AQUAPONICS AND HYDROPONICS: THE EFFECTS OF NUTRIENT SOURCE AND HYDROPONIC SUBSYSTEM DESIGN ON SWEET BASIL PRODUCTION

by

Ryan K. Dunwoody

An Abstract
of a thesis submitted in partial fulfillment
of the requirements for the degree of
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ABSTRACT

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Development and practice of sustainable agriculture is one approach to help offset escalating environmental and production crises. Aquaponics is an emerging sustainable agriculture system that amalgamates aquaculture and hydroponics. This research compared sweet basil (*Ocimum basilicum L. Nufar*), yield within six constant flow recirculating systems. Two hydroponic subsystem designs, media filled and deep water culture, were employed. Independent nutrient sources consisted of General Hydroponics® Flora Series, or metabolic wastes of live channel catfish *(Ictalurus punctatus)* during respective trials. Weekly water quality and macronutrient assessments were recorded. Sweet basil fresh leaf mass (kg) (FLM), yield (leaf) (kg/0.6027 m^2), total yield of vegetative (non-root) biomass (kg) (TVB), plant height (cm), and absolute growth rate (cm/day) (AGR) data was analyzed following each trial. For overall combined media filled and DWC aquaponic and hydroponic systems, FLM, yield, TVB, height, and AGR were significantly higher during the hydroponic trial ($p=<0.001$). Furthermore, there were significant differences in basil production between aquaponic and hydroponic media and DWC hydroponic subsystems ($p<0.05$). Additionally, there was no significant difference between aquaponic and hydroponic DWC hydroponic subsystems for FLM, yield, and TVB ($p>0.05$). Lastly, analysis revealed significant differences between water quality and macronutrient parameters, except for temperature (°C), D.O. (ppm), and PO_4^{3-} (ppm).

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CHAPTER 1

INTRODUCTION

Global human population recently reached seven billion and is increasing at an exponential rate. As population continues to increase, it is estimated, that the demand for global crop and livestock will double within the next fifty years (Tilman *et al.* 2002). By the year 2050, an estimated global population of 9.4 to 10 billion will reach the earths' carrying capacity (Ehrlich *et a*l. 1993; Harris 2001).

In 2007, approximately 958.8 million tonnes of vegetables and melons were produced globally (FAOSTAT 2011). That same year, capture and aquaculture fish production was estimated at 139.8 million tonnes (FAO 2010). Utilizing these statistics, according to Tilman *et al*. (2002), globally 1.9 billion tonnes of vegetables and melons along with 279.6 million tonnes of capture and aquaculture fish must be produced by 2050 to meet global demands. Correspondingly, these predictions are supported by current production assessments. In 2011, global aquaculture production alone (66 million tons) surpassed global beef production (63 million tons) for the first time in world history (EPI 2013).

Global agricultural production primarily utilizes three natural resources, arable land, water, and fossil fuels. Currently, 85% of current agricultural land is degraded by human-induced erosion, salinization, compaction, nutrient depletion, or pollution. In extreme cases, arable land is lost to desertification at a rate of 12 million hectares per year. Furthermore, 70% of Earth's fresh surface and groundwater is utilized for agricultural purposes (WBCSD and IUCN 2008). Congruently, future agriculture demands will lead to increased forest conversions, natural resource degradation, and environmental pollution as traditional farming cannot sustain the demand for the growing population. Innovating new sustainable agriculture practices will be essential to offset the escalating food crises and environmental degradation in a sustainable manner (Fedoroff *et al.* 2010)

Sustainability is defined as "a method of harvesting or using a resource so that the resource is not depleted or permanently damaged" (Merriam-Webster 2012). When applied to agriculture, producers will be able to maximize net benefits of agricultural production and natural resources, while decreasing human impacts on the environment (Tilman *et al,* 2002). Sustainable agriculture systems are focused on relatively small local farms, which utilize fewer off-farm inputs, combine animal and plant production where appropriate, employ appropriate scaled technologies, convert to renewable forms of energy, and mitigate environmental degradation (Horrigan *et al.* 2002).

Aquaponics

Aquaponics has been considered as a sustainable agriculture system that amalgamates aquaculture and hydroponics in an enclosed symbiotic environment (Nelson 2008). Aquaculture is simply the production of fresh or saltwater aquatic organisms. Hydroponics is the method of cultivating plants with roots submerged in aerated, dilute nutrient solutions (Marr 1994).

Aquaponic systems are usually designed as an enclosed recirculating system, but a few systems can be open, depending upon environmental factors. Fish or other aquatic organisms are reared in tanks and excrete nutrient-rich waste or effluents into the water. Metabolic byproducts excreted by fish, un-ionized ammonia $NH_3 – N$, ionized ammonia NH_4^+ - N, or combined equal Total Ammonia Nitrogen (TAN) are oxidized and broken down into nitrite (NO_2^--N) by nitrifying bacteria of the genera *Nitrosomonas*, *Nitrosococcus*, *Nitrosospira*, *Nitrosolobus*, and

Nitrosovibrio. Genera that oxidize nitrite to nitrate (NO_3^--N) include *Nitrobacter, Nitrococcus*, *Nitrospira*, and *Nitrospina* (Tyson *et al.* 2004; Timmons and Ebeling 2007). These nitrifying bacteria are also known to be light sensitive (Yoshioka and Saijo 1984). Mineralization also occurs, releasing essential inorganic nutrients into the water for plant uptake (Timmons and Ebeling 2007). These dissolved nutrients accumulate and reach concentrations equal to hydroponic nutrient solutions (Timmons and Ebeling 2007). The water is continuously circulated to hydroponically grown crops that absorb non-toxic nutrients from the water to fulfill growth requirements. The water is then circulated back to the rearing tanks where the process starts again.

Aquaculture

One of the most popular studied and developed areas of biology is agriculture. Agriculture is the science, art, and business of crop and livestock production. Without agriculture, the human race would still be dependent on hunter and gatherer practices to fulfill nutritional requirements. Today billions of tonnes of crops and livestock are produced yearly, which feed the greater part of the seven billion people living on earth. One important area of agriculture is the process of aquaculture. The word aquaculture derives from the amalgamation of aqua, Latin for water, and culture, English for cultivation (Merriam-Webster 2013). Aquaculture is the science, art, and business of aquatic organism production. Due to a decreasing supply of wild caught fish species, the demand for fish culture is increasing; thus, making aquaculture the fastest growing sector of agriculture (Timmons and Ebeling 2007). Throughout history, humans have been dependent on aquatic organisms as a major source of nutrition. Today, it has been estimated that over 500 million people in developing countries are directly or indirectly dependent on fisheries and aquaculture. Worldwide, billions of individuals that are not dependent on fisheries or aquaculture do consume some sort of aquatic organism in their diet periodically (FAO 2008).

As early as 6,000 BCE, indigenous Australians developed one of the earliest forms of aquaculture using channels, dams, and traps to catch eels for harvest (Nash 2011). Many indigenous islanders, Hawaiian, Indonesian, etc., also may have independently developed oceanic aquaculture practices by using nets and salt water ponds. Around 2,000 BCE, Chinese societies are thought to have developed the first freshwater aquaculture, raising common carp (*Cypriuns carpio*) with harvestable aquatic plants (Nash 2011). The earliest records of humans utilizing aquaculture date between 1,112 – 221 BCE during the Chou Dynasty. Fish were thought to have been kept in captivity for food, ornament, and status purposes (Nash 2011). The first monograph on the topic of aquaculture was written by Fan Lai entitled "The Classic of Fish Culture" in 475 BCE (Rabanal 1988). In China, aquaculture practices were improved over the span of many dynasties and spread throughout southern Asia and India around 321 – 300 BCE. In Thailand, fish and other aquatic organisms were symbiotically raised together with rice patties for crop and livestock production. Through exploration and trade, aquaculture practices were brought to Europe where bodies of water were utilized for fish culture as well as provisional holding environments (Rabanal 1988). Romans also developed aquaculture practices for oyster production. As trade and migration increased aquaculture practices soon were being utilized throughout the world, eventually reaching North America during the 19th century (Rabanal 1988).

Recirculating aquaculture

Recirculating aquaculture systems (RAS) is a method of aquatic organism production that is gaining popularity throughout the world. These systems which are man-made and typically ran indoors are intensive due to the ability to completely control the environment (air and water temperature, water quality, and pathogens). RAS are usually comprised of four components rearing tanks, settling tanks, clarifier, and biological filter (Swann 2000). These components allow water to be recycled and continuously recirculated through the system. Waste is a concern with all aquaculture systems, but depending on the removal methods RAS tend to produce less volume of waste but at a higher concentration. This concentrated waste can be detrimental to the environment or increase treatment costs if cycled through a municipal sewer system (Timmons and Ebeling 2007).

RAS can be sustainable and have multiple advantages compared to pond, cage, and raceway aquaculture systems (Timmons and Ebeling 2007). Aquatic organisms housed within a RAS cannot escape when ran indoors, or even outdoors when precautionary measures are taken. Recirculating aquaculture systems conserve heat and water by water recirculation and use of biofilters. RAS systems utilize 90 - 99% less water than previously mentioned aquaculture methods. The systems also utilize sustainable waste management which decreases the amount of environmental pollution when properly managed. RAS allow year-round production of consistent quantities of product. Indoor RAS environments are completely controllable by the manager, and have the highest production per unit area and per unit worker compared to previously mentioned aquaculture methods (Timmons and Ebeling 2007).

The exposure to various chemicals and heavy metals must be a concern for organisms in aquaculture based systems (Timmons and Ebeling 2007). With a RAS that is ran indoors, it has the potential to guarantee a 100% safe product. Since RAS's are considered sustainable and environmentally friendly, systems can be developed and managed at almost any location. This allows producers to locate systems near a specified market, thus decreasing the use of natural resources to transport products and increasing shelf life (Timmons and Ebeling 2007).

Hydroponics

The word hydroponics originated in 1937, after its introduction in the magazine *Science* by W.F. Gericke (Jones 2005). The word originates from the amalgamation of two Greek words, hydro and ponos, interpreted as water labor. Today hydroponics is defined in many different ways. The basic definition is the science, method, and technology of cultivating plants with roots submerged in aerated, dilute nutrient solutions with or without an artificial medium (Marr 1994; Jensen 1997). The practice of hydroponics is said to date back to the ancient Hanging Gardens of Babylon around the sixth century BCE. Little evidence has been found which supports said existence of the Hanging Gardens. Until recently, new evidence suggests that the Gardens were constructed by the Assyrian empire in Nineveh, around the seventh century BCE (Dalley 2013). Other ancient practices include the floating gardens of the Aztecs in Mexico. Following, in the 1800's, hydroponic practices were investigated, and finally became popular in the 1930's due to research by Gericke. Applications of hydroponics have been utilized throughout the 20th century including World War II on Pacific islands to feed soldiers, as well as commercial production around the world. Today, applications of hydroponics are utilized for commercial horticulture and floriculture production utilizing well established growing techniques. The most popular growing methods utilized today for hydroponics are nutrient film technique (NFT) and deep water culture (DWC). Brooke (1995) stated that hydroponic growers today can securely grow crops in geographically barren regions including deserts, artic, and even space. Currently, there is little research being conducted in regards to hydroponics as well as fallout of hydroponic societies.

Aquaponic history

In the past decade, aquaponics has increased in popularity (Rakocy *et al.* 2006) and is globally gaining attention as a bio-integrated food production system (Diver 2006). The oldest use of aquaponic culture methods are from the 5th century BCE in China where the symbiotic relationships between ducks, finfish, catfish, and crops were used. Around 1,000 CE Aztecs utilized floating rafts, called chinampas, on lakes for plant production. Recent aquaponics research and development began in the 1970's, and is still being investigated today. The utmost cited research has been conducted at the University of the Virgin Islands by J.E. Rakocy who utilized outdoor methods for Nile tilapia (*Oreochromis niloticus*) and various plant productions. Other key aquaponic researchers include W.A. Lennard from the Department of Biotechnology and Environmental Biology, Royal Melbourne Institute of Technology University, Victoria, Australia, and D.E. Seawright at AmeriCulture Animas, New Mexico.

System design

There are multiple aquaponic system designs that have been analyzed and utilized for crop production. Depending upon the system scale there are five main components to an aquaponic system: rearing tank, solids removal, biofilter, hydroponic subsystem, and sump (Rakocy and Hargreaves 1993). Some systems are able to eliminate one or two of the components - again scale and primary production focus are the key factors determining the system design. Some aquaponic systems are able to efficiently operate with the use of hydroponic subsystems acting as a biofilter. This is possible with the aid of media such as hydroton, pea gravel, and expanded shale (Lewis *et al.* 1978; Sutton and Lewis 1982; Rakocy 1984; Watten and Busch 1984; McMurtry *et al.* 1990). Floating raft hydroponics also known as DWC, which utilize polystyrene sheets and net pots for plant support, may also provide adequate biofiltration provided the hydroponic subsystem is large enough (Rakocy 1995). When utilizing media within hydroponic subsystems, care must be taken to prevent an overload of suspended solids; therefore, media filled subsystems are not ideal for commercial scale production (Timmons and Ebeling 2007).

One of the most important components of an aquaponic system is the hydroponic subsystem: media filled, NFT, and DWC (Lennard and Leonard 2006). A media filled hydroponic subsystem contains a grow bed filled with a soilless medium for plant support. Popular soilless media include hydroton (expanded clay pebbles), gravel, sand, and perlite. The NFT system consists of troughs that expose suspended plant roots (net cup) to a thin film of water. DWC is similar to the media filled subsystem but instead of using media in the hydroponic bed, a floating raft (polystyrene sheets and net cup) supports the plants.

Currently there are two main irrigation methods for hydroponic subsystems, flood and drain (ebb and flow) or continuous flow. An ebb and flow system uses a siphon to periodically drain water when it reaches a specified level. A continuous flow system allows water to constantly run throughout the system (Rakocy *et al.* 2006). Lennard and Leonard (2006) found that hydroponic subsystem design and water flow have a significant effect on Green oak lettuce (*Lactuca sativa*) yield where media>DWC>NFT; NFT systems were 20% less efficient in nitrate removal. Also with their previous research (2004), they found increased lettuce yields with constant flow recirculating systems compared to reciprocating flow systems.

Lastly, producers should realize that differing aquaponic or hydroponic methods (system designs) do not alter the genotypic characteristics of plants (FLM, yield, AGR, etc.). Production will not surpass genetic limitations regardless of growing techniques (Resh 1995). Plants can reach peak production when optimum requirements are met (nutrient assimilation, light, temperature, etc.).

Advantages

This sustainable system is advantageous compared to other agriculture production systems, and has become very popular today (Rakocy et al. 2006). Since aquaponic systems are designed as enclosed recirculating systems, their agricultural waste and environmental footprints decrease, compared to conventional agriculture practices. Furthermore, utilization of plants as a secondary crop reduces the pollution load (waste concentration) through nutrient uptake and assimilation (Timmons and Ebeling 2007). Nitrate accumulation has been shown to be reduced by 97% within aquaponic systems compared to regular recirculating aquaculture systems (RAS) (Lennard 2006). Since water within systems is recirculated, the quantity of water needed to run the system is minute compared to most fish and crop production systems. On average, 98% of the water in aquaponic systems is recycled for the duration of operation (Al-Hafedh *et al.* 2008). The periodical input of water is only necessary when too much water has evaporated from the system. Aquaponic systems decrease the amount of space needed to produce two crops at once. This allows plants and fish to be raised together within a relatively small environment. Aquaponics can range from an in-home counter top system to large scale commercial systems. Additionally aquaponics on average utilizes less than 1% of land compared to conventional agriculture systems. Along with space, aquaponic systems use fewer resources than average crop and fish production systems due to symbiotic relationships (Treadwell *et al.* 2010). For example, aquaponics utilizes 90-99% less water than conventional agriculture systems. Also, carbon dioxide (CO_2) from fish rearing tanks can also be used to increase crop production within an indoor facility (Timmons and Ebeling 2007). Furthermore, aquaponic systems can be deployed in various environments allowing for year round crop production, and potentially a closer farmer-to-consumer interaction. Lastly, successful aquaponic systems utilize secondary crops that are of economic importance or beneficial to the aquatic organisms being produced (Timmons and Ebeling 2007).

Jones (2005) noted various advantages for hydroponic systems as well. These advantages can also be applied to aquaponics and vice versa. First, crops can be produced essentially anywhere, in disregards to soil conditions. Second, labor found in traditional agriculture practices are excluded (tilling, cultivating, etc.). Third, maximum yields are probable. Fourth, soilborne plant diseases are greatly decreased. Lastly, managers have thorough control of the growing environment if ran indoors.

Disadvantages

As with all food production systems, there are a few disadvantages with aquaponic systems. First, the ratio of hydroponic growing area compared to fish rearing surface area is relatively large. Ratios have been used ranging from 1:1 to 10:1, which are dependent upon the scale of the system, primary species of focus, and space. Another disadvantage includes the labor involved with plant management. The majority of aquaculturists do not have horticulture experience or knowledge, so additional personnel is often needed. Furthermore, due to the close relationship between fish and plants within an aquaponic system, poor management practices can easily affect the sensitive system. Pesticides cannot be utilized within systems and thus, biological control or natural methods must be used to eliminate plant pests (Timmons and Ebeling 2007). When entering into a competitive market, aquaponic producers should evaluate competitors and their species of production. It has been stated that hydroponics can produce heads of lettuce cheaper than what aquaponic systems can produce (Ako and Baker 2009).

Lastly, materials utilized for aquaponic production (hydroton, fish feed, etc) are not considered sustainable. For example, hydroton (clay) is mined from the earth, and fish feed may come from wild caught fisheries or commodity crops. These materials utilize nonrenewable resources for production and may also contribute to environmental pollutants.

Hydroponic disadvantages may include high capital costs for construction, incidences of root disease and introduction of soilborne diseases, quick plant reaction to nutrient element insufficiencies (Jones 2005), and anoxic conditions that may impede ion uptake (Wignarajah 1995). Also, hydroponic nutrients are produced with refined minerals that are mined from the earth. Furthermore, ammonia production, utilized in hydroponic nutrients, originates from nonrenewable resources such as natural gas, coal, or petroleum (petroleum naphtha, propane, butane, or petroleum coke) for hydrogen production. The hydrogen is then combined with nitrogen to produce ammonia. These disadvantages can also be applied to aquaponics and vice versa

Species selection

There are wide arrays of plants and aquatic species that can be grown together within an aquaponic system. Some popular fish species include Nile tilapia (*Oreochromis niloticus*), channel catfish *(Ictalurus punctatus)*, rainbow trout *(Oncorhynchus mykiss)*, and various carp species *(Cyprinus* sp.*).* Some popular plants grown in an aquaponic system are various lettuce (*Lactuca* spp.), tomato (*Solanum* spp.), and herb species including sweet basil (*Ocimum basilicum*).

A study conducted in 1978 at Southern Illinois University, Carbondale, showed that aquaponically grown tomatoes had better-quality fruit compared to field grown tomatoes (Lewis et al. 1978). Furthermore, within the aquaponic field, there seems to be a disagreement between the core revenue crops of the industry; whether plants or fish will bring the highest profit. Plant selection, specifically regarding market profits, is essential for system operations; with this in mind culinary herbs, micro-greens, and fruiting crops are the best species for production. The University of the Virgin Island's Commercial Aquaponic System's basil profit for one year was an estimated $110,000, compared to a year of okra production with a profit of $6,400 (Timmons and Ebeling 2007). Additionally, same should be applied to the aquaculture aspect of aquaponics, where species selection will be determined by the market demand. Therefore, when entering into a competitive market, aquaponic/hydroponic producers should evaluate competitors and their species of production.

Water quality

Water quality management is essential to increase fish/plant health and growth. The most essential parameters to measure within a RAS/aquaponic system are nitrogenous waste, pH, alkalinity, dissolved oxygen, temperature, carbon dioxide, and suspended solids (Timmons and Ebeling 2007). Since the parameters influence each other, understanding their interactions can be a daunting task. It is essential to understand their relationships to ensure fish and plant health.

Within a RAS/aquaponic system nitrogenous waste is of concern. Nitrogen is essential for all living organisms, but is needed in small quantities. It is important to be able to rid excess waste from the system whether from nitrification or decomposition. Nitrogen within a system derives from fish waste through gill diffusion, cation exchange, urine, feces, excess food, and dead organisms (Timmons and Ebeling 2007). An excess of nitrogen including ammonia (NH_3 - N, NH_4^+ - N), nitrite (NO_2^- - N), and occasionally nitrate (NO_3^- - N) at certain levels can be detrimental to fish health. The most toxic form of nitrogen to fish is NH_3 - N and NO_2^- - N. Nitrite has the ability to decrease blood hemoglobin's ability to transfer oxygen, which creates methemoglobin and turns the blood brown. This reaction can kill fish within hours. Adequate nitrification is possible with sufficient surface area and or biofilters. NH_3 - N should stay below 0.05 mg/L and TAN below 1.0 mg/L (Timmons and Ebeling 2007).

Another very influential water parameter is pH or the acid or basic composition of water. pH has a strong relationship with all other parameters especially TAN and NO_2^- - N. An increase in pH will in turn cause an increase in the concentration of TAN and NO_2^- - N. The optimum pH range for most aquatic organisms is between 6.5 and 9.0 (Timmons and Ebeling 2007). Swings in pH are also said to have detrimental effects on fish health, although in natural habitats pH can vary from 7.0 to 9.0 in a day, with no effects on aquatic organisms (Boyd 1990). It has also been stated that fish can tolerate pH swings as long as it stays within the optimum range (Brown and Jewell 1926; Wiebe 1931). Multiple bases (buffer) can be added to raise pH which includes sodium bicarbonate, calcium hydroxide, potassium carbonate, and potassium hydroxide. The most popular addition of acid to lower pH includes phosphoric acid, nitric acid, and General Hydroponics pH Down, and white distilled vinegar. There are other forms of acid that have been used but are not recommended including hydrochloric and sulphuric acid (Losordo *et al.* 1998; Lennard and Leonard 2004; Tyson *et al.* 2004; Rakocy 2006; Timmons and Ebeling 2007; Bernstein 2011). Optimum nitrification pH ranges between 7.0 - 9.0 (Haug and McCarty 1972; Chen *et al.* 2006). *Nitrosomanas* ranges from 7.2 - 7.8 (Loveless and Painter 1968; Antoniou *et al.* 1990) and 7.2 – 8.2 for *Nitrobacter*.

Alkalinity is the measure of pH-buffering capacity of water, or total amount of titratable bases such as calcium carbonate ($CaCO_3$) (Timmons and Ebeling 2007). Carbonate (CO_3^-) and bicarbonate (HCO_3^-) are the two main ions that act as the buffer. Alkalinity has a relationship with carbon dioxide and pH. Carbon dioxide should be controlled with degasification with utilization of some sort of air diffuser. This will allow for management of alkalinity and pH more easily. pH should range between 7.0 – 7.4 with an alkalinity concentration between 70 – 190 mg/L as $CaCO_3$. (Timmons and Ebeling 2007). Alkalinity can easily be manipulated with the use of a base sodium bicarbonate (baking soda). A parameter often confused with alkalinity is hardness. Hardness is defined as the ability of water to precipitate soap, or the total concentration of calcium (Ca^{2+}) and magnesium (Mg^{2+}) mg/L comparable to $CaCO_3$. Often in areas where groundwater is exposed to limestone, alkalinity and hardness concentrations possibly could be the same. Ideal ranges for hardness range between 20 – 300 mg/L (Timmons and Ebeling 2007).

Dissolved oxygen (D.O.) is considered the most important water quality parameter in aquaculture. D.O. should be constantly monitored within an aquaponic system. The University of the Virgin Islands commercial system maintains D.O. oxygen levels at a range of 6 to 7 mg/L with air diffusers (Timmons and Ebeling 2007). It has been argued whether or not certain hydroponic subsystem designs provide adequate oxygen levels to plants. Most systems use a flood and drain method in which water is drained from the grow beds pulling oxygen down to the roots. Dissolved oxygen should be maintained at least 5 mg/L for warm water fish growth, health, and feeding (Masser *et al.* 1999). Dr. Lennard analyzed flood and drain systems and continuous flow systems to see if there was a significant difference between the system design and D.O. and its effects on plant production. Lennard (2004) found plant biomass and yield was greater in continuous flow systems when DO is around 7.43 mg/L (Lennard and Leonard 2004).

Since fish are poikilothermic, temperature requirements of aquaponic systems rely heavily upon the species of fish that are utilized within the system and their optimum temperature ranges. Although one should keep in mind the optimum temperature ranges of biofilters, nitrifying bacteria, and plants. Fluctuating temperatures will affect the rate of biochemical reactions. As temperature increases fish are more active and consume more dissolved oxygen, while at the same time producing more carbon dioxide and waste. Once thought to be an important factor for nitrifying bacteria, researchers have found that nitrification has a wide optimum temperature range, as bacteria are well suited to adapt to their environment (7 - 35°C) (Jones and Morita 1985; Okey and Albertson 1989; Wortman and Wheaton 1991; Zhu and Chen 2002; Chen *et al.* 2006; Malone and Pfeiffer 2006).

Carbon dioxide (CO_2) is another important water parameter to constantly monitor. Since carbon dioxide is highly soluble in water fish have a risk of high exposure (Timmons and Ebeling 2007). High carbon dioxide in the water inhibits fishes' ability to excrete carbon dioxide from gills and will increase levels of CO_2 in the blood. The affect will lower the blood plasma pH which will create respiratory acidosis in the fish. High levels of carbon dioxide in the water will decrease the bloods hemoglobin's ability to transfer oxygen throughout an organisms system. Carbon dioxide is unlike other elements as its concentration is determined by a gas-liquid equilibrium, which controls its transfer between air and water (Timmons and Ebeling 2007).

Solids are considered to be classified into three groups, settleable, suspended, and dissolved solids (Timmons and Ebeling 2007). Settleable solids usually take an hour to settle out, and suspended solids need some sort of mechanical/treatment process to collect. Dissolved solids on the other hand are not easily managed or removed. Solids come in the form of waste from fish fecal matter, uneaten fish feed, and dead organisms. Solids should be removed from systems because of carbonaceous oxygen demand, in which biological organisms decrease the amount of dissolved oxygen in the water as they decompose/nitrify waste (Timmons and Ebeling 2007). Dissolved nutrients are measured as Total Dissolved Solids (TDS). For aquaponic systems the recommended TDS levels of 200 to 400 ppm are sufficient. If TDS levels rise about 2,000 ppm then phytotoxicity can become a problem and a water exchange needs to take place (Timmons and Ebeling 2007).

Channel catfish biology

Channel catfish is an omnivorous freshwater fish species in the Family Ictaluridae. Channel catfish originally ranged from the Gulf States, north through the Mississippi Valley to Canada. Today, channel catfish can be found throughout the United States, and have been introduced to all continents except Antarctica (Wellborn 1988). Channel catfish have a cylindrical body, lack scales, and have spines in the dorsal and pectoral fin. An adipose fin is also present between the dorsal and caudal fin. Channel catfish have six barbels that surrounding the mouth (Wellborn 1988), and their upper jaws extend beyond the lower jaw (Pflieger 1997). Channel catfish can be easily distinguished from blue catfish (*Ictalurus furcatus*) by their convex anal fin compared to straight, and are the only spotted (absent in small juveniles and adults) North American catfish with a forked caudal fin (Wellborn 1988). They typically are olive-brown or slate-blue, with black spots, and a silvery-white belly. Ventrally their coloration is silvery-white (Pflieger 1997). Fins usually are yellowish with a black fringe (Pflieger 1997). Coloration has been noted to be dependent upon color of the water, in which the individuals reside (Wellborn 1988). Channel catfish can be identified also by 24-29 anal fin rays (Pflieger 1997). Spawning occurs at nest sites designated by males, which guard the nest until fingerlings hatch.

Catfish importance

Channel catfish are the most popular aquaculture farmed fish in the United States (FAO 2004). Currently, channel catfish rank 7th in U.S. consumption per-capita. They are preceded by Pangasius *(Pangasianodon hypophthalmus)*, commonly known as Swai, ranked 6th, and tilapia ranked 5th (NMFS 2013). Channel catfish are not a popular aquaponic fish species, but past studies suggest that effluents from channel catfish could be a cost effective nutrient application for crops (Kouka and Engle 1996; Lin and Yi 2003).

Basil biology and importance

Basil (*Ocimum*) is an annual herb in the Family Lamiaceae, containing 64 species of basil (Paton *et al*. 2005). Although its origin cannot be traced to a specific location, basil is thought to have originated from either central Africa or Southeast Asia (Simon 1995). Characteristics of basil include a square stem, opposite petiolate or sessile leaves, zygomorphic flowers, no rhizomes, and an aromatic smell as a result of essential oils (Paton *et al*. 2005). The majority of cultivated varieties of basil belong to the species *O. basilicum* (sweet basil) (Simon *et al*. 1999). Historically there have been at least eight popular varieties of *O. bascilicum*; *O. b. crispum*, *O. b. lactucaefolium*, *O. b. purpurascens*, *O. b.* {dark opal}, *O. b. citriodorum*, *O. b.* [from Nigeria], *O. b.* [from Mexico], and *O. b. minimum* (Darrah 1980). Certain varieties have been selectively bred for specific characteristics, most important among them is *O. b.* 'Nufar F1', which is resistant to fusarium wilt caused by *Fusarium oxysporum basilicum*. Fusarium wilt causes stunting, browning, and wilt without defoliation, has become a major issue within the Israeli, European, and U.S. basil industries (Dudai *et al*. 2002).

Basil is considered an important economic and medicinal herb, with greater culinary demands in the U.S. as fresh-cut and dried foods (Simon 1999). Sweet basil is in high demand from specialty produce markets and restauranteurs (Succop and Newman 2004) as well as the aquaponic and hydroponic community.

Hydroponics vs. Aquaponics

Rakocy (2006) stated that nutrient concentrations found within aquaponic systems can reach comparable nutrient concentrations found in hydroponic systems, while Pantanella (2013) stated that hydroponic nutrient solutions are typically ten times higher in nutrient concentrations than aquaponic solutions. Unfortunately for aquaponics, there is not a plant to fish biomass ratio to result in optimum nutrient concentrations for plant assimilation (Seawright *et al*. 1998). Nichols and Savidov (2012) stated that it is important to compare productivity of new technologies (aquaponics) with an already established technology (hydroponics). Currently, there is very little research comparing hydroponic and aquaponic production (Nichols and Savidov 2012). To my knowledge, there are four published studies that have compared aquaponic and hydroponic production, with none of them comparing sweet basil production. Pantanella *et al*. (2012) reported comparable production between aquaponic and hydroponic DWC yields for romaine lettuce (*Lactuca sativa L.* 'Integral'). Nichols and Lennard (2010) also found comparable and even better yields (aquaponic) for multiple lettuce cultivars between aquaponic and hydroponic systems. Both studies, suggest leafy greens have comparable yields in aquaponic and hydroponic systems (Nichols and Savidov 2012). For fruiting crops, Roosta and Afsharipoor (2012) observed significantly higher DWC hydroponic yields than aquaponic DWC for strawberries (*Fragaria sp.*). Also Roosta and Hamidpour (2011) reported higher yields in DWC hydroponic tomato (*Solanum sp.*) production compared to aquaponics DWC.

Study goals and objectives

This study will provide important data pertaining to sweet basil (*Ocimum basilicum L.* 'Nufar F1') production (Fresh leaf mass (FLM), yield (leaf), total vegetative (non-root) biomass (TVB), plant height, and absolute growth rate (AGR), macronutrient dynamics (NH_3, NO_2^--N, NO_3^- - N, PO_4^{3-}, and SO_4^{2-}), water quality (pH, D.O., temperature, E.C., TDS, Alkalinity, and Hardness), and hydroponic subsystem designs (media vs. DWC).

Sweet basil was chosen for this study because of its high demand (Succop and Newman 2004), as well as fast growth rates. Channel catfish (*Ictalurus punctatus*) were reared due to their resilience and popularity within aquaculture. General Hydroponics® Flora Series was utilized due to its popularity within the hydroponic field.

This study consisted of two trials, aquaponic and hydroponic. Six continuous flow recirculating systems were designed and constructed, three (replicates) of which contained media filled hydroponic subsystems (hydroton). The three remaining were DWC. Each trial consisted of two independent variables media and DWC.

Aquaponic trial: Channel catfish and Sweet Basil

<u>Objective 1</u>: Collect macronutrient and water quality data in aquaponic systems containing two hydroponic subsystems utilizing effluents from channel catfish.

<u>Objective 2:</u> Record sweet basil growth in aquaponic systems containing two hydroponic subsystems utilizing effluents from channel catfish.

<u>Objective 3:</u> Record final sweet basil production as well as channel catfish weight gain and specific growth rates (SGR).

Rationale: This treatment will utilize the effluents from channel catfish to supply the nutrient requirements of sweet basil.

Hydroponic trial: General Hydroponics Flora Series and Sweet Basil

Objective 1: Collect macronutrient and water quality data in hydroponic systems containing two hydroponic subsystems utilizing only commercial hydroponic nutrients.

Objective 2: Record sweet basil growth in aquaponic systems containing two hydroponic subsystems utilizing only commercial hydroponic nutrients.

Objective 3: Record final sweet basil production.

Rationale: This treatment will serve as the control for this study, and will utilize commercial hydroponic nutrients to supply the nutrient requirements of sweet basil.

Hypotheses

H_o: There is no significant difference in basil FLM (kg) between aquaponic and hydroponic media filled and DWC hydroponic subsystems.

H_o: There is no significant difference in basil yield (kg/0.6027 m^2) between aquaponic and hydroponic media filled and DWC hydroponic subsystems.

H_o: There is no significant difference in basil TVB (kg) between aquaponic and hydroponic media filled and DWC hydroponic subsystems.

H_o: There is no significant difference in basil height (cm) between aquaponic and hydroponic media filled and DWC hydroponic subsystems.

H_o: There is no significant difference in basil AGR (cm/day) between aquaponic and hydroponic media filled and DWC hydroponic subsystems.

H_o: There is no significant difference in water quality and macronutrient parameters between aquaponic and hydroponic media filled and DWC hydroponic subsystems.

CHAPTER 2

MATERIALS AND METHODS

Systems

Six identical continuous flow (Lennard and Leonard 2004) recirculating systems (Fig 2.1) were designed and constructed, three of which contained media filled hydroponic subsystems. The three remaining were deep water culture (DWC). Each system contained a rearing tank/reservoir, hydroponic subsystem, and biofilters (Fig 2.2). The rearing tank/reservoir entailed, of a green plastic 208.198 L trash can that held ca. 170.344 L of water throughout both trials. The rearing tank/reservoir also contained a submersible pump (560 GPH), 75.708-227.125L double outlet aquarium air pump, airline tubing, air stone, and ca. 5, 1.905 cm PVC piping (ca. 0.914m) as a matrix for fish cover. During the aquaponic trial the rearing tanks were covered with wildlife netting secured with bungee rope.

Each system contained a hydroponic subsystem, consisting of two black plastic 30.48 x 60.96 x 45.72 cm general totes supported by laboratory tables. Hydroponic subsystems during the hydroponic trial contained 2 air stones to prevent stagnant/anoxic conditions (Wignarajah 1995). The three systems that contained media filled hydroponic subsystems were filled with hydroton. The remaining systems, DWC, were constructed out of Dow 1.27 cm extruded polystyrene (Fig 2.3). The floating rafts were coated with water based swimming pool paint (Sherwin Williams) to prevent dissolving by 85% phosphoric acid for pH control. Hydroponic subsystems were plumbed (output) at the same height for consistency (25.4cm), allowing for plants in both hydroponic subsystem designs to reside at the same height. Total water capacity for media filled hydroponic subsystems were 234.69 L and for DWC hydroponic subsystems 310.40 L.

Biofilters comprised of an emergent trickling design (Lennard and Leonard 2006; Timmons and Ebeling 2007), consisted of approximately 18.927 liter translucent plastic water jugs supported by a cinder block. Each biofilter was filled with 0.118 kg of bactitwist, 75 bio balls, 1 liter of ceramic beads, 13 nylon kitchen scrubbies, and ca. 11.356 liters of red lava rock. Between the media and spray bar, two layers of polyester fiber were positioned.

The plumbing for each system was comprised of 1.905 cm PVC pipe, and two ball valves for flow regulation. Water was concurrently pumped from the rearing tank to the biofilter, hydroponic subsystem, and rearing tank (aeration), while all output water returned to the rearing tank via gravity. A spray bar, constructed of the PVC piping, was located above each biofilter (Lennard and Leonard 2006).

Lighting for the systems was supplied by three 600W High Pressure Sodium (HPS) grow lights with ballasts on timers. Grow lights were suspended and centered over the hydroponic subsystem of two systems. Suspension heights of the grow lights (ca. 3000 ft-c) were determined by an Extech Foot candle/Lux meter. Additionally, fans were positioned facing west to east, one for each grow light for plant health.

Orientation of the systems within the lab was randomized. The researcher stood on the east side of the tables and flipped a coin. If heads, a media filled system was positioned on the east side of the table. If tails, a media filled system was positioned on the west side of the table. This process was repeated three times (Fig 2.1).

