Integrating Effluent from Recirculating Aquaculture Systems with Greenhouse Cucumber and Tomato Production

by

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Abstract

Experiments were conducted to evaluate the feasibility of greenhouse vine crop production using aquaculture effluent as a water and nutrient source. In the summer of 2012, cucumbers grown with aquaculture effluent (AE) from a 100 m^3 biofloc system were compared to cucumbers grown with a commercial hydroponic fertilizer. Plants were grown conventionally in a soilless hydroponic system utilizing standard drip irrigation equipment for 42 days. Plants receiving AE yield was 5.1 kg/m^2, and was 28% lower than plants that received commercial fertilizer (CF) 7.2 kg/m^2. Tissue analysis of shoot and fruit tissue suggested phosphorus to be a deficient nutrient in plants receiving AE. The second study investigated the feasibility of integrating biofloc tilapia production with greenhouse cherry tomato production. This study compared commercial fertilizer to aquaculture effluent from a 100 m^3 biofloc system. Three thousand Nile tilapia (*Oreochromis niloticus*) (157 grams/fish) were stocked at 40 $fish/m^3$ and grown for 149 days. Two cherry tomato varieties (*Solanum lycopersicum* var. *cerasiforme)* were used, 'Favorita' and 'Goldita' were grown with AE and compared to plants grown with conventional fertilizer in soilless culture for 158 days. No differences were observed between treatments until fish harvest (117 days after treatment). Yields for 'Favorita' were 11.8 kg/m^2 and 11.1 kg/m^2 for CF and AE plants, respectively, at fish harvest and were not different. Post fish harvest the 'Favorita' cherry tomato had an 19% difference in total yield between treatments at crop termination. 'Goldita' plants were different both

pre- and post- fish harvest and overall had less yield than ‘Favorita’ regardless of treatment. An economic analysis was performed using data from cherry tomato production and tilapia production extrapolated to a commercial scale operation. When fertilizer savings associated with integration was applied to the tilapia production variable cost, the net return above variable cost increased by 12% and lowered the breakeven price by 7% for tilapia. Water use index and nitrogen conversion ratio was reduced by 50% and 68%, respectively, when comparing the integrated scenario to the non-integrated scenario. This research demonstrates that utilizing AE from biofloc tilapia production as a nutrient and irrigation source is feasible and there can be economic and environmental benefits to integration.

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Chapter I

Literature Review

Aquaculture Current Status and Outlook.

Seafood is a major staple for a large percentage of the world's population. On a global scale the Food and Agriculture Organization of the United Nations (FAO) has reported fish provide 3.0 billion people with approximately 20% of their animal protein and 4.3 billion with about 15 % of their total protein (FAO, 2012). Fish production has continued to grow globally with demand with improved cultural techniques and advancements in distribution, fish production has grown at an average rate of 3.2% annually from 1960's to 2009 (FAO, 2012). As of 2010, growth increased beyond the increase in global population (1.5%), indicating more fish products are being consumed per capita (FAO, 2012). Per capital fish supply has nearly doubled from 9.9 kg to 18.4 kg per person in that same amount of time (FAO, 2012).

The increase in fish products sold may be largely attributed to increased affluence in the populations financially able to afford fish, primarily populations in China and India (Kharas, 2010; Jenson 2006). By 2020 the middle class in Asia is expected to double (Kharas 2010) creating anticipation that fish consumption will increase rapidly as a direct result of increased wealth. Reliance on aquaculture products as an important protein

source is predicted to increase as the global population increases (Naylor et al., 2000). Increases in aquacultures contribution to fish products sold has taken place rapidly since the mid-1990's, due to the percent of captured fisheries leveling off (Naylor et al., 2000). In 1995, aquaculture accounted for 20% of produced fish but had increased to 47% in 2010 (FAO, 2012). Forecasting the growth of aquaculture production is difficult and can be affected by numerous factors.

Fish production is very efficient in feed conversion compared to other livestock animals but there is still a large amount of waste produced. Fish waste containing nutrients can have negative environmental impacts to encompassing or nearby water bodies (Cao et al., 2007; Herbeck et al., 2014; Farmaki et al., 2014). Feed can account for over 50% of production cost in aquaculture production (FAO 2009), so it is desirable to convert as much of that feed into a sellable product as possible. Improving the nutrient use efficiency (NUE) can increase both the economic and environmental sustainability of an aquaculture system.

Improving efficiency and reducing waste

Fish waste has been extensively studied in a variety of production systems and species in an effort to determine methods to improve NUE and reduce environmental impact. Shrimp are able to assimilate 25 to 30% of the nitrogen and phosphorus applied within the feed into harvestable biomass (Boyd and Tucker, 1998). Schneider et al., (2004b) in an evaluation of fishmeal alternatives, observed 33 to 40% of fed phosphorus was lost to fecal waste, 60 to 70% was assimilated into tilapia biomass and a very small

percent was lost as non-fecal waste (branchial-urinary waste). 43 to 48% of fed nitrogen was assimilated into biomass leaving 52 to 57% of fed nitrogen lost to fish waste. Unlike phosphorus, the majority of nitrogen lost was attributed to non-fecal losses (Schneider et al., 2004). Van Weerd et al., (1999) also reported similar low amounts of P loss to bronchial-urinary pathways (3 to 6%) in soy and fish meal based diets. Gross et al., (2000) in catfish pond production reported 31.5% of nitrogen was assimilated into fish biomass. Understanding what proportion of a nutrient is lost to fecal or branchial-urinary waste can aid in the improvement of NUE of a given nutrient.

Indicators can be used to compare agriculture systems in terms of different efficiencies. The most common efficiency measured in aquaculture is feed conversion ratio (FCR) (Boyd et al., 2007) where:

$$Feed\ Conversion\ Ratio\ = \frac{\text{Feed fed(kg)}}{Final\ biomass(kg) - initialy\ stocked\ biomass(kg)}$$

Nutrient Use Efficiency (NUE) can be calculated using this same method, where:

$$Nutrient\ Use\ Effeciency\ = \frac{(\%\ nutrient\ in\ feed\ x\ feed\ fed\ (kg))}{Net\ Fish\ biomas\ produced\ (kg)}$$

(Adapted from Boyd et al., 2007)

Boyd (2005) has suggested using a water index that would allow systems to be evaluated based on water use, where:

$$Water\ Use\ Index\ m3/t\ = \frac{\text{Total water used in production } (m^3)}{Biomas\ Production\ (t)}$$

(Adopted from water use indices proposed by Boyd, 2005.)

Recirculating Aquaculture Systems

In order improve efficiencies in space, water, and feed utilization, recirculating aquaculture systems (RAS) have been extensively researched and developed. RAS utilize specialized equipment engineered to enhance filtration to treat and mechanically remove waste (Timmons and Ebeling, 2013). Filtration allows water to be recirculated back to the fish production resulting in considerable water savings. Most RAS operate with only 5 to 10% daily water exchange (Masser et al.,1999) Recirculating aquaculture systems (RAS) are input intensive and require high fish production densities to account for cost associated with development and operation (Lasordo et al., 1998). In order for RAS to be ecomomical they need to operate at maximum capacity (Masser et al., 1999). Densities of 0.5 pounds per gallon or greater may be required for RAS to be cost effective compared to the 0.005 to 0.007 lbs. per gallon densities associated with traditional aerated aquaculture pond (Masser et al., 1999; Losordo et al., 1998).

Most RAS rely heavily on nitrification; the bacteria based biological oxidation of ammonium to nitrate (Sharma and Ahlert, 1977). Nitrification is a two-step process, with he first step involving the bacteria *Nitrosomonas* sp. oxidizing ammonium into nitrite. Nitrite is still a toxic compound to fish and must be converted to nitrate after further oxidation by *Nitrobacter* sp. (Sharma and Ahlert, 1977). Nitrification can be enhanced in a system by increasing available surface area for bacterial growth. This is accomplished

through the use of media with a high surface area, such as plastic beads or pvc shavings. The substrate and its housing is referred to as a biofilter.

