquaponics Practitioners. *PLoS ONE* 9.
- Malcolm J, Arcaro F. 2011. *The IBC of Aquaponics*. Backyard Aquaponics. Edition 1.0.

- Manukyan Artur. 2011. Effect of Growing Factors on Productivity and Quality of Lemon Catmint, Lemon Balm and Sage under Soilless Greenhouse Production: I. Drought Stress. *Medicinal and Aromatic Plant Science and Biotechnology*. 5:119-125.
- McClintock N, Cooper J, Khandeshi S. 2013. Assessing the potential contribution of vacant land to urban vegetable production and consumption in Oakland, California. *Landscape and Urban Planning* 111:46–58.
- Missouri U. 2020. Soils, Plant Nutrition and Nutrient Management. University of Missouri Extension.
- Näsholm T, Kielland K, Ganeteg U. 2009. Uptake of Organic Nitrogen by Plants. *New Phytologist* 182:31–48.
- Nelson RL, 2008. *Aquaponics Food Production: Raising fish and plants for food and profit*. Montello: Nelson and Pade Inc.
- Peters M. 2016. *Essential Oils: Historical Significance, Chemical Composition and Medicinal Uses and Benefits*. Nova Science Publishers.
- Ramalingam MR, Ramalingam C. 2010 “Health Benefits of Spices with Special Reference to Antimicrobial Activity and Bio Active Components”. *Journal of Experimental Sciences*, 1(7)
- Roosta HR, Afsharipoor S. 2012. Effects of Different Cultivation Media on Vegetative Growth, Ecophysiological Traits and Nutrients Concentration in Strawberry Under Hydroponic and Aquaponic Cultivation Systems. *Adv. Environ. Biol.* 6:543–555.

Singh A, Singh K, Ajay, Agrawal, Shashi, Siddharth, Pradesh BR, Uttar. 2019. Cultivation, Oil Extraction and Chemical Composition of Sweet basil (*Ocimum basilicum*) in Kannauj Region. 10.15680/IJRSET.2017.0611040.

Sousa DP. 2012. Medicinal Essential Oils: Chemical, Pharmacological and Therapeutic Aspects. Nova Science Publishers, Inc. Sustain. Dev. Law Policy XVI:16–24.

Surnar SR, Sharma OP, Saini VP. 2015 Nov 26. Aquaponics: Innovative farming. International Journal of Fisheries and Aquatic Studies.

Tapsell LC, Hemphill I, Cobiac L, Sullivan DR, Fenech M, Patch CS, Roodenrys S, Keogh JB, Clifton PM, Williams PG, et al. 2006. Health benefits of herbs and spices: the past, the present, the future. Medical Journal of Australia 185.

Woodcock J. 2004. The Concept of Pharmaceutical Quality. ResearchGate.