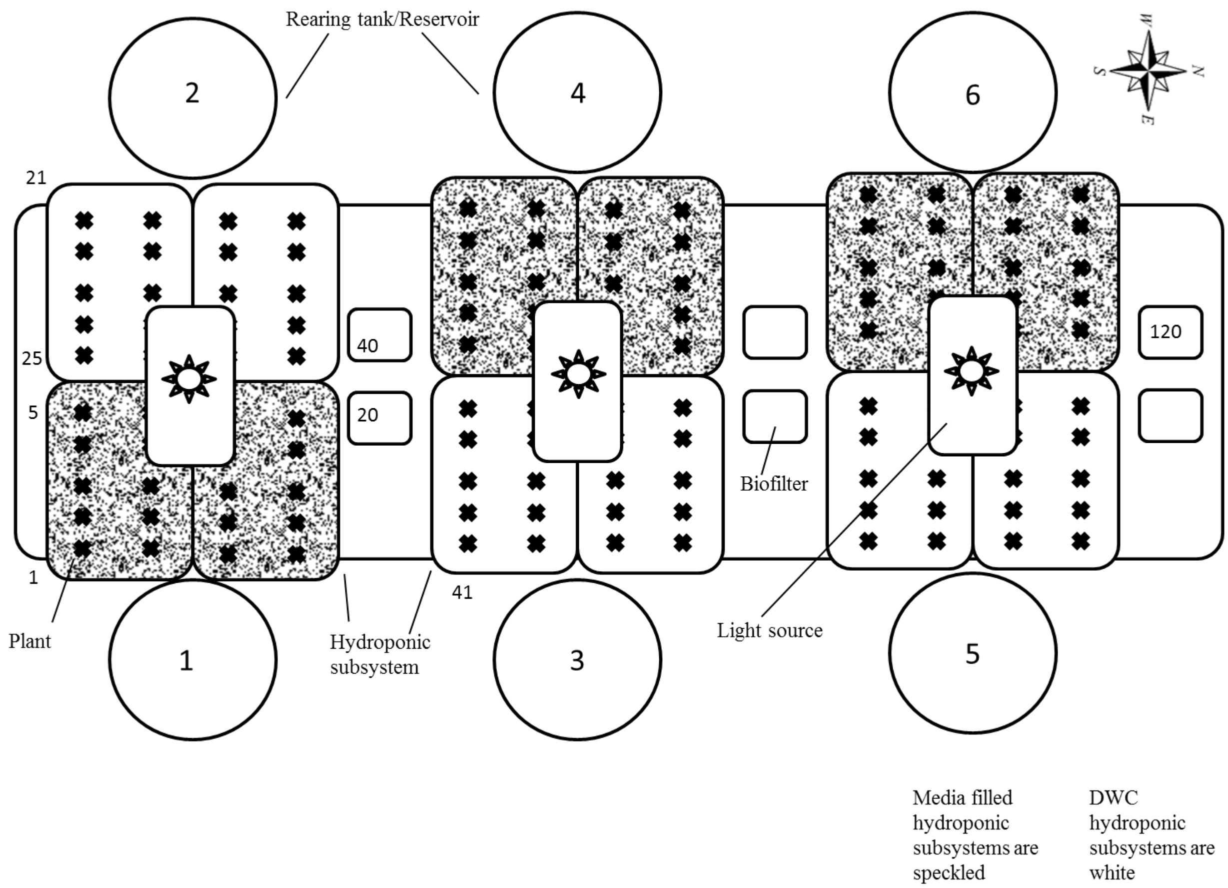

Fig 2.1 Aerial view of system design and orientation, as well as plant schematics

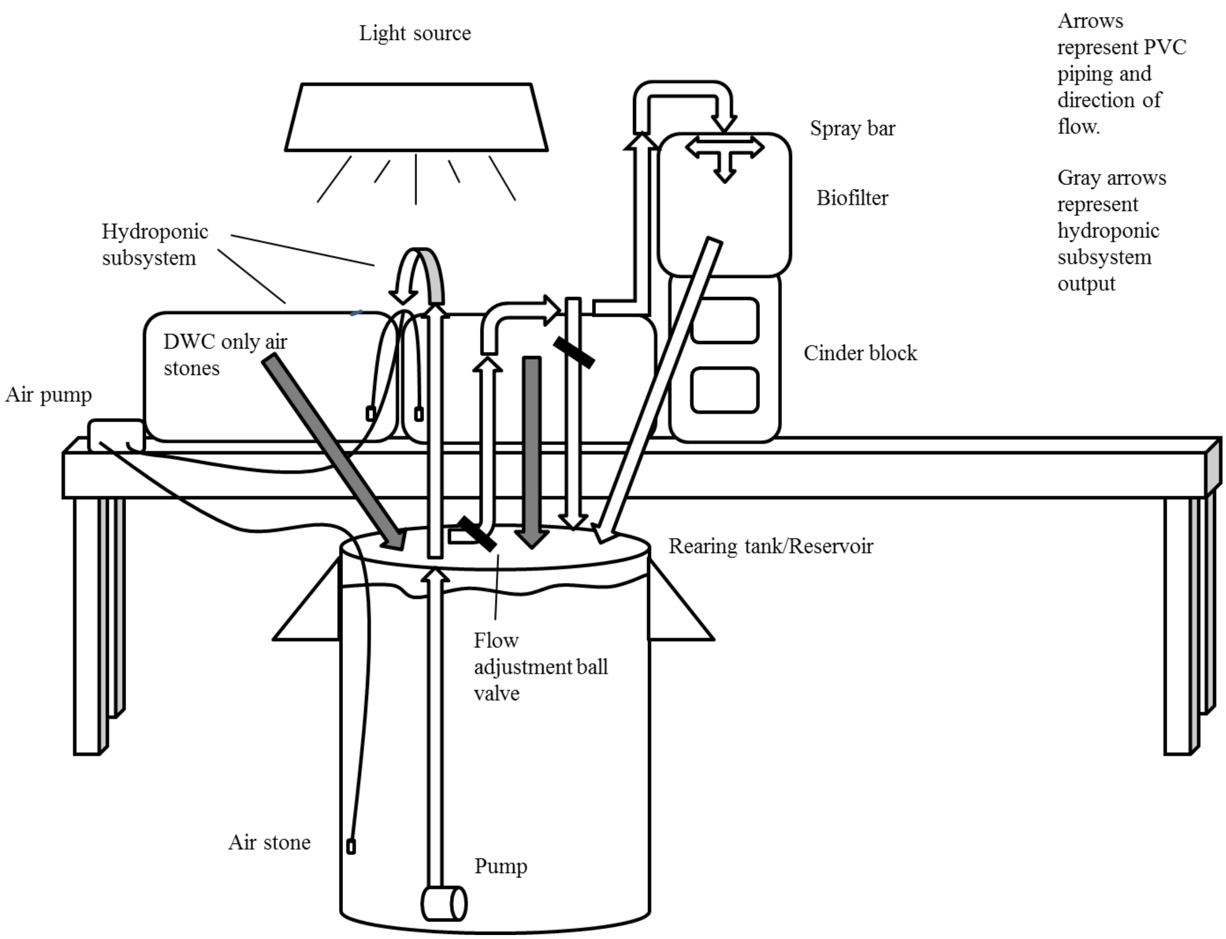

Fig 2.2 Lateral view of one system design

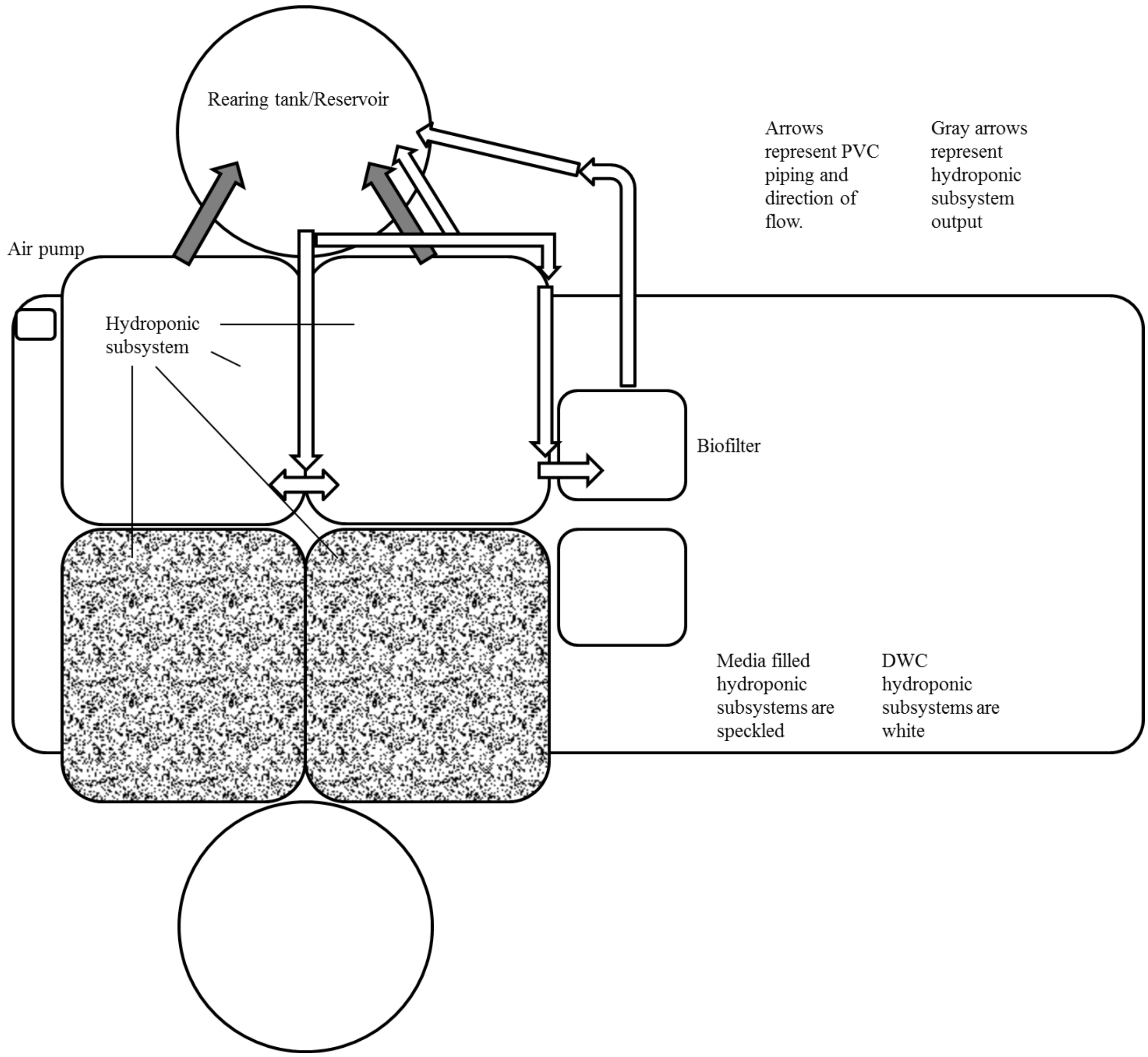

Fig 2.3 Aerial view of one system design

Germination and placement

Seeds were germinated in 5.08 cm net cups filled with a mix of 0.645 kg of Eco Earth coconut coir and 0.215 kg of play sand (75%/25%). For the first trial (aquaponics) seeds were germinated on November 29, 2012, and March 7, 2013 for the second trial (hydroponics). Net cups were lightly misted (spray bottle) with tap water and then covered with black trash bags for ca. eight days. After the eight days, the net cups were misted with tap water every day, or as needed. A 600W High Pressure Sodium (HPS) light was suspended 0.762 meters above the net cups. The light was set on an 8:16 hour light/dark photoperiod until the first set of true leaves appeared. Once appearing, the photoperiod changed to 12:12 hour light/dark. Once plants fully developed their first set of true leaves (barely showing second set of true leaves) they were transplanted into the aquaponic systems. Plants were placed randomly into the systems utilizing a random number generator (1-6 representing systems). Each plant was placed at 12.70 and 17.78 cm from each other, encompassing two rows of 5 plants (20 plants per system).

Fishless cycling

To cycle the systems, biofilter media was inoculated (52 days) with bacteria from six 800L, 1.3m recirculating systems utilized in previous experiments.

Channel catfish

Channel catfish fingerlings (172 individuals), ca. 25.4-30.48cm, were obtained from Chesapeake Fish Hatchery on November 30, 2012 (IACUC protocol: Appendix G). The fish were transferred to the University of Central Missouri and evenly distributed in three 800L, 1.3m recirculating system tanks for a 40 day quarantine period. Channel catfish were fed a 1.5% Food Conversion Ratio (FCR) of 32% floating catfish feed every other day (starting January 8, 2013). Daily water quality was assessed for NH_3/NH_4^+, NO_2^- with an API Freshwater Master Test Kit and pH with Milwaukee pH55 meter. One industrial fan was positioned at the southern part of the systems (pointed north), and blew between the rearing tank/reservoirs to ensure optimum water temperatures. Fish were transported to the aquaponic systems once basil developed their first set of true leaves. After the trial channel catfish were reweighed for wet weight and SGR's.

Aquaponic trial

The first trial (aquaponic) lasted for 40 days, from January 8, 2013 to February 16, 2013. Channel catfish mass was recorded before introduction into the aquaponic rearing tanks and randomly allocated utilizing a random number generator. Average fish mass per tank was 1.089kg (Lennard and Leonard 2006) at an average quantity of 28 fish per system. The grow lights were set on a 16:8 hour light/dark photoperiod for the first 16 days, following they were changed to an 18:6 hour light/dark photoperiod (Skrubis and Markakis 1976).

Water quality samples were recorded every other day for fish health (API Freshwater Master Test Kit) for total ammonia nitrogen NH_3/NH_4^+ (TAN), nitrite NO_2^- , and nitrate NO_3^- . Other parameters included dissolved oxygen (D.O.) (YSI 55 Dissolved Oxygen Meter), electrical conductivity (E.C.) and temperature (AquaPro Digital Water Tester: Conductivity meter HM Digital Inc.), and total dissolved solids (TDS) (Sun Leaves TDS Essential TDS pen). pH was kept between 6.8 – 7.2 (compromise between suggested hydroponic and aquaculture pH (Jones 2005; Timmons and Ebeling 2007) with 85% food grade phosphoric acid. Proper management actions were implicated if certain parameters did not meet specific levels (TAN <3.0 mg/L, pH between 6.8 – 7.2, 25 - 30 °C, NO_2 <1 mg/L, NO_3 <0-400 mg/L, D.O. >5 mg/L (Piper *et al.*

1982; Meade 1985; Tucker and Robinson 1990; Lawson 1995). Furthermore, room temperature, room humidity, minimum and maximum temperatures per two systems were collected.

Every eight days, three water samples were collected from each rearing tank (1000mL wide mouth sample bottle). Bottles were completely submerged in the rearing tank and poured out three times before the final sample was collected. Parameters analyzed include hardness and alkalinity (titration), and ammonia (NH_3), NO_2^- -N, NO_3^- - N, orthophosphate (PO_4^{3-}), and sulfate SO_4^{2-} utilizing VacuVial test kits and a Spectrophotometer 20D$^+$. If parameter assessments could not be completed following sampling, then samples were refrigerated and analyzed at a later date. Additionally, basil growth for each plant (height in cm) was measured and recorded from the base of the stem where it met the potting medium (coconut coir) to the apical meristem utilizing a cloth measuring tape. After sampling was complete, the two layers of polyester fiber in the biofilters were replaced. Afterward, API Stress Zyme Plus Biological Filtration Booster was added to each system for system health. Media filled systems received 60 ml and DWC systems received 80ml. Lastly, Maxicrop® Liquid Seaweed Plus Iron was added to the systems due to signs of chlorosis. During the first sample date a diluted (29.573g/3.785L water) 768.911g were sprayed evenly across the plants. For following sample dates, 10ml of the concentrate liquid was added to each hydroponic subsystem (Rakocy *et al*. 2006; Roosta and Hamidpour 2011).

After either sampling every other day or every eight days, water was replenished (due to evapotranspiration) to the ca. 170.344L mark from two aerated holding reservoirs for chlorine and CO_2 release. pH was treated within the holding reservoirs, and on rare occasions within the rearing tank themselves.

After the trial (February 17, 2013), each individual plant was harvested with a pair of gardening scissors or knife (stem meeting potting medium). Each individual plant was weighed (wet weight) to the nearest 0.001 kg for total vegetative (non-root) biomass (TVB) and fresh leaf mass (FLM), respectively. First, plants were weighed on a scale (TVB), and then leaves and petioles were plucked from the stem and reweighed (FLM). For height, plants were measured to the nearest 0.1 cm from the base of the stem to the upmost apical meristem/bud using a cloth measuring tape. Also, harvest and measurement times were recorded for each plant.

In preparation for the hydroponic trial, aquaponic systems were drained, rinsed with a high pressure hose, and filled. Hydroton was removed from the systems and treated in larger holding tanks. Any macro organic matter was removed if possible. Systems and hydroton, were exposed to a 3% hydrogen peroxide (H_2O_2) solution for at least 6 hours. 15 ml of H_2O_2 was added for every 3.78L of water. Systems were then thoroughly rinsed again and filled for the hydroponics trial.

Hydroponic trial

The second trial (hydroponics) lasted for 40 days, from April 10, 2013 to May 19, 2013. A hydroponic nutrient feeding regime was based off of General Hydroponics® Recirculating Expert Feeding Schedule (General Hydroponics® 2013) (Appendix B). Due to suggested reservoir water changes (every 7 days) the feeding schedule was modified to help conserve water (Appendix B). Flora series nutrients were added to the reservoir according to General Hydroponics®; Flora Micro was added first, followed by Flora Gro, and Flora Bloom. The same management, operations, and data collection was engaged during the second trial as the first, except for fish related management/operations including feeding, Stress Zyme Plus addition, polyester fiber change (no solid waste), API assessments, and Maxicrop® Liquid Seaweed Plus Iron (Macro and Micronutrients within Flora Series).

Sweet basil harvest (May 20, 2013) methods were identical to the aquaponic trial.

Analysis

All data was entered and organized within Microsoft Excel 2013 and was analyzed with SigmaPlot 12.5. Mann-Whitney Rank Sum Test ($p>0.05$), non-parametric analysis was utilized for channel catfish weight. For catfish SGR, Two-tailed T-test ($p>0.05$), parametric analysis was utilized. Separate trial (aquaponic and hydroponic) hydroponic subsystem designs were analyzed using Mann- Whitney Rank Sum Test ($p>0.05$), non-parametric analysis. Overall combined hydroponic subsystem designs were analyzed utilizing Mann- Whitney Rank Sum Test ($p=<0.001$), non-parametric analysis. For replicate hydroponic subsystems, Kruskal-Wallis One Way Analysis of Variance on Ranks ($p>0.05$), non-parametric analysis was utilized. Nitrate was analyzed utilizing Mann-Whitney Rank Sum Test ($p>0.05$) and hardness was analyzed utilizing Two Tailed T-test, $p>0.05$). Lastly, all other parameters were analyzed using Kruskal- Wallis One Way Analysis of Variance on Ranks and all pairwise multiple comparison post hoc procedures (Tukey Test or Holm-Sidak method) where suitable ($p>0.05$).

CHAPTER 3

RESULTS

Aquaponic trial

a. Fish

During the aquaponic trial, channel catfish had a 100% survival rate. There was no significant difference between channel catfish wet weights in media filled and DWC hydroponic subsystems (Mann-Whitney Rank Sum Test, $n_1 = n_2 = 3$, $p>0.05$). Mean fish wet weight ($\overline{x} \pm$SE) for media filled hydroponic subsystems was 1.095$\pm$0.00437 kg and for DWC hydroponic subsystems was 1.084$\pm$0.0219 kg (Fig 2.4).

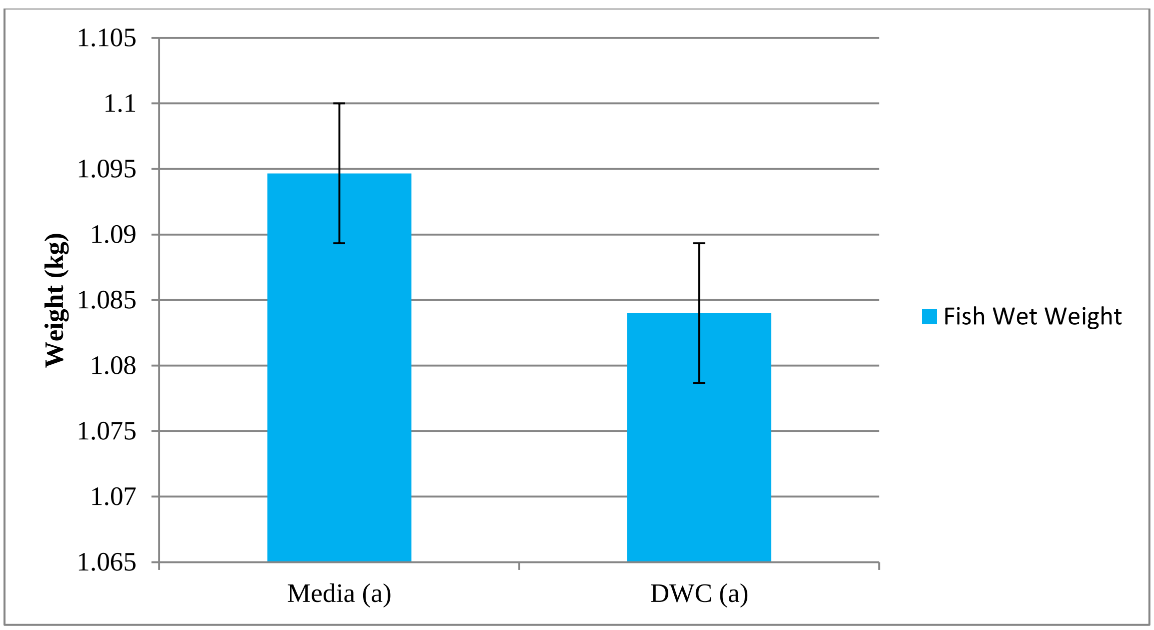

Fig 2.4 Mean ($\overline{x} \pm$SE) channel catfish weight (kg) for media filled and DWC aquaponic systems. a and b: treatments showing the same letter are not significantly different ($p>0.05$).

There was no significant difference between channel catfish specific growth rate (SGR) in media filled and DWC hydroponic subsystems (Two-tailed T-test, $n_1 = n_2 = 3$, df = 4, p>0.05). Mean fish SGR ($\overline{x}$ ±SE) for media filled hydroponic subsystems was 1.125±0.0419 kg and for DWC hydroponic subsystems was 1.073±0.0347 kg (Fig 2.5).

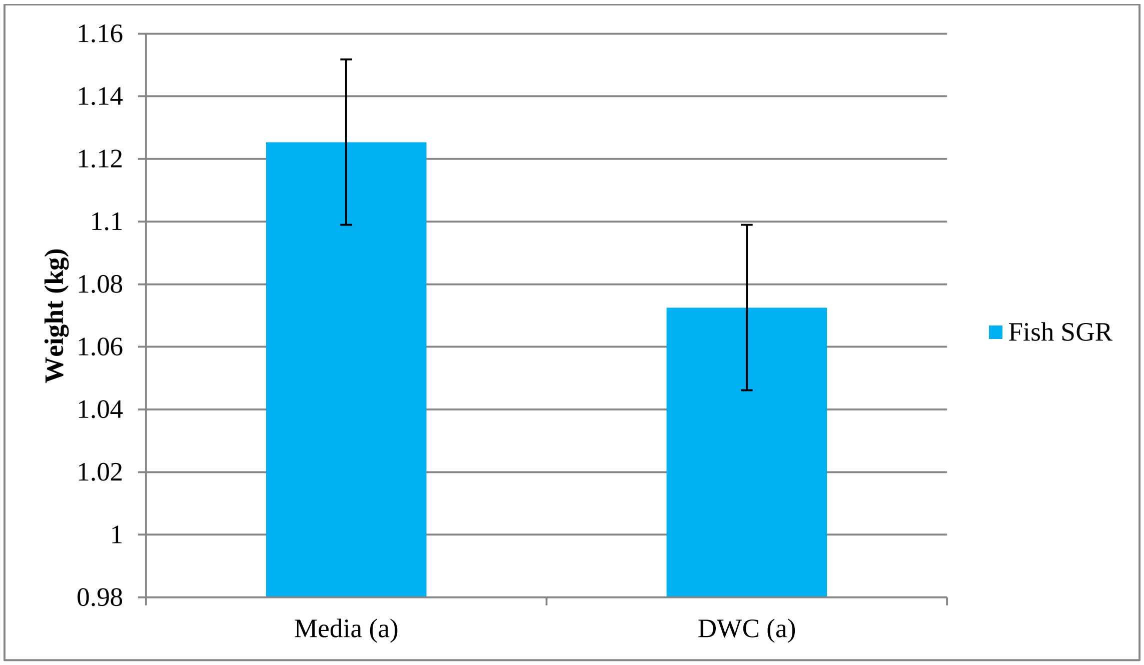

Fig 2.5 Mean ($\overline{x}$ ±SE) channel catfish SGR (kg) for media filled and DWC aquaponic systems. a and b: treatments showing the same letter are not significantly different (p>0.05).

b. Fresh leaf mass (FLS)

There was no significant difference in basil FLM (kg) between aquaponic media filled and DWC hydroponic subsystems (Mann- Whitney Rank Sum Test, $n_1 = n_2 = 60$, p>0.05). Mean ($\overline{x}$ ±SE) FLM (kg) for aquaponic media filled hydroponic subsystems was 0.0533±0.00388 kg, and for aquaponic DWC hydroponic subsystems was 0.0640±0.00523 kg (Fig 2.6).

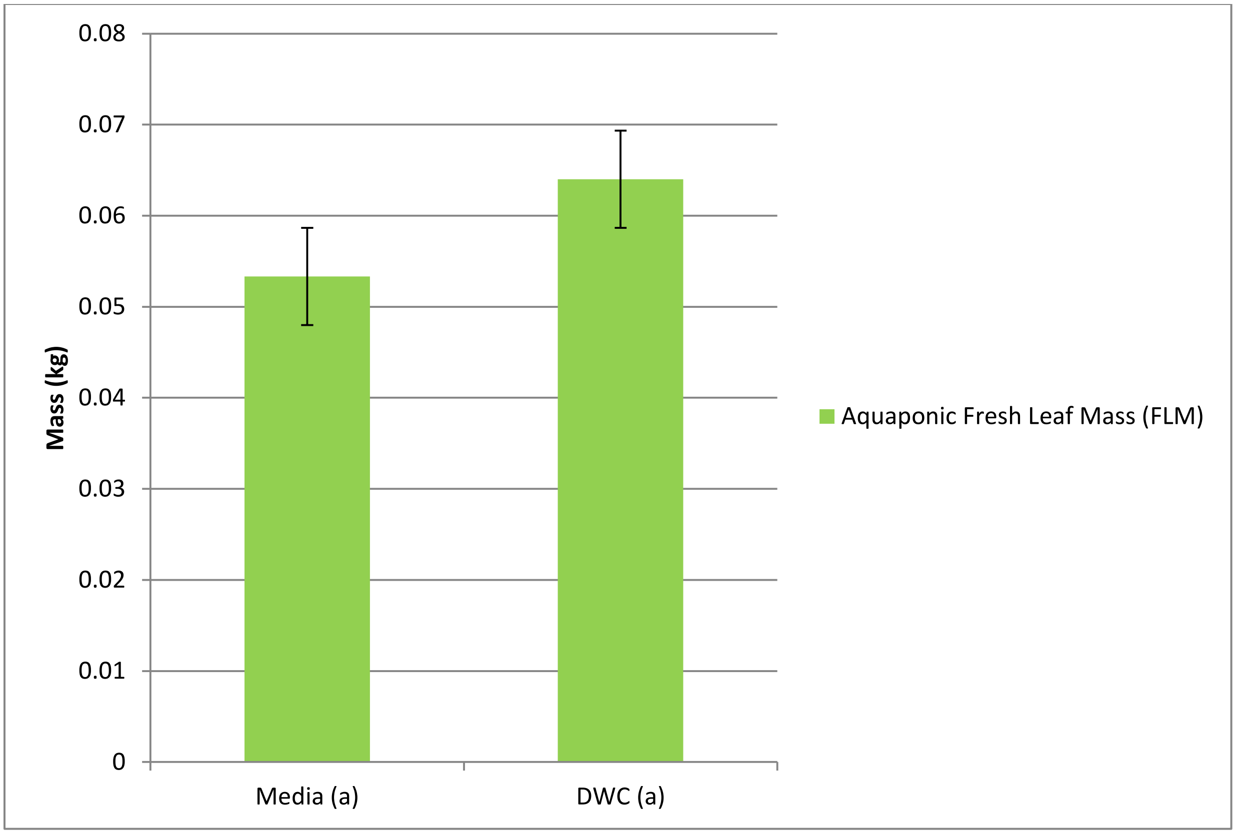

Fig 2.6 Mean ($\overline{x}$ $\pm$SE) aquaponic basil FLM (kg) for media filled and DWC hydroponic subsystems. a and b: treatments showing the same letter are not significantly different ($p>0.05$).

c. Yield (leaf)

Yield is equal to fresh leaf mass (kg) divided by 0.6027 m^2. Results for basil yield are statistically equivalent to fresh leaf mass (Fig 2.7).

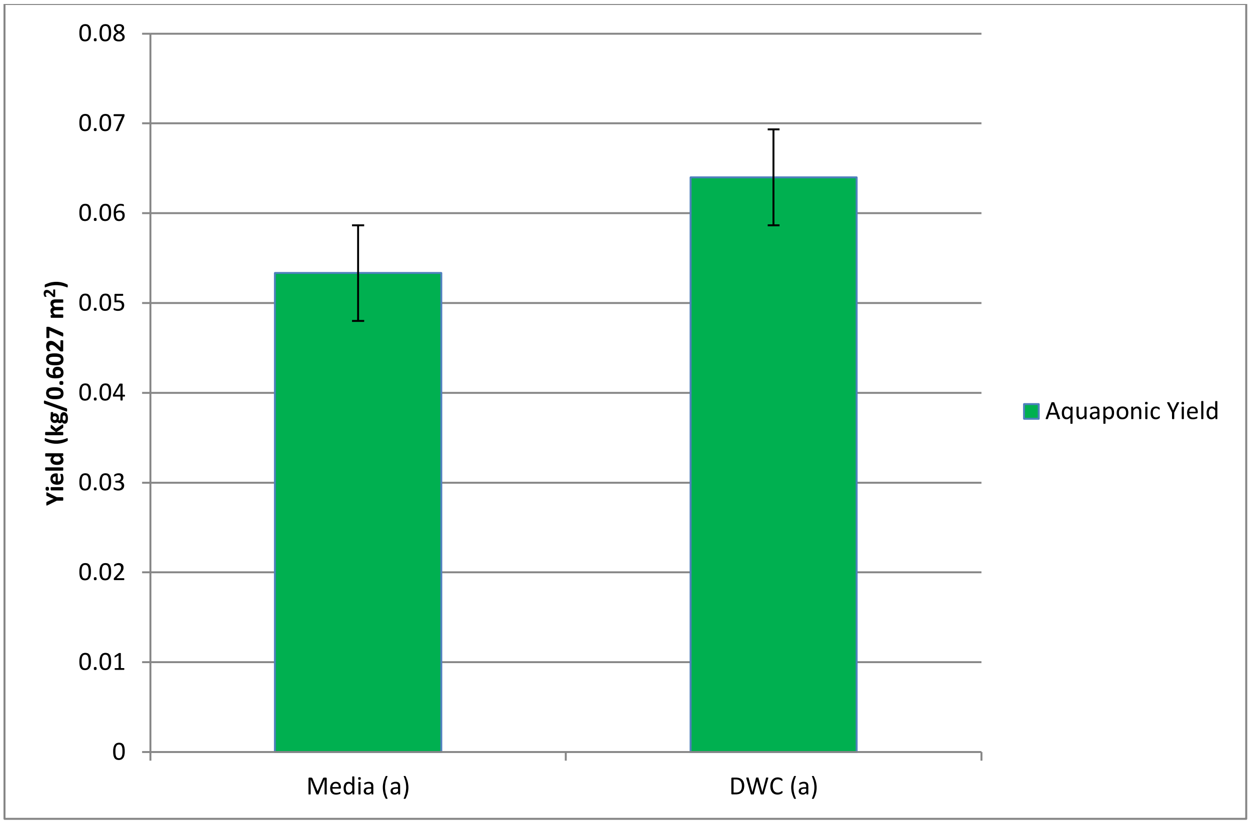

Fig 2.7 Mean ($\bar{x}$ ±SE) aquaponic basil yield (kg/0.6027 m^2) for media filled and DWC hydroponic subsystems. a and b: treatments showing the same letter are not significantly different ($p>0.05$).

d. Total vegetative (non-root) biomass (TVB)

There was no significant difference in basil TVB (kg) between aquaponic media filled and DWC hydroponic subsystems (Mann- Whitney Rank Sum Test, $n_1 = n_2 = 60$, $p>0.05$). Mean ($\bar{x}$ ±SE) TVB (kg) for aquaponic media filled hydroponic subsystems was 0.0897±0.00678 kg, and for aquaponic DWC hydroponic subsystems was 0.102±0.00865 kg (Fig 2.8).

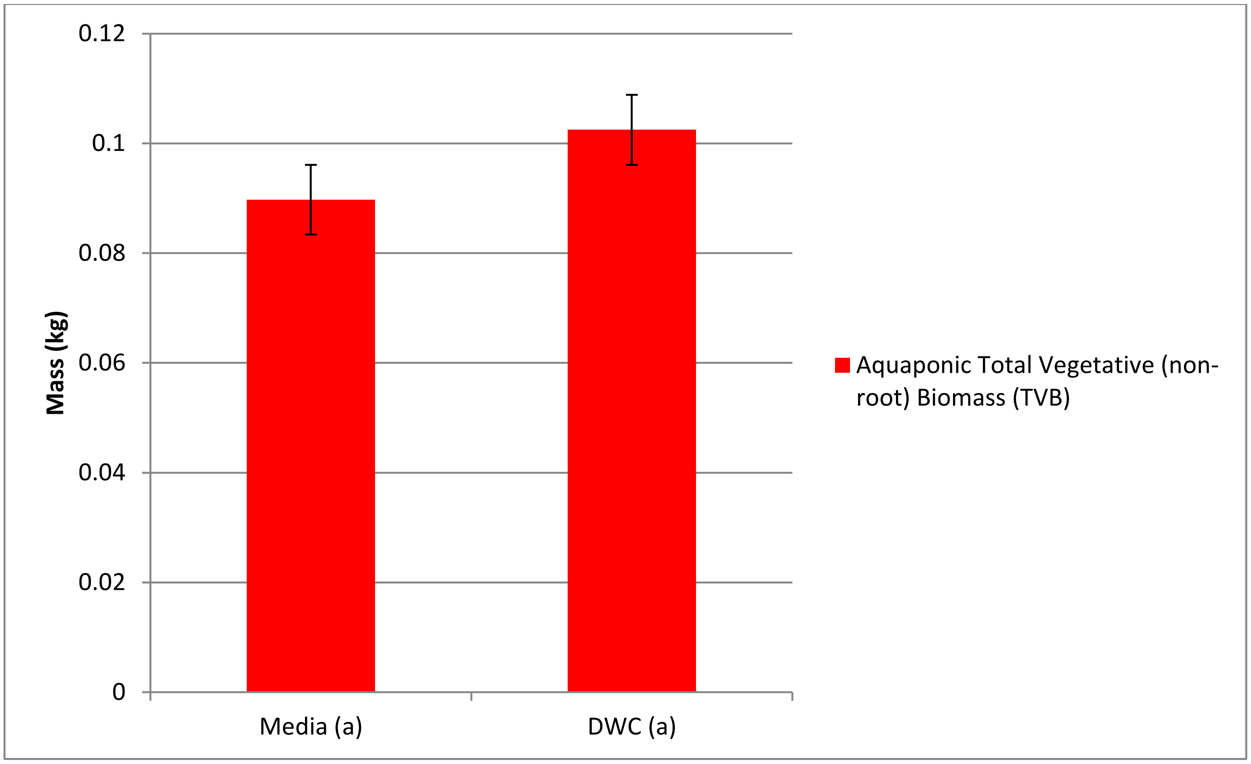

Fig 2.8 Mean ($\bar{x}$ $\pm$SE) aquaponic basil TVB (kg) for media filled and DWC hydroponic subsystems. a and b: treatments showing the same letter are not significantly different ($p>0.05$).

e. Height

There was no significant difference in basil plant height (cm) between aquaponic media filled and DWC hydroponic subsystems (Mann- Whitney Rank Sum Test, $n_1 = n_2 = 60$, $p>0.05$). Mean ($\bar{x}$ $\pm$SE) plant height (cm) for aquaponic media filled hydroponic subsystems was 42.3$\pm$1.22 cm, and for aquaponic DWC hydroponic subsystems was 41.2$\pm$1.05 cm (Fig 2.9).