Nitrification has a significant impact on water quality in RAS and without it total ammonia nitrogen would quickly build up to toxic levels. Nitrification is significantly affected by pH, with the process favoring alkaline conditions (Sharma and Ahlert, 1977). Nitrification is most efficient in aquaculture systems at pH 7.0-8.5 (Masser et al., 1999; Boyd and Tucker, 1998). The process of nitrification creates conditions that work against its own optimum water quality conditions needed for the process to continue. Nitrification is an acid forming process. For every one gram of total ammonia nitrate (TAN) converted to nitrate, 7 grams of alkalinity will be consumed and 4.5 to 5.85 grams of CO_2 will be produced leading to acid forming conditions (Ebeling et al., 2006; Boyd 2000).

In minimum or zero exchange systems, nitrate can build up to high concentrations. A cost effective method of removing nitrate is a major problem facing aquaculture filtration technology (Lee et al., 2000). Nitrate has historically been thought to have low toxicity (Masser et al., 1999; Losordo et al., 1998), but recent research has shown that fish species and maturity may be more sensitive than once thought (Davidson et al., 2014, Lee et al., 2000; Colt 2006). In an investigation of acute toxicity of nitrate to five marine species, toxicity ranging from 573 Nitrate mg/l (129 mg/l NO_3^--N) to 3000 (688 NO_3^--N) were reported (Pierce et al., 1993). Given acute toxicity exists, chronic exposure to elevated nitrate concentrations likely have negative impacts on yield.

In traditional RAS, nitrate concentrations can cost effectively be reduced by two methods; water exchange (dilution) or through denitrification. Denitrification involves

treating culture water by recirculation in an anaerobic vessel where bacteria are able to use nitrate or nitrite in anaerobic respiration (Van Rijn et al., 2006). The end result of denitrification is the conversion of nitrate and/or nitrite into nitrogen gas that is subsequently lost through volatilization (Van Rijn et al., 2006; Lee et al., 2000). Both dilution and denitrification result in lowering NUE as nitrogen is lost from the system and recovered into sellable products.

While RAS systems are traditionally very efficient in water conservation, the same mass of waste is still being produced. In a RAS comparing two trout feed, Heinen et al., (1996) reported 57 to 66% Nitrogen lost to waste and 35 to 45% of P lost to waste. Rafiee and Saad (2005) reported only 32.5% of fed N and 16% of fed P being captured by tilapia in a RAS. Traditional RAS allow for easier handling of waste, but outside of increased management abilities (improved FCR) traditional RAS technology does little to improve the NUE of a system.

Biofloc Technology (BFT) is a form of RAS but lacks a formal biofilter and has different management techniques. BFT involves the retention and mixing of settable solids within the system. Retention of solids allows for the following: re-release of nutrients from solid waste, surface area for bacteria, and a food source for fish species with filter feeding abilities (De Schryver et al., 2008; Avnimelech 2006).

BFT utilizes heterotrophic bacteria to convert ammonia into microbial proteins by increasing the C:N ratio. Increasing C:N ratio can be accomplished by adding highly available carbon sources or lowering the percent protein in feed (Avenemilich 1999; Azim et al., 2008). Certain species can graze on this microbial protein allowing for improved feed conversions. BFT systems may also utilize photoassimilation by

converting nitrogen into algae biomass. BFT systems also involve some degree of nitrification. BFT has been shown to improve FCR over clear water systems (Azim and Little, 2008).

BFT can significantly improve NUE compared with traditional RAS systems by using fish to consume the protein rich waste. Not all waste is utilized by fish, and a degree of solid removal may be necessary (Azim et al., 2008). BFT systems are inexpensive, can greatly decrease water usage and can improve NUE. BFT is limited to only certain fish species that can filter feed and handle the associated water quality conditions.

Nutrient waste such can be also be handled through uptake and assimilation into plant biomass. This concept has been successfully employed in constructed wetlands using aquaculture effluent. Constructed wetlands mimic natural wetlands and associated nutrient cycles, including plant assimilation, denitrification, and microbial degradation (Summerfelt et al., 1999) Constructed wetlands require large amounts of space, efficiency and can be seasonally influenced. Constructed wetlands do not lend well to incorporation within a RAS but can have important applications for RAS effluent treatment. In a study by Alder et al., (1996) constructed wetlands using various grass species were able to capture 40 % and 90% of effluent N and P, respectively. The biweekly harvest of grass clippings captured removed 50% of effluent N and 80% of effluent P (Alder et al., 1996). Constructed wetlands typically do not involve a sellable product and is a control technique involving a net loss of nitrogen and thus improves NUE, but not nutrient conversion into sellable products.

Utilizing plant biomass to assimilate nitrogen into sellable plant products can dramatically improve the NUE of fed N into a system. This can be accomplished with food, ornamental crops or biofuel crops. Research has shown the solid fraction in BFT is similar to other manures and could be used to an extent for land application or as a substrate amendment (Naylor et al., 1999; Salazar and Saldana, 2007; Castro et al., 2006; Danaher et al., 2013). Naylor et al., (1999) observed that salmonid waste from cage culture was similar to livestock manures in regards to N, P, Ca, and Mg but fish manure was lower in potassium. Dewatered aquaculture effluent has been shown to be a nutrient source and a suitable substrate amendment in the production of floriculture crops and vegetable transplants (Danaher et al., 2013, Danaher et al, 2014, Sleeper et al., 2009).

Integrating fish production with greenhouse vegetable production

Hydroponic vegetable production has been shown to lend itself well with integration into RAS, improving NUE. The integration of intensive aquaculture with hydroponic vegetable production is commonly referred to as aquaponics (Rakocy et al., 2006). Aquaponics utilizes plant production to remove dissolved nutrients directly from fish culture water by assimilating nutrients into plant biomass. The decrease in dissolved nutrients improves water quality for fish. Fish replenish nutrients in the water as they are fed and release more waste. The synergistic benefits of integrating RAS with hydroponics has been well documented.

The most notable and popular aquaponic research and system design can be traced to the work of James E. Rakocy at the University of the Virgin Islands (UVI) (Rakocy

2006). This system incorporates raft culture into RAS technology. UVI has validated and provided much of the information that is used today in regards to system sizing, nutrient supplementation and general management strategies (Rakocy, 1988, Rakocy et al., 2004, Rakocy et al., 2007).

Aquaponic systems have been shown to improve NUE and nutrient conversion, decrease water consumption, and improve water quality over conventional RAS systems (Rakocy, 1988; Al-Hafedh et al., 2008; Clarkson and Lane, 1991; Takeda et al., 1997). The impact integration has on water quality and NUE varies depending on plant and fish species and stocking densities, along with and RAS design. Quiller et al., (1995) reported that 60 % of applied N was recovered with 28% assimilated into plant biomass and 31% being assimilated into fish biomass when fish production was integrated with hydroponic tomato production. Chaves et al., (2000) compared an integrated system to both monoculture fish system and monoculture plant system and observed 13 to 14% reduction in nitrates and 14 to 19% reduction in PO_4 when compared to an identical fish production system without an integrated plant component. Mariscal-Largarda et al., (2012) reported a 97-98% reduction in water usage per kg of shrimp when comparing with traditional monoculture systems in Mexico and a 93 to 96% reduction in water used for tomato production.

Research with BFT or RAS indicate that some essential plant nutrients require supplementation. Nutrient deficiency can depend on nutrient concentration in fish feed, nutrient availability as relates to pH, and interactions with other ions in a systems. Iron (Fe) deficiency has been attributed to high pH levels associated with RAS (Lewis et al., 1978). McMurty et al. (1993) reported both potassium to be limiting and calcium to be

low in fish feed. These deficiencies are now commonly handled by managing pH with calcium hydroxide and potassium hydroxide (Rakocy et al., 2006). Fe chelates are also commonly used to handle Fe deficiency in plants. Managing pH below 6.8 can reduce the need for Fe chelates as more Fe is available in solution (personal experience).