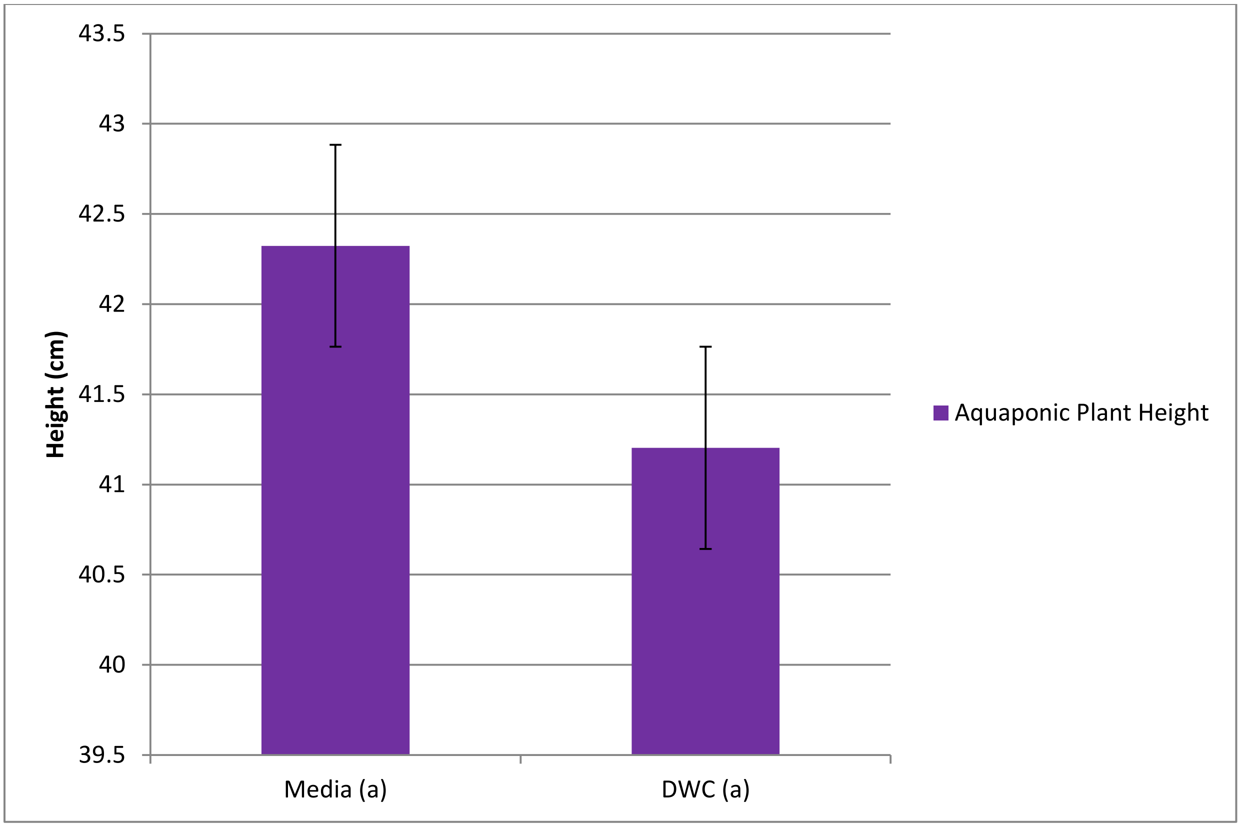

Fig 2.9 Mean ($\bar{x}$ ±SE) aquaponic basil height (cm) for media filled and DWC hydroponic subsystems. a and b: treatments showing the same letter are not significantly different (p>0.05).

f. Absolute growth rate (AGR)

There was no significant difference in basil AGR (cm/day) between aquaponic media filled and DWC hydroponic subsystems (Mann- Whitney Rank Sum Test, $n_1 = n_2 = 60$, p>0.05). Mean ($\bar{x}$ ±SE) AGR (cm/day) for aquaponic media filled hydroponic subsystems was 1.20±0.0349 cm/day, and for aquaponic DWC hydroponic subsystems was 1.16±0.0287 cm/day (Fig 2.10).

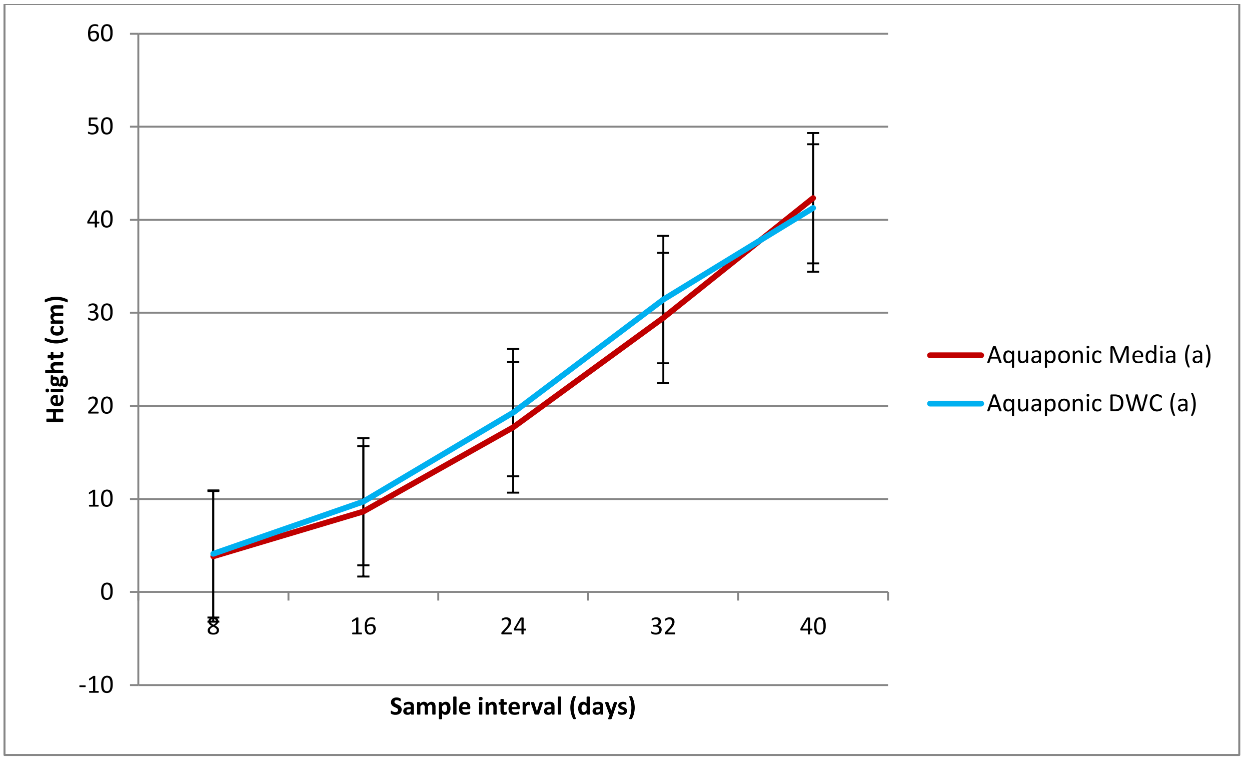

Fig 2.10 Mean ($\bar{x}$ ±SE) aquaponic basil AGR (cm/day) for media filled and DWC hydroponic subsystems. a and b: treatments showing the same letter are not significantly different ($p>0.05$).

g. Physical, water quality, and macronutrient parameters

Mean ($\bar{x}$ ±SE) water addition (L) for the 40 day aquaponic trial was 29.6±6.3 L. Mean ($\bar{x}$ ±SE) water quality and macronutrient parameters can be found in Table 1.2.

Table 1.1 Mean water quality parameters sampled five times (15-Jan, 23-Jan, 31-Jan, 8-Feb, and 16-Feb) during the aquaponic trial

Parameter	Aquaponic Media	Aquaponic DWC
pH[1]	7.0±0.079	7.2±0.12
TDS[1] (ppm)	659±40.6	523±25.1
E.C.[1] (µS)	1319±62.18	1078±46.50
D.O.[1] (ppm)	8.24±0.134	8.34±0.118
Temperature[1] (°C)	20.7±0.529	20.9±0.526
NH_3[1] (ppm)	2.14±0.166	6.95±0.45
NO_3—N[1] (ppm)	11.0±0.578	2.78±0.0839
NO_2—N[1] (ppm)	0.501±0.22	0.513±0.2
PO_4^{3-} [1](ppm)	260.82±29.619	322.07±28.006
SO_4^{2-} [1](ppm)	88.63±6.037	35.54±3.518
Hardness[1] $CaCO_3$ (ppm)	363.43±25.306	282.183±19.702
Alkalinity[1] $CaCO_3$ (ppm)	45.78±3.212	66.01±4.864

[1]Values are means ± SE

-: indicates error during analysis

Hydroponic trial

a. Fresh leaf mass (FLM)

There was no significant difference in basil FLM (kg) between hydroponic media filled and DWC hydroponic subsystems (Mann- Whitney Rank Sum Test, $n_1 = n_2 = 60$, $p>0.05$). Mean ($\bar{x}$ ±SE) FLM (kg) for hydroponic media filled hydroponic subsystems was 0.0940±0.00758 kg, and for hydroponic DWC hydroponic subsystems was 0.0848±0.00717 kg (Fig 2.11).

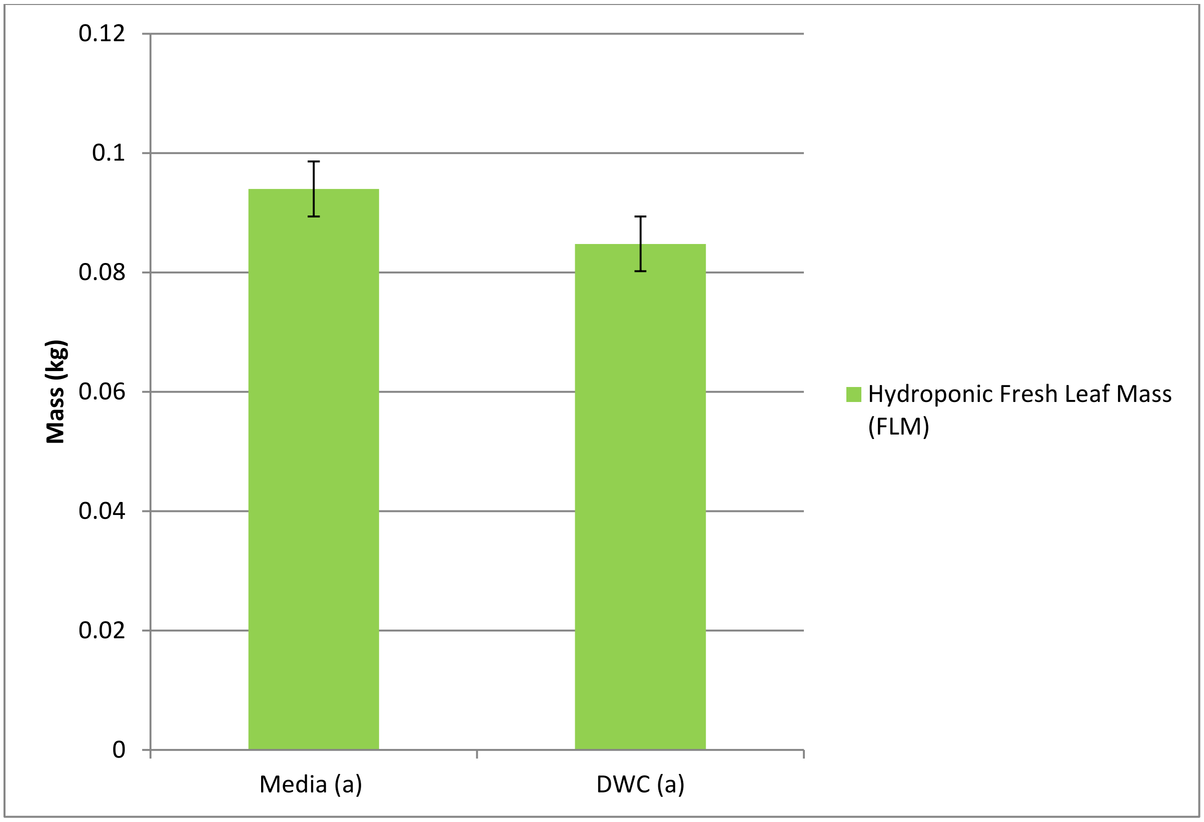

Fig 2.11 Mean ($\bar{x}$ $\pm$SE) hydroponic basil FLM (kg) for media filled and DWC hydroponic subsystems. a and b: treatments showing the same letter are not significantly different (p>0.05).

b. Yield (leaf)

Yield is equal to fresh leaf mass (kg) divided by 0.6027 m^2. Results for basil yield are statistically equivalent to fresh leaf mass (Fig 2.12).

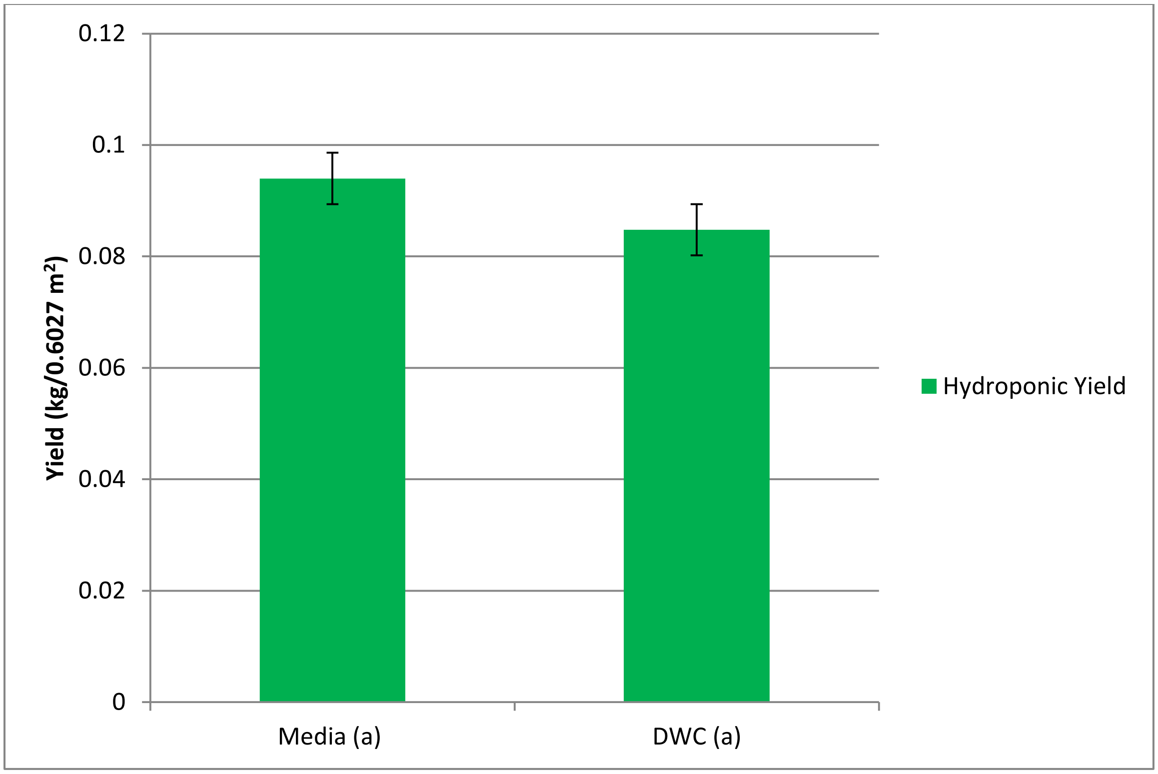

Fig 2.12 Mean ($\overline{x}$ $\pm$SE) hydroponic basil yield (kg/0.6027 m^2) for media filled and DWC hydroponic subsystems. a and b: treatments showing the same letter are not significantly different ($p>0.05$).

c. Total vegetative (non-root) biomass (TVB)

There was no significant difference in basil TVB (kg) between hydroponic media filled and DWC hydroponic subsystems (Mann- Whitney Rank Sum Test, $n_1 = n_2 = 60$, $p>0.05$). Mean ($\overline{x}$ $\pm$SE) TVB (kg) for hydroponic media filled hydroponic subsystems was 0.166$\pm$0.0139 kg, and for hydroponic DWC hydroponic subsystems was 0.148$\pm$0.0134 kg (Fig 2.13).

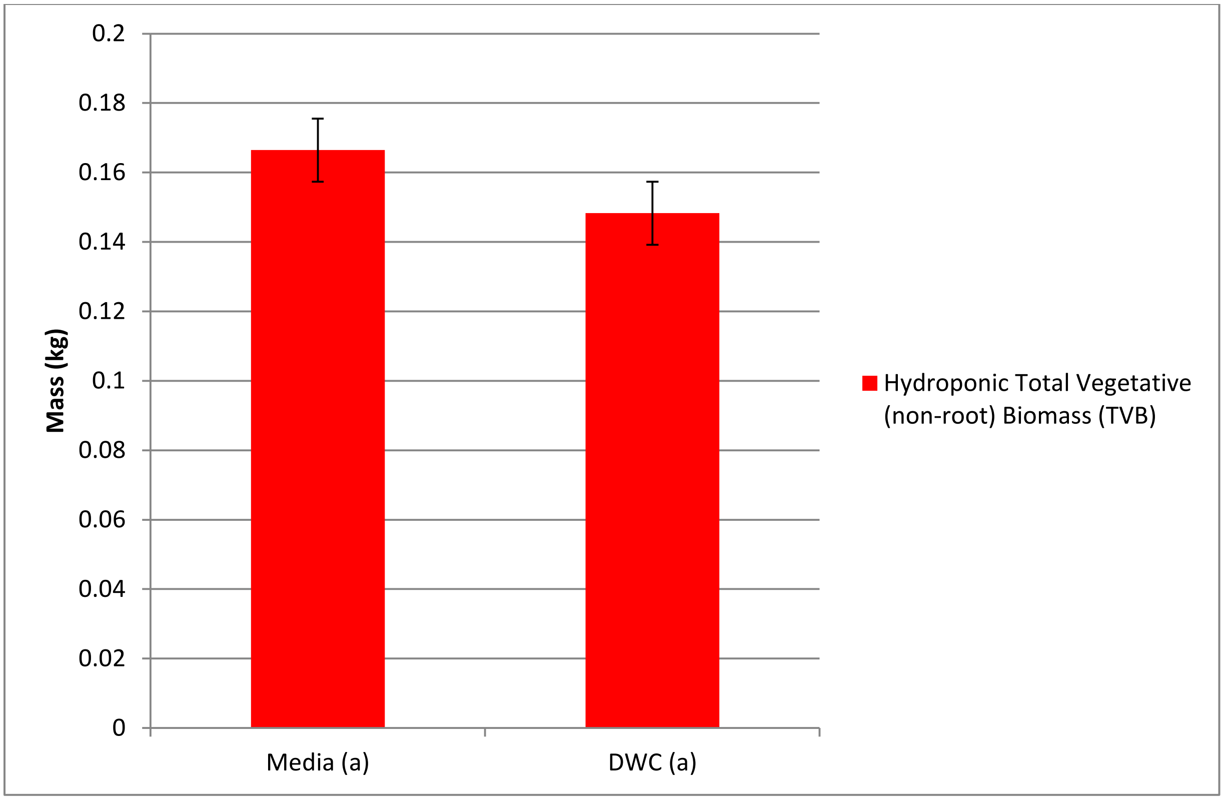

Fig 2.13 Mean ($\bar{x}$ ±SE) hydroponic basil TVB (kg) for media filled and DWC hydroponic subsystems. a and b: treatments showing the same letter are not significantly different ($p>0.05$).

d. Height

There was a significant difference in basil plant height (cm) between hydroponic media filled and DWC hydroponic subsystems (Mann- Whitney Rank Sum Test, $n_1 = n_2 = 60$, $p<0.05$). Mean ($\bar{x}$ ±SE) plant height (cm) for hydroponic media filled hydroponic subsystems was 59.9±1.33 cm, and for hydroponic DWC hydroponic subsystems was 53.3±2.02 cm (Fig 2.14).

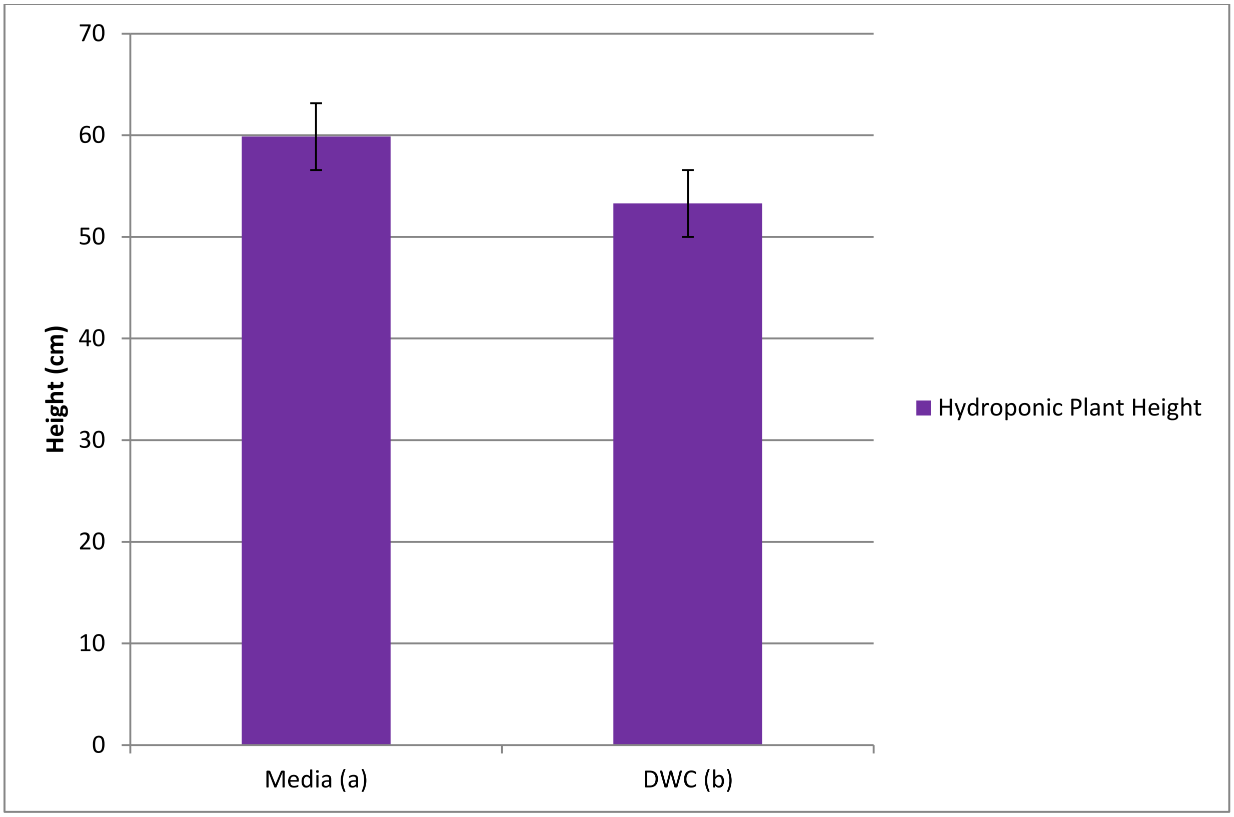

Fig 2.14 Mean ($\bar{x}$ ±SE) hydroponic basil height (cm) for media filled and DWC hydroponic subsystems. a and b: treatments showing the same letter are not significantly different ($p>0.05$).

e. Absolute growth rate (AGR)

There was a significant difference in basil AGR (cm/day) between hydroponic media filled and DWC hydroponic subsystems (Mann- Whitney Rank Sum Test, $n_1 = n_2 = 60$, $p<0.05$). Mean ($\bar{x}$ ±SE) AGR (cm/day) for hydroponic media filled hydroponic subsystems was 1.67±0.0404 cm/day, and for hydroponic DWC hydroponic subsystems was 1.50±0.059 cm/day (Fig 2.15).

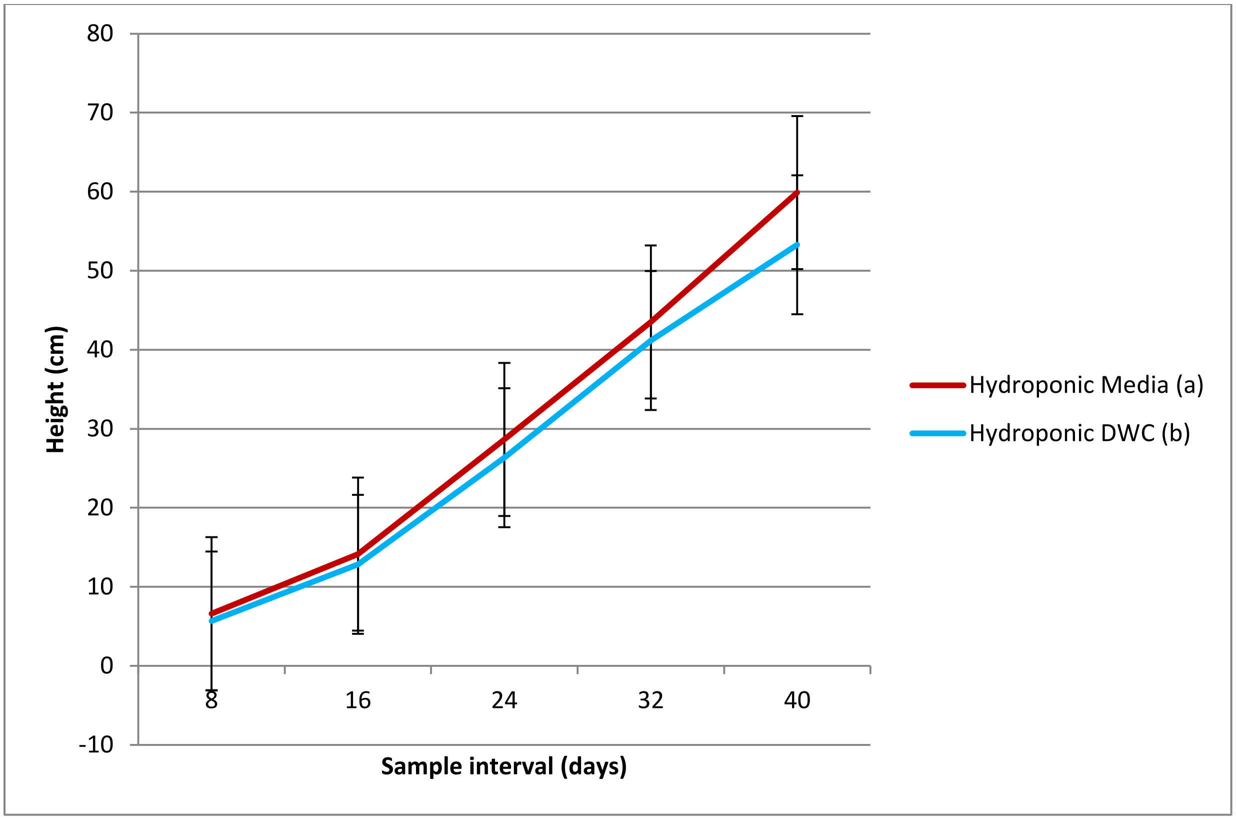

Fig 2.15 Mean ($\overline{x}$ ±SE) hydroponic basil AGR (cm/day) for media filled and hydroponic subsystems. a and b: treatments showing the same letter are not significantly different (p>0.05).

f. Physical, water quality, and macronutrient parameters

Mean ($\overline{x}$ ±SE) water addition (L) for the 40 day hydroponic trial was 22.9±8.3 L. Mean ($\overline{x}$ ±SE) water quality and macronutrient parameters can be found in Table 1.4.

Table 1.4 Mean water quality parameters sampled five times (17-Apr, 25-Apr, 3-May, 11-May, and 19-May) during the hydroponic trial

Parameter	Hydroponic Media	Hydroponic DWC
pH[1]	6.7±0.066	6.8±0.11
TDS[1] (ppm)	1084±105.7	1265±161.2
E.C.[1] (µS)	2138±235.6	2348±293
D.O.[1] (ppm)	7.77±0.114	7.76±0.119
Temperature[1] (°C)	22.7±0.76	22.8±0.754
NH_3[1] (ppm)	4.84±1.18	19.8±3.66
NO_3—N[1] (ppm)	-	-
NO_2—N[1] (ppm)	0.0347±0.0048	0.112±0.0447
PO_4^{3-} [1](ppm)	273.02±74.357	370.87±78.971
SO_4^{2-} [1](ppm)	205.11±27.837	200.26±46.94
Hardness[1] $CaCO_3$ (ppm)	-	-
Alkalinity[1] $CaCO_3$ (ppm)	213.78±20.952	240.11±22.819

[1]Values are means ± SE

-: indicates error during analysis

CHAPTER 4

DISCUSSION

As demand for sustainability increases, research in regards to sustainable agriculture practices need to be conducted. Comparisons of well-established food production practices (hydroponics) to relatively new production practices (aquaponics) need to be examined. Thus, leading to the question, is there a significant difference between sweet basil production between aquaponic and hydroponic media filled and DWC hydroponic subsystems, as well as water quality and macronutrient parameters?

a. Fish

During the aquaponic trial there was a 0% mortality rate in channel catfish, as well as no significant difference in fish wet weights (kg) between replicates and hydroponic subsystems. Also, there was no significant difference in SGR for the catfish. Water quality parameters were targeted at recommended levels, but water changes were necessary for fish health and safety. Unfortunately, water changes will remove essential nutrients for plant growth in aquaponics. Also during the aquaponic trial catfish were feed every two days, instead of feeding once or multiple times a day. This procedure was instilled due to the relatively small and new systems; thus, decreasing chances of overloading biofilters with nutrients. This is not indicative of large or commercial aquaponic systems, unless plants are the focus crops.

b. Fresh Leaf Mass (FLM)/Yield

During the aquaponic trial for FLM (kg) analysis revealed that there was no significant difference between aquaponic media filled and DWC hydroponic subsystems (Fig 2.16). These results are dissimilar to Lennard and Leonard (2006) where media>DWC>NFT for lettuce yields. The difference between the results may be due to differences between fish and plant species utilized during the studies. Also, during the hydroponic trial for FLM, analysis indicates there is no significant difference between hydroponic media filled and DWC hydroponic subsystems. This attests to the popular methods utilized today in the hydroponic industry which are NFT and DWC for lettuce and herb production. Media substrate typically is expensive compared to DWC, and is more difficult to manage. When comparing hydroponic media filled hydroponic subsystems to both aquaponic system designs, hydroponic media was significantly different. This reinforces the idea that hydroponics has higher nutrient solutions (Pantanella 2013) which more adequately supports plant nutrient requirements. Additionally, there was no significant difference between hydroponic DWC and aquaponic DWC, which supports Pantanella *et al*. (2012) results for leafy greens. Additionally, these results are dissimilar from Nichols and Lennard (2010), Roosta and Afsharipoor (2012), and Roosta & Hamidpour (2011); as their studies utilized leafy greens as well as fruiting crops. Lastly, hydroponic DWC was significantly different than aquaponic media which, again, could have been a result to high nutrient concentrations (Pantanella 2013) (Fig 2.16).

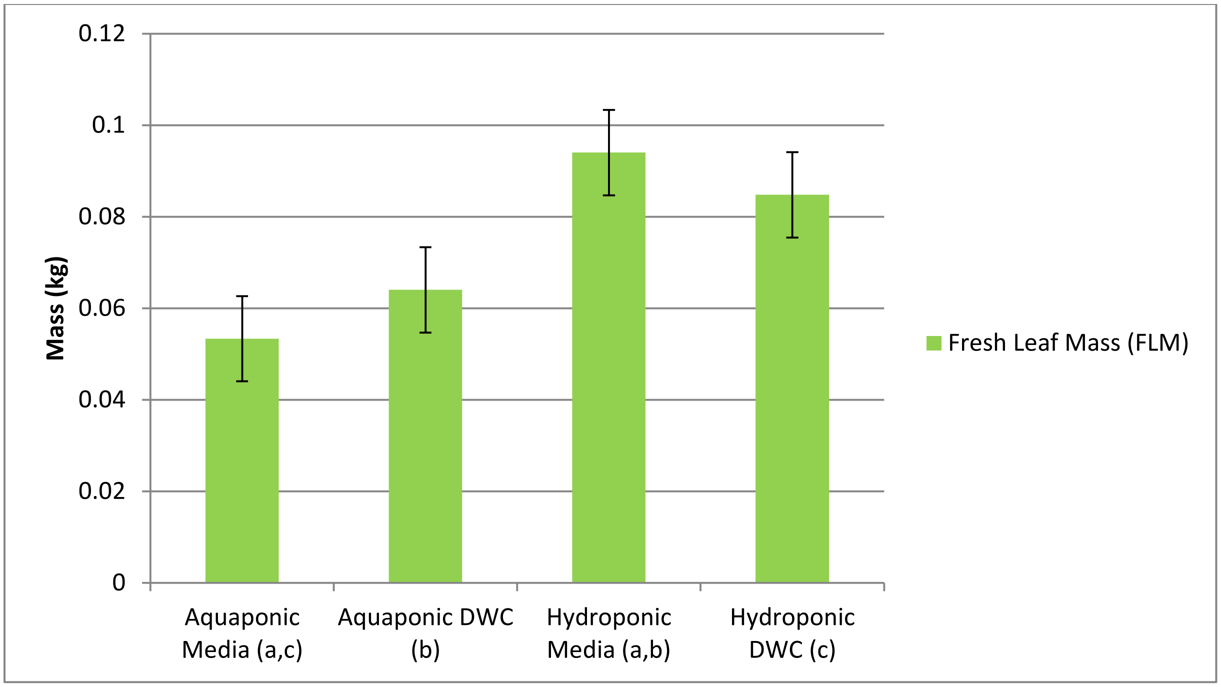

Fig 2.16 Mean ($\overline{x}$ ±SE) basil FLM (kg) for aquaponic and hydroponic media filled and DWC hydroponic subsystems. a,b,c: treatments showing the same letter are significantly different (Kruskal- Wallis One Way Analysis of Variance on Ranks, $n_1 = n_2 = n_3 = n_4 = 60$, p=<0.001, Tukey Test, p<0.05).

After analyzing combined hydroponic subsystem designs for aquaponic and hydroponic trials, the hydroponic trial had significantly different basil FLM (kg) (Fig 2.17). This is most likely due to higher nutrient solution concentrations (Pantanella 2013), therefore providing essential nutrients for plant growth requirements.

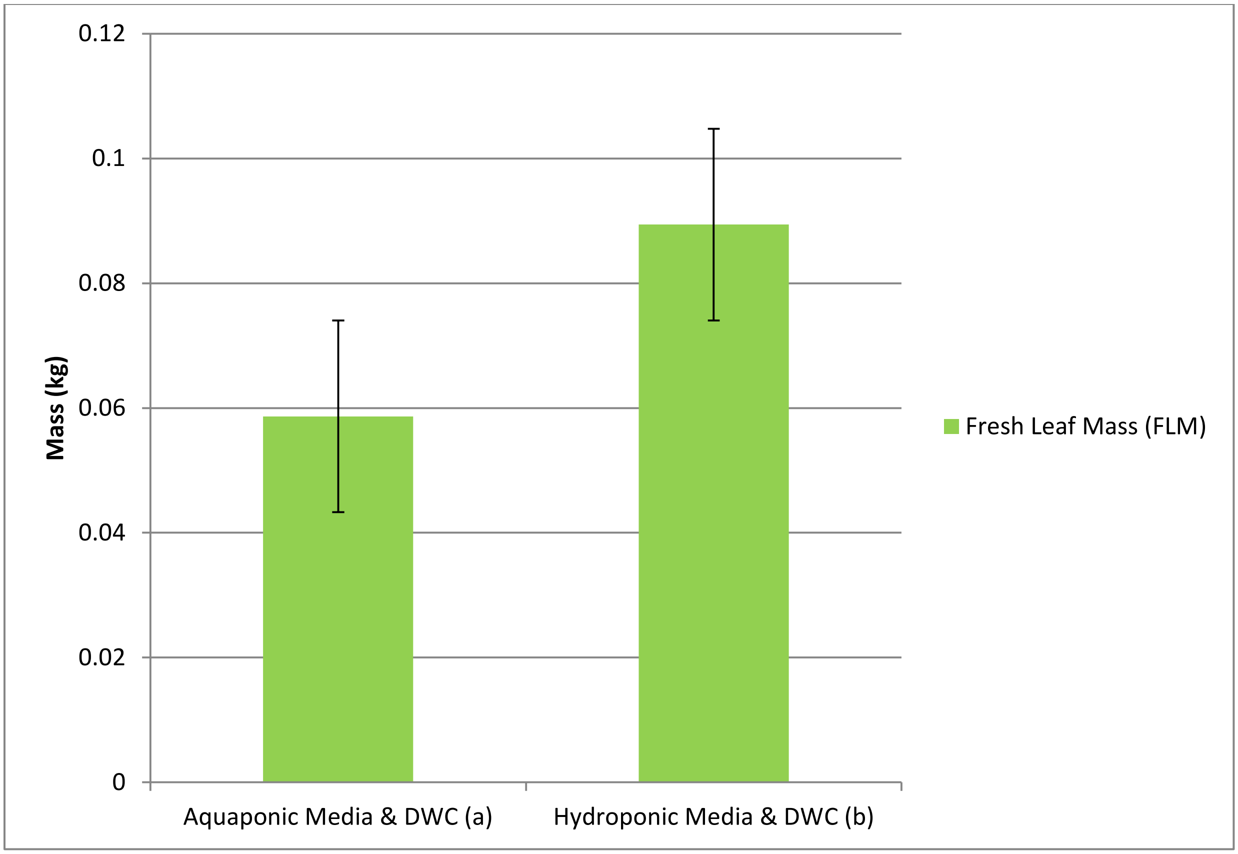

Fig 2.17 Mean ($\overline{x}$ ±SE) basil FLM (kg) for overall combined media filled and DWC aquaponic and hydroponic systems. a and b: treatments showing the same letter are not significantly different (Mann-Whitney Rank Sum Test, $n_1 = n_2 = 60$, $p=<0.001$).

c. Yield (leaf)

Yield is equal to fresh leaf mass (kg) divided by 0.6027 m^2. Results for basil yield are statistically equivalent to fresh leaf mass (Fig 2.18 and 2.19).

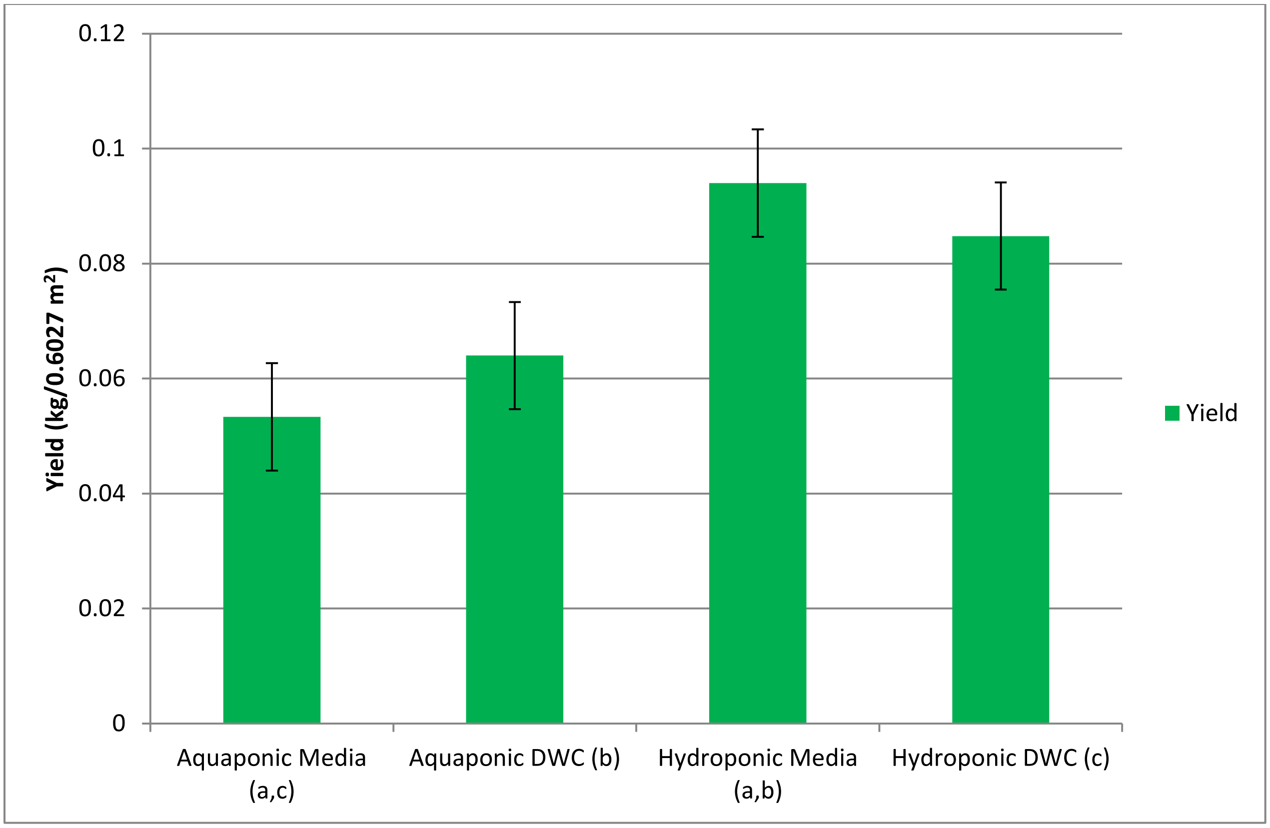

Fig 2.18 Mean ($\bar{x}$ ±SE) basil yield (kg/0.6027 m^2) for aquaponic and hydroponic media filled and DWC hydroponic subsystems. a,b,c: treatments showing the same letter are significantly different (Kruskal- Wallis One Way Analysis of Variance on Ranks, $n_1 = n_2 = n_3 = n_4 = 60$, p=<0.001, Tukey Test, p<0.05).

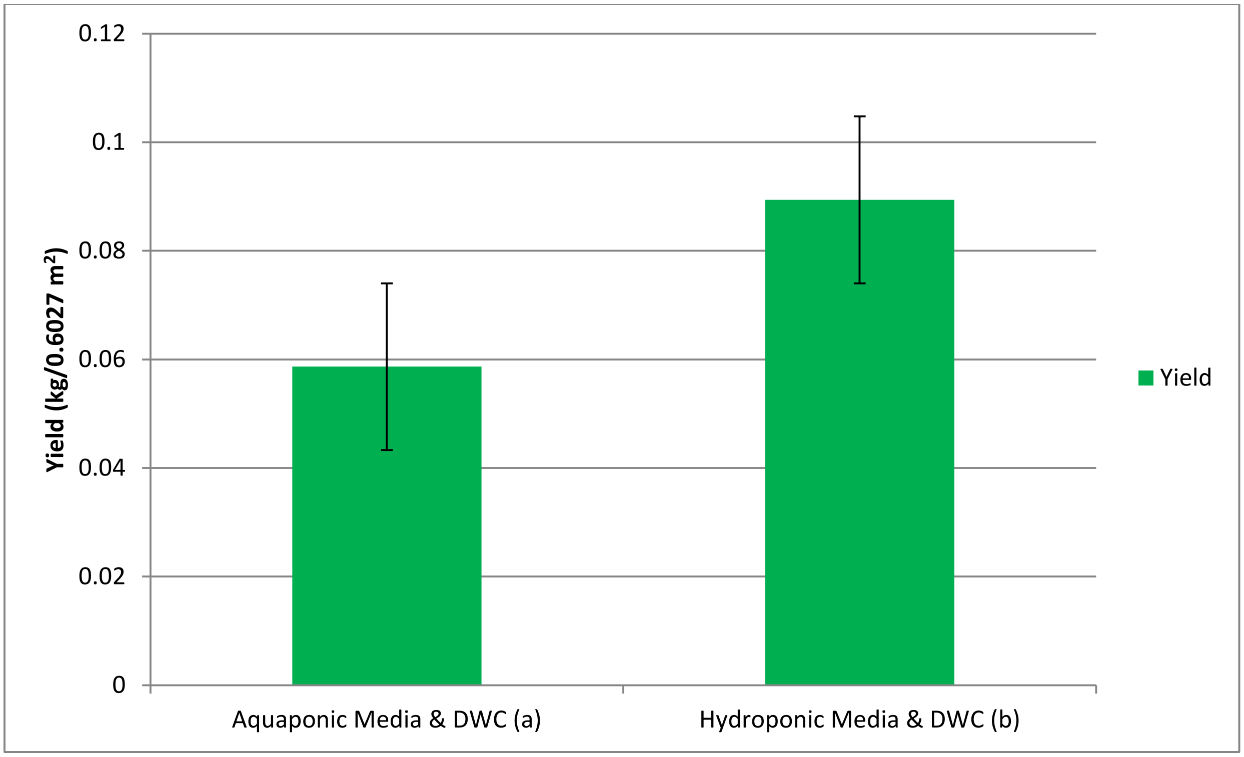

Fig 2.19 Mean ($\bar{x}$ ±SE) basil yield (kg/0.6027 m^2) for overall combined media filled and DWC aquaponic and hydroponic systems. a and b: treatments showing the same letter are not significantly different (Mann-Whitney Rank Sum Test, $n_1 = n_2 = 60$, p=<0.001).

d. Total Vegetative (non-root) Biomass (TVB)

Analysis for TVB (kg) (Fig 2.20) had the same significance between aquaponic and hydroponic media filled and DWC hydroponic subsystems as FLM (kg) (Fig 2.16). Consequently, interpretations of the results are similar.

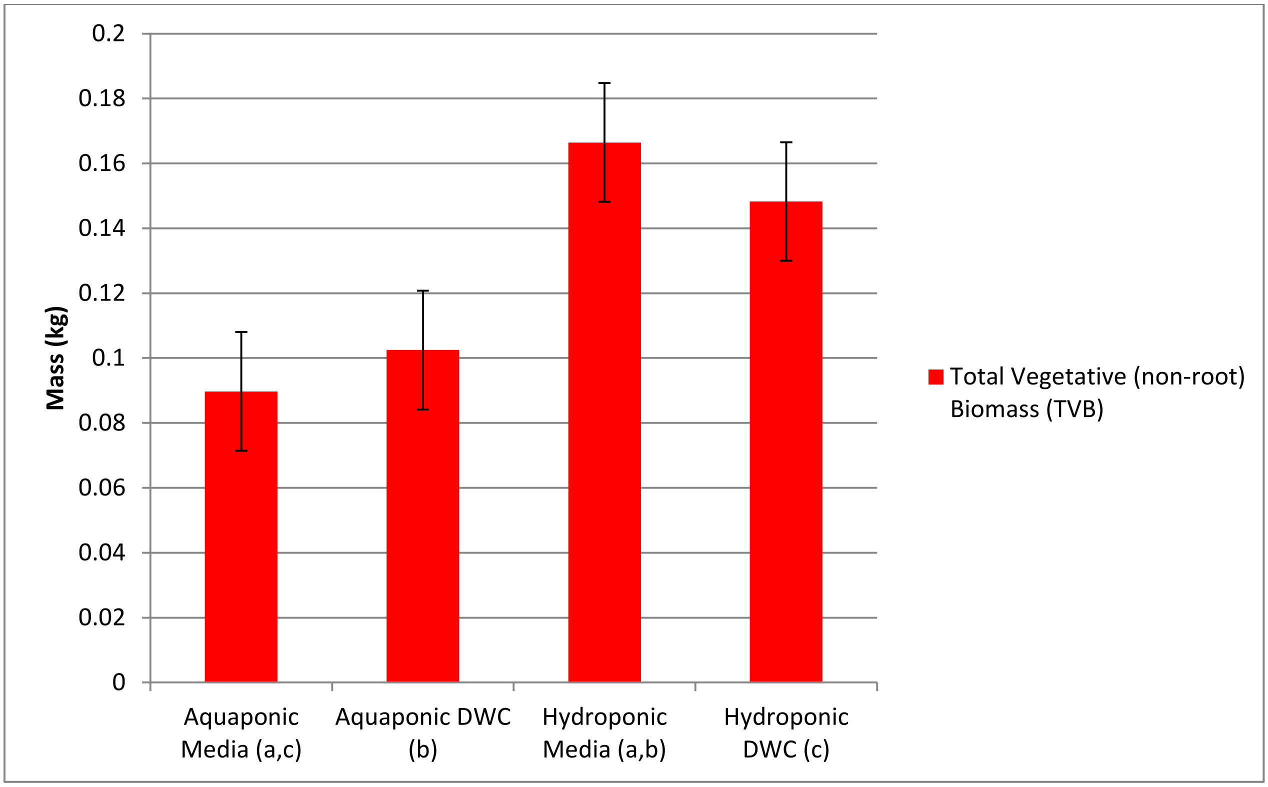

Fig 2.20 Mean ($\overline{x}$ ±SE) basil TVB (kg) for aquaponic and hydroponic media filled and DWC hydroponic subsystems. a,b,c: treatments showing the same letter are significantly different (Kruskal- Wallis One Way Analysis of Variance on Ranks, $n_1 = n_2 = n_3 = n_4 = 60$, p=<0.001, Tukey Test, p<0.05).

After analyzing combined hydroponic subsystem designs for aquaponic and hydroponic trials, the hydroponic trial had significantly different basil TVB (kg) (Fig 2.21); therefore interpretations of the results are similar to FLM.

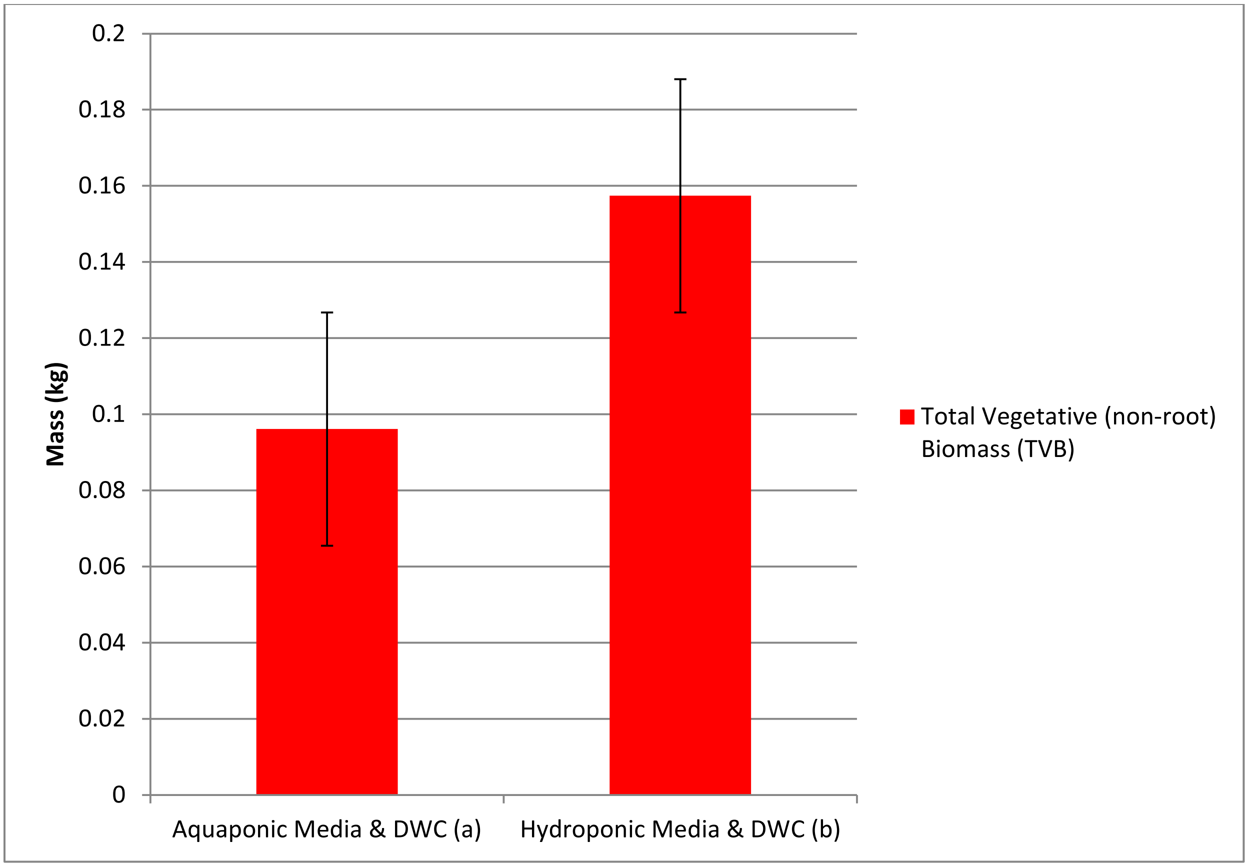

Fig 2.21 Mean ($\bar{x}$ ±SE) basil TVB (kg) for overall combined media filled and DWC aquaponic and hydroponic systems. a and b: treatments showing the same letter are not significantly different (Mann-Whitney Rank Sum Test, $n_1 = n_2 = 60$, p=<0.001).

e. Height

Sweet basil height (cm) between aquaponic and hydroponic media filled and DWC hydroponic subsystems was comparable to that of FLM (kg) and TVB (kg), except for the comparison between hydroponic DWC and aquaponic DWC (Fig 2.22). For height (cm) there was a significant difference between hydroponic DWC and aquaponic DWC. In this case, these results are dissimilar to Pantanella *et al.* (2012) and Nichols and Lennard (2010) leafy green studies, but are supportive of Roosta and Afsharipoor (2012) and Roosta and Hamidpour (2011) fruiting crop studies (Fig 2.22).

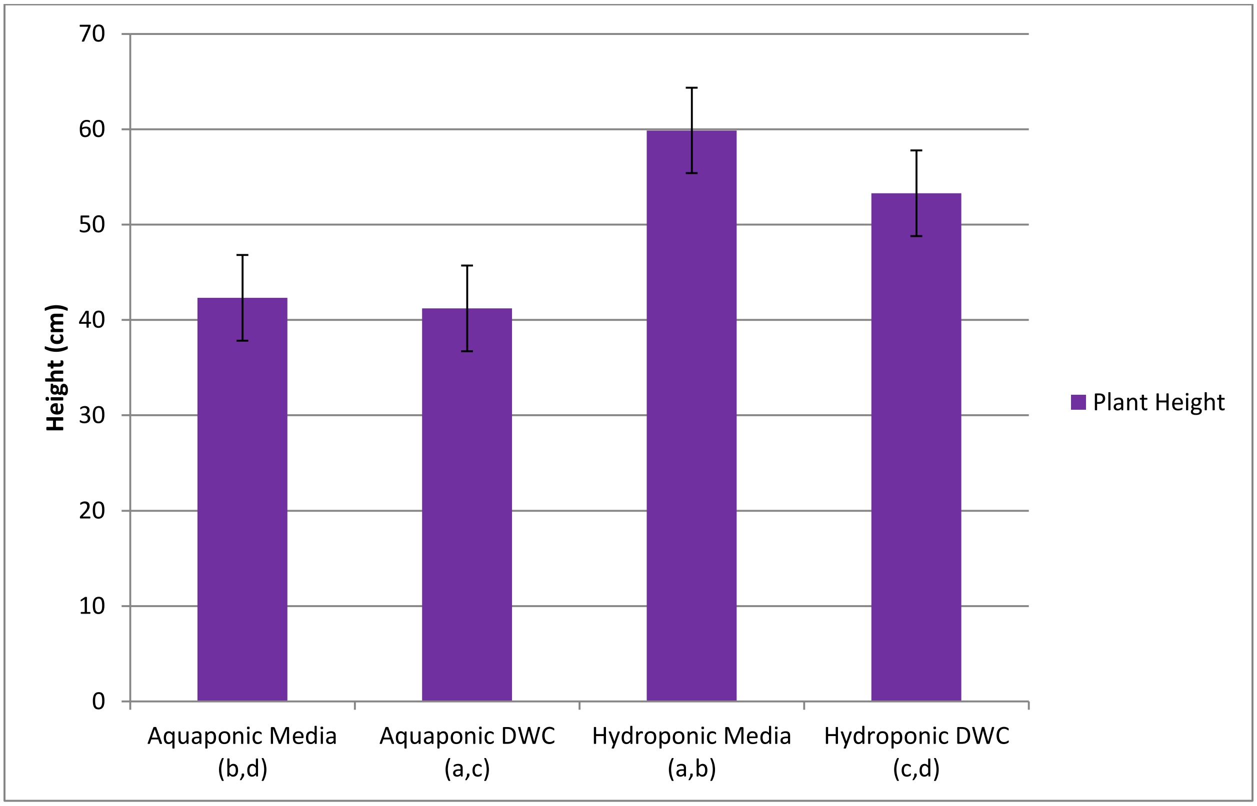

Fig 2.22 Mean ($\bar{x}$ ±SE) basil height (cm) for aquaponic and hydroponic media filled and DWC aquaponic and hydroponic systems. a,b,c,d: treatments showing the same letter are significantly different (Kruskal- Wallis One Way Analysis of Variance on Ranks, $n_1 = n_2 = n_3 = n_4 = 60$, $p=<0.001$, Tukey Test, $p<0.05$).

Subsequently analyzing combined hydroponic subsystem designs for aquaponic and hydroponic trials, the hydroponic trial had significantly different basil height (cm) (Fig 2.23); therefore interpretations of the results are similar to FLM, yield, and TVB.

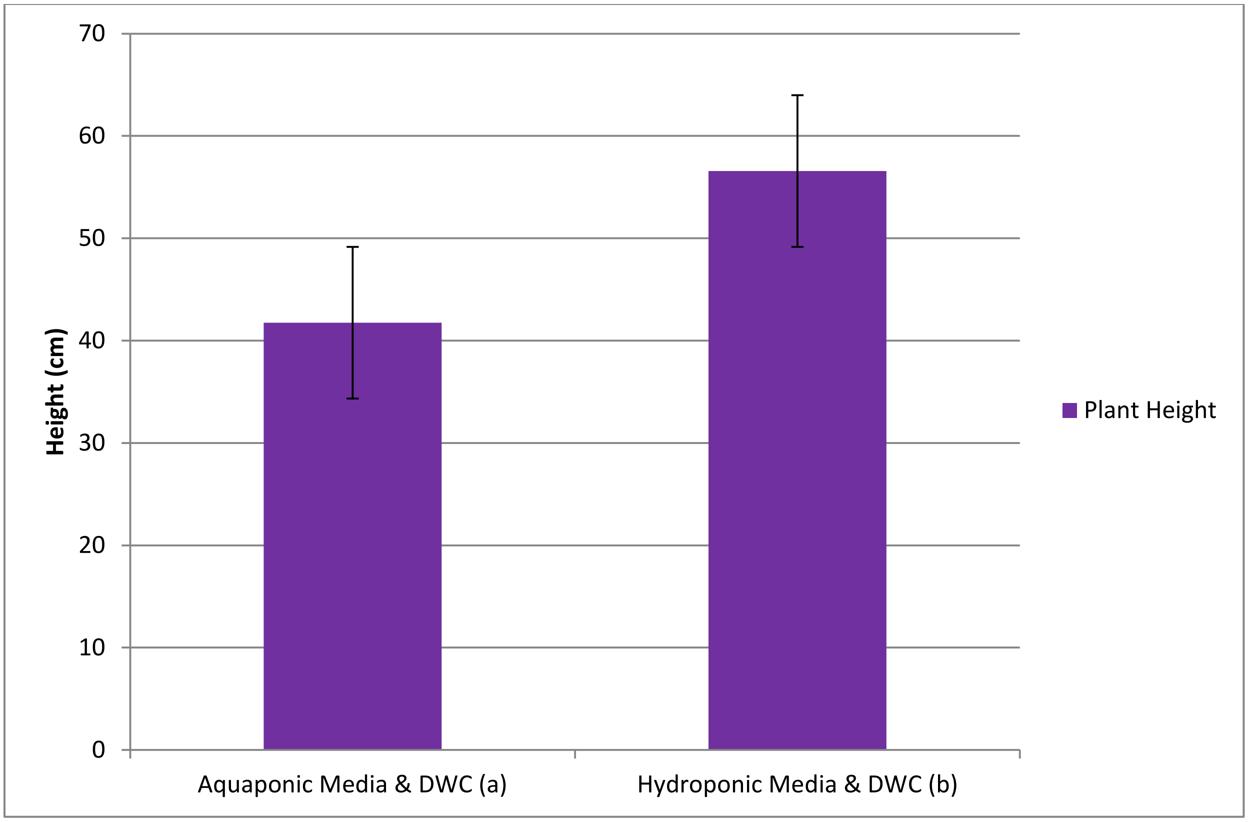

Fig 2.23 Mean ($\bar{x}$ ±SE) basil height (cm) for overall combined aquaponic and hydroponic media filled and DWC hydroponic subsystems. a and b: treatments showing the same letter are not significantly different (Mann-Whitney Rank Sum Test, $n_1 = n_2 = 60$, $p=<0.001$).

f. Absolute Growth Rate (AGR)

Analysis for ARG (cm/day) (Fig 2.24) had the same significance between aquaponic and hydroponic media filled and DWC hydroponic subsystems as height (cm) (Fig 2.20). Consequently, interpretations of the results are similar.

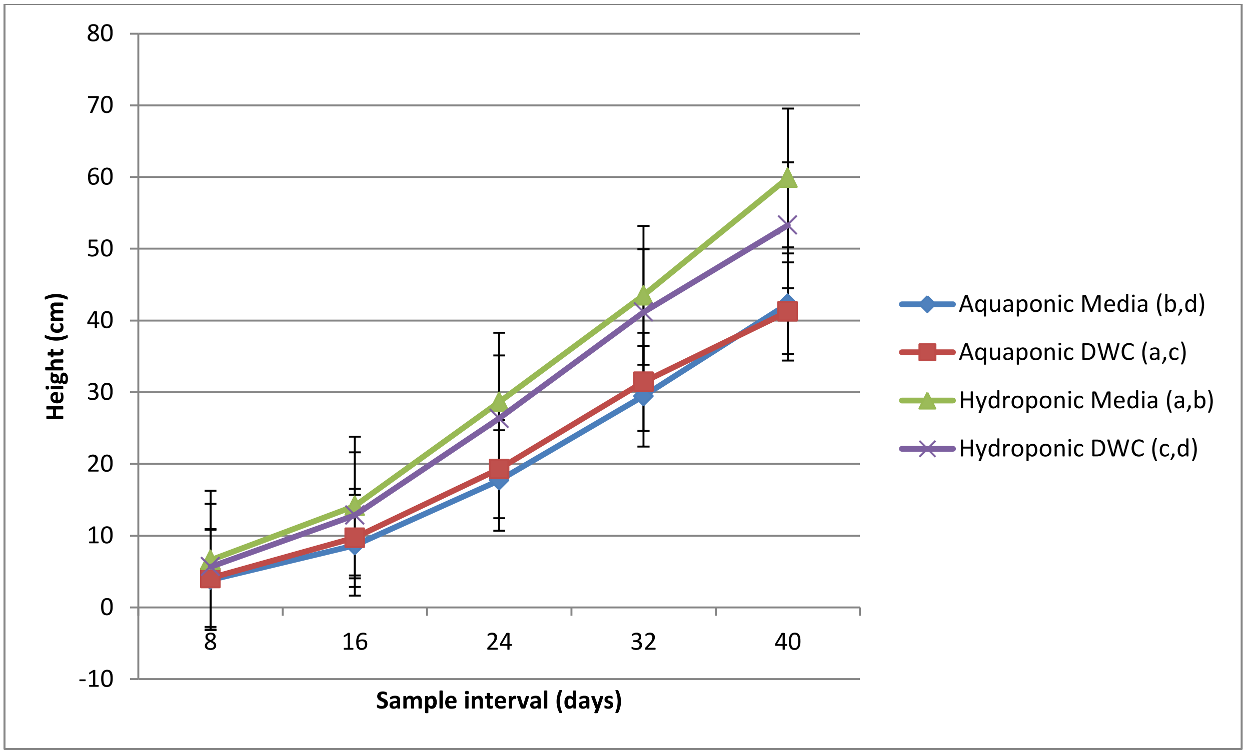

Fig 2.24 Mean ($\bar{x}$ ±SE) basil AGR (cm/day) for aquaponic and hydroponic media filled and DWC aquaponic and hydroponic systems. a,b,c,d: treatments showing the same letter are significantly different (Kruskal- Wallis One Way Analysis of Variance on Ranks, $n_1 = n_2 = n_3 = n_4 = 60$, $p = < 0.001$, Tukey Test, $p < 0.05$).

Analyzing combined hydroponic subsystem designs for aquaponic and hydroponic trials, the hydroponic trial had significantly higher basil AGR (cm/day) (Fig 2.25); therefore interpretations of the results are similar to FLM, yield, TLB, and height.

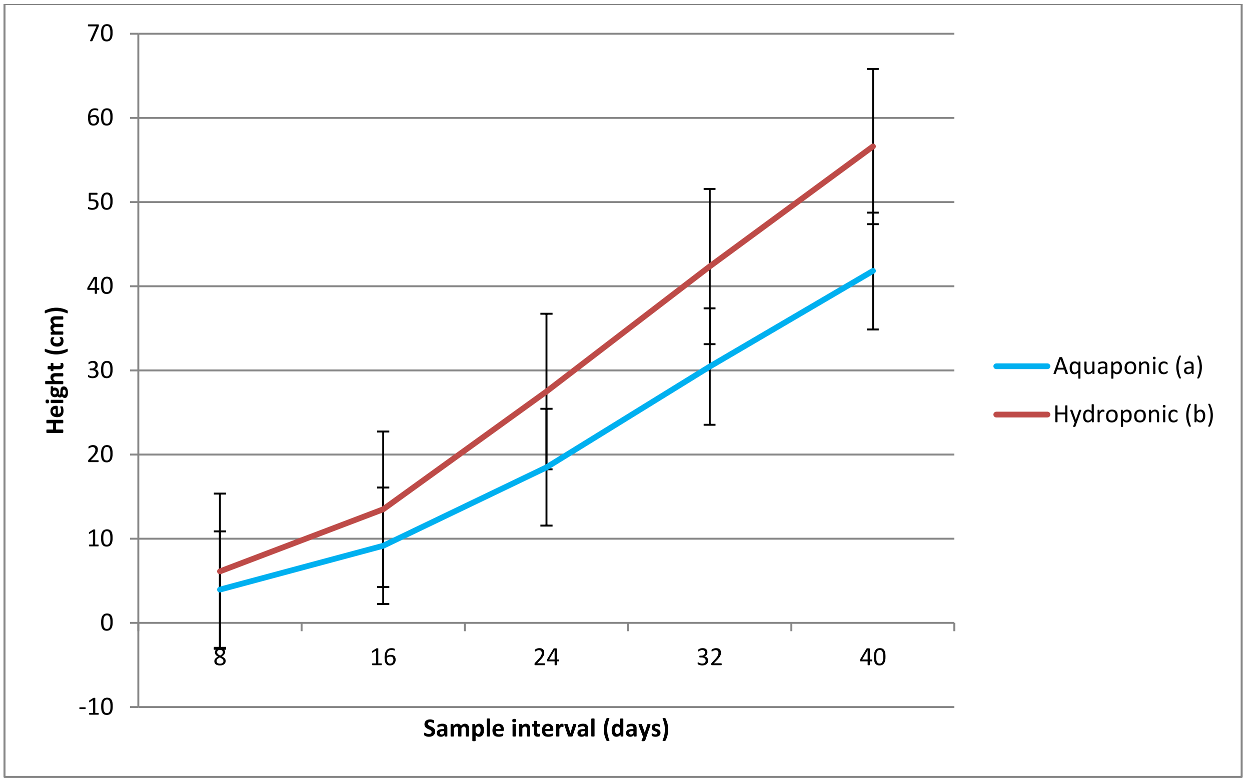

Fig 2.25 Mean ($\bar{x}$ ±SE) basil AGR (cm/day) for overall combined aquaponic and hydroponic media filled and DWC hydroponic subsystems. a and b: treatments showing the same letter are not significantly different (Mann-Whitney Rank Sum Test, $n_1 = n_2 = 60$, $p=<0.001$)

Physical, water quality, and nutrient parameters

g. Water addition and room temperature

Mean ($\bar{x}$ ±SE) water addition (L) for the 40 day aquaponic trial was 29.6±6.3 L and 22.9±8.3 L for the hydroponic trial. These values could have been decreased if rearing tanks/reservoirs were covered (Lennard and Leonard 2006). Also biofilters should have been covered as nitrifying bacteria are light sensitive (Yoshioka and Saijo 1984). Biofilters were positioned above hydroponic subsystems (Fig 2.2) allowing gravity to distribute water efficiently. With photo-inhibited bacteria, NO_3^--N (ppm) concentrations could have been at lower than expected levels, as well as higher NH_3 (ppm) concentrations (Fig 2.32 and 2.31). Also, there was not a significant difference in room temperature (°C) between the aquaponic and hydroponic trials (Mann- Whitney Rank Sum Test, $p>0.05$).

h. pH

pH was significantly different for aquaponic DWC 7.2 ± 0.12 (pH) compared to hydroponic media filled 6.7 ± 0.07 (pH) hydroponic subsystems (Fig 2.26) possibly due to the lack of surface area for bacteria to colonize while decreasing nitrification. The process of nitrification creates acidic conditions, which would decrease pH. Aquaponic DWC hydroponic subsystems could have had lower bacteria populations, decreasing nitrification, allowing for a higher pH (basic) compared to the other treatments. The water utilized for the study originated from the tap. This water is very hard (calcium hydrogencarbonate) and is known to be so throughout Missouri due to the abundance of limestone throughout the state. As holding water was aerated to release carbon dioxide (acid) and chlorine (base) the pH of the water rose from ca. 8.7 to ca. 9.2; thus, leading to the strong 85% phosphoric acid that was utilized to decrease pH. There were no detectable levels of chlorine in the water.

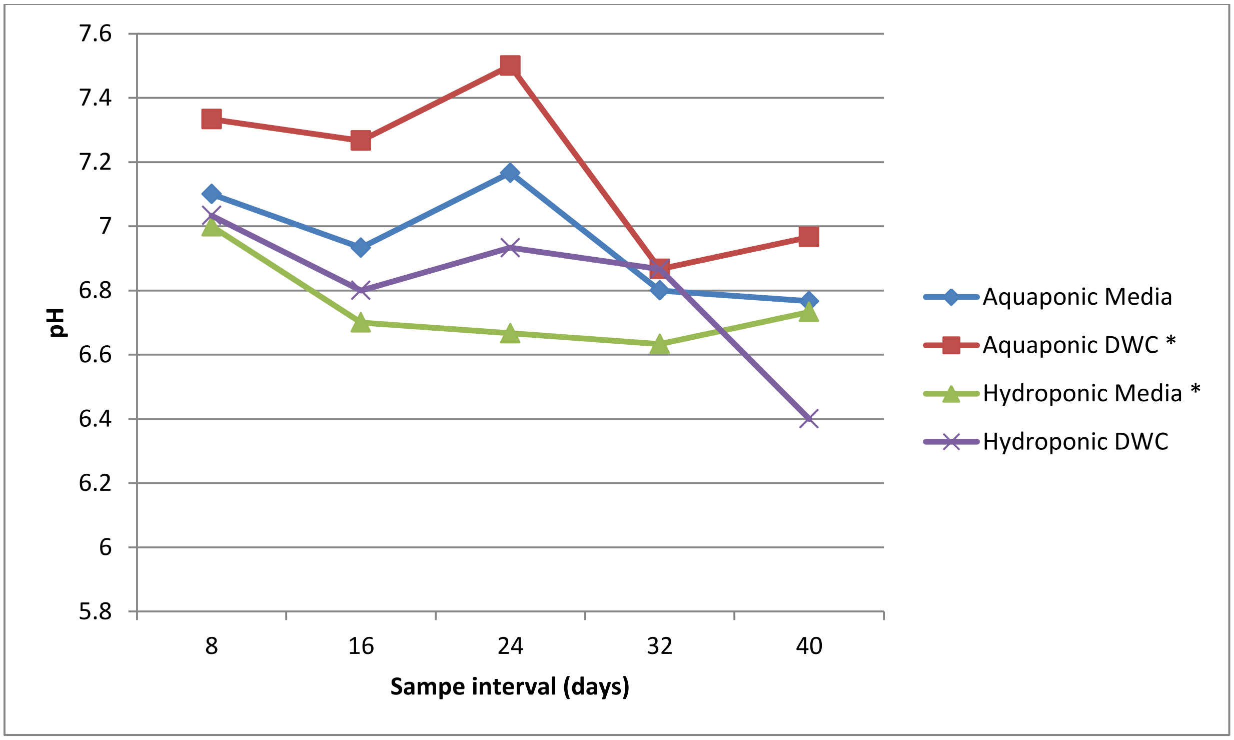

Fig 2.26 Mean ($\overline{x}$) pH levels for both aquaponic and hydroponic trials. *'**: treatments showing the same symbol are significantly different (One Way Analysis of Variance, $n_1 = n_2 = n_3 = n_4 = 5$, $p<0.05$), Holm-Sidak method, $p<0.05$).

i. TDS

TDS was significantly different between hydroponic DWC 1265±161.2 (ppm) and aquaponic DWC 523±25.1 (ppm), as well as hydroponic media 1084±105.7 (ppm) being significantly different that aquaponic DWC 523±25.1 (ppm). These findings are indicative of the higher nutrient concentrations that are associated with hydroponic solutions. Aquaponic media 659±40.6 (ppm) was not significantly different compared to other hydroponic subsystem designs. This could be due to hydroton that was utilized and dissolved nutrients that may have been residing within the porous material (Fig 2.27).

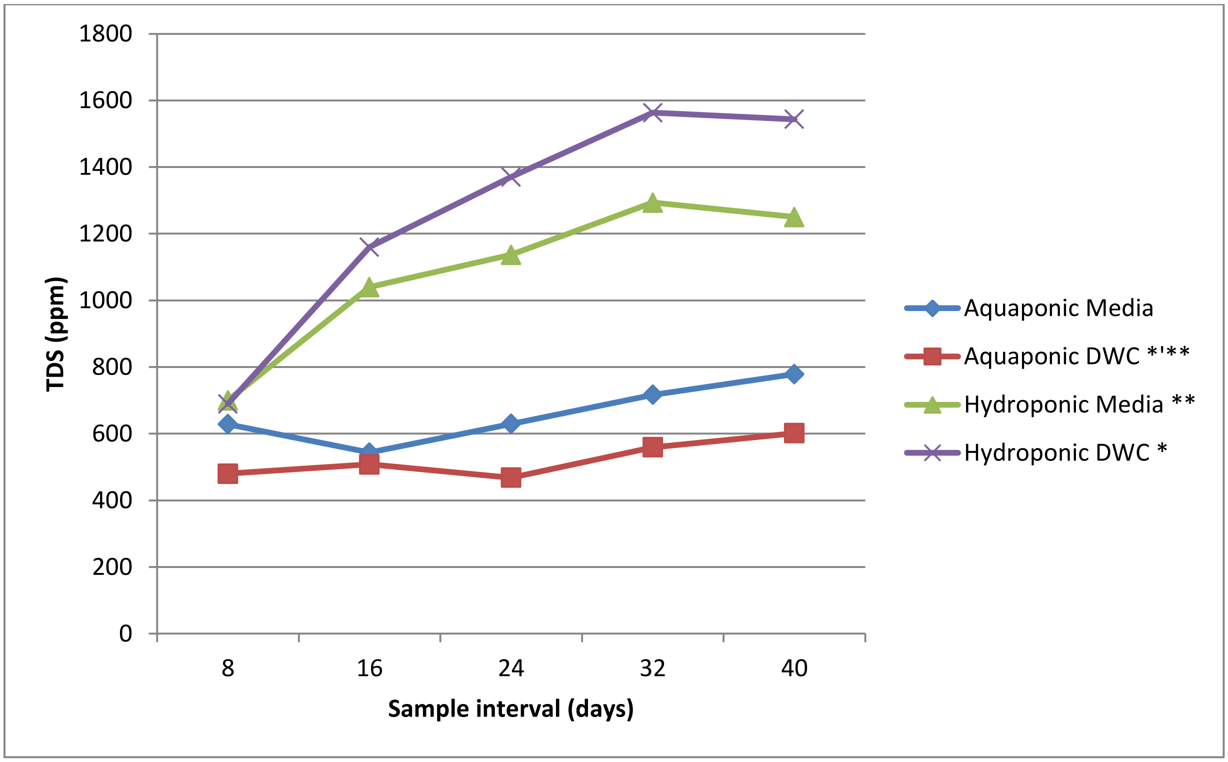

Fig 2.27 Mean ($\bar{x}$**)** TDS (ppm) levels for both aquaponic and hydroponic trials. *’**: treatments showing the same symbol are significantly different (Kruskal- Wallis One Way Analysis of Variance on Ranks, $n_1 = n_2 = n_3 = n_4 = 5$, $p<0.05$, Tukey Test, $p<0.05$).

j. E.C.