Amount of fish feed to plant area ratios are commonly used as a tool to help with system sizing. This is usually expressed in terms of g of feed/m^2/day, the area referring to plant production area. The UVI system recommends a ratio of 100 grams of feed per m2 of plant production. Al-Hafedh et al., (2008) reported that 56 g of fish feed/m^2 was sufficient for lettuce growth. In a system that predates the modern UVI system Rakocy (1988) observed that 56 g of fish feed per m^2 (calculated from reported 3.2 g/m^3/m^2.) was sufficient for lettuce growth. In one of the earliest of aquaponics systems 84 to 91 g/m^2 was calculated from Zweig's (1986) descriptions of his system. The ratio calculated from Zweig (1986) is similar to what Rakocy et al., (2004) reported for basil (99.6 g/m^2) in the UVI system.

Improving nutrient and water use efficiencies is also desirable for the vegetable producer. Greater NUE in all agriculture production is advantageous as the cost of nutrients can be influenced by availability and fuel cost. (Cordell et al., 2009: Huang, 2007; Huang 2009). Environmental concerns have also been directed toward the low NUE of some field grown vegetable crop systems (McNeal et al., 1995; Stanley et al., 1995). Sato et al., (2010) reported N losses of 35 to 43% but phosphorus losses were 0 to 2%. The NUE for P was calculated to be 10 to 14% efficient indicating a likely large percentage of P became unavailable for plant uptake depending on soil type (Sato et al., 2010).

Greenhouse production of vegetables utilizing hydroponic and soilless culture techniques improves nutrient and water use efficiency over conventional open field production. (Grewal, et al., 20011) 2005, El-Behairy 2003). Jovicich et al., (2007) demonstrated a 33% reduction in water and a 28% reduction in N per kg of cucumber fruit when comparing greenhouse grown to conventional field grown cucumbers. Greenhouse vegetable growers using soilless culture commonly discharge irrigation without recycling that nutrient laden water. This is commonly referred to as "drip to waste". This leachate solution is not recycled for biosecurity reasons and difficulty related to managing nutrient concentrations in recycled solutions. Drip to waste soilless systems may allow a 20 to 25% leaching fraction to prevent the buildup of fertilizer salts in the media that would otherwise cause damage to the crop (Resh, 2013).

Aquaponic research has primarily revolved around the following 2 major crops: leafy greens (Rakocy et al., 2004, Rakocy 1988; Clarkson and Lane, 1991; Chaves, et al., 2007; Sikawa and Yakupitiyague 2010; Al-Hafedh et al., 2008) tomatoes (Lewis et al 1978; Watten and Busch 1984; McMurty et al., 1993; Mariscal-Lagarda et al., 2012) Savidov et al., (2007) evaluated 24 different plant species grown in aquaponic system, demonstrating the variety of crops that can be gown aquaponically.

Most aquaponic systems research has focused on system designs that cater to fish production. In many cases this could be considered "reinventing the wheel" and ignores the principles of greenhouse production such as: maximizing space utilization, maximizing yield per area, and produce crops where the net profit justifies growing the crop. The greenhouse vegetable industry has already developed a system for vine crop culture that maximizes plant densities and yields.

There are several synergistic advantages formed when fish and plant systems are integrated. One of the most popular claims is a reduction in the cost of fertilizer, but however limited work demonstrating whether this reduction has any economic significance has not been conducted. Most aquaponic systems and related research involves the production of leafy greens. This purpose of this research is to utilize and integrate already existing and proven horticulture technology to grow vine crops with existing RAS systems and to evaluate economic impact associated with the proposed integration.

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Chapter II

Integrating Beit Alpha Cucumber Production with Biofloc Tilapia Production

Abstract

In the summer of 2012, cucumbers grown with effluent from a 100 m^3 biofloc systems and compared to cucumbers grown with a commercial hydroponic fertilizer. Plants were grown conventionally in a soilless hydroponic system utilizing standard drip irrigation equipment for 44 days. Plants receiving effluent yielded 28% less fruit than those receiving the commercial fertilizer. Tissue analysis of shoot and fruit tissue suggested phosphorus as being a deficient nutrient in plants receiving AE. Results from this study indicate that despite the high concentrations of solids suspended in the water column, integration with conventional soilless hydroponic systems with biofloc tilapia production is feasible.

1.0 Introduction

Feed cost can account for over 50% of production cost in an aquaculture system (FAO 2009), consequently it is important to recover as much cost as possible through feed conversion into sellable products. Fish are among the most efficient cultured animals in regards to feed conversion but there is still a considerable amount of wasted nutrients associated with fish production (Heinen et al., 1996; Rhaphie and Saad, 2005). Recirculating aquaculture systems (RAS) are highly efficient in improving water and

space use efficiency but traditional RAS systems do little to improve the nutrient use efficiency of the system (NUE).

Biofloc Technology (BFT), is a form of RAS that does not use a traditional biofilters. BFT relies on the constant mixing of suspended solids in the water column. Solids in suspension in BFT culture water provide surface area for both heterotrophic and autotrophic bacteria growth. Most BFT are operated where nitrogenous waste is primarily handled through mineralization utilizing heterotrophic bacteria. Nitrogenous waste (primarily Ammonia) is assimilated into microbial protein, converting the N into a non-toxic form (Schryver et al., 2008; Avnimelech 2006). This management technique can be enhanced by increasing the C:N ratio by supplamenting highly available carbon sources or by lowering the percent protein in feed (Avenemilich, 1999; Azim and Little, 2008). BFT has been shown to improve feed conversion ratio (FCR) over clear water systems thereby improving the nutrient use efficiency of the system (Azim and Little 2008). BFT systems contain high degrees of settable solids that include microbial flocs, uneaten feed and fecal waste.

Hydroponic vegetable production has been shown to lend itself well with integration into RAS improving NUE. The integration of RAS with hydroponic vegetable production is commonly referred to as aquaponics (Rakocy 2006). Aquaponic systems have been shown to improve NUE, decrease water consumption and improve water quality over conventional RAS systems (Rakocy 1988; Al-Hafedh et al., 2008; Clarkson and Lane 1991; Takeda et al., 1997)). Quillere et al (1995) reported that 60 % of applied nitrogen was recovered with 28% being assimilated into plant biomass and

31% being assimilated into fish biomass when fish production was integrated with hydroponic tomato production.

Aquaponic research has primarily revolved around the following 2 major crops: leafy greens (Rakocy et al, 2004, Rakocy 1988; Clarkson and Lane 1991; Chavez, et al., 2007; Al-Hafedh et al., 2008) and tomatoes (Lewis et al 1978; Watten and Busch 1984; McMurty et al., 1993; Mariscal-Largardah et al 2012; Castro et al., 2006). Savidov et al., (2007) evaluated 24 different plant species grown in an aquaponic system, demonstrating the variety of crops that can be gown aquaponically.

Little research has focused on integrating soilless plant production systems that utilize conventional soilless growing systems common in the greenhouse vegetable industy. Soilless systems utilize growing substrates that are highly porous and have a low water holding capacity. This allows growers to manipulate the nutrients in the root zone with frequent irrigation with drip irrigation. Little research has been conducted on integrating soiless hydroponic systems with fish production. Which has often been attributed to problems with drip irrigation and substrate clogging from solid fish waste. High concentrations of settable solids associated with BFT have also limited integrated research on BFT systems. The purpose of this research is to investigate the integration of BFT aquaculture effluent (AE) with greenhouse cucumber production using soilless plant production using soilless hydroponic systems.

2.0 Materials and Methods

2.1 Facility

The facilities used in this study consisted of two commercial size greenhouses, located at the E.W. Shell Fisheries Center, North Auburn Unit, approximately 10 km north of Auburn, Alabama, USA. The fish culture system was housed in a 267.6 m^2 double polyethylene covered greenhouse (9.1 m x 29.2 m) with an east to west orientation consisting of two rectangular tanks (1.2 m x 3.7m x 26.8 m) each with a volume capacity of 125 m^3 and an average volume of 100 m^3. These systems were operated as a BFT system but without supplemental carbon (Avnimelech 2006). A 1.9 m^3 cone bottomed clarifier (30% slope) adjacent to the greenhouse was used to reduce the concentration of suspended solids from the system. Water flowed through the clarifier at an approximate flow rate of 18.9 l/min. and then entered a 1.1 m^3 cone bottomed sump used for irrigation (irrigation sump) before re-entering the fish production tank. Both vessels had an uninterrupted and constant flow of water driven by air lift pumps. Both the clarifier and irrigation sump were flushed of collected solids twice daily.