E.C. analysis was comparable to TDS; therefore interpretations of the results are similar (Fig 2.28).

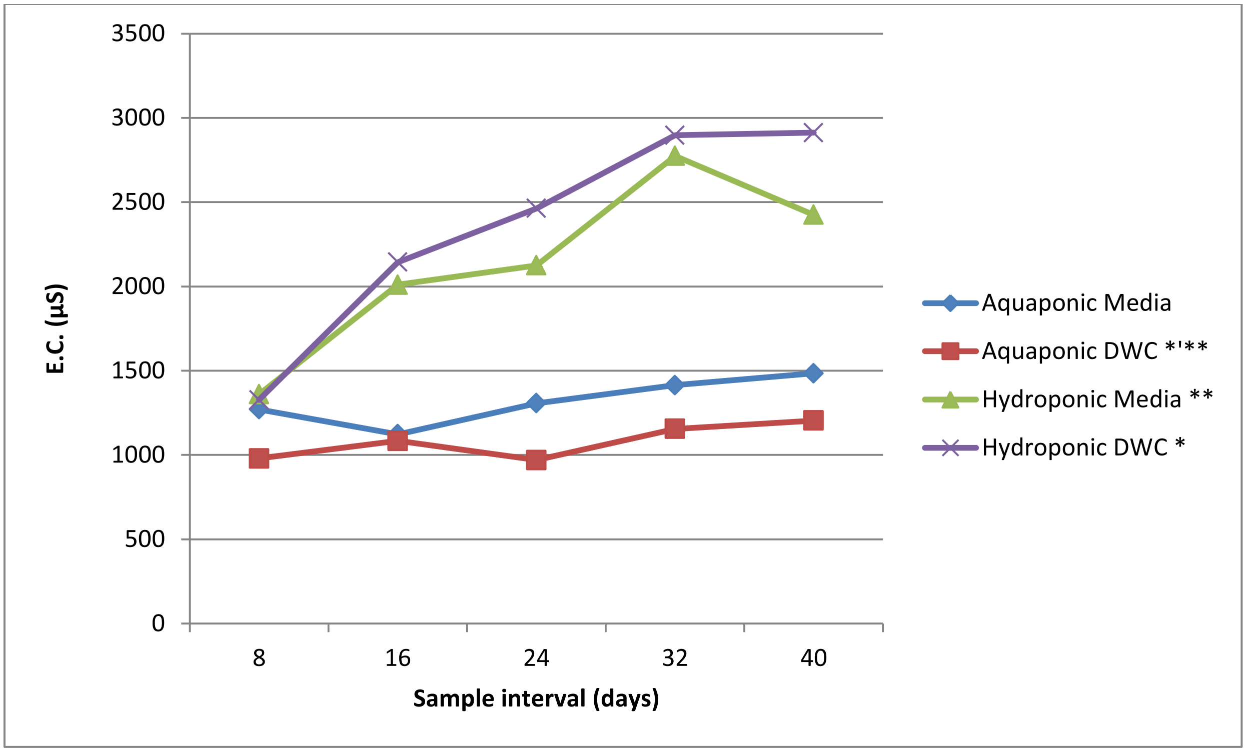

Fig 2.28 Mean ($\bar{x}$) E.C. (µS) levels for both aquaponic and hydroponic trials. *'**: treatments showing the same symbol are significantly different (Kruskal- Wallis One Way Analysis of Variance on Ranks, $n_1 = n_2 = n_3 = n_4 = 5$, $p<0.05$, Tukey Test, $p<0.05$).

k. D.O.

There was no significant difference in D.O. (ppm) levels between aquaponic and hydroponic media filled and DWC hydroponic subsystems. The same systems and equipment were utilized for both trials, which ensured D.O. would not vary (Fig 2.29).

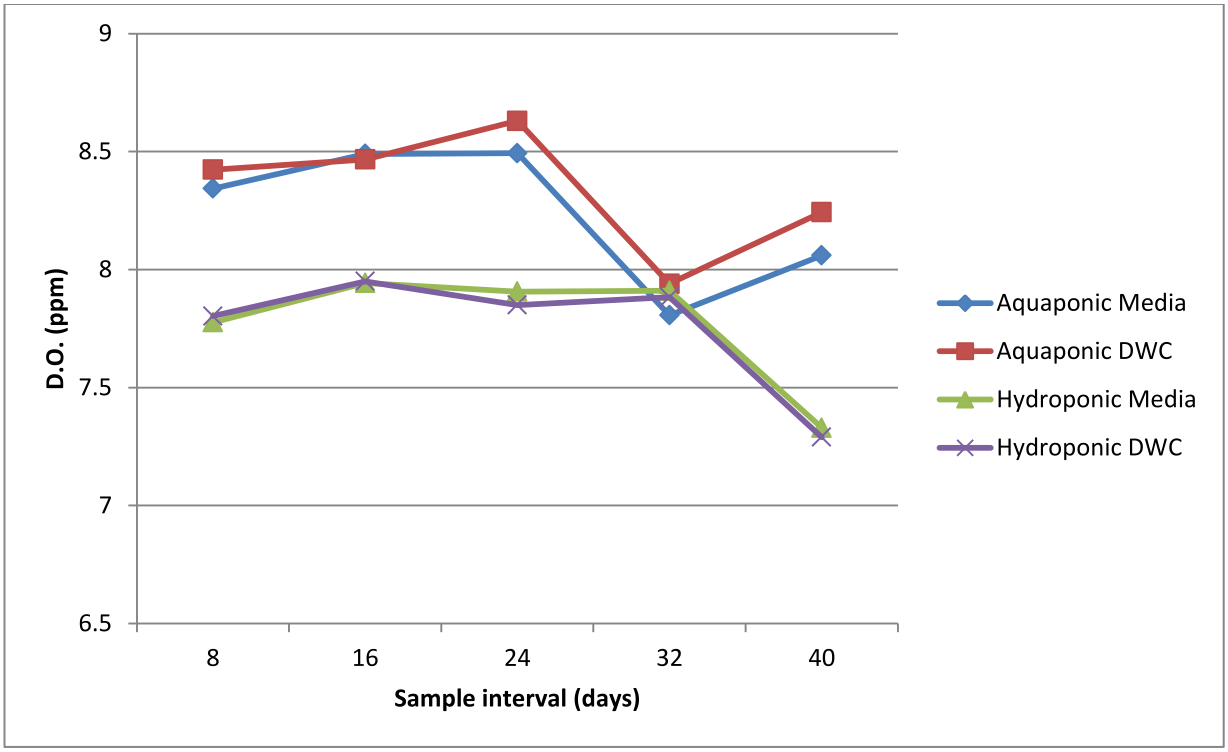

Fig 2.29 Mean ($\bar{x}$) D.O. (ppm) levels for both aquaponic and hydroponic trials. *'**: treatments showing the same symbol are significantly different (Kruskal- Wallis One Way Analysis of Variance on Ranks, $n_1 = n_2 = n_3 = n_4 = 5$, $p>0.05$).

l. Water Temperature

There is no significant difference in water temperature (°C) for both aquaponic and hydroponic media filled and DWC hydroponic subsystems. Again, the same systems and equipment were utilized for both trials, which ensured temperature (°C) would not vary. Also, during both trials, fans where positioned at the plants as well as between the rearing tank/reservoirs; thus leading to like water temperatures (Fig 2.30)

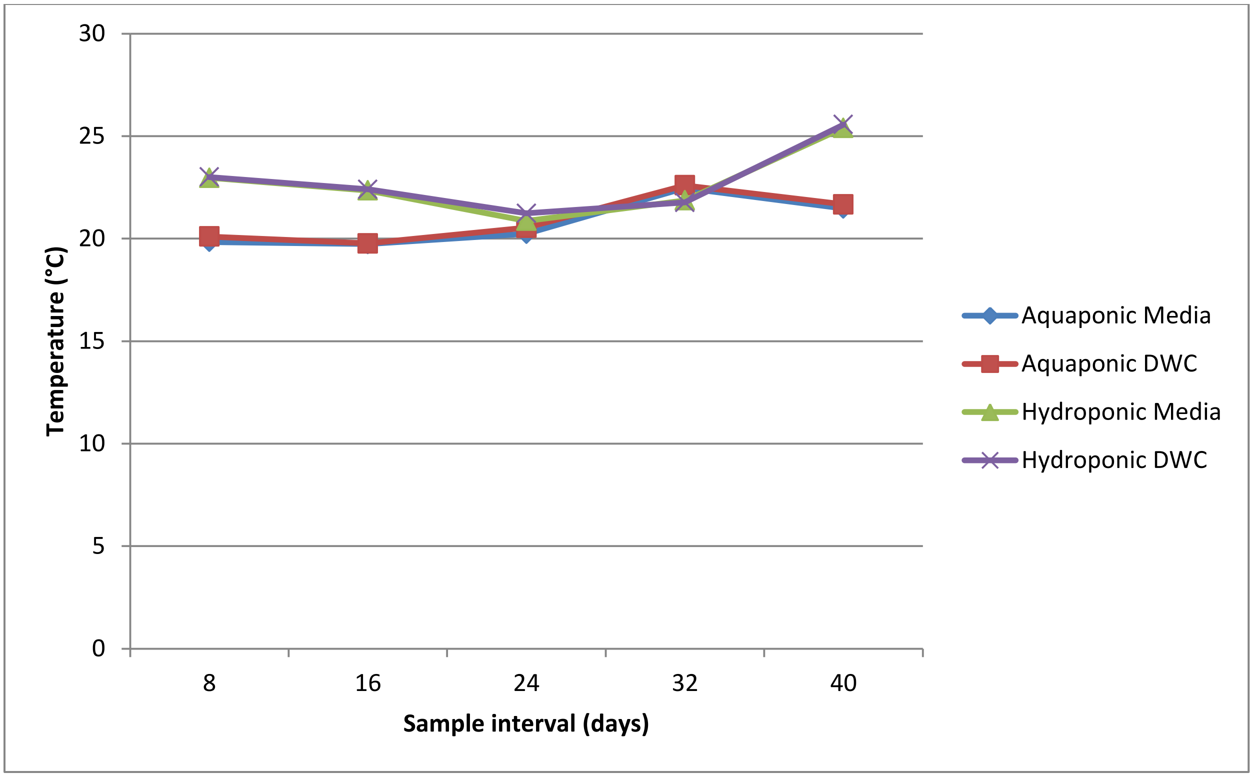

Fig 2.30 Mean ($\overline{x}$) temperature (°C) levels for both aquaponic and hydroponic trials. *'**: treatments showing the same symbol are significantly different (Kruskal- Wallis One Way Analysis of Variance on Ranks, $n_1 = n_2 = n_3 = n_4 = 5$, $p>0.05$).

m. Ammonia (NH_3)

There was significantly different NH_3 (ppm) concentrations between aquaponic media 2.14±0.166 (ppm) and hydroponic DWC 19.8±3.66 (ppm) hydroponic subsystems. Since hydroponic nutrient solutions are known to be 10 times higher in nutrient concentration than aquaponic solutions (Pantanella 2013) these results are expected. Hydroponic media filled hydroponic subsystems had greater surface area allowing for increased nitrification, decreasing NH_3 (ppm) concentrations. Since hydroponic DWC hydroponic subsystems did not have sufficient surface area, NH_3 (ppm) concentrations are anticipated to be much higher as seen in Fig 2.31.

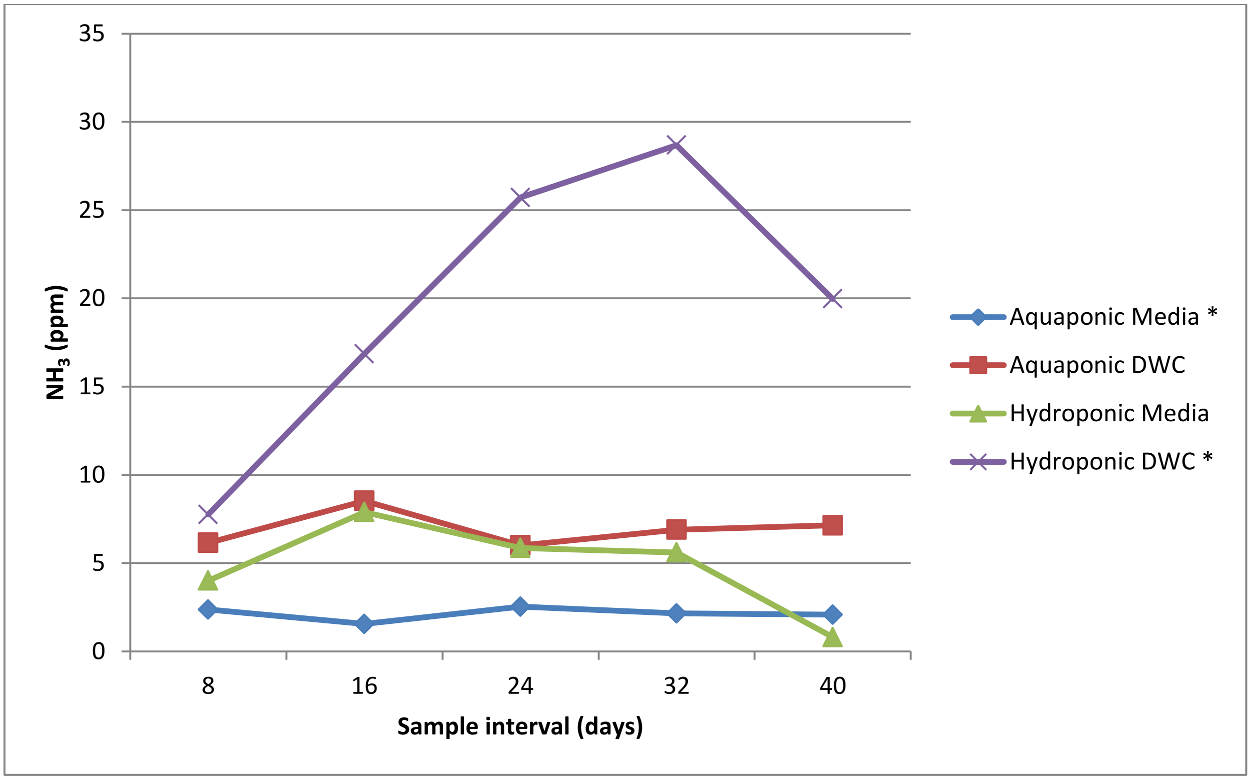

Fig 2.31 Mean ($\overline{x}$) NH_3 (ppm) concentrations for both aquaponic and hydroponic trials. *'**: treatments showing the same symbol are significantly different (Kruskal- Wallis One Way Analysis of Variance on Ranks, $n_1 = n_2 = n_3 = n_4 = 5$, $p<0.05$, Tukey Test, $p<0.05$).

n. Nitrate (NO_3^-)

Due to chemical reactions with hydroponic nutrients and VacuVial tests, nitrate analysis could only be completed for the hydroponic trial. There was a significant difference in NO_3^--N (ppm) concentrations between aquaponic media filled 11.0$\pm$0.578 (ppm) and aquaponic DWC 2.78$\pm$0.08 (ppm) hydroponic subsystems. This could have been caused by increased surface area (hydroton) for bacteria to colonize, leading to increased nitrification of NH_3 (ppm) into NO_3^-N (ppm) (Fig 2.32).

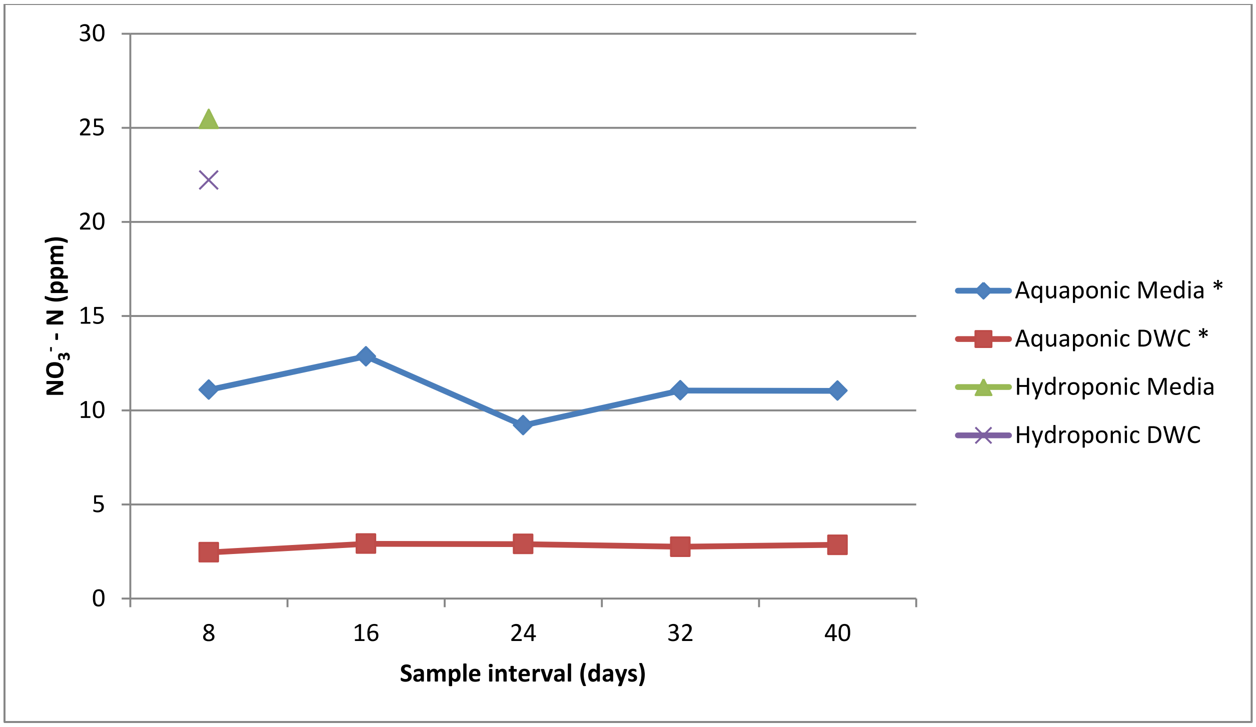

Fig 2.32 Mean ($\bar{x}$) NO_3^- - N (ppm) concentrations for both aquaponic and hydroponic trials. *'**: treatments showing the same symbol are significantly different (Mann- Whitney Rank Sum Test, $n_1 = n_2 = 5$, $p>0.05$).

o. Nitrite (NO_2^-)

There was significantly different NO_2^--N (ppm) concentrations between aquaponic and hydroponic media filled and DWC hydroponic subsystems, with aquaponic media 0.501 ± 0.22 (ppm) significantly different than hydroponic media 0.0347 ± 0.0048 (ppm), as well as aquaponic DWC 0.513 ± 0.2 (ppm) significantly different than hydroponic media 0.0347 ± 0.0048 (ppm). This was expected during the aquaponic trial as channel catfish, waste, and feed would eventually be converted to NO_2^--N (ppm). The major form of ammonia in the General Hydroponic® nutrients is NO_3^--N (ppm) (1.75%), which is readily available for plant assimilation, therefore severely decreasing the process of nitrification and lowering NO_2^--N (ppm) concentrations (Fig 2.33).

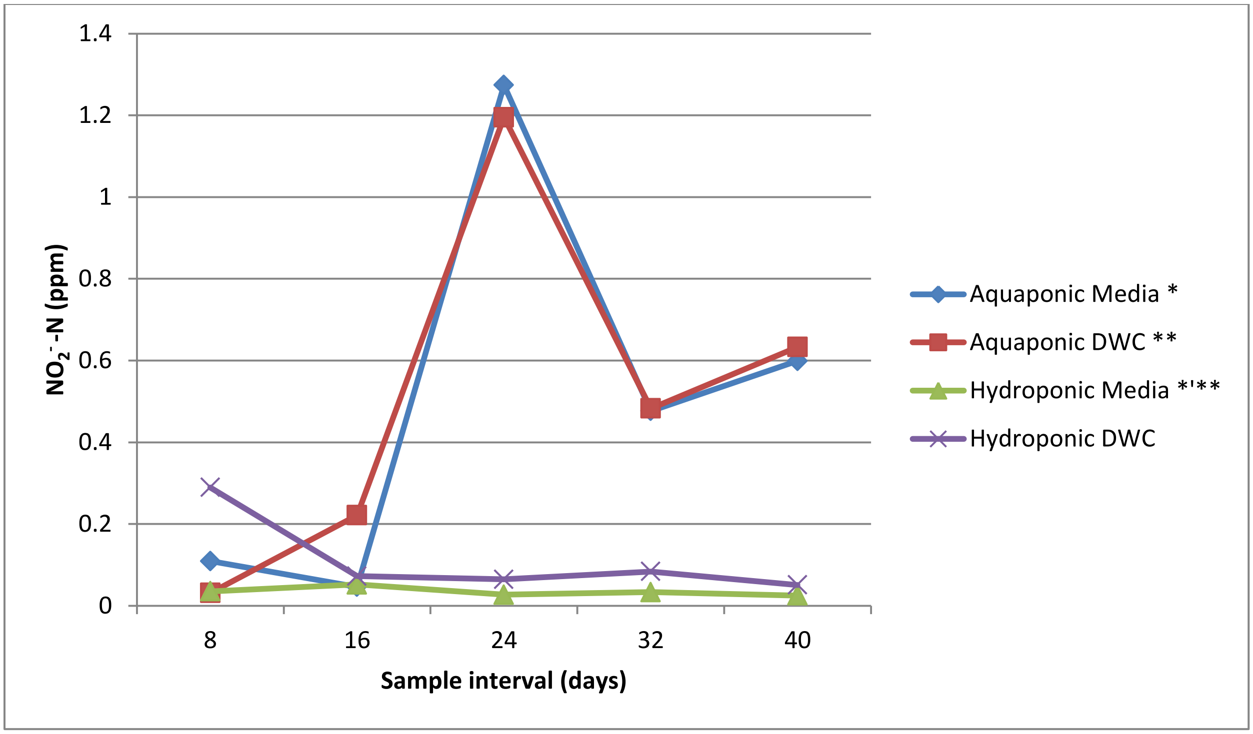

Fig 2.33 Mean ($\bar{x}$) NO_2^--N (ppm) concentrations for both aquaponic and hydroponic trials. *'**: treatments showing the same symbol are significantly different (Kruskal- Wallis One Way Analysis of Variance on Ranks, $n_1 = n_2 = n_3 = n_4 = 5$, $p<0.05$, Tukey Test, $p<0.05$).

p. Orthophosphorus (PO_4^{3-})

During both trials (aquaponic and hydroponic), PO_4^{3-} (ppm) concentrations were extremely high due to the addition of 85% food grade phosphoric acid that was utilized to control pH. Since water from both trials originated from the same source (tap), as well as same management practices there was no significant difference between the trials (Fig 2.34).

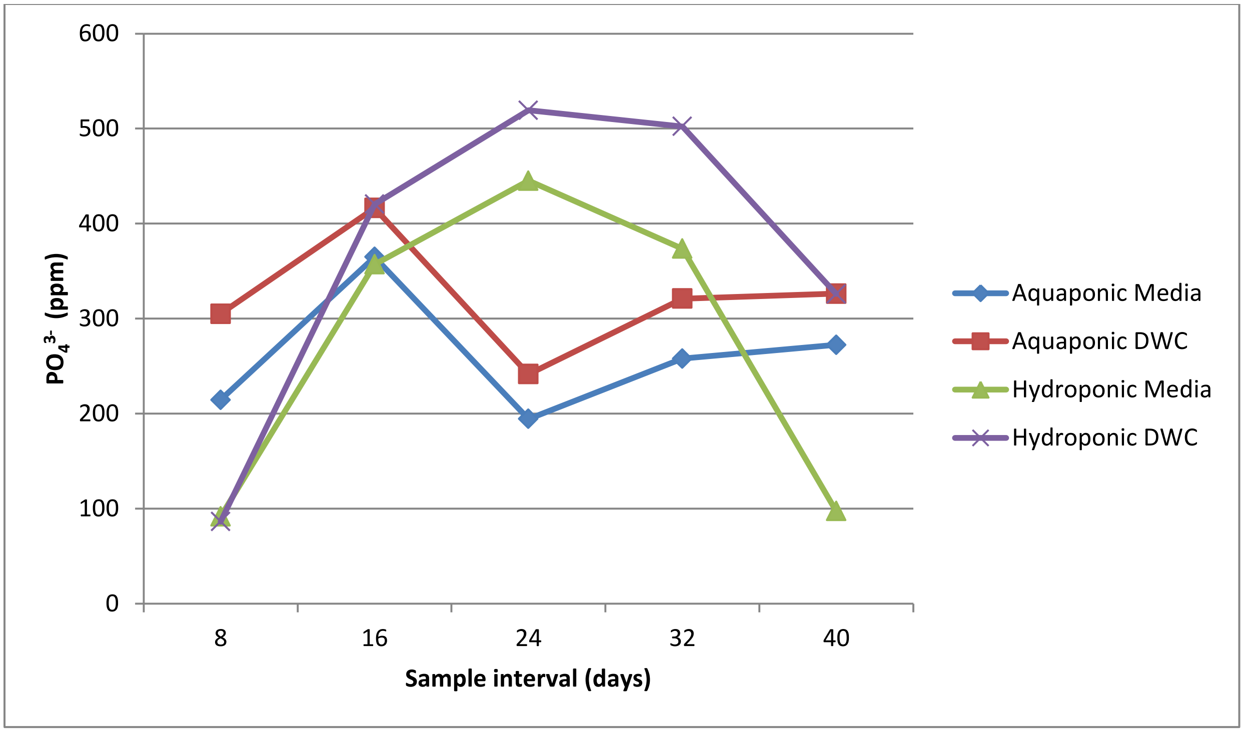

Fig 2.34 Mean ($\overline{x}$**)** PO_4^{3-} (ppm) concentrations for both aquaponic and hydroponic trials. *'**: treatments showing the same symbol are significantly different (One Way Analysis of Variance, $n_1 = n_2 = n_3 = n_4 = 5$, p>0.05).

q. Sulfate (SO_4^{2-})

There was significantly different SO_4^{2-} (ppm) concentrations between hydroponic media filled 205.11±27.837 (ppm) and aquaponic DWC 35.54±3.518 (ppm) hydroponic subsystems, as well as hydroponic DWC 200.26±46.94 (ppm) and aquaponic media filled 88.63±6.037 (ppm) hydroponic subsystems (Fig 2.35). SO_4^{2-} (ppm) was higher during the hydroponic trial which is expected due to higher nutrient concentrations in the hydroponic solution.

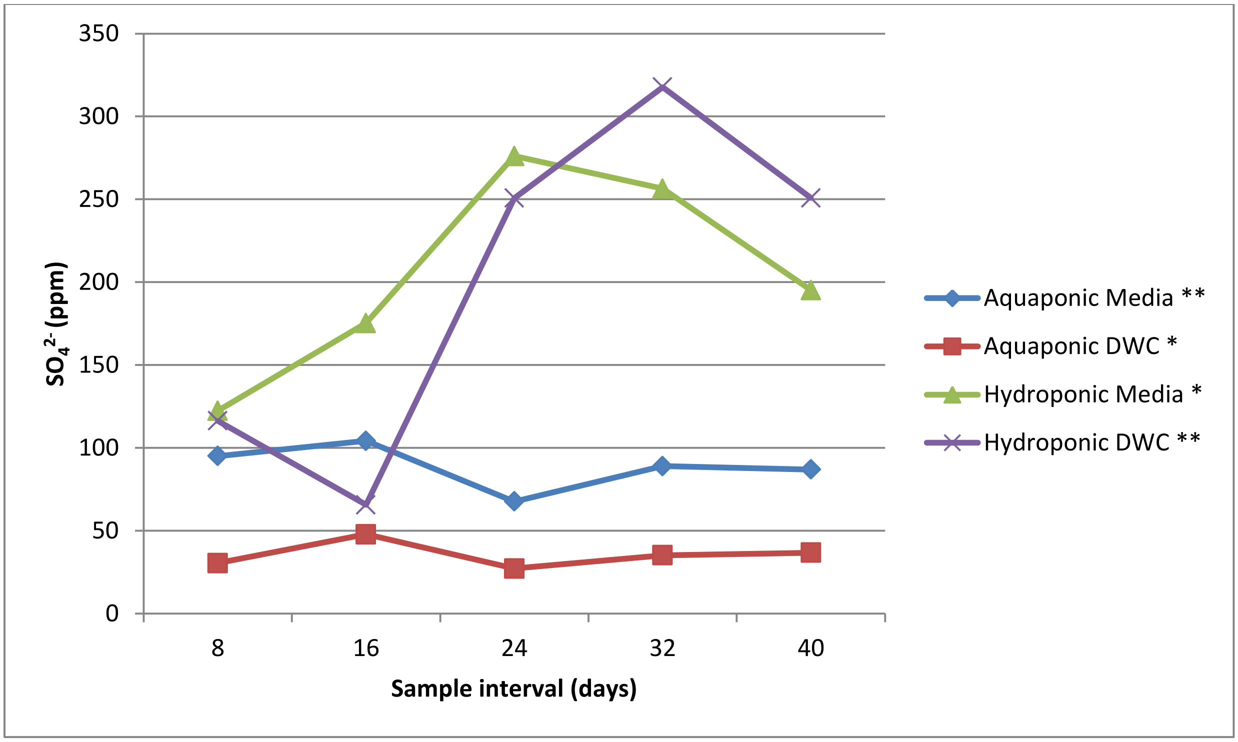

Fig 2.35 Mean ($\overline{x}$) SO_4^{2-} (ppm) concentrations for both aquaponic and hydroponic trials. *'**: treatments showing the same symbol are significantly different (Kruskal- Wallis One Way Analysis of Variance on Ranks, $n_1 = n_2 = n_3 = n_4 = 5$, $p<0.05$, Tukey Test, $p<0.05$).

r. Hardness as $CaCO_3$

Due to chemical reactions with hydroponic nutrients and VacuVial tests, hardness titrations could only be completed for the aquaponic trial. There was a significant difference in hardness (ppm) between aquaponic media 363.43$\pm$25.306 (ppm) and aquaponic DWC 282.183$\pm$19.702 (ppm) hydroponic subsystems (Fig 2.36). This could be the result of the hydroton and calcium accumulation on the media, or introduced in excess to the system by the media itself.

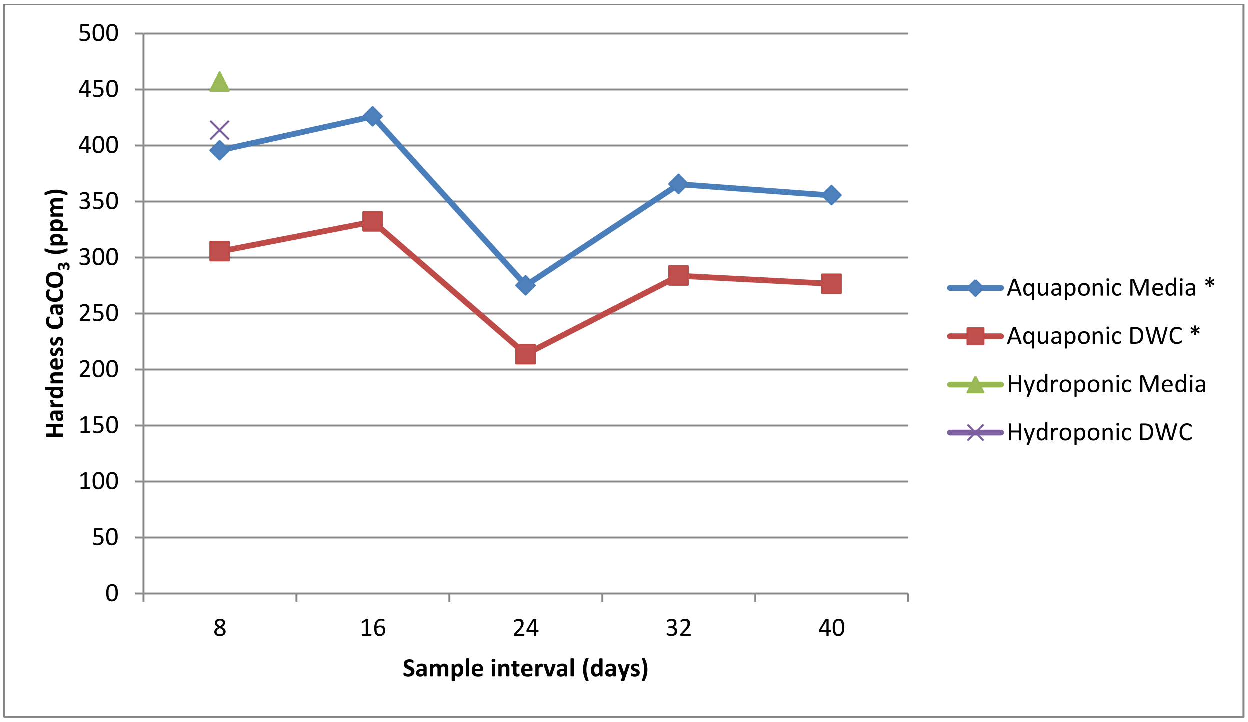

Fig 2.36 Mean ($\overline{x}$) Hardness $CaCO_3$ (ppm) levels for both aquaponic and hydroponic trials. *'**: treatments showing the same symbol are significantly different (Mann- Whitney Rank Sum Test, $n_1 = n_2 = 5$, $p<0.05$).

s. Alkalinity as $CaCO_3$

Alkalinity (ppm) was significantly different between hydroponic DWC 240.11±22.819 (ppm) and aquaponic media filled 45.78±3.212 (ppm) hydroponic subsystems, and hydroponic media filled 213.78±20.952 (ppm) and aquaponic DWC 66.01±4.864 (ppm) hydroponic subsystems (Fig 2.37). This could be attributed to the higher nutrient concentrations within the water solution. With these higher nutrient concentrations there will be greater conservative elements which increase the pH-buffering capacity of the solution.

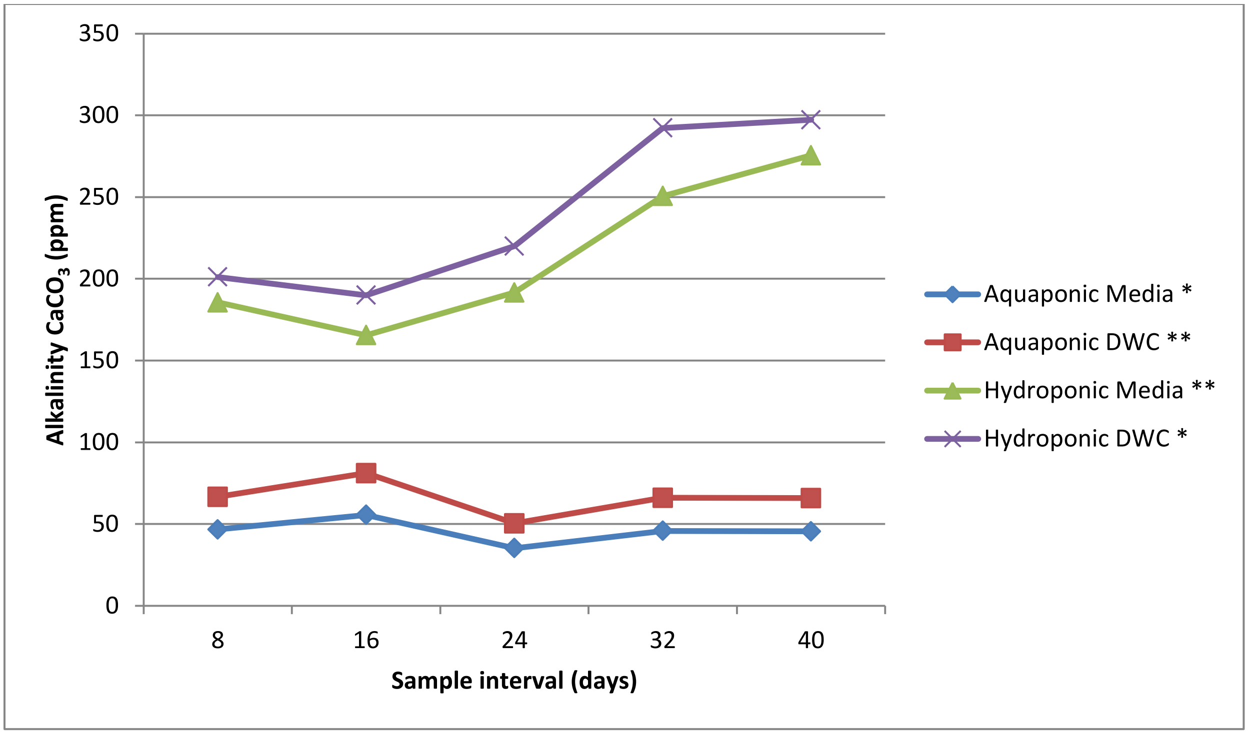

Fig 2.37 Mean ($\overline{x}$) Alkalinity $CaCO_3$ (ppm) levels for both aquaponic and hydroponic trials.

*'**: treatments showing the same symbol are significantly different (Kruskal- Wallis One Way Analysis of Variance on Ranks, $n_1 = n_2 = n_3 = n_4 = 5$, $p<0.05$, Tukey Test, $p<0.05$).

CHAPTER 5

CONCLUSION

Continued studies of well-established and sustainable food production practices and relatively new production practices are essential to meet future food demands. Although aquaponics and hydroponics are not perfect, they are steps in the right direction to solving natural resource degradation while increasing production. With results from this study and other related studies in regards to crop production in different systems, producers should realize that aquaponics or hydroponics methods do not alter the genotypic characteristics of plants. Production will not surpass genetic limitations regardless of growing techniques (Resh 1995). Plants can reach peak production when optimum requirements are met. However, results from this study do indicate that certain system designs and practices can be utilized to optimize basil production.

Additionally, within the aquaponic field, the disagreement whether plants or fish will bring the highest profit, will be determined by the market demand. As the hydroponic industry has established a successful plant only market, theoretically the aquaponic industry can operate in the same manner. On the flip side, the core revenue crop for an aquaponic system may be aquaculture production. Essentially, the market will determine the species demand of the grower, whether the majority is fish or plants.

After analyzing overall combined hydroponic subsystem designs for both aquaponic and hydroponic trials, the hydroponic trial had significantly higher sweet basil FLM, yield, TVB, height, and AGRs. When looking at basil production on the basic level, hydroponics should produce the highest yields, faster, and with decreased production costs compared to aquaponics.

Although many may argue with this statement, commercially, aquaponics currently does not have means to compete with hydroponic nutrient concentrations, source, and inexpensive costs. With that said, hydroponic nutrients originate from mined minerals as well as natural gas, coal, or petroleum based products. These nutrients are not as sustainable as utilizing fish excretions for plant production. Although, current commercial fish feed is typically not considered being produced sustainably either, future fish feed innovations have an increased likelihood of becoming sustainable (compared to hydroponic nutrient production). Regardless, both practices are steps in the right direction for sustainable food production.

This study has also shown that hydroponic subsystem designs between aquaponic and hydroponic systems have an effect on sweet basil production. For FLM (kg), yield (kg/0.6027 m^2), and TVB (kg) there were significant differences between hydroponic media and aquaponic media filled hydroponic subsystems, hydroponic media and aquaponic DWC hydroponic subsystems, and hydroponic DWC and aquaponic media filled hydroponic subsystems; with hydroponic subsystem designs being significantly higher. Additionally, differences within each trial between hydroponic subsystem types were not significantly different from each other, except for height and AGR during the hydroponic trial. Furthermore, there was no significant difference between hydroponic DWC and aquaponic DWC hydroponic subsystems.

For height (cm) and AGR (cm/day) there were significant differences in sweet basil between hydroponic media and aquaponic DWC hydroponic subsystems, hydroponic media and aquaponic media filled hydroponic subsystems, hydroponic DWC and aquaponic DWC hydroponic subsystems, and lastly hydroponic DWC and aquaponic media filled hydroponic subsystems; with hydroponic subsystem designs being significantly higher. Moreover, differences within each trial between hydroponic subsystem types were not significantly different from each other.

There were significant differences between aquaponic and hydroponic media and DWC hydroponic subsystems for water quality and macronutrient parameters, except for temperature (°C), D.O. (ppm), and PO_4^{3-} (ppm).

Results from this study have given insight to production comparisons of aquaponics and hydroponics as well as hydroponic subsystem design. In summary, hydroponics will have significantly higher basil production. For DWC basil production (FLM, yield, TVB), aquaponic and hydroponic systems produced comparable yields.

CHAPTER 6

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APPENDIX A

Aquaponic Sweet Basil Growth

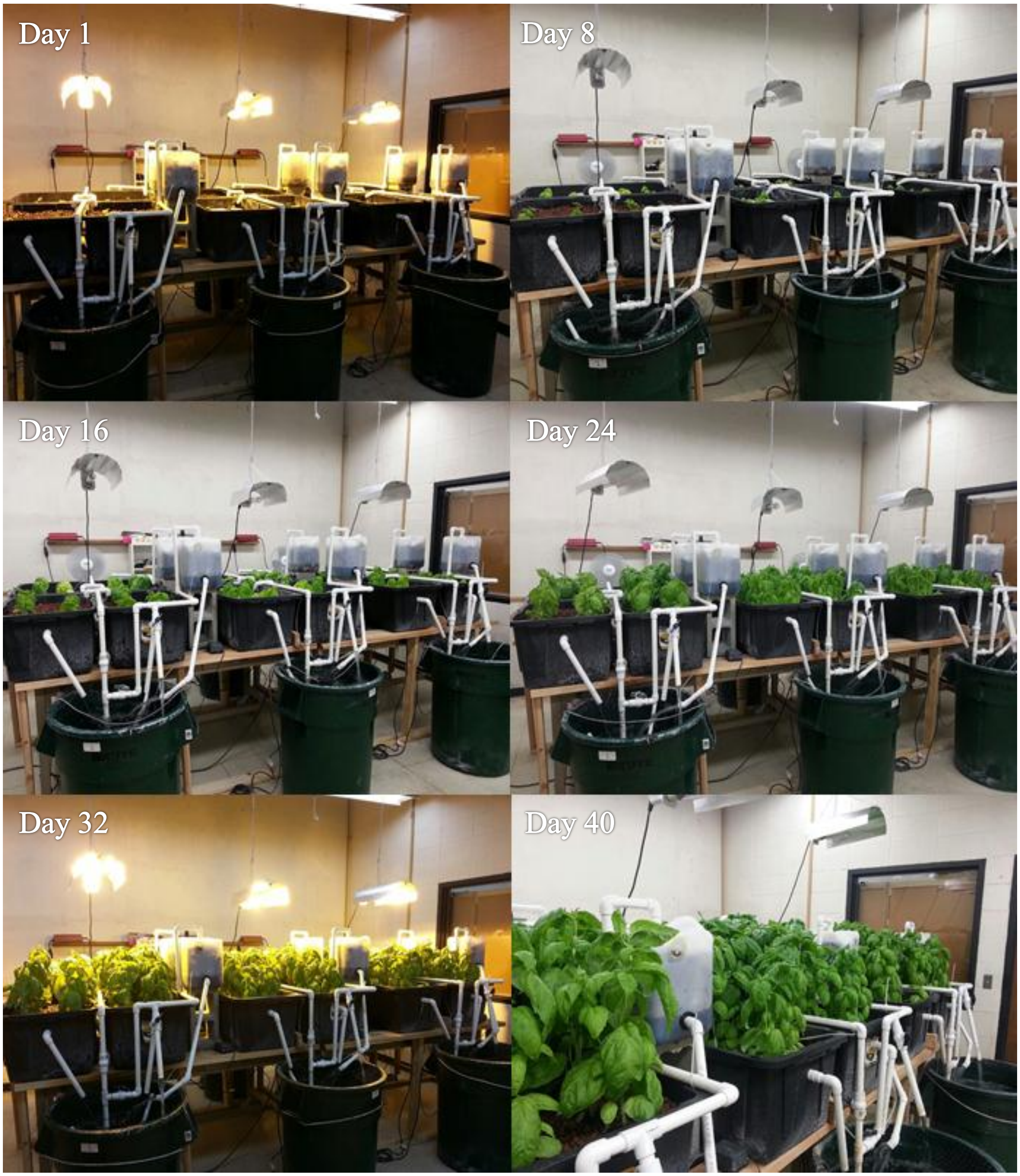


Plate 3.1 Aquaponic sweet basil growth

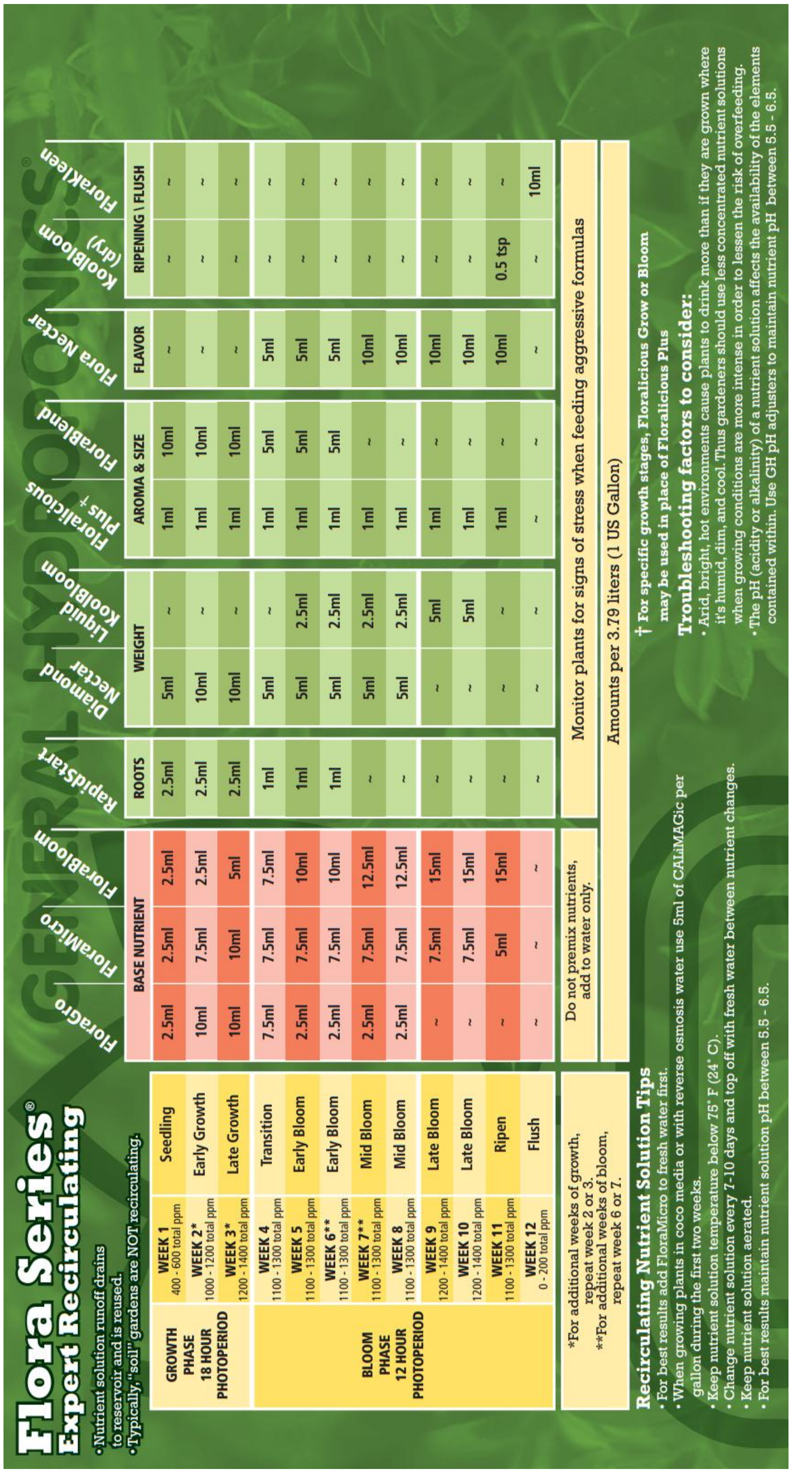
APPENDIX B

Hydroponic Sweet Basil Growth

Plate 3.2 Hydroponic sweet basil growth

APPENDIX C

General Hydroponics® Flora Series Expert Recirculating Feeding Schedule



Flora Series®
Expert Recirculating

- Nutrient solution runoff drains to reservoir and is reused.
- Typically, "soil" gardens are NOT recirculating.

			BASE NUTRIENT			ROOTS	WEIGHT		AROMA & SIZE		FLAVOR	RIPENING \ FLUSH	
			FloraGro	FloraMicro	FloraBloom	RapidStart	Diamond Nectar	Liquid KoolBloom	Floralicious Plus †	FloraBlend	Flora Nectar	KoolBloom (dry)	FloraKleen
GROWTH PHASE 18 HOUR PHOTOPERIOD	WEEK 1 400 - 600 total ppm	Seedling	2.5ml	2.5ml	2.5ml	2.5ml	5ml	~	1ml	10ml	~	~	~
	WEEK 2* 1000 - 1200 total ppm	Early Growth	10ml	7.5ml	2.5ml	2.5ml	10ml	~	1ml	10ml	~	~	~
	WEEK 3* 1200 - 1400 total ppm	Late Growth	10ml	10ml	5ml	2.5ml	10ml	~	1ml	10ml	~	~	~
BLOOM PHASE 12 HOUR PHOTOPERIOD	WEEK 4 1100 - 1300 total ppm	Transition	7.5ml	7.5ml	7.5ml	1ml	5ml	~	1ml	5ml	5ml	~	~
	WEEK 5 1100 - 1300 total ppm	Early Bloom	2.5ml	7.5ml	10ml	1ml	5ml	2.5ml	1ml	5ml	5ml	~	~
	WEEK 6** 1100 - 1300 total ppm	Early Bloom	2.5ml	7.5ml	10ml	1ml	5ml	2.5ml	1ml	5ml	5ml	~	~
	WEEK 7** 1100 - 1300 total ppm	Mid Bloom	2.5ml	7.5ml	12.5ml	~	5ml	2.5ml	1ml	~	10ml	~	~
	WEEK 8 1100 - 1300 total ppm	Mid Bloom	2.5ml	7.5ml	12.5ml	~	5ml	2.5ml	1ml	~	10ml	~	~
	WEEK 9 1200 - 1400 total ppm	Late Bloom	~	7.5ml	15ml	~	~	5ml	1ml	~	10ml	~	~
	WEEK 10 1200 - 1400 total ppm	Late Bloom	~	7.5ml	15ml	~	~	5ml	1ml	~	10ml	~	~
	WEEK 11 1100 - 1300 total ppm	Ripen	~	5ml	15ml	~	~	~	1ml	~	10ml	0.5 tsp	~
	WEEK 12 0 - 200 total ppm	Flush	~	~	~	~	~	~	~	~	~	~	10ml

*For additional weeks of growth, repeat week 2 or 3.
**For additional weeks of bloom, repeat week 6 or 7.

Do not premix nutrients, add to water only.

Monitor plants for signs of stress when feeding aggressive formulas

Amounts per 3.79 liters (1 US Gallon)

Recirculating Nutrient Solution Tips
- For best results add FloraMicro to fresh water first.
- When growing plants in coco media or with reverse osmosis water use 5ml of CALiMAGic per gallon during the first two weeks.
- Keep nutrient solution temperature below 75° F (24° C).
- Change nutrient solution every 7-10 days and top off with fresh water between nutrient changes.
- Keep nutrient solution aerated.
- For best results maintain nutrient solution pH between 5.5 - 6.5.

† For specific growth stages, Floralicious Grow or Bloom may be used in place of Floralicious Plus

Troubleshooting factors to consider:
- Arid, bright, hot environments cause plants to drink more than if they are grown where it's humid, dim, and cool. Thus gardeners should use less concentrated nutrient solutions when growing conditions are more intense in order to lessen the risk of overfeeding.
- The pH (acidity or alkalinity) of a nutrient solution affects the availability of the elements contained within. Use GH pH adjusters to maintain nutrient pH between 5.5 - 6.5.

Plate 3.3 General Hydroponics® Flora Series Expert Recirculating Feeding Schedule

APPENDIX D

General Hydroponics® Flora Series Feeding Schedule Utilized During Hydroponic Trial

Recommendations			FloraGro	FloraMicro	FloraBloom
Growth Phase	Week 1	Seedling	2.5 ml	2.5 ml	2.5 ml
18 hour Photoperiod	Week 2	Early Growth	7.5	5	0
	Weed 3	Late Growth	0	2.5	2.5 * water change
Bloom Phase	Week 4	Transition	7.5 ml	7.5 ml	7.5 ml
12 hour Photoperiod	Week 5	Early Bloom	0	0	2.5
	Week 6	Early Bloom			
	Week 7	Mid Bloom			
	Week 8	Mid Bloom			
	Week 9	Late Bloom			
	Week 10	Late Bloom			
	Week 11	Ripen			
	Week 12	Flush			

Amounts per 3.79 liters (1 US Gallon)

http://generalhydroponics.com/site/gh/docs/feeding_sched/GH-FloraSeries-REC-Charts.pdf

Media Filled

Per Gallon	Per 62 Gallons
2.5ml	155ml
5ml	310ml
7.5ml	465ml
10ml	620ml
12.5ml	775ml
15ml	930ml

Floating Raft

Per Gallon	Per 82 Gallons
2.5ml	205ml
5ml	410ml
7.5ml	615ml
10ml	820ml
12.5ml	1025ml
15ml	1230ml

Actual Media			FloraGro (ml)	FloraMicro	FloraBloom
Growth Phase	Week 1	Seedling	155	155	155
18 hour Photoperiod	Week 2	Early Growth	465	310	0
	Weed 3	Late Growth	0	155	155
Bloom Phase	Week 4	Transition	465	465	465
12 hour Photoperiod	Week 5	Early Bloom	0	0	155
	Week 6	Early Bloom			
	Week 7	Mid Bloom			
	Week 8	Mid Bloom			
	Week 9	Late Bloom			
	Week 10	Late Bloom			
	Week 11	Ripen			
	Week 12	Flush			

Actual Raft			FloraGro (ml)	FloraMicro	FloraBloom
Growth Phase	Week 1	Seedling	205	205	205
18 hour Photoperiod	Week 2	Early Growth	615	410	0
	Weed 3	Late Growth	0	205	205
Bloom Phase	Week 4	Transition	615	615	615
12 hour Photoperiod	Week 5	Early Bloom	0	0	205
	Week 6	Early Bloom			
	Week 7	Mid Bloom			
	Week 8	Mid Bloom			
	Week 9	Late Bloom			
	Week 10	Late Bloom			
	Week 11	Ripen			
	Week 12	Flush			

APPENDIX E

Aquaponic Trial Data

pH	9-Jan	11-Jan	13-Jan	15-Jan	17-Jan	19-Jan	21-Jan	23-Jan	25-Jan	27-Jan	29-Jan	31-Jan	2-Feb	4-Feb	6-Feb	8-Feb	10-Feb	12-Feb	14-Feb	16-Feb
Systems	9-Jan	11-Jan	13-Jan	15-Jan	17-Jan	19-Jan	21-Jan	23-Jan	25-Jan	27-Jan	29-Jan	31-Jan	2-Feb	4-Feb	6-Feb	8-Feb	10-Feb	12-Feb	14-Feb	16-Feb
1	7.2	7.5	7.3	7.1	7	7	7.7	7	7.3	7.2	7	7.3	7.2	7.4	7.1	7.1	7.1	6.8	6.8	6.8
2	7.2	7.2	7.4	7.4	7.3	7.3	7.3	7.3	7.4	7.2	6.9	7.4	7.2	6.9	6.9	6.8	7.2	7	6.9	6.8
3	7.1	7.3	7.4	7.4	7.3	7.3	7.4	7.3	7.5	7.4	7.1	7.5	7.3	7	7	6.9	7.4	7	7	6.9
4	7.4	7.4	7.4	7.1	7	7	6.7	6.8	7.1	7	6.8	7.1	6.8	6.6	6.7	6.7	6.9	6.7	6.6	6.7
5	7.1	7.3	7.2	7.2	7.2	7.2	7.1	7.2	7.5	7.5	7.2	7.6	7.5	6.8	7	6.9	7.5	7.1	7.2	7.2
6	7.2	7.1	7.3	7.1	7.1	7.1	6.9	7	7	6.9	6.7	7.1	6.8	6.8	6.8	6.6	6.9	6.7	6.7	6.8

TDS																				
Systems	9-Jan	11-Jan	13-Jan	15-Jan	17-Jan	19-Jan	21-Jan	23-Jan	25-Jan	27-Jan	29-Jan	31-Jan	2-Feb	4-Feb	6-Feb	8-Feb	10-Feb	12-Feb	14-Feb	16-Feb
1	505	516	573	606	553	592	398	333	443	473	447	486	473	meter brk	553	563	627	565	665	660
2	365	383	437	469	452	473	510	499	500	526	533	458	319		484	533	556	568	562	584
3	573	400	473	499	460	473	525	486	529	543	551	473	517		582	577	578	610	617	624
4	381	595	640	656	603	648	680	683	712	713	720	724	602		818	829	885	879	886	875
5	568	404	451	473	460	518	512	539	527	555	555	473	517		578	568	568	584	588	597
6	374	573	623	623	573	602	614	614	670	659	665	678	554		751	759	809	808	821	802

E.C.																				
Systems	9-Jan	11-Jan	13-Jan	15-Jan	17-Jan	19-Jan	21-Jan	23-Jan	25-Jan	27-Jan	29-Jan	31-Jan	2-Feb	4-Feb	6-Feb	8-Feb	10-Feb	12-Feb	14-Feb	16-Feb
1	1073	1100	1212	1227	1190	1250	860	755	932	953	970	1011	1063	1116	1140	1173	1256	1280	1273	1315
2	769	786	916	930	924	988	1017	1020	1058	1055	1100	940	995	1030	1050	1098	1084	1110	1051	1175
3	1173	846	971	1006	992	1064	1082	1096	1114	1120	1154	989	1091	1153	1175	1195	1149	1192	1223	1236
4	828	1230	1320	1333	1275	1383	1414	1384	1470	1459	1491	1533	1555	1547	1594	1610	1676	1610	1604	1617
5	1128	857	970	1002	980	1103	1120	1135	1138	1140	1155	981	1077	1137	1147	1172	1142	1173	1184	1201
6	844	1136	1246	1252	1175	1222	1249	1230	1328	1353	1350	1377	1440	1445	1415	1460	1509	1450	1455	1521

D.O.																				
Systems	9-Jan	11-Jan	13-Jan	15-Jan	17-Jan	19-Jan	21-Jan	23-Jan	25-Jan	27-Jan	29-Jan	31-Jan	2-Feb	4-Feb	6-Feb	8-Feb	10-Feb	12-Feb	14-Feb	16-Feb
1	8.18	8.18	8.43	8.4	8.26	8.03	8.87	8.79	8.26	8.08	7.68	8.68	8.35	8.35	8.13	8.24	8.16	8.22	7.88	8.25
2	8.01	7.99	8.22	8.36	8.08	7.97	8.33	8.46	8.12	7.93	7.56	8.67	8.03	8.33	8.01	7.81	7.66	8.04	8.05	8.29
3	8.16	8.24	8.4	8.44	8.25	8.13	8.88	8.64	8.22	8.22	7.67	8.68	8.45	8.4	8.1	8.28	8.04	8.22	7.88	8.05
4	8.03	8.16	8.22	8.43	8.13	7.97	8.66	8.52	8.26	8.08	7.63	8.61	8.27	8.33	8.1	7.84	7.98	8.26	8.29	8.25
5	7.89	8.19	8.49	8.47	8.37	8.22	8.7	8.3	8.22	8.56	7.46	8.54	8.14	8.23	7.8	7.73	7.98	8.29	7.91	8.39
6	8.27	7.88	8.14	8.2	7.9	7.65	8.63	8.16	7.91	7.92	7.25	8.19	7.76	7.8	7.58	7.34	7.25	7.7	7.78	7.68

Temp

Systems	9-Jan	11-Jan	13-Jan	15-Jan	17-Jan	19-Jan	21-Jan	23-Jan	25-Jan	27-Jan	29-Jan	31-Jan	2-Feb	4-Feb	6-Feb	8-Feb	10-Feb	12-Feb	14-Feb	16-Feb
1	21.7	21.4	19.9	19.5	20.7	21.5	17.6	19.1	20.8	22.2	22.9	19.9	20.2	20.8	2	22.1	21.9	21.8	21.7	20.9
2	22.2	21.7	20.5	20.5	21.4	22.1	19.2	20	21.3	22.7	23.3	20.4	20.7	21.4	8	22.3	22.4	22.2	22.1	21.2
3	22.1	21.9	20.2	19.8	21	21.9	18.6	19.4	21.1	22.5	23.2	20.3	20.5	21.4	8	22.5	22.5	22.1	22.3	21.9
4	22.4	21.5	20.2	19.9	21	21.7	18.9	19.9	20.9	22.4	22.3	20.1	20.6	21.3	1	22.4	22.3	22	22.1	21.6
5	22.4	22.1	20.5	20	21	22	19	19.9	21.5	22.8	23.5	20.9	21	21.9	8	23	22.7	22.2	22.5	21.9
6	22.4	21.8	20.5	20.1	21.2	22.1	19.3	20.2	21.4	22.8	23.4	20.7	21.8	21.7	1	22.9	22.7	22.7	22.7	21.9

TAN

Systems	9-Jan	11-Jan	13-Jan	15-Jan	17-Jan	19-Jan	21-Jan	23-Jan	25-Jan	27-Jan	29-Jan	31-Jan	2-Feb	4-Feb	6-Feb	8-Feb	10-Feb	12-Feb	14-Feb	16-Feb
1	0.25	1	2	2	2	2	0.5	0.25	0.25	0.5	0.5	0.5	1	1	0	2	1	1	2	2
2	0.25	1	2.0-4.0	8	8	8	8	8	8	8	8	8	4	8	0.25	8	4	4	4	4
3	0.25	1	4	4	8	8	8	8	8	8	8	8	8	8	0.25	8	4	8	8	8
4	0.25	0.5	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	0.5	1	0.5
5	0.25	1	2.0-4.0	4	8	8	8	8	8	8	8	8	8	8	0-0.25	8	4	8	8	8
6	0.25	0.5	1	0.5	0.5	0.5-1	0.5	1	1	1	0.5	0.5	0.5	0.5	0	1	0.5	0.5	0.5	0.5

NO2

Systems	9-Jan	11-Jan	13-Jan	15-Jan	17-Jan	19-Jan	21-Jan	23-Jan	25-Jan	27-Jan	29-Jan	31-Jan	2-Feb	4-Feb	6-Feb	8-Feb	10-Feb	12-Feb	14-Feb	16-Feb
1	0	0.25	2	0.5	0.25	0.0-0.25	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0.25	0.25	0.5	0.5	1	0.0-0.25	0.5	0-0.25	0	0.25	0-0.25	0.25	0-.25	0-.25	0
3	0	0	0	0	0	0.0-0.25	0.5	5	5	5	0.25	5	0-0.25	0.25	0.25	0-0.25	5	0-.25	0.25	0.25
4	0	0.25	1	0	0.25	0.0-0.25	0	0	0.0-0.25	0	0	0	0	0.25	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0.25	0.25	5	0.25	5	0	0	0-0.25	0-0.25	0.5	0-.25	0	0
6	0	0	0.0-0.25	0	0	0.0-0.25	0.0-0.25	0.0-0.25	0.0-0.25	0	0	0	0	0	0	0	0	0	0	0

NO3

Systems	9-Jan	11-Jan	13-Jan	15-Jan	17-Jan	19-Jan	21-Jan	23-Jan	25-Jan	27-Jan	29-Jan	31-Jan	2-Feb	4-Feb	6-Feb	8-Feb	10-Feb	12-Feb	14-Feb	16-Feb
1	0	0.0-5	5	5.0-10	0.0-0.5	0.0-5	0	0	0	0	0	0	0	0	0-5.0	0	0	10	0	0
2	0	0	0	0	0	5	5	5	5	5	0	5	0	5	5	0-5	0	5	0	0
3	0	0	0	0	0	0.0-5	5	10	10	10	0	10	0	0-5.0	5	0-5	0	10	0	0.5
4	0	0.0-5	5	5	0	0.0-5	0	0	0	0	0	0	0	5	20	0	0	20-40	0	0
5	0	0	0	0	0	0	0.0-5	0.0-5	5	5	5	10	0	0	0-5.0	0	0	0-5.0	0	0
6	0	0	0	0	0.0-5	0.0-5	5	0	0	0	0	0	0	5	10	0	0	20	0	0

	9-Jan	11-Jan	13-Jan	15-Jan	17-Jan	19-Jan	21-Jan	23-Jan	25-Jan	27-Jan	29-Jan	31-Jan	2-Feb	4-Feb	6-Feb	8-Feb	10-Feb	12-Feb	14-Feb	16-Feb
Room Temp C	24	23	22	21	23	23	18	21	23	23	24	21	22	23	22	24	23	23	24	23
Humidity %	49	45	31	32	33	33	26	38	30	52	43	28	36	32	39	35	34	34	34	31
Bed Temp F	9-Jan	11-Jan	13-Jan	15-Jan	17-Jan	19-Jan	21-Jan	23-Jan	25-Jan	27-Jan	29-Jan	31-Jan	2-Feb	4-Feb	6-Feb	8-Feb	10-Feb	12-Feb	14-Feb	16-Feb
1. Min		70	77	67	68	74	64	65	80	72	72		67	70				70	70	69
1. Max		80	78	77	80	81	74	77	80	82	83		79	80				78	73	72
2. Min		70	78	67	69	73	64	65	80	72	72		67	64				70	71	69
2. Max		83	78	77	79	80	74	77	80	81	82		78	80				77	77	75
3. Min		70	80	67	69	74	64	65	82	72	72		67	70				70	71	69
3. Max		85	80	79	82	83	77	80	83	85	85		81	82				74	74	72
H20 L	9-Jan	11-Jan	13-Jan	15-Jan	17-Jan	19-Jan	21-Jan	23-Jan	25-Jan	27-Jan	29-Jan	31-Jan	2-Feb	4-Feb	6-Feb	8-Feb	10-Feb	12-Feb	14-Feb	16-Feb
1	7.2	16.2	26.127	56.781	18.927	18.927	170.344	132.489	18.927	15.141	113.562	39.746	11.356	26.497	18.927	26.497	15.141	18.927	18.927	
2	7.2	10.8	18.927	56.781	9.463	9.463	11.356	85.171	34.068	11.356	113.562	28.39	7.57	18.927	18.927	90.849	18.927	18.927	18.927	
3	7.2	1.8	18.927	51.103	9.463	13.248	11.356	85.171	28.39	11.356	113.562	18.927	15.141	18.927	15.141	90.849	9.463	9.463	18.927	
4	3.6	16.2	28.39	58.673	18.927	11.356	11.356	28.39	18.927	7.57	113.562	28.39	13.248	18.927	15.141	18.927	18.927	18.927	18.927	
5	3.6	7.2	18.927	62.459	18.927	11.356	11.356	87.064	28.39	13.248	113.562	18.927	7.57	18.927	13.248	94.635	9.463	18.927	18.927	
6	2.4	12.6	18.927	66.244	9.463	15.141	11.356	18.927	11.356	11.356	113.562	18.927	18.927	18.927	15.141	18.927	18.927	9.463	15.141	
Stress Zyme	9-Jan	11-Jan	13-Jan	15-Jan	17-Jan	19-Jan	21-Jan	23-Jan	25-Jan	27-Jan	29-Jan	31-Jan	2-Feb	4-Feb	6-Feb	8-Feb	10-Feb	12-Feb	14-Feb	16-Feb
1		60			60			60				60				60				
2		80			80			80				80				80				
3		80			80			80				80				80				
4		60			60			60				60				60				
5		80			80			80				80				80				
6		60			60			60				60				60				
	9-Jan	11-Jan	13-Jan	15-Jan	17-Jan	19-Jan	21-Jan	23-Jan	25-Jan	27-Jan	29-Jan	31-Jan	2-Feb	4-Feb	6-Feb	8-Feb	10-Feb	12-Feb	14-Feb	16-Feb
Maxicrop				26 oz				26oz 5ml				26oz 5ml				26oz 5ml				
1																				
2																				
3																				
4																				
5																				
6																				

NH3	15-Jan				23-Jan				31-Jan				8-Feb				16-Feb			
System	a	b	c	X̄	a	b	c	X̄	a	b	c	X̄	a	b	c	X̄	a	b	c	X̄
1	3.17656	2.81856	2.94744	2.48564	1.21224	1.29816	1.12632	1.21224	0.42464	0.45328	0.4676	0.448507	1.30064	1.79468	1.30064	1.46532	3.57752	5.55368	3.54888	4.226693
2	6.7136	6.7494	7.0358	5.6247	8.38656	8.18608	7.49872	8.023787	14.6444	13.9284	13.9284	14.16707	3.9212	4.26488	4.19328	4.126453	4.17896	4.10736	4.17896	4.155093
3	7.9308	7.3938	7.8592	6.54595	8.35792	7.87104	7.21232	7.81376	15.1456	16.0048	15.0024	15.38427	6.0692	3.241	6.3914	5.233867	8.2888	8.2888	8.2888	8.2888
4	1.76604	1.52976	1.62284	2.22966	2.05712	1.828	2.14304	2.009387	1.24088	1.26952	1.38408	1.29816	0.88536	0.90684	0.8782	0.890133	1.74456	1.57988	1.31496	1.546467
5	6.642	6.6062	6.9642	6.3031	10.1336	10.19088	8.93072	9.751733	12.9976	12.4248	11.9236	12.44867	6.0334	5.8186	6.5704	6.1408	8.9332	8.79	8.8616	8.8616
6	1.22904	1.18608	1.17176	2.39672	1.45568	1.36976	1.52728	1.450907	1.3984	1.5416	1.828	1.589333	0.8066	0.76364	0.77796	0.782733	0.6276	1.4868	0.93548	1.016627

NO3	15-Jan				23-Jan				31-Jan				8-Feb				16-Feb			
System	a	b	c	X̄	a	b	c	X̄	a	b	c	X̄	a	b	c	X̄	a	b	c	X̄
1	11.0676	11.0676	11.0676	11.0676	11.70566	11.80858	11.27269	11.59564	7.3784	7.39565	7.39485	7.389633	12.46933	12.00802	12.38133	12.28622	20.86588	19.67593	21.11859	20.55347
2	2.615553	2.549949	2.493808	2.553104	2.697179	2.395777	2.619411	2.570789	5.562163	5.640647	5.316439	5.506416	3.947905	3.769092	3.716207	3.811068	4.158221	3.792566	6.468496	4.806428
3	2.108057	2.081845	2.081845	2.090583	3.535401	4.342038	3.989755	3.955732	4.13203	4.247364	3.982246	4.120547	5.487942	4.280318	4.135559	4.634606	6.533428	7.070803	8.519404	7.374545
4	11.09348	11.09348	11.09348	11.09348	13.41941	13.56084	13.56084	13.51369	11.09228	11.09348	11.1009	11.09555	13.68894	13.68894	13.68894	13.68894	26.46425	26.05132	26.59337	26.36965
5	2.959857	2.6263	2.615553	2.733903	2.305727	2.294447	2.01071	2.203628	3.408227	4.110838	3.728887	3.749317	1.573053	1.665831	1.573053	1.603979	3.215769	3.053073	3.053073	3.107305
6	11.1009	11.09228	11.09228	11.09515	13.29669	13.41941	13.68894	13.46835	11.1009	11.09228	11.09228	11.09515	13.56084	13.56084	13.41941	13.51369	25.75473	24.01604	25.11039	24.96039

NO2	15-Jan				23-Jan				31-Jan				8-Feb				16-Feb			
System	a	b	c	X̄	a	b	c	X̄	a	b	c	X̄	a	b	c	X̄	a	b	c	X̄
1	0.16485	0.170165	0.159516	0.164843	0.049896	0.032678	0.030755	0.037776	0.029793	0.027866	0.02883	0.028829	0.024973	0.027866	0.015294	0.022711	0.0346	0.025938	0.02883	0.029789
2	0.030755	0.0346	0.048944	0.038099	0.138899	0.133475	0.135285	0.135886	0.096845	0.099621	0.099621	0.098695	0.050847	0.051799	0.053699	0.052115	0.042264	0.036519	0.056546	0.04511
3	0.039394	0.02883	0.026902	0.031709	0.250172	0.256845	0.264314	0.25711	0.222293	0.229952	0.242624	0.231623	0.059389	0.063172	0.069772	0.064111	0.076346	0.06883	0.107	0.084059
4	0.107921	0.105159	0.099621	0.104233	0.03556	0.032678	0.067888	0.045375	0.050847	0.080092	0.047991	0.059643	0.206849	0.023041	0.024007	0.084632	0.026902	0.027866	0.026902	0.027223
5	0.023041	0.025938	0.024007	0.024328	0.279944	0.26762	0.266794	0.271453	0.079156	0.069772	0.076346	0.075091	0.047991	0.046084	0.051799	0.048625	0.037478	0.04513	0.031717	0.038108
6	0.059389	0.056546	0.060335	0.058757	0.081961	0.041308	0.04322	0.055496	0.056546	0.057494	0.067888	0.060643	0.032678	0.030755	0.032678	0.032037	0.03556	0.029793	0.031717	0.032356

PO4	15-Jan				23-Jan				31-Jan				8-Feb				16-Feb			
System	a	b	c	X̄	a	b	c	X̄	a	b	c	X̄	a	b	c	X̄	a	b	c	X̄
1	229.676	254.948	243.716	242.78	391.136	363.056	377.096	377.096	357.44	320.936	326.552	334.976	396.752	396.752	419.216	404.24	419.216	413.6	413.6	415.472
2	263.372	288.644	315.32	289.112	441.68	399.56	413.6	418.28	354.632	377.096	351.824	361.184	407.984	424.832	424.832	419.216	354.632	385.52	402.368	380.84
3	320.936	306.896	306.896	311.576	407.984	407.984	424.832	413.6	374.288	365.864	377.096	372.416	413.6	441.68	436.064	430.448	377.096	360.248	379.904	372.416
4	226.868	206.931	193.452	209.0837	368.672	379.904	374.288	374.288	295.664	304.088	276.008	291.92	340.592	329.36	343.4	337.784	402.368	396.752	391.136	396.752
5	284.432	320.936	337.784	314.384	424.832	413.6	413.6	417.344	374.288	377.096	357.44	369.608	374.288	419.216	413.6	402.368	396.752	385.52	363.056	381.776
6	211.424	177.166	186.152	191.5807	346.208	349.016	334.976	343.4	240.908	306.896	298.472	282.092	430.448	419.216	413.6	421.088	407.984	391.136	391.136	396.752