The plant greenhouse was also a covered, double layered polyethylene sheeting and was a 267.6 m^2 greenhouse (9.1 m x 29.2 m) with a north to south orientation. The plant greenhouse was outfitted for soilless vine crop production with a cable trellis system running the length of the greenhouse. This trellis consisted of steel cables suspended approximately 2.1 meters above the greenhouse floor. Two cables were suspended above each row approximately 0.1 meters from the row center. Each row was 1.5 meters apart and plant growing containers were spaced 40.6 cm apart within the row. Both greenhouses were equipped with environmental controls for year round production.

2.2 Fish production

For the purpose of this experiment only one tank in the fish greenhouse was utilized. The tank was stocked with 4000 Nile tilapia (*Oreochromis niloticus*) (138 grams/fish) at a stocking density of 40 fish/m^3. The fish were fed a 36% protein floating feed at 1-3% body weight/day. Tilapia were fed *ad libitum* with a 36% protein extruded diet (Cargill® , Franklinton, LA) twice daily (0830 and 1600 hr.) for approximately twenty minutes. Calcium-hydroxide [$Ca(OH)^2$] was applied after each feeding to maintain a targeted pH of 6.8 to 7.0 (Rakocy et al., 2006). This experiment was initiated on June 19 when fish biomass was estimated to be 16.14 kg/m^3 and average daily feed input was approximately 18 kg per day. Dissolved oxygen and temperature of fish culturing water were recorded twice daily (YSI 550A, YSI Inc., Yellow Springs, OH.

2.3 Plant Production and Experiment Design

Two evaluate yields of cucumbers grown with AE, a conventional hydroponic fertilizer was used as a control. On June 19, 2012 two week old cucumbers plants, Beit Alpha cucumber type, were transplanted into 11 liter, Bato Pots (Bato Plastics B.V. Zevenbergon, The Netherlands) filled with commercial grade perlite. The variety 'Manar' was selected based on the varieties powdery mildew resistance (Hochmuth et al., 2004) Beit Alpha cucumbers are a relatively new greenhouse crop in the U.S. Because it is parthenocarpic, no supplemental pollination was required. The planting density was calculated to be 1.6 plants/m^3. There were two treatments, AE and a commercially available hydroponic fertilizer. Plants receiving the fertilizer treatment were grown with 30 mg/l N Total Grow 3-13-29, (STD Industries Inc. Winnsboro, Louisiana) and 150

mg/l N calcium nitrate 15.5-0-0 providing a total nitrogen concentration of 180 mg/l N (Shaw and Cantliffe 2009). Both fertilizers were injected separately using fertilizer injectors (Model DM11 Dosatron USA. Clearwater Florida). The fish effluent was pumped from the irrigation sump adjacent to the fish greenhouse. Both treatments were delivered through drip irrigation and pressure compensated emitters at a flow rate of 3.785 l/hour. The plants were arranged in a completely randomized design with 75 replications per treatment. Plants were grown for 43 days. Harvest began on 22 days after transplanting (DAT) and continued daily until termination of the study.

2.4 Irrigation

This experiment consisted of two treatments, AE and a commercially available hydroponic fertilizer. The irrigation sump was used to access clarified water for drip irrigation system for soilless culture of cucumbers in the adjacent greenhouse. A 1.5 horse power irrigation pump was used to deliver the pressurized water at 30 psi. Pressure was regulated by bleeding excess pressure back into the irrigation sump. Both treatments, AE and conventional fertilizer, were delivered to appropriate plants through standard drip irrigation equipment used in soilless production of greenhouse vegetable crops. Both treatments were delivered to plants using a clog resistant pressure compensated emitter (Bowsmith Non-Stop Emitter, Bowsmith Inc. Exeter California.) at a flow rate of 3.785 l/hour. Plants grown with AE received water directly from the irrigation sump. Fertilizer was delivered to plants grown conventionally through two fertilizer injectors that allowed separate but simultaneous injection of the hydroponic fertilizer blend and calcium nitrate. The solenoid valves responsible for delivering the respective treatments were wired in

tangent so both treatments were applied at the same time. Previous studies had shown potassium to be limiting (data not shown) and potassium supplementation has been found to be necessary in aquaponic systems (McMurty et al., 1993; Rakocy et al., 2006). Potassium was supplemented once at 110 mg/L using potassium chloride. This also provided 100 mg/l of chloride for nitrate management, concerning fish.

3.0 Data collected and Analysis

Cucumber fruit was harvested daily at a target weight of 90 to 110 grams. Tissue samples were taken weekly. Five replications were randomly selected for each treatment and pruning's, fruit and tissue samples were collected weekly from these plants for dry weight and tissue elemental analysis. Entire plant samples were also collected at crop termination.

3.1 Nutrient Analysis and Water Quality

Nutrient analysis was performed twice weekly where total ammonia nitrogen (TAN), nitrate, nitrite, potassium and orthophosphate were determined. A three-liter composite sample of the fish culture water and AE from the irrigation sump was collected twice weekly to characterize the nutrient concentration of water being used to irrigate cucumber plants receiving AE (Table 1). Prior to analyses each sample was filtered through a 40-micron Whatman™ glass fiber filter (VWR International, Radnor, PA). Standard curves were made for TAN, nitrate-nitrogen (NO_3-N) , potassium (K) and orthophosphate on a GENESYS 20 visible spectrophotometer (Spectronic Unicam, Rochester, NY). TAN was determined with the Nessler Method 8038 (Hach Company,

Loveland, CO). Orthophosphate was determined using the ascorbic acid method 8048 (Hach Company, Loveland, CO). Nitrate-nitrogen and was analyzed using the ferrous sulfate method 8153 (Hach Company, Loveland CO). Potassium was determined using the tretraphenylborate method 8049 (Hach Company, Loveland CO). Calcium and magnesium were determined with titration method 8329 using ethylenediaminetetraacetic acid (Hach Company, Loveland, CO). Total Phosphorus and Total Nitrogen were determined through persulfate digestion (Rice et al., 2012). Digestates of nitrate and orthophosphate were determined using spectrophotometric screening and ascorbic acid method (Prapaiwang and Boyd 2012; Rice et al 2012; Gross and Boyd 1998)

Settable Solids were determined for water contained in the fish tank and water returning to the tank from the irrigation sump using an adopted procedure of Standard Method 2540 F (Rice et al, 2012). Aveliminech (2007), reported floc particles become reanimated if left undisturbed for the 1 hour recommended in the procedure described in Standard Method 2450, due to gas bubbles forming. For the purposes of this study, a 30 minute period was used for settling. Suspended solids were measured as according to Standard Method 2540 D (Rice et al, 2012) using glass fiber filtration followed gravimetric analysis. The pH of AE was taken twice daily.

3.2 Statistical Analysis

Means were analyzed using Proc Means (SAS version 9.2 SAS Institute, Cary, NC.) Means comparisons were analyzed using Proc Ttest (SAS version 9.2 SAS Institute, Cary, NC.) If variances were found to be equal the pooled method was used to determine

significance. If variances were unequal Satterthwaite method was used to determine significance.

4.0 Results

The study was terminated on August 1, 2012 (43 DAT) due to a fish kill resulting from a disease. Conventional crops could last over 100 days from transplanting (Jovicich et al., 2007).

4.1 Yield

Plants receiving fish effluent yield was 3.2 kg/plant (5.1 kg/m^2), and was 28% lower than plants that received commercial fertilizer 4.5 kg/plant (7.2 kg/m^2)(Table 1, Table2). The number of fruit harvested from fish effluent grown plants (28 fruit/plant) was 28% less than plants grown with the commercial fertilizer (39 fruit/plant) (Table 1.) Little information is available on commercial yields of greenhouse cucumbers. Yields and crop duration found in the literature are presented in Table 2. It is important to note that some of these studies did not report yield as kg/plant and some in kg/area and it was necessary to calculate yield based on given information. Yields for cucumber plants grown with commercial fertilizer in this study were calculated to be 164 g/m2/day when yield per area was averaged over the crop length and was comparable to other studies when calculated in the same manner (126 to 257 g/m2/day) (Table 2).

4.2 Elemental Tissue Analysis

Elemental tissue analysis was conducted on leaves and pruned shoots at each pruning date with the exception of 44 DAT, where the entire above ground portion of the

plant was harvested for elemental tissue analysis (Table 3). Nutrient analysis of shoot and fruit tissue indicated that plants fertilized with fish effluent were significantly lower in phosphorus throughout the study (Table 3, Table 4). Elemental tissue analysis of fruit revealed no significance in nitrogen, potassium, calcium and magnesium but phosphorus was 63% lower in AE grown cucumbers when compared to CF grown cucumber plants (Table 4). Calcium concentrations in plant tissue were different at 30, 37 and 44 DAT. At 44 DAT, calcium concentration in leaf and stem tissue for AE grown plants were 17% higher than what was found in the control. This is likely due to high concentrations of free calcium found in the fish effluent (418 mg/l) (Table 5). High calcium concentrations in AE were a direct result from daily additions of calcium hydroxide to the fish culture tanks for pH management.

Calcium, magnesium, and potassium are known to have an antagonistic relationship in regards to plant uptake (Epstein and Bloom 2005). High calcium and magnesium concentrations in the fish effluent could have inhibited optimum uptake of potassium. Potassium concentrations were significantly lower in AE plants compared to CF plants throughout the study with the exception of 30 DAT. Potassium concentrations in the fish effluent were 31 % lower than concentrations in the hydroponic fertilizer at 43 DAT (Table 4.) High calcium concentrations and a higher than optimum pH may have influenced the percentage of phosphorus available to the plant. Phosphorus concentrations in plant shoot tissue were significant throughout the study. At 44 DAT phosphorus levels were 60% lower in AE than CF grown plants. Nitrogen levels in shoot tissue of CF grown cumbers were significantly lower when compared to AE at 37 and 44 DAT. AE nitrate nitrogen concentration averaged 400 ± 62 mg/l NO_3-N and were 56%

greater than CF grown cucumbers (175 ± 10 mg/l NO_3-N) (Table 5). Elemental tissue analysis of fruit from both plants grown with AE and CF revealed no significance in nitrogen, potassium, calcium and magnesium but phosphorus was 63% lower in AE grown cucumbers when compared to CF grown cucumber plants (Table 5).

The clarifier was effective in reducing both total suspended solids and settable solids (Table 6). Solids were seen accumulating in perlite receiving AE but little problems with irrigation and media clogging were observed.

5.0 Discussion

This experiment revolved around the use of a BioFloc production system that was managed with minimum water exchange. Concentrations of nutrient levels were significantly more than would be allowed in conventional production systems. Total phosphorus in AE was 33 mg/l and available phosphorus concentrations in AE was 3.3 mg/l P_2O_4 (Table 6). A greater percentage of phosphorus has been shown to be lost to solid waste rather than Bronchial-urinary waste (Van Weerd et al., 1999). Settable solids in the fish culture water were reduced by 60% when exiting the clarifier and Total Phosphorus was reduced by 27% (Table 6). Calcium hydroxide applications could have also significantly reduced orthophosphate as it would temporarily significantly increase pH (> 8.0) in portions of the tank before it could be mixed thoroughly into the water column. High calcium concentrations coupled with high pH can favor the formation of hydroxyapatite (Boyd, 2000). Most soilless growing systems utilize a nutrient solution pH of 5.8 to 6.5 (Jones, 2005).

Aquaculture effluent solution contained 95% less phosphorus than the commercial fertilizer solution. This correlates to what was found in shoot and fruit tissue. Fish effluent orthophosphate concentrations would be considered too low for most hydroponic crops but plants may have been able to utilize other phosphorus sources through active uptake that may have accumulated in the plant substrate (Epstein and Bloom, 2005). Increased irrigation frequency has also been shown to improve uptake of P in solutions of low concentrations. This has been demonstrated in bell pepper (Silber et al., 2005) and lettuce (Silber et al., 2003; Xu et al., 2003). Increasing irrigation frequency in plants grown with AE could alleviate some deficiencies in AE but substrate porosity would need to be increased to prevent root rot and other conditions associated with water logged containers.

AE pH averaged 6.7 over the 44 days of the experiment (Table5). Lowering pH may be key to improving the availability of phosphorus and other nutrients while also providing a more favorable pH for the plant growth. Because most RAS depend heavily on nitrifying bacteria, lowering pH may provide less than optimum conditions for biofiltration of fish waste. Nitrifying bacteria are efficient at a variety of pH levels that range from 7.0 to 9.0 (Boyd and Tucker 1998; Chin et al 2005). Villaverde et al (1996) reported the most efficient pH to be 8.0 taking into account the pH needs for nitrosomas and nitrobacter. Most integrated systems utilize large volumes of water and revolve around principles associated with a closed system. Manipulating water pH in closed aquaponics systems utilizing raft technology to accommodate the plant component is cost prohibitive due to the large volume of water that would need to be treated. The system

designed and used for this experiment utilizes micro-irrigation and requires small volumes of water for the plant component.

We estimated that the daily volume of AE used in one greenhouse of cucumber production would be less than 2% of the tank volume. Because such a small volume of water is being applied to the plants, acid can be injected into the irrigation system lowering the pH and possible allowing more phosphorus and iron to become available. The practice of injecting acid into irrigation water is already used by greenhouse growers in both greenhouse vegetable production and the floriculture industry where irrigation water may have high concentrations of alkalinity (Whipker et al., 1996; Bailey and Bilderback 1997). This technology is inexpensive and could also be used to supplement nutrients typically limiting in integrated fish and plant systems such as potassium, calcium, and iron, (Rakocy et al., 2006).

The argument has been made that closing this system while utilizing the technique of acid injection would affect pH of the fish culture system. Maintaining a 20 to 25% leaching fraction is common practice among greenhouse vegetable producers using media based production (Resh, 2013). Closing this system and returning pH manipulated AE leached from one greenhouse would have significantly less of an effect on fish tank pH than that of the makeup water used to refill the tank after irrigation events.

6.0 Conclusion

Results from this study suggest that while conventional yields were achieved, drip irrigated biofloc tilapia with greenhouse cucumber is a viable option. The solid separation and irrigation system used in this study was effective in delivering AE in the same

manner this crop would be grown conventionally. The clarifier was effective in reducing both total suspended solids and settable solids (Table 6). Solids were seen accumulating in perlite receiving AE but little problems with irrigation and media clogging was observed. Future work should include nutrient supplementation and pH manipulation of both the fish culture unit and the plant production unit.

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Table 1. Yield of Beit Alpha cucumbers 'Manar' grown with aquaculture effluent or conventional fertilizer.

Treatment	Fruit Count[Z]	Wet Weight (kg)[Y]	Dry Matter[X]	Dry Weight(kg)[W]
Aqua. Effluent	28	3.2	3.7%	0.12
Conv. Fertilizer	39	4.5	3.4%	0.15
Significance[V]	***	***	N/A	N/A

[Z] Average fruit count over 44 days of production, N= 68 plants.

[Y] Average fruit weight over 44 days of production N = 68 plants.

[X] Percent dry matter of fruit, N= 10 plants.

[W] Dry weight of fruit was calculated by taking Wet weight and multiplying it by the percent dry matter.

[X] Means were analyzed using Proc Ttest(SAS Version 9.2 SAS Institute, Cary, NC). If variances were found to be equal the Pooled method was used to determine significance. If variances were unequal Satterthwaite method was used to determine significance. $P \leq 0.05$ (*), 0.01 (**), 0.001 (***); NS = nonsignificant.

Table 2. Greenhouse cucumber yields found in literature.