SO4	15-Jan				23-Jan				31-Jan				8-Feb				16-Feb			
System	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$
1	140.7537	132.8067	140.7537	138.1047	86.4412	86.73337	83.56818	85.58092	60.17455	66.32208	61.73254	62.74306	87.32042	86.4412	82.72315	85.49492	100.8771	89.70532	88.80402	93.12881
2	38.73626	24.29849	24.60443	29.21306	47.20545	44.22463	50.43653	47.28887	56.48277	54.15588	29.6248	46.75449	57.34043	28.5315	34.5414	40.13778	33.26944	33.17146	54.78608	40.40899
3	19.94363	22.24231	25.11299	22.43298	48.81332	50.84498	47.60609	49.08813	56.05632	53.52882	54.78608	54.79041	30.61435	28.73068	45.61079	34.98527	36.7861	30.12006	32.09201	32.99939
4	28.73068	40.88478	50.43653	40.01733	123.2303	62.18206	38.05361	74.48866	135.0315	115.2883	127.4	125.9066	36.7861	83.85156	60.6173	60.41832	63.08716	166.0751	57.98797	95.71675
5	43.04216	36.88361	40.10277	40.00951	48.0076	47.20545	46.60602	47.27302	46.80563	52.07721	50.23271	49.70518	26.12531	28.63111	29.02912	27.92851	29.6248	34.24815	31.8954	31.92278
6	101.724	163.3589	56.48277	107.1885	166.0751	139.5907	152.9116	152.8592	139.5907	152.9116	152.9116	148.4713	97.55688	39.71212	52.07721	63.1154	81.60822	40.5914	47.00544	56.40169

Hardness	15-Jan				23-Jan				31-Jan				8-Feb				16-Feb			
System	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$
1	256	268	404	309.3333	376	344	352	357.3333	280	316	264	286.6667	496	372	468	445.3333	528	400	448	458.6667
2	352	276	324	317.3333	304	352	312	322.6667	304	336	292	310.6667	332	404	644	460	316	404	372	364
3	324	296	308	309.3333	372	320	300	330.6667	284	308	280	290.6667	496	432	364	430.6667	380	380	404	388
4	388	664	460	504	428	520	572	506.6667	400	436	492	442.6667	440	600	424	488	516	444	472	477.3333
5	284	268	316	289.3333	312	304	412	342.6667	312	348	348	336	324	388	432	381.3333	328	324	368	340
6	352	372	396	373.3333	376	448	416	413.3333	428	388	472	429.3333	428	416	488	444	508	424	524	485.3333

Alkalinity	15-Jan				23-Jan				31-Jan				8-Feb				16-Feb			
System	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$
1	60	50	40	50	50	70	60	60	60	50	70	60	70	60	60	63.33333	90	70	70	76.66667
2	70	70	70	70	80	80	80	80	70	80	80	76.66667	60	60	70	63.33333	70	70	70	70
3	80	80	60	73.33333	80	70	70	73.33333	90	80	80	83.33333	60	60	70	63.33333	80	70	90	80
4	50	40	40	43.33333	40	60	70	56.66667	40	50	40	43.33333	50	60	60	56.66667	60	80	80	73.33333
5	60	60	50	56.66667	90	90	90	90	80	80	70	76.66667	60	80	70	70	90	100	90	93.33333
6	50	40	50	46.66667	50	50	50	50	55	50	50	51.66667	60	50	50	53.33333	60	70	60	63.33333

Fish Initial					Fish Final		
System	Kg	#	FCR		System	Kg	#
1	1.1	25	0.0165		1	1.672	25
2	1.122	26	0.0168		2	1.762	26
3	1.084	28	0.0162		3	1.67	28
4	1.098	30	0.0164		4	1.732	30
5	1.046	31	0.0156		5	1.566	31
6	1.086	32	0.0162		6	1.748	32
Specific Growth Rate					1	0.572	
system	kg				2	0.64	
1	1.0467				3	0.586	
2	1.1283				4	0.634	
3	1.0804				5	0.52	
4	1.1394				6	0.662	
5	1.0088				Average mass gain/ fish	0.602333	
6	1.1899						

Plant (cm)	15-Jan	23-Jan	31-Jan	8-Feb	16-Feb	Absolute growth rate
1	4.1	11	21	33	41.1	1.15625
2	6.5	14	26.5	39	53	1.453125
3	3.5	8.9	20.5	33.6	45.5	1.3125
4	4.6	10.4	21.2	32.9	45	1.2625
5	1.6	5	14.4	23.5	39	1.16875
6	3.7	8.4	19.1	31	41.8	1.190625
7	2.6	5.8	13	25.6	38.9	1.134375
8	4	10	22.2	32.3	45.5	1.296875
9	2.6	7.4	15.4	23.1	42.3	1.240625
10	3.8	7.5	13.4	27.2	36.2	1.0125
11	4	9.4	19.8	34	46.2	1.31875
12	3.7	8.5	16.8	29.5	42.2	1.203125
13	6.4	13.5	22.2	36.6	44.2	1.18125
14	5.6	12.4	26	37.2	53.1	1.484375
15	6.1	13	25	32	47.9	1.30625
16	5	9.7	20.4	35.8	41	1.125
17	3.9	10	20.5	35.3	46	1.315625
18	2.1	5.4	15.1	25.6	47	1.403125
19	2.6	7	17.2	28.9	40.6	1.1875
20	3.4	7.4	15.8	29	43.1	1.240625
21	6.9	12.6	19.5	33	38	0.971875
22	5.4	12.8	23.5	38.5	48	1.33125
23	6.6	15	23.5	34.8	47.3	1.271875
24	3.1	8	16.8	35.8	42.1	1.21875
25	5.7	13.3	24	35.2	47.1	1.29375
26	2.8	7.4	16.7	29.4	38.8	1.125
27	4.5	9.4*	20.5	32.5	42.1	1.175
28	5.4	11.6	19.6	34	45.7	1.259375
29	4	12.1*	23.1	35	47.2	1.35
30	2	6*	15.6	39.5	38	1.125
31	4.4	12	23	35.9	46.7	1.321875
32	3.5	8*	17	31	39.1	1.1125
33	5.7	14	25.1	36.5	47.5	1.30625
34	1.2	3.5	10.4	23	22.8	0.675
35	2.3	7	18	31.4	38.5	1.13125
36	5.1	12.8	25	36.5	49.8	1.396875
37	3.2	9	14.4	34.4	42.5	1.228125

38	3	9.4	21	35	44.5	1.296875
39	3.9	10.2	22.2	35.9	40.4	1.140625
40	6.1	16	30	42.1	51.1	1.40625
41	3	6.9	13	21.1	28.1	0.784375
42	6.4	13	24.6	32.5	34.5	0.878125
43	4.5	10.7	20.9	30.2	41	1.140625
44	3.2	10.2	22	34	45	1.30625
45	2.6	6.5	14.3	30.4	38.6	1.125
46	6.1	11.5	20	29.4	35.6	0.921875
47	4	7.4	15.8	28	36.1	1.003125
48	2.3	4.7*	10	20.2	36.6	1.071875
49	6.2	14.4	25.9	35.6	50	1.36875
50	2	6	16.8	18	39.1	1.159375
51	1.1	3	8	14.9	21.4	0.634375
52	5	11.5	23.6	34	44.1	1.221875
53	5.5	12*	21.5	34.5	48.5	1.34375
54	4.4	4.6	19.5	33	53.4	1.53125
55	3.9	9.9	20.6	32.1	44.2	1.259375
56	3.6	8	18.7	30.2	38.1	1.078125
57	2.2	5.3	12.4	25.1	36.9	1.084375
58	6.7	15	26	38.2	51.7	1.40625
59	1	2	5	10.9	24.7	0.740625
60	4.3	10.6	21	34.2	44.9	1.26875
61	3.1	6.4	13	15.5	0	-0.096875
62	2.7	7.3	16.1	25.6	36.6	1.059375
63	3.7	9.2	18.8	28	43.5	1.24375
64	2	4.5	10.7	22.5	38	1.125
65	3.4	8	9.4	13.9	36.4	1.03125
66	1.5	1.5	3.1	10.5	13.5	0.375
67	5.3	9.5	16.8	29	43.4	1.190625
68	3.4	8	14.5	24.6	35.6	1.00625
69	5.8	11.5	18.5	30	55.1	1.540625
70	4	10	22.4	36	49	1.40625
71	3.1	6.6	12.3	18	23.1	0.625
72	6.1	12	22	32.8	47	1.278125
73	4.8	11.1	23.1	38.4	53	1.50625
74	2.4	6.9	14.9	30.7	47.1	1.396875

75	4	9	20.2	33	57	1.65625
76	5	11	18.2	27	38.9	1.059375
77	3.6	8.2	16.5	30.4	41.2	1.175
78	6	12.2	24	35.6	52	1.4375
79	4.2	9.5	18.3	34	45	1.275
80	4.3	10.6	25	40.5	54.1	1.55625
81	4.2	10.1	20.5	32	38.6	1.075
82	4.1	7	12.8	26	35.7	0.9875
83	4.2	11.8	23.4	34.9	43.5	1.228125
84	1.1	3	8.8	19.6	33.3	1.00625
85	4.3	9.9	19.5	32	41.9	1.175
86	1.2	3.8	6.5	10.5	12.6	0.35625
87	6.1	14.4	23.6	34.9	47	1.278125
88	4.1	9.4	19.4	35.6	45	1.278125
89	6	13.4	27.2	41.1	55.3	1.540625
90	5.4	13.3	24.3	32.9	50.1	1.396875
91	2.9	6.1	13.1	25	33.1	0.94375
92	3.1	7.9	17.3	29.5	36.4	1.040625
93	6	14.3	27.5	35	52	1.4375
94	4.5	11.1	22	34.9	45	1.265625
95	4.7	10.4	22.9	31.5	45.5	1.275
96	4	8.3	18.1	35.4	42.1	1.190625
97	6	11.5	22.2	38.3	46.1	1.253125
98	5	10.9	21.9	34.9	42.8	1.18125
99	3.4	12.4	24.5	41	46.9	1.359375
100	2.5	4	12.8	25.1	29.6	0.846875
101	2.5	5.6	12.4	22.5	31.4	0.903125
102	2	4.9	11.1	22.9	34.9	1.028125
103	4.8	10.5	22.3	38.2	47.5	1.334375
104	4	10	20.4	33.9	47.9	1.371875
105	3.1	5	12	25.8	41.4	1.196875
106	1.5	4.8	11.5	20	29.8	0.884375
107	4.1	4.3	19	28.5	43.7	1.2375
108	4.6	10.6	17.5	32.5	48	1.35625
109	6	14.8	27.2	42.3	54.9	1.528125
110	2.5	7	16	29.5	44.4	1.309375

111	3.7	7.4	16.1	26	37.5	1.05625
112	3.6	7.9	13.9	29	45.4	1.30625
113	4	9.3	19.2	31.9	47.3	1.353125
114	3.7	8.4	20	33	46	1.321875
115	3	7.3	14.8	34	40.4	1.16875
116	4.1	8.4	13.6	28.2	32.2	0.878125
117	5	12.2	21	22	43.7	1.209375
118	3	7.6	13.5	27	41	1.1875
119	3.7	11	23.4	36.5	54.5	1.5875
120	3	5	13.9	22.1	38.4	1.10625

Basil Weight (kg)	Whole Plant (kg)	Leaf (kg)	Time
System 1 Media			
1	0.048	0.032	0.104167
2	0.074	0.048	0.081944
3	0.072	0.046	0.069444
4	0.104	0.062	0.077778
5	0.076	0.044	0.077083
6	0.058	0.04	0.055556
7	0.038	0.022	0.043056
8	0.082	0.05	0.080556
9	0.06	0.034	0.060417
10	0.11	0.068	0.064583
11	0.054	0.032	0.0625
12	0.038	0.022	0.045833
13	0.136	0.076	0.075694
14	0.172	0.1	0.090278
15	0.208	0.116	0.107639
16	0.064	0.046	0.048611
17	0.082	0.054	0.064583
18	0.056	0.038	0.045833
19	0.094	0.05	0.0625
20	0.12	0.068	0.065972
System 2 DWC			
21	0.056	0.04	0
22	0.1	0.064	0.063194
23	0.1	0.062	0.090972
24	0.074	0.046	0.0625
25	0.19	0.114	0.102778
26	0.054	0.04	0.052778
27	0.078	0.054	0.065972
28	0.124	0.074	0.080556
29	0.184	0.114	0.099306
30	0.086	0.052	0.054861
31	0.118	0.074	0.084722
32	0.042	0.022	0.072222
33	0.246	0.148	0.126389
34	0.032	0.014	0.09375
35	0.14	0.08	0.131944
36	0.134	0.094	0.109028

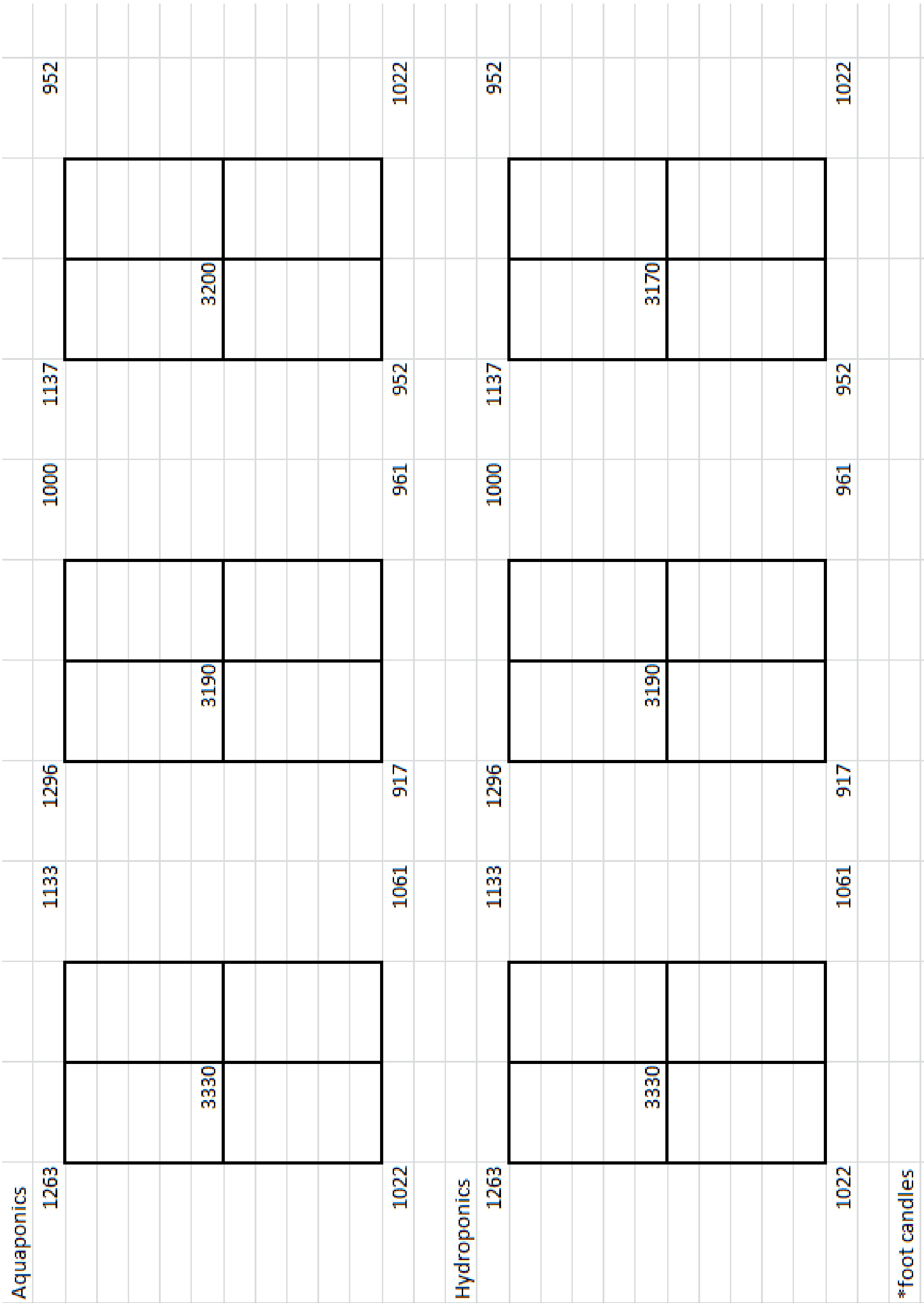
37	0.102	0.064	0.084722
38	0.154	0.094	0.098611
39	0.184	0.114	0.113194
40	0.298	0.18	0.149306
System 3 DWC			
41	0.024	0.018	0.048611
42	0.062	0.04	0.090278
43	0.074	0.05	0.076389
44	0.154	0.092	0.076389
45	0.112	0.064	0.075694
46	0.042	0.028	0.056944
47	0.048	0.032	0.050694
48	0.022	0.014	0
49	0.28	0.178	0.141667
50	0.078	0.042	0.061806
51	0.014	0.01	0.125
52	0.068	0.04	0.05
53	0.082	0.05	0.056944
54	0.12	0.07	0.059028
55	0.17	0.094	0.111806
56	0.058	0.042	0.083333
57	0.024	0.016	0.040278
58	0.132	0.084	0.11875
59	0.01	0.008	0.039583
60	0.18	0.114	0.080556
System 4 Media			
61	0	0	0
62	0.058	0.038	0.045833
63	0.074	0.044	0.090972
64	0.054	0.034	0.072917
65	0.036	0.02	0.074306
66	0.008	0.006	0.060417
67	0.058	0.032	0.070139
68	0.042	0.018	0.059722
69	0.114	0.064	0.086806
70	0.206	0.118	0.09375

71	0.016	0.008	0.036806
72	0.104	0.066	0.065972
73	0.158	0.092	0.074306
74	0.092	0.052	0.065278
75	0.156	0.088	0.083333
76	0.048	0.032	0.052778
77	0.044	0.03	0.053472
78	0.112	0.064	0.075
79	0.122	0.068	0.072222
80	0.214	0.126	0.098611
System 5 DWC			
81	0.056	0.036	0.048611
82	0.032	0.018	0.0625
83	0.112	0.074	0.070139
84	0.028	0.018	0.0375
85	0.164	0.104	0.106944
86	0.006	0.006	0.047917
87	0.078	0.052	0.052778
88	0.062	0.04	0.05625
89	0.218	0.132	0.121528
90	0.188	0.112	0.079861
91	0.036	0.026	0.0375
92	0.044	0.032	0.038194
93	0.14	0.086	0.066667
94	0.154	0.098	0.081944
95	0.158	0.098	0.070139
96	0.048	0.03	0.040972
97	0.068	0.044	0.05
98	0.088	0.058	0.051389
99	0.138	0.09	0.066667
100	0.08	0.056	0.053472
System 6 Media			
101	0.04	0.024	0.063194
102	0.03	0.02	0.040278
103	0.122	0.076	0.061111
104	0.134	0.078	0.072222
105	0.094	0.054	0.074306
106	0.048	0.032	0.050694
107	0.072	0.044	0.059028

108	0.07	0.04	0.059722
109	0.234	0.14	0.088194
110	0.126	0.068	0.059722
111	0.078	0.052	0.056944
112	0.056	0.036	0.052778
113	0.14	0.082	0.061806
114	0.162	0.096	0.067361
115	0.09	0.054	0.056944
116	0.04	0.026	0.038889
117	0.072	0.044	0.060417
118	0.058	0.032	0.046528
119	0.166	0.098	0.071528
120	0.09	0.056	0.053472

APPENDIX F

Aquaponic and Hydroponic Foot Candle Data



APPENDIX G

Hydroponic Trial Data

pH	11-Apr	13-Apr	15-Apr	17-Apr	19-Apr	21-Apr	23-Apr	25-Apr	27-Apr	29-Apr	1-May	3-May	5-May	7-May	9-May	11-May	13-May	15-May	17-May	19-May
Systems	11-Apr	13-Apr	15-Apr	17-Apr	19-Apr	21-Apr	23-Apr	25-Apr	27-Apr	29-Apr	1-May	3-May	5-May	7-May	9-May	11-May	13-May	15-May	17-May	19-May
1	7.7	7.2	7.1	7.1	7.1	6.9	7	6.5	6.7	6.7	6.6	6.5	7	6.6	6.4	6.4	6.6	6.7	7.3	6.7
2	7.8	7.1	7	7	7.1	6.7	7.1	6.9	7.1	7	7	7	7.5	7.2	7	6.8	6.9	6.9	7.1	6.4
3	7.9	7.2	7.1	7.1	7.1	6.8	7.1	6.8	6.9	7	6.8	6.8	7.3	7	7	6.9	6.9	7	7.3	6.7
4	7.8	7.1	6.9	7	7.1	6.8	7	6.8	6.7	6.6	6.6	6.6	7.3	6.8	6.5	6.6	6.7	6.8	7.1	6.7
5	7.5	6.8	6.9	7	6.9	6.7	7	6.7	6.9	6.9	6.8	7	7.4	7.2	7	6.9	6.9	7.1	7.2	6.1
6	7.8	7	6.8	6.9	7	6.8	7	6.8	7	6.9	6.8	6.9	7.4	7.1	6.8	6.9	6.9	7	7.3	6.8

TDS																				
Systems	11-Apr	13-Apr	15-Apr	17-Apr	19-Apr	21-Apr	23-Apr	25-Apr	27-Apr	29-Apr	1-May	3-May	5-May	7-May	9-May	11-May	13-May	15-May	17-May	19-May
1	647	673	680	697	1080	1060	1050	1040	1220	1180	1160	1150	1380	1370	1350	1350	1350	1340	1320	1340
2	651	677	699	698	1280	1220	1220	1080	1410	1360	1350	1370	1650	1530	1590	1550	1570	1540	1560	1540
3	627	656	664	669	1250	1160	1160	1160	1360	1633	1290	1330	1610	1590	1560	1560	1550	1510	1540	1510
4	672	636	726	719	1160	1040	1090	1020	1260	1090	1070	1170	1420	1350	1340	1320	1350	1300	1310	1290
5	639	685	705	701	1330	1220	1220	1240	1420	1390	1370	1410	1620	1590	1590	1580	1610	1570	1600	1580
6	645	679	711	684	1120	1060	1040	1060	1150	1120	1090	1090	1310	1260	1230	1210	1200	1160	1150	1120

E.C.																				
Systems	11-Apr	13-Apr	15-Apr	17-Apr	19-Apr	21-Apr	23-Apr	25-Apr	27-Apr	29-Apr	1-May	3-May	5-May	7-May	9-May	11-May	13-May	15-May	17-May	19-May
1	1268	1361	1378	1338	2168	2093	2031	2043	2369	2275	2279	2256	2634	2569	2571	2545	2640	2560	2578	2571
2	1152	1297	1303	1311	2363	2167	2101	2016	2660	2535	2482	2336	2916	2550	2820	2880	2920	2800	2728	2857
3	1222	1321	1284	1306	2343	2290	2150	2202	2618	2524	2524	2465	3032	2916	2940	2880	2985	2910	2888	2880
4	1321	1324	1341	1401	2237	2151	2031	2068	2411	2325	2326	2186	2612	2516	2510	3469	2644	2510	2427	2509
5	1240	1353	1362	1364	2481	2365	2291	2215	2710	2610	2365	2589	3033	2955	2965	2930	3062	2985	2965	3000
6	1150	1329	1373	1340	2109	2056	1906	1920	2220	2045	2073	1934	2460	2378	2365	2310	2371	2274	2223	2194

D.O.																				
Systems	11-Apr	13-Apr	15-Apr	17-Apr	19-Apr	21-Apr	23-Apr	25-Apr	27-Apr	29-Apr	1-May	3-May	5-May	7-May	9-May	11-May	13-May	15-May	17-May	19-May
1	8.09	8.36	8.36	7.85	8.27	8.18	8.11	8.08	8.03	7.82	7.73	8	7.82	7.66	7.44	8.01	7.69	7.98	7.95	7.42
2	7.96	8.15	8.09	7.73	8.04	8.08	7.95	7.87	7.97	7.54	7.52	7.82	7.69	7.53	7.31	7.82	7.51	7.85	7.63	7.21
3	8.1	8.27	8.18	7.85	8.19	8.19	8.12	8.06	7.97	7.74	7.63	7.94	7.77	7.64	7.45	7.9	7.65	7.93	7.94	7.37
4	8.05	8.24	8.13	7.75	8.13	8.05	7.98	7.89	7.82	7.56	7.57	7.89	7.64	7.58	7.41	7.95	7.65	7.91	7.78	7.29
5	7.96	8.12	8.05	7.83	8.15	8.02	8.04	7.92	7.89	7.68	7.57	7.79	7.74	7.6	7.42	7.93	7.62	7.93	7.88	7.29
6	7.98	8.23	8.07	7.73	8.07	8.08	7.94	7.86	7.85	7.57	7.77	7.83	7.66	7.55	7.37	7.77	7.68	8.07	7.85	7.28

Temp																					
Systems	11-Apr	13-Apr	15-Apr	17-Apr	19-Apr	21-Apr	23-Apr	25-Apr	27-Apr	29-Apr	1-May	3-May	5-May	7-May	9-May	11-May	13-May	15-May	17-May	19-May	
1	22.9	21.6	21	22.9	21.6	21.7	22.1	22.4	21.6	23	23.9	20.8	22	22.1	23.2	22	21.8	23.8	23.7	25.6	
2	23	22	21.6	23	21.6	21.7	22.2	22.5	21.8	23	23.8	21.2	22.2	22.2	23.3	22.2	22	23.7	23.7	25.6	
3	22.8	21.9	21.6	22.8	21.4	21.3	21.8	22.1	21.7	23	23.8	20.9	22.2	22.2	23.3	22	22	23.8	23.7	25.6	
4	22.4	21.7	21.3	22.8	21.1	21.5	22	22.3	21.6	22.8	23.6	20.7	21.7	22	23	21.7	21.2	23.4	23.4	25.3	
5	23.4	22.5	22	23.2	21.3	21.8	22.2	22.6	22	23.2	24.1	21.6	21.9	22.1	23.2	21.1	21.8	23.6	23.6	25.5	
6	22.9	22.1	21.7	23.2	21.5	21.8	22.3	2..5	21.9	23	23.9	21.1	21.9	21.9	23	21.9	21.5	23.5	23.4	25.3	
	11-Apr	13-Apr	15-Apr	17-Apr	19-Apr	21-Apr	23-Apr	25-Apr	27-Apr	29-Apr	1-May	3-May	5-May	7-May	9-May	11-May	13-May	15-May	17-May	19-May	
Room Temp C	25	23	28	23		23	23	23	22	24	25	22	22	22	24	22	23	25	25	26	
Humidity %	35	40	42	53		39	41	39	55	60	55	43	51	53	62	56	53	67	59	74	
Bed Temp F	11-Apr	13-Apr	15-Apr	17-Apr	19-Apr	21-Apr	23-Apr	25-Apr	27-Apr	29-Apr	1-May	3-May	5-May	7-May	9-May	11-May	13-May	15-May	17-May	19-May	
1. Min	74	72	70			69	70	73	70		73	68	71	69	71	69	0	72	74	76	
1. Max	85	82	81			81	82	83	81		84	80	78	73	74	72	0	76	76	78	
2. Min	74	72	70			70	70	73	70		73	68	71	73	71	69	69	0	0	0	
2. Max	86	85	84			85	86	87	85		90	84	81	83	75	73	72	0	0	0	
3. Min	74	72	70			70	70	72	70		73	68	71	69	71	69	69	72	73	76	
3. Max	87	85	84			85	85	86	84		86	81	81	82	75	73	72	76	75	78	
H20 L	11-Apr	13-Apr	15-Apr	17-Apr	19-Apr	21-Apr	23-Apr	25-Apr	27-Apr	29-Apr	1-May	3-May	5-May	7-May	9-May	11-May	13-May	15-May	17-May	19-May	
1	0	18.927	22.712	18.927	18.927	18.927	15.141	18.927	18.927	15.141	9.463	170.344	18.927		15.141	18.927	18.927	9.463	15.141	0	
2	0	15.141	18.927	13.248	0	18.927	17.034	18.927	18.927	15.141	17.034	170.344	18.927		18.927	18.927	18.927	18.927	13.248	0	
3	0	18.927	15.141	18.927	15.141	18.927	15.141	18.927	18.927	15.141	9.463	170.344	18.927		18.927	18.927	18.927	13.248	15.141	0	
4	18.927	18.927	22.712	15.141	0	17.034	18.927	18.927	18.927	15.141	15.141	170.344	18.927		15.141	18.927	26.497	18.927	15.141	0	
5	0	0	13.248	0	26.497	15.141	11.356	18.927	9.463	9.463	15.141	170.344	18.927		15.141	18.927	18.927	15.141	11.356	0	
6	0	0	28.39	18.927	0	18.927	11.356	22.712	18.927	22.712	9.463	170.344	18.927		18.927	18.927	26.497	18.927	17.034	0	
Nutrients	10-Apr	11-Apr	13-Apr	15-Apr	17-Apr	19-Apr	21-Apr	23-Apr	25-Apr	27-Apr	29-Apr	1-May	3-May	5-May	7-May	9-May	11-May	13-May	15-May	17-May	19-May
62- Grow	155				465				0				465				155				
62- Micro	155				310				155				465				0				
62- Bloom	155				0				155				465				0				
82- Grow	205				615				0				615				205				
82- Micro	205				410				205				615				0				
82- Bloom	205				0				205				615				0				

NH3	17-Apr				25-Apr				3-May				11-May				19-May			
System	a	b	c	$\bar{x}$	a	b	c	$\bar{x}$	a	b	c	$\bar{x}$	a	b	c	$\bar{x}$	a	b	c	$\bar{x}$
1	3.67776	3.57752	3.59184	3.615707	7.1074	7.9308	8.2888	7.775667	7.8972	8.06904	8.3268	8.09768	6.1788	6.26472	6.37212	6.27188	0.8088	0.78732	0.83028	0.8088
2	8.3604	8.0024	8.2888	8.2172	12.728	13.444	12.728	12.96667	24.0072	23.148	25.9404	24.3652	25.9404	29.1624	30.4512	28.518	14.72784	17.8854	15.24336	15.9522
3	5.8544	6.2482	5.9618	6.021467	11.296	12.2984	12.1552	11.91653	20.0334	24.6516	24.4368	23.0406	24.8664	27.6588	27.444	26.6564	16.44624	20.463	17.8854	18.26488
4	3.60616	3.69208	3.76368	3.687307	8.1456	6.6778	6.821	7.2148	5.427	4.65372	4.95444	5.01172	5.12628	6.26472	5.34108	5.57736	0.89472	0.55104	1.21692	0.88756
5	8.79	9.0764	9.2912	9.052533	23.5776	23.5776	30.0216	25.7256	29.1624	30.0216	30.0216	29.7352	36.036	30.0216	26.5848	30.8808	27.8736	24.8664	24.4368	25.7256
6	5.38184	4.9236	3.93552	4.746987	8.5752	8.79	8.7184	8.694533	4.5678	4.6752	4.2456	4.4962	5.1048	4.89	4.95444	4.98308	1.04508	0.46512	0.67992	0.73004

NO3	17-Apr				25-Apr				3-May				11-May				19-May			
System	a	b	c	$\bar{x}$	a	b	c	$\bar{x}$	a	b	c	$\bar{x}$	a	b	c	$\bar{x}$	a	b	c	$\bar{x}$
1	25.90516	24.58239	25.44108	25.30954																
2	13.56084	13.68894	13.68894	13.64624																
3	27.12167	26.05132	26.05132	26.40811																
4	26.33087	26.59337	26.33087	26.41837																
5	26.19323	26.71823	26.83883	26.58343																
6	24.58239	24.58239	24.76265	24.64248																

NO2	17-Apr				25-Apr				3-May				11-May				19-May			
System	a	b	c	$\bar{x}$	a	b	c	$\bar{x}$	a	b	c	$\bar{x}$	a	b	c	$\bar{x}$	a	b	c	$\bar{x}$
1	0.039394	0.062227	0.02883	0.043483	0.052749	0.050847	0.050847	0.051481	0.022074	0.023041	0.027866	0.024327	0.0346	0.0346	0.066946	0.045382	0.027866	0.024007	0.026902	0.026258
2	0.146999	0.118922	0.105159	0.123693	0.09035	0.09035	0.100545	0.093748	0.062227	0.064116	0.064116	0.063486	0.085695	0.07447	0.079156	0.079774	0.080092	0.082896	0.079156	0.080714
3	0.695164	0.687755	0.709634	0.697518	0.037478	0.037478	0.039394	0.038116	0.0346	0.029793	0.027866	0.030753	0.047038	0.046084	0.047038	0.04672	0.03556	0.050847	0.038436	0.041614
4	0.02883	0.046084	0.02883	0.034581	0.04513	0.071653	0.039394	0.052059	0.021107	0.025938	0.025938	0.024327	0.031717	0.030755	0.011408	0.024627	0.023041	0.024007	0.024007	0.023685
5	0.054649	0.046084	0.04322	0.047984	0.087558	0.084762	0.083829	0.085383	0.094992	0.109759	0.094992	0.099914	0.114347	0.136189	0.125305	0.125281	0.025938	0.040351	0.025938	0.030742
6	0.02883	0.02883	0.027866	0.028508	0.053699	0.051799	0.054649	0.053382	0.031717	0.033639	0.032678	0.032678	0.031717	0.02883	0.030755	0.030434	0.023041	0.02883	0.024973	0.025614

PO4	17-Apr				25-Apr				3-May				11-May				19-May			
System	a	b	c	$\bar{x}$	a	b	c	$\bar{x}$	a	b	c	$\bar{x}$	a	b	c	$\bar{x}$	a	b	c	$\bar{x}$
1	92.87	88.658	85.148	88.892	350.275	339.745	369.58	353.2	362.56	439.78	443.29	415.21	481.9	397.66	376.6	418.72	411.7	383.62	11.911	269.077
2	82.34	83.042	83.744	83.042	390.64	404.68	415.21	403.51	436.27	524.02	580.18	513.49	429.25	538.06	453.82	473.71	239.008	301.135	247.432	262.525
3	87.956	85.85	87.254	87.02	425.74	325.705	443.29	398.245	464.35	425.74	488.92	459.67	432.76	587.2	580.18	533.38	267.088	332.725	290.605	296.806
4	94.274	91.466	91.466	92.402	387.13	329.215	360.805	359.05	467.86	450.31	453.82	457.33	390.64	304.645	360.805	352.03	12.964	7.348	18.229	12.847
5	91.466	88.658	86.552	88.892	401.17	446.8	531.04	459.67	601.24	566.14	587.2	584.86	464.35	432.76	601.24	499.45	453.82	404.68	397.66	418.72
6	94.274	94.976	92.168	93.806	376.6	360.805	339.745	359.05	439.78	439.78	509.98	463.18	327.46	353.785	369.58	350.275	15.421	5.944	9.454	10.273

PO4	17-Apr				25-Apr				3-May				11-May				19-May			
System	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$
1	92.87	88.658	85.148	88.892	350.275	339.745	369.58	353.2	362.56	439.78	443.29	415.21	481.9	397.66	376.6	418.72	411.7	383.62	11.911	269.077
2	82.34	83.042	83.744	83.042	390.64	404.68	415.21	403.51	436.27	524.02	580.18	513.49	429.25	538.06	453.82	473.71	239.008	301.135	247.432	262.525
3	87.956	85.85	87.254	87.02	425.74	325.705	443.29	398.245	464.35	425.74	488.92	459.67	432.76	587.2	580.18	533.38	267.088	332.725	290.605	296.806
4	94.274	91.466	91.466	92.402	387.13	329.215	360.805	359.05	467.86	450.31	453.82	457.33	390.64	304.645	360.805	352.03	12.964	7.348	18.229	12.847
5	91.466	88.658	86.552	88.892	401.17	446.8	531.04	459.67	601.24	566.14	587.2	584.86	464.35	432.76	601.24	499.45	453.82	404.68	397.66	418.72
6	94.274	94.976	92.168	93.806	376.6	360.805	339.745	359.05	439.78	439.78	509.98	463.18	327.46	353.785	369.58	350.275	15.421	5.944	9.454	10.273

SO4	17-Apr				25-Apr				3-May				11-May				19-May			
System	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$
1	212.2491	269.814	245.3088	242.4573	269.814	269.814	261.4175	267.0152	345.75	335.3672	325.2472	335.4548	385.0219	332.1502	354.7472	357.3064	79.42423	85.29799	28.42901	64.38374
2	129.5363	143.108	160.6849	144.4431	50.23271	51.04962	53.94652	51.74295	219.228	147.9315	237.5884	201.5826	354.7472	274.5854	250.5963	293.3097	321.3698	385.0219	360.6184	355.67
3	102.5778	115.2883	80.23313	99.36639	42.84552	163.3589	54.99686	87.06708	305.7791	296.4227	296.4227	299.5415	348.9659	391.3577	385.0219	375.1151	90.42788	391.3577	124.3641	202.0499
4	76.75086	50.84498	61.73254	63.10946	155.4618	208.8359	230.0851	198.1276	335.3672	325.2472	315.3859	325.3334	91.22158	224.8825	200.074	172.0593	316.1055	267.8292	337.6684	307.201
5	166.0751	86.4412	63.5428	105.353	51.45977	71.14235	51.66529	58.08913	177.3736	305.7791	269.814	250.9889	248.52	410.9456	195.1138	284.8598	128.9209	300.8034	154.5562	194.7602
6	59.73365	75.18705	50.43653	61.78574	37.4686	98.37695	46.80563	60.88373	145.5004	230.0851	127.4	167.6618	238.3889	228.663	252.6896	239.9138	242.3918	152.9767	246.4606	213.9431

Hardness	17-Apr				25-Apr				3-May				11-May				19-May			
System	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$
1	532	548	464	514.6667																
2	500	392	388	426.6667																
3	388	472	516	458.6667																
4	400	424	468	430.6667																
5	352	372	340	354.6667																
6	376	520	380	425.3333																