Source		Plant Density (plants/m^2)	Crop Duration (days)	Yield per plant (kg/plant)	Yield (kg/m^2)	Yield per plant per day	Yield (g/m2/day)
Shaw et al 2004		4	114	6	20.0	0.05	175
Jovicich et al., 2007		3	105	9	27.0	0.09	257
Bumgarner 2015,		1.4	119	11	15.0	0.09	126
Mean			113	8.7	20.7	0.08	183
This study	AE[Z]	1.6	44	3.2	5.1	0.07	116
	CF[Y]	1.6	44	4.5	7.2	0.10	164

[Z]AE = aquaculture effluent treatment.

[Y]CF = commercial fertilizer treatment.

Table 3. Shoot nutrient analysis of Beit Alpha cucumber 'Manar' grown with aquaculture effluent or conventional fertilizer.

	16 DAT[Z]	23 DAT	30 DAT	37 DAT	44 DAT
Nitrogen					
Aqua. Effluent	5.6%[Y]	5.1%	4.9%	3.8%	3.8%
Conv. Fertilizer	5.8%	5.4%	4.9%	3.2%	3.4%
Significance[X]	NS	NS	NS	*	*
Phosphorus					
Aqua. Effluent	0.5%	0.4%	0.5%	0.1%	0.2%
Conv. Fertilizer	1.1%	1.1%	0.9%	1.0%	0.5%
Significance	***	***	***	**	***
Potassium					
Aqua. Effluent	5.3%	4.6%	5.0%	4.5%	3.3%
Conv. Fertilizer	6.1%	5.3%	4.9%	5.4%	4.3%
Significance	**	**	NS	***	**
Calcium					
Aqua. Effluent	1.8%	1.7%	1.8%	8.5%	4.7%
Conv. Fertilizer	1.7%	1.6%	2.4%	6.8%	3.9%
Significance	NS	NS	***	***	***
Magnesium					
Aqua. Effluent	0.5%	0.5%	0.5%	1.5%	0.8%
Conv. Fertilizer	0.5%	0.5%	0.6%	1.4%	0.7%
Significance	*	NS	***	*	**

[Z]DAT = Days after transplant

[Y]Percentages equal percent of nutrient found in tissue

[X]Means were analyzed using Proc Ttest(SAS Version 9.2 SAS Institute, Cary, NC). If variances were found to be equal the Pooled method was used to determine significance. If variances were unequal Satterthwaite method was used to determine significance. $P \leq 0.05$ (*), 0.01 (**), 0.001 (***); NS = nonsignificant.

Table 4. Fruit nutrient analysis of Beit Alpha cucumber 'Manar' grown aquacutlure effluent or commercial fertilizer.

	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Aqua. Effluent	3.6%[Z]	0.3%	4.4%	0.6%	0.3%
Conv. Fertilizer	3.7%	0.8%	4.6%	0.5%	0.3%
Significance[Y]	NS	***	NS	NS	NS

[Z]Percentages equal percent of nutrient found in tissue.

[Y]Means were analyzed using Proc Ttest (SAS Version 9.2 SAS Institute, Cary, NC). If variances were found to be equal the Pooled method was used to determine significance. If variances were unequal Satterthwaite method was used to determine significance. $P \leq 0.05$ (*), 0.01 (**), 0.001 (***); NS = nonsignificant.

Table 5. Nutrient concentrations of commercial fertilizer and aquaculture effluent applied to Beit Alpha cucumber 'Manar'

	pH	NO_3-N	PO_4-P	K^+	Ca^{2+}	Mg^{2+}
Commercial Fertilizer (mg/l)	6.0 ± 0.0[Z] n = 3	175 ± 10.0 n = 4	61.7 ± 4.37 n = 4	245 ± 5.7 n = 4	254 ± 23.4 n = 4	52 ± 10.0 n = 4
Aquaculture Effluent (mg/l)	6.7 ± 0.2 n = 75	400 ± 62.3 n = 11	3.3 ± 0.98 n = 11	170 ± 14.1 n = 6	418 ± 85 n = 11	125 ± 24.3 n = 11

[Z]Means were analyzed using Proc Means (SAS Version 9.2 SAS Institute, Cary, NC).

Table 6. Fish culture system and effluent water quality

Water Source	Total Suspended Solids (mg/l)	Total Nitrogen	Total Phosphorus	Settable Solids
Fish Tank	337	414	45	7.4
Tank Effluent	214	371	33	2.9

[z]Means were analyzed using Proc Means (SAS Version 9.2 SAS Institute, Cary, NC).

Chapter III

Integrating Greenhouse Cherry Tomato Production with

Biofloc Tilapia Production

Abstract

Integration of intensive aquaculture systems with greenhouse plant production has been shown to improve aquaculture water quality conditions and improve plant nutrient use efficiency. The majority of the focus of integrated systems has involved raft culture or true hydroponics. Little work has been done on soilless culture utilizing drip irrigation. This study investigated the feasibility of integrating biofloc tilapia (*Oreochromis niloticus*) production with greenhouse cherry tomato production *(Solanum lycopersicum* var. *cerasiforme)*. Nile tilapia (*Oreochromis niloticus*) (157 grams/fish) were stocked at 40 fish/m^3 and grown for 149 days. Two varieties of cherry tomato (*Solanum lycopersicum* var. *cerasiforme)* were used, 'Favorita' and 'Goldita' and grown with AE waste and compared to plants grown with conventional fertilizer in soilless culture. Plants were grown for 158 days. No differences were observed between treatments until fish harvest (117 DAT).Yields for 'Favorita were 11.8 and 11.1 for CF and AE plants, respectively, at fish harvest and were the same. Post fish harvest 'Favorita' there was a 19% difference in total yield between treatments at crop termination. Goldita plants were different both pre and post fish harvest with overall yield less than Favorita despite treatment applied. This study demonstrates that greenhouse cherry tomato production

utilizing soilless growing techniques can be successfully integrated with AE from a tilapia biofloc production system.

Introduction

Feed cost can account for over 50% of production cost in an aquaculture system (FAO 2009), consequently it is important to efficiently convert feed into sellable products. Fish are among the most efficient cultured animals in regards to feed conversion, but there is still a considerable amount of wasted nutrients associated with fish production (Heinen et al., 1996; Rafiee and Saad, 2005). Recirculating aquaculture systems (RAS) are highly efficient in improving water and space use efficiency but traditional RAS systems do little to improve the nutrient use efficiency of a system (NUE).

Biofloc Technology (BFT) is a form of RAS that does not use a traditional biofilters. BFT relies on the constant mixing of suspended solids in the water column. Solids in suspension in BFT culture water provide surface area for both heterotrophic and autotrophic bacteria growth. Most BFT are operated where nitrogenous waste is primarily handled through mineralization utilizing heterotrophic bacteria. Nitrogenous waste (primarily Ammonia) is assimilated into microbial protein, converting the N into a non-toxic form (De Schrymer et al., 2008; Avnimelech 2006). This management technique is enhanced by increasing the C:N ratio of food adding highly available carbon sources or by lowering the percent protein in feed (Avnimelech, 1999; Azim and Little, 2008). BFT has been shown to improve feed conversion ratio (FCR) over clear water systems which improves the nutrient use efficiency of the system (Azim and Little,

2008). BFT systems contain high concentrations of settable solids that include microbial flocs, uneaten feed and fecal waste.

Hydroponic vegetable production lends itself well with integration into RAS improving NUE. The integration of RAS with hydroponic vegetable production is commonly referred to as aquaponics (Rakocy 2006). Aquaponic systems have been shown to improve NUE, decrease water consumption and improve water quality over conventional RAS systems (Rakocy, 1988; Al-Hafedh et al., 2008; Clarkson and Lane, 1991; Takeda et al., 1997). Quillere et al., (1995) reported that 60% of applied nitrogen was recovered with 28% being assimilated into plant biomass and 31% being assimilated into fish biomass when fish production was integrated with hydroponic tomato production.

Aquaponic research has primarily revolved around 2 major crops: leafy greens (Rakocy et al., 2004, Rakocy, 1988; Clarkson and Lane, 1991; Chaves, et al., 2007; Al-Hafedh et al., 2008) and tomatoes (Lewis et al., 1978; Watten and Busch, 1984; McMurty et al., 1993; Mariscal-Lagarda et al., 2012; Castro et al., 2006) Savidov et al., (2007) evaluated 24 different plant species grown in an Aquaponic system, demonstrating the variety of crops that can be gown aquaponically.

Little research has addressed integrating aquaponics and soilless plant production systems that utilize conventional soilless growing systems commonly in the greenhouse vegetable industry. Soilless systems utilize highly porous growing media with low water holding capacity. This allows growers to manipulate nutrients in the root zone with frequent short irrigation cycles using drip irrigation. Clogging of the micro orifices associated with micro irrigation with fish waste has been a concern with aquaponics.

High concentrations of settable solids associated with BFT have also limited integrated research for soilless systems with BFT systems. The purpose of this research is to investigate the integration of BFT aquaculture effluent (AE) with greenhouse cherry tomato using soilless hydroponic systems for plant production.

2.0 Materials

2.1 Facility

Facilities used in this study consisted of two commercial size greenhouses, located at the E.W. Shell Fisheries Center, North Auburn Unit and approximately 10 km north of Auburn, Alabama, USA (32.649171, -85.486725). The fish culture system was housed in a 267.6 m^2 double polyethylene covered greenhouse (9.1 m x 29.2 m) with an east to west orientation and consisted of two rectangular tanks (1.2 m x 3.7m x 26.8 m) each with a volume capacity of 125 m^3 and an average volume of 100 m^3, operated as a Biofloc system (Avnimelech, 2006). A 1.9 m^3 cone bottomed clarifier (30% slope) adjacent to the greenhouse was used to reduce the concentration of suspended solids from the system. Water flowed through the clarifier at an approximate flow rate of 18.9 l/min. and then entered a 1.1 m^3 cone bottomed sump used for irrigation (irrigation sump) before re-entering the fish production tank. Both of these vessels had an uninterrupted and constant flow of water driven by air lift pumps. Both the clarifier and irrigation sump were flushed of collected solids twice daily.

The 267.5 m^2 (9.1 m x 29.2 m) plant greenhouse was also covered double layered polyethylene sheeting with a north to south orientation. The plant greenhouse was

outfitted for soilless vine crop production with a steel cable trellis system running the length of the greenhouse with cables suspended approximately 2.1 meters above the greenhouse floor. Two cables were suspended above each row approximately 0.1 meters from the row center. Each row was 1.5 meters apart and plant growing containers were spaced 40.6 cm apart within the row. Both greenhouses were equipped with environmental controls for year round production.

2.2 Fish production

Only one fish tank (100 m^3) was used in this study. The tank was stocked with 3,000 Nile tilapia (*Oreochromis niloticus*) (157 grams/fish) 40 fish/m^3 on August 29, 2012. Fish were fed a 36% protein floating feed (Cargill® , Franklinton, LA) at 1-3% body weight/day, *ad libitum* twice daily (0830 and 1600 hr.) for approximately twenty minutes. Calcium-hydroxide [$Ca(OH)^2$] was applied after each feeding to maintain a targeted pH of 6.8 to 7.0 (Rakocy et al., 2006). Dissolved oxygen and temperature of fish culture water were recorded twice daily (YSI 550A, YSI Inc., Yellow Springs, OH). Fish were harvested 150 days after stocking (Jan 24, 2013).

2.3 Plant Production and Experiment Design

To evaluate yields of tomatoes grown with AE against conventionally grown plants, a commercially available hydroponic fertilizer “Bag Culture Tomato Special 3-13-29” (Total Grow™, Winnsboro, LA) and greenhouse grade calcium nitrate (15.5-0-0) were used for the control treatment. Plants were irrigated and fertilized at conventional rates. Which loosely followed recommendations by Hanna (2013) (Table 1.) Two cherry

tomato varieties (*Solanum lycopersicum* var. *cerasiforme)* were used, 'Favorita' and 'Goldita'. On October 1, 2012 eight week old tomato transplants were transplanted into 11 liter Bato pots (Bato Plastics B.V. Zevenbergon, The Netherlands) filled with commercial grade perlite. Following commercial practices two tomatoes were planted in each pot resulting in a plant density of 3.2 plants/m^3. Each pot served as a single experimental unit.

This study consisted of two treatments, aquaculture effluent (AE) and the previously mentioned commercial fertilizer (CF). The AE was pumped from the irrigation sump adjacent to the fish greenhouse. The tomato varieties were evaluated simultaneously but in separate experiments. Both treatments were delivered through drip irrigation and pressure compensated emitters at a flow rate of 3.8 l/hour. Plants were arranged in a completely randomized design with 10 replicates for both treatments of 'Favorita'. Goldita had 9 replicates of AE and 11 replicates of CF grown plants. Harvest began 61 days after transplanting (DAT) and continued daily until termination of the study (158 DAT). Tomato fruit were harvested based on ripeness, with fruit color used as an indicator. Tissue samples were taken at final harvest.

2.4 Irrigation

This experiment consisted of two treatments, AE and a commercially available hydroponic fertilizer. The irrigation sump was used to access clarified water for the drip irrigation system for soilless culture of cherry tomatoes in the adjacent greenhouse. A 1.5 horse power irrigation pump was used to deliver pressurized water at 30 psi. Pressure was regulated by bleeding excess pressure back into the irrigation sump. Both treatments,

AE and CF, were delivered to appropriate plants through standard drip irrigation equipment used in soilless production of greenhouse vegetable crops. Both treatments were delivered to plants using a clog resistant pressure compensated emitter (Bowsmith Non-Stop Emitter, Bowsmith Inc. Exeter California.) at a flow rate of 3.785 l/hour. Plants grown with AE received water directly from the irrigation sump. Plants grown with CF received water and fertilizer through two fertilizer injectors (Model DM11 Dosatron USA. Clearwater Florida). This allowed separate but simultaneous injection of the hydroponic fertilizer blend and calcium nitrate. Solenoid valves responsible for delivering the respective treatments were wired in tangent so both treatments were applied at the same time.

3.0 Data collected and Analysis

3.1 Nutrient Analysis and Water Quality

Nutrient analysis was performed twice weekly where TAN, nitrate, nitrite, potassium and orthophosphate were determined. A three-liter composite sample of the fish culture water and AE from the irrigation sump was collected twice weekly characterize the nutrient concentration of water being used to irrigate tomato plants receiving AE (Table 1). Each sample was filtered using a 40-micron Whatman™ glass fiber filter (VWR International, Radnor, PA). Standard curves were fit for TAN, nitrate-nitrogen, potassium and orthophosphate on a GENESYS 20 visible spectrophotometer (Spectronic Unicam, Rochester, NY). Nessler method 8038 (Hach Company, Loveland, CO) was used to determine TAN the ascorbic acid method 8048 (Hach Company, Loveland, CO) was used to determine orthophosphate. Nitrate-nitrogen and potassium

were analyzed using a Cardy twin nitrate and potassium meters (Spectrum Technologies, Inc., Plainfiled, IL). Titration method 8329 using ethylenediaminetetraacetic acid (Hach Company, Loveland, CO to determine calcium and magnesium. Total Phosphorus and Total Nitrogen were determined through persulfate digestion (Rice et al., 2012). Digestates of nitrate and orthophosphate were determined using spectrophotometric screening and ascorbic acid method (Prapaiwong and Boyd, 2012; Rice et al., 2012; Gross and Boyd, 1998)

Settable Solids were determined for water contained in the fish tank and water returning to the tank from the irrigation sump using an adopted procedure of Standard Method 2540 F (Rice et al, 2012). Avliminech (2007), reported floc particles become reanimated if left undisturbed for the 1 hour recommended settling time in the procedure described in Standard Method 2450, due to gas bubbles forming. For the purposes of this study, a 30 minute period was used for settling. Suspended solids were measured according to Standard Method 2540 D (Rice et al, 2012) using glass fiber filtration followed by gravimetric analysis. The pH of AE of samples were taken twice daily.

3.2 Statistical Analysis

Means were analyzed using Proc Means (SAS version 9.2 SAS Institute, Cary, NC.) Means comparisons were analyzed using Proc Ttest (SAS version 9.2 SAS Institute, Cary, NC.) If variances were equal, the pooled method was used to determine significance. If variances were unequal the Satterthwaite method was used to determine significance.