Alkalinity	17-Apr				25-Apr				3-May				11-May				19-May			
System	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$	a	b	c	$\bar{X}$
1	150	160	180	163.3333	110	160	160	143.3333	190	170	190	183.3333	220	250	240	236.6667	230	260	270	253.3333
2	170	190	210	190	190	190	190	190	220	220	215	218.3333	290	290	285	288.3333	280	290	290	286.6667
3	200	240	220	220	200	200	200	200	200	205	205	203.3333	295	285	295	291.6667	310	300	295	301.6667
4	200	210	210	206.6667	170	180	190	180	180	190	190	186.6667	275	255	265	265	285	310	290	295
5	240	130	210	193.3333	190	160	190	180	220	250	245	238.3333	305	280	305	296.6667	300	300	310	303.3333
6	200	180	180	186.6667	160	180	180	173.3333	205	210	200	205	250	240	260	250	270	285	280	278.3333

Plant (cm)	17-Apr	25-Apr	3-May	11-May	19-May	Absolute growth rate
1	6.5	13.1	26.6	40.5	47.9	1.29375
2	6	13.5	27.5	42	51.8	1.43125
3	4.6	11	19.6	28.1	34.7	0.940625
4	6.9	14.5	27.7	46.5	67	1.878125
5	5.9	13.6	27.6	43.3	65.9	1.875
6	5	11	23.1	40	55.6	1.58125
7	7.2	17	30.4	47	61	1.68125
8	6.5	14	27.6	44.1	68.3	1.93125
9	5.1	12.4	26.7	41.5	67	1.934375
10	8	17.2	30.5	43.2	68	1.875
11	6.7	15	32.1	54.5	72	2.040625
12	4.9	12.5	26.4	40.1	50.1	1.4125
13	10	17.9	33.1	50.4	68.6	1.83125
14	5.6	13.4	29.4	46	64	1.825
15	7.5	17.7	29.6	52	76	2.140625
16	5.9	12.2	22.1	35.6	40.1	1.06875
17	7.1	15	30.2	48	63.1	1.75
18	8.2	16	30.2	44.4	58.1	1.559375
19	5.3	11.4	27.1	45	66.5	1.9125
20	5.2	13.1	28	43.4	58	1.65
21	5	11	23.4	34	44	1.21875
22	5.8	10.9	22.4	37	45	1.225
23	7.1	14.1	29.1	44	54	1.465625
24	6.6	14	30.5	45	64	1.79375
25	6	12.5	25.1	36	61.7	1.740625
26	5.9	13.4	25.4	33.6	40.8	1.090625
27	4.4	9.4	22.8	28.2	0	0
28	6.2	13.5	27.9	35.9	55.2	1.53125
29	6.5	18	25.8	40.2	60.4	1.684375
30	5	10	24.3	42	52.7	1.490625
31	7.1	16	29.1	47.1	45.1	1.1875
32	4.6	12.1	25	41.6	55.6	1.59375
33	7.4	18	30	41.6	0	0
34	6.9	15.5	31.7	49.1	62	1.721875
35	5.4	14.9	30.9	45.2	66.9	1.921875
36	6.2	14.4	26.4	36.5	37.9	0.990625
37	5.2	10	21.8	38.5	49	1.36875
38	7.1	15.2	30.2	45.8	66.1	1.84375

39	4.4	9.6	19.1	30.2	40.4	1.125
40	7.2	15.3	30	40.5	64.4	1.7875
41	5	10.5	21	35.4	18.6	0.425
42	6	12.7	26.4	46	61.3	1.728125
43	6.4	14	28.3	45.6	63.2	1.775
44	5.5	11.6	27.9	46	66	1.890625
45	5.1	14	27	44.9	64.1	1.84375
46	4.5	9.6	19	29	38.5	1.0625
47	4.9	11.3	25	40.1	43.6	1.209375
48	7.1	16.2	30.5	46.1	58	1.590625
49	4.5	12	25.2	41.5	31.1	0.83125
50	6.8	15.8	24.7	44.3	64	1.7875
51	6	10.3	21.8	36.3	41.2	1.1
52	4	8.1	20	39	46	1.3125
53	7.5	15	30	41.5	63	1.734375
54	6.4	15.3	31	50	66.4	1.875
55	6.1	15.1	31.4	50	78.2	2.253125
56	6.1	12.3	24.8	36.4	45.1	1.21875
57	4	10	23	40	49	1.40625
58	5.2	11.3	26.4	49.1	52.4	1.475
59	4.6	12	26.2	44	58.5	1.684375
60	5.3	13.1	26.7	42.8	57.9	1.64375
61	7.1	13.2	24.3	40	50.2	1.346875
62	5.5	10.1	22.5	32.5	48.4	1.340625
63	5.5	9.8	17.4	28.6	46.8	1.290625
64	6.6	14.6	26.1	41.5	54	1.48125
65	9.3	19.4	36.4	53.5	80.2	2.215625
66	8.6	17.9	31.2	45.1	57.2	1.51875
67	7	15.8	31.7	47	66.6	1.8625
68	6.4	13	27	44.5	66	1.8625
69	6	14.9	29	45	71	2.03125
70	6.1	14.9	30.7	40.5	70	1.996875
71	7.2	14.6	28.9	50	40.6	1.04375
72	6.9	15	32.7	47	67.9	1.90625
73	5	12.4	27.2	43	70.1	2.034375
74	4.6	8.9	25	42	58.7	1.690625

75	4.9	11.5	28	41	66.5	1.925
76	6.4	14	29.4	42.2	52.2	1.43125
77	5.8	12.2	27.3	39.1	56.1	1.571875
78	5	10.4	25.6	40	48.1	1.346875
79	5.7	14.1	30.4	46	54	1.509375
80	8.5	18.2	37	51	74.5	2.0625
81	4.1	9.9	19.9	32.9	43.6	1.234375
82	3	9.8	20.9	36	46.4	1.35625
83	5.1	12	25.3	42	56.5	1.60625
84	4.4	10	22.2	41.1	60.4	1.75
85	5.8	15.3	28	44	59.5	1.678125
86	5	10.1	21	36.5	49	1.375
87	3.4	8	18.9	40	51.4	1.5
88	5.5	13.1	26.2	39.6	56.5	1.59375
89	7.5	16.1	30.9	48.7	68.8	1.915625
90	6	15	30.8	48.6	69	1.96875
91	3.9	8.1	18.4	35	48.5	1.39375
92	7.1	13.9	29	44.1	54.8	1.490625
93	8.1	17.4	31.5	40.8	65.1	1.78125
94	5.5	13.8	30.7	42	63.2	1.803125
95	5.4	13.1	30.2	46	68.5	1.971875
96	6	12.2	27.8	40	53	1.46875
97	4.4	11.3	26.7	42	50	1.425
98	7.5	18.6	39	48	98.1	2.83125
99	6.8	14.4	30.5	46	59.9	1.659375
100	4.2	11	24.6	36.3	44	1.24375
101	10	17.4	28.7	38	44.5	1.078125
102	6.5	13.1	28	33.8	57.8	1.603125
103	5.5	10.6	27.4	41	60.1	1.70625
104	7.2	12.6	32.9	27	54.6	1.48125
105	6.9	16	31.5	47	63.6	1.771875
106	5.3	12.1	24.5	28	35.5	0.94375
107	6.9	13.8	30.6	44	53.4	1.453125
108	5.7	12.6	26.2	44	60.4	1.709375
109	8.5	17	30	48	74.4	2.059375
110	7.7	15.5	26.5	43	70.7	1.96875
111	8	15.4	28.8	47.1	48.2	1.25625
112	5.9	14	32	44.2	58.1	1.63125
113	6	13.3	30.6	46	62.2	1.75625

114	8.4	19	36.5	52	73.4	2.03125
115	8.4	16.6	31.9	47.6	63	1.70625
116	8.1	17.5	32.3	48	54	1.434375
117	6.7	13.3	28.1	47	53.2	1.453125
118	5.2	12	29.5	54	64.2	1.84375
119	6	14.4	28.6	48.6	67.1	1.909375
120	7.3	16	30.1	47	71.2	1.996875

Basil Weight (kg)	Whole Plant (kg)	Leaf (kg)	Time
System 1 Media			
1	0.044	0.028	2:00
2	0.078	0.046	2:04
3	0.048	0.028	1:32
4	0.12	0.068	2:39
5	0.138	0.082	2:41
6	0.07	0.046	1:35
7	0.11	0.058	2:08
8	0.158	0.09	2:57
9	0.168	0.1	2:56
10	0.442	0.236	7:23
11	0.092	0.05	2:23
12	0.072	0.048	1:39
13	0.204	0.11	3:20
14	0.202	0.11	3:48
15	0.316	0.158	5:25
16	0.054	0.036	0:00
17	0.092	0.054	2:06
18	0.182	0.104	3:27
19	0.228	0.13	4:16
20	0.34	0.192	6:34
System 2 DWC			
21	0.07	0.046	2:46
22	0.05	0.034	2:13
23	0.186	0.112	3:23
24	0.186	0.119	4:08
25	0.142	0.08	4:07
26	0.058	0.028	3:04
27	0	0	0:00
28	0.15	0.086	0:00
29	0.308	0.164	6:23
30	0.18	0.102	5:06
31	0.094	0.05	2:59
32	0.124	0.07	3:35
33	0	0	0:00
34	0.388	0.216	6:50
35	0.338	0.19	6:35
36	0.118	0.076	3:06

37	0.056	0.036	2:09
38	0.324	0.196	6:12
39	0.1	0.07	2:36
40	0.362	0.196	5:26
System 3 DWC			
41	0.032	0.022	1:22
42	0.088	0.052	2:39
43	0.18	0.106	3:40
44	0.21	0.118	4:12
45	0.242	0.134	3:49
46	0.036	0.024	1:36
47	0.052	0.028	1:33
48	0.164	0.088	3:09
49	0.122	0.072	2:33
50	0.384	0.202	8:01
51	0.064	0.042	1:47
52	0.034	0.018	1:18
53	0.116	0.064	3:34
54	0.266	0.148	4:27
55	0.326	0.18	6:06
56	0.048	0.03	1:50
57	0.054	0.034	1:45
58	0.052	0.024	1:56
59	0.172	0.106	3:06
60	0.168	0.09	3:27
System 4 Media			
61	0.122	0.078	3:49
62	0.07	0.044	1:55
63	0.032	0.02	1:27
64	0.168	0.092	5:09
65	0.5	0.296	10:15
66	0.13	0.082	3:13
67	0.212	0.122	4:25
68	0.1	0.052	2:54
69	0.202	0.108	4:17
70	0.342	0.186	5:45
71	0.052	0.03	3:29
72	0.146	0.088	3:36
73	0.164	0.09	3:29

74	0.12	0.068	2:21
75	0.208	0.106	4:46
76	0.082	0.05	2:21
77	0.084	0.048	2:30
78	0.062	0.038	1:45
79	0.164	0.088	3:15
80	0.376	0.212	7:59
System 5 DWC			
81	0.052	0.036	1:21
82	0.062	0.042	1:47
83	0.08	0.048	2:08
84	0.104	0.058	1:58
85	0.244	0.132	5:55
86	0.078	0.058	1:46
87	0.06	0.04	1:24
88	0.106	0.062	2:29
89	0.232	0.126	3:33
90	0.276	0.142	3:55
91	0.04	0.028	0:59
92	0.098	0.06	2:21
93	0.208	0.122	3:11
94	0.142	0.08	2:48
95	0.232	0.12	3:45
96	0.082	0.052	1:41
97	0.09	0.06	1:52
98	0.366	0.186	7:19
99	0.166	0.1	3:19
100	0.136	0.082	3:19
System 6 Media			
101	0.054	0.028	2:26
102	0.1	0.062	2:07
103	0.08	0.056	4:21
104	0.08	0.046	2:45
105	0.382	0.21	5:43
106	0.04	0.018	1:26
107	0.136	0.084	2:51
108	0.138	0.072	2:19
109	0.266	0.142	4:23
110	0.244	0.126	5:01

111	0.132	0.086	3:25
112	0.122	0.078	2:51
113	0.17	0.088	2:54
114	0.378	0.214	5:29
115	0.28	0.15	4:08
116	0.144	0.09	2:36
117	0.1	0.058	1:58
118	0.14	0.078	2:26
119	0.23	0.128	3:46
120	0.278	0.154	3:30

APPENDIX H

Note: Aquaponics and Tilapia

Blue tilapia (*Oreochromis aureus*) were originally stocked 5 fish (ca. 0.307 kg per fish) per rearing tank and fed at 1.5% FCR with crushed 32% floating catfish feed after added to the aquaponic systems. Water quality complications arose during the first trial week and a 1/3 water change happened one day after fish were added to the system. Ammonia levels reached 4 ppm before the first water change. Two days after the water change, ammonia levels reached 11.4 ppm (spec20). Water was topped off and I decided to follow the advice from Bernstein (2011) to let the water quality slowly regulate itself without making drastic management implications. The following day 4 fish were lost due to nitrites (brown blood disease). The coloration of the surviving fish were white and behaviorally gulped for air, were lethargic, and aggressive towards others. A ca. 33 gallon water change took place, and amquil was added to the water. Biofilters were rinsed of uneaten food. Fish were restocked at a density of 3 fish per tank, more bacteria was added to the systems, as well as PVC piping for matrix within tanks for cover. Also, fish were fed a floating feed instead of crushed feed. Fish were fed and 30 minutes later checked for excess food and removed. Trial 1 ended on Oct 26th, 2012 due to fish mortality rates ca. 33%. Tilapia also did not eat from the time they arrived on campus (Oct. 6th, 2012) till Thanksgiving Day (Nov 22nd, 2012). Once back in the quarantine tanks, fish stocking densities increased (closer to the density of supplier) and fish aggressiveness decreased.

During the first attempt at a hydroponic trial possible sweet basil showed signs of fusarium wilt 31/2 weeks into the study. Basil started showing symptoms of browning at the base of the stem. Plants started to fall over due to poor stem durability. No foliage was lost during the incidence.

General Hydroponics pH Down compared to 85% food grade phosphoric acid was relatively week and more difficult to manage. Also, originally oasis cubes were utilized for germination, which is neither sustainable nor recyclable. Therefore, coco coir was utilized for the rest of the study.

APPENDIX I

IACUC Protocol

PROTOCOL FOR ANIMAL USE AND CARE

University of Central Missouri
E-mail to: iacuc@ucmo.edu
Please use a minimum font size of 10

IACUC USE ONLY
PROTOCOL: 11-
EXPIRES:

1. Contacts:

	Investigator		**Alternate Contact**
Last Name:	Cairns	Last Name:	Dunwoody
First:	Stefan MI:	First :	Ryan MI: K
E-mail:	cairns@ucmo.edu	E-mail:	dunwoody@ucmo.edu
Department/ Affiliation:	Department of Biology: WCM 319A, UCM	Department/ Affiliation:	Department of Biology: Graduate Program
Phone / after hrs:	660-543-8291	Phone / after hrs:	66-676-7343

2. Title AQUAPONICS: GROWTH, NUTRIENT DYNAMICS, AND SYSTEM DESIGN

3. Species (common names):	Total number for study	Name of source of the animals:
Nile tilapia (*Oreochromis niloticus*)	45	Duda-Lang Farms
Channel catfish (*Ictalurus punctatus*)	45	Raccoon Valley Fishery

4. Procedures: Briefly describe the animal procedures included in this project using language for non-scientific personnel. This page is posted on the animal room door for animal care staff and must be clear and understandable to the staff. There will be additional space for a detailed experimental protocol.

Fish will be housed in aerated 800L, 1.3m tanks equipped with recirculating filtration for quarantine and acclimation purposes. Each lot of species will be transferred to six 208.19L barrels for specific study treatments with a stocking density of 450g of fish per 38L of water (5 fish/barrel). Each lot of species will be in possession for 82 days. Fish will be fed Purina Mills 32% protein floating fish feed at a calculated Food Conversion Ratio (1.5% feeding rate = 33.75g per 5 fish). While fish reside in

5. Animal Location	Overnight housing	Study area / Laboratory **(Room/Bldg.)**
	Animal Research Facility in the basement of W.C. Morris	Room (TBD)

Animals will be maintained by: [x] Vivarium [ ] Investigator *(If investigator maintained, please attach husbandry SOPs.)*

6. Special Husbandry Requirements: Briefly describe any *special* food, water, temperature, humidity, light cycles, caging type, and bedding requirements. Please include any special instructions for animal care staff with regard to procedures to follow for disposal of dead animals and if pest control can be performed in the animal area.

Fish will be housed in two types of polyethylene tanks/barrels. Fish will be fed Purina Mills 32% protein floating fish feed. Transfer holding tank water temperature may vary compared to source water. However if the temperature differs more than 3°C then fish will be brought up to temperature. Aquaponic water will not be regulated. Lights will be left at a 12:12 hour ratio (12 lights on, 12 lights off). If fish mortality is present fish will be put in plastic bags and placed in the trash.

7. Hazardous Materials (If used specifically in this protocol, please fill out the Room/Lab Safety Information Sheet):

Infectious Agents?	[ ] Yes [x] No	Material:		[ ] Lab [ ] Vivarium
Radioisotopes?	[ ] Yes [x] No	Material:		[ ] Lab [ ] Vivarium
Chemical Carcinogens?	[ ] Yes [x] No	Material:		[ ] Lab [ ] Vivarium
Recombinant DNA?	[ ] Yes [x] No	Material:		[ ] Lab [ ] Vivarium
Hazardous Chemicals?	[ ] Yes [x] No	Material:		[ ] Lab [ ] Vivarium

Hazardous chemicals would include chemicals that are flammable, toxic, corrosive, or chemotherapeutic.**8. Funding and Funding Source**

Is the protocol for **newly** funded NIH research? Yes [ ] No [x] Funding Source: URC Level II pending/other

****If this protocol is submitted for a <u>newly funded</u> NIH grant, please attach the relevant animal-related pages from section *D. Experimental Design and Methods* and section *F. Vertebrate Animals* that will allow a direct comparison between this protocol and the animal work proposed in your grant. This comparison of NIH grants and Animal Use and Care protocols is required by PHS policy and only applies to <u>newly funded</u> NIH grants. Please contact IACUC staff if you have questions associated with this requirement.**

9. What Veterinarian or veterinary service will provide care for your animals?

Veterinarian:	N/A	Address:	
Day phone:			
Emergency phone:		E-mail:	

10. Objective and Significance:

Please provide a brief description of the **objectives and significance** of the study, bearing in mind your target audience may be a faculty member from an unrelated discipline.

Objective:

1. Analyze macronutrients and micronutrients of hydroponic fertilizer and fish waste in an aquaponic system.
2. Measure plant growth in two different aquaponic systems utilizing three different nutrient sources.

Significance: Please provide a statement of relevance to human or animal health, the advancement of knowledge, or the good of society.

As global human population increases, the demand for a sustainable food production system is essential to offset a food and nutrition crisis. Aquaponics is a sustainable agricultural system that combines aquaculture and hydroponics into one recirculating system. These systems contain aquatic organisms and plants that are simultaneously raised together. A few key advantages of aquaponics include water recycling, year round crop production, closer farmer-to-consumer interactions, and a reduction of environmental footprints. Aquaponics is an emerging sustainable production system. Investigations optimizing systems, growth, and production are necessary to advance this field. This preliminary study will provide vital data pertaining to sweet basil (*Ocimum basilicum*) growth, nutrient dynamics, and system designs. Each treatment will utilize one of three nutrient sources, which include General Hydroponics fertilizers, Nile tilapia (*Oreochromis niloticus*), and Channel catfish *(Ictalurus punctatus).* For each treatment sweet basil will be grown in two hydroponic subsystems media filled and floating raft. Macronutrient and micronutrient concentrations as well as sweet basil growth will be analyzed after each treatment.

11. Literature search for alternatives and unnecessary duplication: ***Federal law specifically requires this section.***
Alternatives should be considered for any aspect of this protocol that may cause more than momentary or slight pain or distress to the animals. Alternatives to be considered include those that would: 1) **refine** the procedure to minimize discomfort that the animal(s) may experience; 2) **reduce** the number of animals used overall; or 3) **replace** animals with non-animal alternatives.

**

a) Databases: List a **minimum** of two databases searched and/or other sources consulted. Include the years covered by the search. *The literature search must have been performed within the last six months.*

Database Name	Years Covered	Keywords / Search Strategy	Date
Google Scholar	1955 to present	Aquaponics, Optimum, Macro, Micro, Channel catfish, Tilapia	4/12/12
Jstor	1970 to present	Management Recirculating Systems	4/12/12

b) <u>Result of search for alternatives</u>: Please comment on the application(s) of any identified alternatives, including how these alternatives may be or may not be incorporated to modify a procedure to either lessen or eliminate potential pain and distress.

This project cannot be possible without Nile tilapia and channel catfish as they are the nutrient providers for plant growth. Also reducing the number of fish per tank would create a deficit of nutrients available to the plants. To my knowledge there is no data available that would enable a model to replace live specimens within this novel system.

c) <u>Animal numbers justification</u>: Please describe the consideration given to reducing the number of animals required for this study; this could include any *in vitro* studies performed prior to the proposed animal studies. Please also provide information on how you arrived at the number of animals required. If preliminary data is available and if relevant, please provide a power analysis or other statistical method used to determine the number of animals necessary. For studies where a statistical method such as a power analysis is not appropriate (such as pilot studies, tissue collection), please provide a brief narrative describing how the requested animal numbers were determined to be necessary.

Three Biological replicates of this novel system are essential for the analysis of macro and micro nutrients, as well as the two different styles of hydroponic subsystems. Therefore 6 rearing tanks are required for each of the three trials. For the treatments that utilize fish species I originally intended to stock fish at a density of 450g fish per 19L of water. To insure an absence of stress levels and a safe environment (Total Ammonia Nitrogen) I adopted the proposed density 450g fish per 38L of water (Bernstein, 2011).

d) Species rationale: Please provide the rationale for the species chosen, and any consideration given to the use of non-mammalian or invertebrate species, or the use of non-animal systems (e.g., cell or tissue culture, computerized models).

I propose to use Nile tilapia for Treatment 2 due to their popularity within the aquaponics community, demand of consumers, and wide environmental tolerances. For Treatment 3, Channel catfish were selected due to their popular status within the aquaculture industry, demand of consumers, and wide environmental tolerances. Both species can be readily bought within the state of Missouri.

e) Has this study been previously conducted? [ ] Yes [x] No

If the study has been previously conducted, please provide scientific justification for why it is necessary to repeat the experiment.

N/A

12. Summary of Procedures:

a) **Describe the use of animals in your project in detail.** Using terminology that will be understood by individuals outside your field of expertise. Please write a detailed description of all animal procedures in a logical progression, beginning with receipt of the animals and ending with euthanasia or the study endpoint. **List each study group and describe all the specific procedures that will be performed on each animal in each study group.**

Please provide a complete description of the surgical procedure(s) including **Anesthesia, Analgesia, and/or Neuromuscular blocking agents**. If the procedure(s) will be performed by vivarium or veterinary staff with an established, IACUC-approved SOP, please identify the SOP title and number.

Field Studies: If animals in the wild will be used, describe how they will be observed, any interactions with the animals, whether the animals will be disturbed or affected, and any special procedures anticipated. Indicate if Federal or State permits are required and whether they have been obtained.

This cell will expand, but please try to be concise. Please define all abbreviations. Broodstock Nile tilapia will be supplied from Duda-Lang Farms and channel catfish will be received from Raccoon Valley Fishery. (Only one species will be housed at UCM at a time; they will arrive two weeks before treatment). Fish will be transferred to UCM in six 208.19L aerated barrels. Fish will be transferred, separated, and divided into six aerated 800L, 1.3m holding tanks equipped with recirculating filtration; located in the Animal Research Facility in the basement of W.C. Morris. Holding tanks will be set to the temperature of the hauling water which will allow for less stress on fish and easier acclimation to the new environment. Fish will be held in the holding tanks for quarantine and acclimation for two weeks (Masser et al., 1999).

While fish reside in the holding tanks, multiple water quality parameters will be tested every other day to ensure the safety of the fish including ammonia, total dissolved solids, pH, dissolved oxygen, and electrical conductivity. Observations of fish habits will be noted, any changes will result in management alterations (Masser et al., 1999). Both fish species will be fed Purina Mills 32% protein floating fish feed at a calculated Food Conversion Ratio (FCR) (Rakocy, 1989; Masser et al., 1999; Rakocy et al., 2006).

Before each treatment in the study, the holding tanks will be raised or lowered to the same temperature as the rearing tanks within the aquaponic systems. During appropriate treatments, each fish species will be transferred to Six 208.19L commercial plastic barrels at a stocking density of 450g of fish per 38L of water (5 fish/barrel). Each species will reside within the barrels for exactly 2 months. Water temperature will not be regulated within the aquaponic systems due to the species wide temperature tolerance 8.0- 40.0° C. Water will be analyzed weekly for macro and micronutrients for each of the trials. Water quality parameters will be tested every other day to ensure the safety of the fish including ammonia, total dissolved solids, pH, dissolved oxygen, and electrical conductivity. Observations of fish habits will be noted, any changes will result in management alterations. Fish will be fed the same FCR ratio within the aquaponic systems.

After the treatments are complete, fish will be ethically euthanized by means of MS-222 (Borski and Hodson, 2003).

b) Study Groups and Numbers Table: Define the numbers of animals to be used in each experimental group described above. The table may be presented on a separate page as an attachment to this protocol if preferred. This table must account for all animals proposed for use under this protocol.

Group	Procedures / Treatments	Number of Animals
1	Nile tilapia within the aquaponics system	45 fish, 5/ tank
2	Channel catfish within the aquaponics system	45 fish, 5/ tank

c) Is death an endpoint in your experimental procedure? [ ] Yes [x] No

(Note: "Death as an endpoint" refers to acute toxicity testing, assessment of virulence of pathogens, neutralization tests for toxins, and other studies in which animals are not euthanized, but die as a direct result of the experimental manipulation). If death is an endpoint, explain why it is not possible to euthanize the animals at an earlier point in the study. If you can euthanize the animals at an earlier point, based on defined clinical signs, then death is not an endpoint.

N/A

d) Surgery: This project will involve: **Survival surgery** [ ] Yes [x] No **Terminal surgery** [ ] Yes [x] No

Location: Building:	N/A	Room:	N/A

Name of the surgeon: **N/A**

e) This project will involve **Multiple Major Surgical Procedures** [ ] Yes [x] No

Please provide scientific justification for multiple major surgical procedures:

N/A

f) Drugs to be used (except for euthanasia) - anesthetics, analgesics, tranquilizers, neuromuscular blocking agents or antibiotics:

Post-procedural analgesics should be given whenever there is possibility of pain or discomfort that is more than slight or momentary.

Provide the following information about any of these drugs that you intend to use in this project.

Species	Drug	Dose (mg/kg)	Route	When and how often will it be given?

g) Anesthesia monitoring: Please complete the following:

Please identify the physiologic parameters monitored during the procedure to assess adequacy of anesthesia and when additional anesthesia will be administered.

N/A

h) Neuromuscular blocking agents can conceal inadequate anesthesia and, therefore, require special justification. If you are using a neuromuscular blocking agent, please complete the following:

Why do you need to use a neuromuscular blocking agent?

N/A

What physiologic parameters are monitored while under a neuromuscular block to assess adequacy of anesthesia?

N/A

Under what circumstances will incremental doses of anesthetics-analgesics be administered while under a neuromuscular block?

N/A

i) Post-surgical monitoring: please complete the following:

Please identify the physiologic parameters monitored, and interval(s) and for what duration of monitoring.

N/A

When will analgesics be administered and at what interval(s)?

N/A

If post-operative analgesics cannot be given, please provide scientific justification.

N/A

13. Adverse effects:

Describe **all significant** adverse effects that may be encountered during the study (such as pain, discomfort; reduced growth, fever, anemia, neurological deficits; behavioral abnormalities or other clinical symptoms of acute or chronic distress or nutritional deficiency). If genetically-altered animals are used, please describe any potential adverse effects that could be associated with the desired genotype, if known.

Feeding behavior, swimming abnormalities, and physiological abnormalities are possible during this study. Due to proper management practices there should be no adverse effects.

Describe criteria for monitoring the well-being of animals on study and criteria for terminating/modifying the procedure(s) if adverse effects are observed.

Fish will be observed (visually) and fed daily. If abnormalities are observed proper management practices will be enforced and fish will be checked randomly throughout the day. Water quality will be tested every other day. If water quality changes, parameters will be tested randomly throughout the day.

How will the signs listed above be ameliorated or alleviated? Please provide scientific justification if these signs cannot be alleviated or ameliorated.

If adverse effects are present, proper management applications will be enforced (Masser et al., 1999). If water quality poses a threat fish will be transferred to the holding tanks or aquaponic tanks (whatever system is not in use). Proper alterations will be applied to restore water quality to a safe level including the addition of pH buffers and water exchange. If fish continue to show adverse effects after management applications and transfer, an aquaculture manager will be contacted for advice. If health problems cannot be alleviated fish will be euthanized by means of MS-222 (Borski and Hodson, 2003).

***Note**: If any significant adverse effects not described above occur during the course of the study, a complete description of these unanticipated findings and the steps taken to alleviate them must be submitted to the IACUC as an amendment to this protocol.*

14. Methods of euthanasia: Even if your study does not involve euthanizing the animals, please provide a method that you would use in the event of unanticipated injury or illness. If anesthetic overdose is the method, please provide the agent, dose, and route.

Species	Method	Drug	Dose (mg/kg)	Route
Oreochromis niloticus	Immersion	MS-222	500 mg/L	Gills
Ictalurus punctatus	Immersion	MS-222	500 mg/L	Gills

15. Disposition of animals: What will you do with any animals not euthanized at the conclusion of the project?

N/A

16. Project Roster: Please provide the names of all the individuals who will work with animals on this project. Please provide either the University ID number **OR** a valid UCM e-mail address in order for the IACUC to confirm that the requirements of training and occupational health for regulatory agencies have been met. Include all investigators, student employees, post-doctoral fellows, staff research associates, post-graduate researchers, and laboratory assistants who will actually work with the animals. You do not need to include the staff of the vivarium in which your animals will be housed, or staff members that are only working with tissues or animals post-euthanasia. **This roster is specifically for individuals working with live vertebrate animals.**

<u>Training</u>: Supervisors are responsible for insuring that their employees are adequately trained, both in the specifics of their job and in the requirements of the Federal Animal Welfare Act.

The PI is responsible for keeping this roster current. If staff is added or removed from this project, please amend the protocol to reflect this change.

Last Name	**First Name**	**Middle Initial**	**Title/Degree**
Cairns	Stefan		Primary Investigator
UCM ID Number **OR** E-mail address: cairns@ucmo.edu			
Describe training and experience relevant to the procedures described in this protocol: Dr. Cairns has maintained a broad research interests that include applied aquatic biology problem solving, environmental stream ecotoxicology, environmental education, application of remote sensing to environmental assessment, eutrophication monitoring of lakes and reservoirs, restoration and recovery of damaged ecosystems, limnology, and aquatic ecosystem population dynamics. He also has knowledge in hydroponics, aquaponics, and aquaculture.			

Last Name	**First Name**	**Middle Initial**	**Title/Degree**
Lankford	Scott		Secondary Investigator
UCM ID Number **OR** e-mail address: lankford@ucmo.edu			
Describe training and experience relevant to the procedures described in this protocol: Dr. Lankford maintains research interests center on how the neuroendocrine system orchestrates the reallocation of biological resources to allow vertebrates to physiologically cope with environmental disturbances, while maintaining the biological functions that are essential to life. He has utilized fish as a research model due to their intimate relationship with their environment. He also has experience/knowledge within the aquaculture industry.			

Last Name	**First Name**	**Middle Initial**	**Title/Degree**
Dunwoody	Ryan	K	Tertiary Investigator
UCM ID Number **OR** e-mail address: dunwoody@ucmo.edu			

Describe training and experience relevant to the procedures described in this protocol: I have worked with various fish species as an intern with the Missouri Department of Conservation using different sampling and handling methods. I have also taken Aquatic ecology, Ichthyology, and Marine biology courses. I have a varying knowledge of aquatic organisms, ecosystems, and recirculating systems. I currently run a small personal aquaponics system at my residence.

Last Name	First Name	Middle Initial	Title/Degree
UCM ID Number **OR** E-mail address:			
Describe training and experience relevant to the procedures described in this protocol:			

Last Name	First Name	Middle Initial	Title/Degree
UCM ID Number **OR** e-mail address:			
Describe training and experience relevant to the procedures described in this protocol:			

Assurance for the Humane Care and Use of Vertebrate Animals

Principal Investigator's Statement:

This project will be conducted in accordance with the ILAR Guide for the Care and Use of Laboratory Animals, and the UCM Animal Welfare Assurance on file with the US Public Health Service. These documents are available from the IACUC Chair. I will abide by all Federal, state and local laws and regulations dealing with the use of animals in research.

I will advise the Institutional Animal Care and Use Committee in writing of any significant changes in the procedures or personnel involved in this project.

Stefan Cairns | Associate Professor | 3-2-12

Principal Investigator | Rank/Title | Date

Committee Use Only Below

**** Conditions necessary for Committee Approval:**

Final Disposition of this protocol:

__________ Approved

__________ Not Approved

__________ Withdrawn by Investigator

Date of Action: ______/______/______

I verify that the Institutional Animal Care and Use Committee of the University of Central Missouri acted on this protocol as shown above.

IACUC Chair	*Date*
IACUC Attending Veterinarian	*Date*
IACUC Community Representative	*Date*
IACUC Member	*Date*
IACUC Member	*Date*
IACUC Member	*Date*
IACUC Member	*Date*
IACUC Member	*Date*

ROOM /LAB SAFETY INFORMATION

Complete this form if you will be using infectious agents, radioisotopes, chemical carcinogens, recombinant DNA or hazardous chemicals.

PROTOCOL #________
EXPIRES: ________

RUA#: __________ BUA#: __________ CCA#: __________

Identity of Hazard:			
Investigator Last Name:		Department:	
First Name:		Phone:	
E-mail:		Fax:	

Provide a short description of the agent:

This agent / material is hazardous for: [ ] Humans only [ ] Animals only [ ] Humans and Animals
For which Animal Species?

The agent can be spread by:
[ ] Blood
[ ] Saliva/nasal droplets
[ ] Other:
[ ] Feces/urine
[ ] Does not leave animal

Describe any human health risk associated with this agent:

The precautions checked below apply to this experiment:

[ ] The researcher or his/her technicians are responsible for the feeding and care of these animals.
[ ] The following items must be assumed to be contaminated with hazardous material and must be handled only by the researcher or his/her technicians.
- [ ] Cage [ ] Stall [ ] Water Bottle [ ] Animal Carcasses
- [ ] Bedding [ ] Other:

[ ] Cages must be autoclaved before cleaning.
[ ] Label cages and remove label after decontamination.
[ ] Animal carcasses must be labeled and disposed of as follows:
- [ ] Incineration [ ] Biohazardous Waste Container
- [ ] Bag and Autoclave [ ] EH&S will pick-up.

[ ] All contaminated waste (soiled bedding or other animal waste) must be properly labeled and disposed of as follows
- [ ] Incineration [ ] Biohazardous Waste Container
- [ ] Bag and Autoclave [ ] EH&S will pick-up.

Personal Protective Equipment Required:

[ ] The following personal protective equipment must be worn/used in the room:
- [ ] Lab Coat/Coveralls [ ] Shoe Covers/Booties
- [ ] Disposable Gloves [ ] Head Cover
- [ ] NIOSH Certified Dust Mask [ ] Disinfectant footbath
- [ ] Eye Protection/Face Shield [ ]
- [ ] Fitted Respirator Type:
- [ ] Other: Describe:

[ ] Personal protective equipment must be removed before leaving the room.
[ ] Personal protective equipment must be discarded or decontaminated at the end of the project
[ ] Hands and arms must be thoroughly washed upon leaving the room
[ ] Full shower, including washing of hair, must be taken upon leaving the room.
[ ] Decontaminate Room (Inform ARS area supervisor when cage and/or room can be returned to general use).

Provide any other information needed to safely work in this room:

UNIVERSITY OF CENTRAL MISSOURI
— Est. 1871 —

Biology and Earth Science
WC Morris 306
Warrensburg, MO 64093
Office 660-543-4933
FAX 660-543-4355

April 17, 2012

Dr. Stefan Cairns

Department of Biology and Earth Science, WCM 306

University of Central Missouri

Dear Dr. Cairns,

Congratulations! Your animal use protocol entitled, *Aquaponics: Growth, Nutrient Dynamics, and System Design,* has been reviewed and approved by the University of Central Missouri Institutional Animal Care and Use Committee (IACUC). Upon receipt of this letter, implementation of described research procedures may begin. Please remember that a statement of any modification to this animal use protocol, including personnel and procedural modifications, must be submitted to the IACUC prior to implementation of said modifications. Likewise, animal use training of all personnel must be completed before work may begin. Approval by this committee does not imply that equipment or facilities are available. Please contact animal facility managers to make specific arrangements.

Your approved protocol has been issued a protocol number and an expiration date listed below. Please keep this information in your records, as you may need it for granting and publication purposes. Please reference your protocol number on correspondence concerning this animal use protocol. This protocol is approved for three years; however, every protocol must be reviewed by the IACUC once a year. If you intend to use animals purchased under this protocol number after the expiration date, you must resubmit the protocol as a new initial submission.

Animal use protocol #: 12-3222

Protocol expiration Date: 4/9/2015

If you have further questions and/or concerns regarding the use of animals in research or the classroom at the University of Central Missouri, please notify:

Dr. Scott Lankford (lankford@ucmo.edu) - Institutional Animal Care and Use Committee Chair

Dan Metcalf, M.S. (dmetcalf@ucmo.edu) - Institutional Animal Care and Use Committee Liaison

Sincerely,

Scott Lankford, PhD

Institutional Animal Care and Use Committee Chair

Dept. of Biology and Earth Science

WCM 303, University of Central Missouri

lankford@ucmo.edu