4. Results

4.1 Fish Production

Fish were grown in the biofloc system for 149 days. Final harvested biomass was 1,501.8 kg (15.0 kg/m^3) live weight of tilapia (Table 2). This biomass load is comparable to Rakocy et al., (2005) in a similarly managed outdoor system (14.4 kg/m3 and 13.7 kg/M3) with similar tank volume and horsepower aeration (0.75 HP/ 100 m^3). Timmons and Ebeling (2013) lists 40 kg/m3 as the maximum biomass that can be produced through aeration and no supplemental oxygen. The total harvested fish biomass produced (final – initial) was 1,032 kg (10.3 kg/m3) (Table 1). Survival was approximately 96% with 3,000 fish stocked and 2,872 fish harvested. This yield represents a 220% increase in growth over 149 days of production and fish grew at a rate of 2.3 g/day/fish. This is a lower growth rate than was observed by Rakocy et al., (2005) however, initial and final stocking weight may have influence this rate.

Total water use was approximately 168 m^3 and translated to 6.14 kg/m3 per kg of fish biomass produced (Table 2). The power required was 5.2 kw/kg of tilapia biomass produced and translated to 35.8 kw/day (Table 2). Base addition using calcium hydroxide would be considered a minor input of 158.9 kg or 0.2 kg per kg of fish biomass gained. Feed inputs totaled 2,010 kg (20.1 kg/m^3) and represented a FCR of 1.9 (Table 2). FCR's in this experiment were comparable to FRC reported by Rakocy et al., (2005) of 2.2 and 1.9.

The FCR associated with tilapia was average. Tilapia can perform more efficiently in regards to feed conversion. Water quality conditions and feeding practices could have affected FCR. Total ammonia nitrogen averaged to 2.3 ± 0.95 mg/l in the fish

production tanks (Table 3). The mean nitrite within fish production tanks was 6.2 ± 1.5 mg/l, above recommended levels, but could have been alleviated some by the initial chloride supplementation of 100 mg/l Cl (Table 3). This concentration was likely depleted by the end of the fish crop through water exchange.

Dissolved oxygen (DO) concentrations averaged 5.7 mg/l and 4.9 mg/l for morning and afternoon, respectively (Table 4). DO concentrations was approximately 16% higher in the morning than in the evening (Table 4). The difference observed in temperature between morning (26.9 C) and afternoon (27.8 C) in combination with feed inputs were likely the reason for DO temperature fluctuations. PH of water within the fish culture tanks was maintained at approximately 6.7 (Table 4).

4.2 Plant Production

No differences in yield were observed between plants grown with AE and CF for each harvest date until fish harvest for the cherry tomato 'Favorita' (Table 5). Some differences were seen between treatments before fish harvest in the 'Goldita.' At fish harvest the total yield across all harvest dates for 'Favorita' grown with AE was 11.83 kg/m^2 (CF) and 11.11 (AE) kg/m^2 and were not different (Table 6). However, 'Goldita' plants were 10.80 kg/m^2 (CF) and 8.33 kg/m^2 (AE) kg/m^2 at fish harvest (Table 6). Fish were withheld feed approximately 7 days from fish harvest. AE used for irrigation was pumped from the clarifier. Nitrate-nitrogen concentrations exiting the clarifier averaged 331 mg/l and ranged from 170 to 520 mg/l (Table 7). Nitrate-nitrogen concentrations might be considered very high for the soilless production of greenhouse tomatoes. Nitrate samples for AE were taken from the clarifier and not at the drip emitter. It is

possible that some degree of denitrification could have taken place inside the irrigation system. Anaerobic conditions would have been favored due to the high organic matter concentration in the AE and the slow rate of water exchanged in the irrigation lines. Future studies should monitor AE at the drip emitters. Orthophosphate phosphate averaged 46.7 mg/l. Potassium levels during the study were within acceptable levels for tomato production. The mean potassium concentration was 239 mg/l. (Table 7).

Tomato harvest continued for an additional 43 days. In all, the fish production system went 22 days without feed input until a new crop of fish was stocked. Total yield at tomato crop termination (158 DAT) for 'Favorita' was 23.10 kg/m^2 for CF grown plants and 18.84 kg/m^2 for AE grown plants (Table 6). At tomato crop termination, total yield for Goldita plants was 20.54 kg/m^2 for CF grown plants and 14.4 kg/m^2 for AE grown plants (Table 6).

For both varieties, no differences were seen across treatments for the total mean number of fruit clusters formed for 'Favorita' from CF grown plants was 13 and 12 for AE grown plants. Differences were observable between AE and CF grown plants for both varieties for each fruit harvest after the fish harvest. Halmann and Kobryn (2003) investigated 'Favorita' response to different growing media over a two year study. The mean yield was 10.4 kg/m^2 at the 12 to 14 the fruit cluster at a plant density of 2.7 plants when the data were pooled over the two years. The Halmann and Kobryn (2003) yield was considerably less than yields found in this study but it is important to consider the lower plant density and the fact that Poland has lower light intensity when compared to the Southeastern United States.

Feeding of the fish crop was terminated approximately one week prior to fish harvest. In all, the fish production system had 22 days without feed input until a new crop of fish was stocked. Plant tissue was analyzed at the termination of the study. With high concentrations of macro nutrients in the fish production tank and the small volume of water used to irrigate this low number of tomato plants allows a reasonable assumption that tomato plants receiving AE would have enough nutrients to maintain yields. Reasons for differences in nutrient concentration in plant tissue between treatments cannot be determined, because water quality data was not taken between fish harvest and when tissue analysis was conducted. It is important to consider that a percentage of fruit harvested after the fish crop was harvested would have already been set on the vine. It is likely that an imbalance of nutrients is responsible for the differences in treatments observed after fish harvest.

Elemental analysis of both fruit and leaf tissue are presented in Tables 8, 9 10, and 11. Optimum levels of elements in tissue are reported in Table 12 (Snyder, 2007). Nitrogen is lower in both tomato varieties across treatments when compared to recommended levels. While differences in elemental concentrations were observed for both varieties between CF and AE, it is difficult to determine which differences could be responsible for the lower yield in plants receiving AE.

5.0 Discussion

Greenhouse vegetable production allows year round production depending on the environmental control capacity of a given greenhouse and the market. Greenhouse tomato production in the Southeastern United States, occurs during months where field

crops are not available due to the much higher cost of production associated with greenhouse production. Plants may be actively growing and present in the greenhouse while outdoor tomato crops are being harvested but they are in a juvenile stage and fruit set may not occur for several months after transplanting. In other regions of the world, several factors lend more toward year round production such as, water availability, product availability, climate, and food cost associated with that region. Both fish and plant crop timing, staggering and proper sizing (fish production: plant production) are areas needing further research.

Knowing plant water demand and the volume of water needed to maintain a specific nitrogen concentration could allow for a better model to determine the scalability of RAS systems integrated with soilless crop production. Because such a small volume of water is being applied to the plants; acid and nutrients could be supplemented to optimize plant nutrition. Nutrients that are typically limiting in integrated fish and plant systems are potassium, calcium, and iron, (Rakocy et al., 2006). The practice of injecting acid into irrigation water is already used by greenhouse growers in both greenhouse vegetable production and the floriculture industry where irrigation water may have high concentrations of alkalinity (Whipker et al., 1996; Bailey and Bilderback 1997).

Maintaining this system as a closed loop while utilizing the technique of acid injection might affect pH of the fish culture system. Recommendations for soilless crop production include a 20 to 25% leaching fraction (Resh 2013). Closing this system and returning pH manipulated AE leached from one greenhouse would have significantly less of an effect on fish tank pH than that of the makeup water used to refill the tank after irrigation events.

6.0 Conclusion

Results from this study suggest that conventional yields are achievable with AE as a fertilizer and irrigation source for cherry tomato production. The solid separation and irrigation system used in this study was effective in delivering AE in the same manner as would occur when tomatoes are grown conventionally. The clarifier was effective in reducing both total suspended solids and settable solids (Table 3). Solids were seen accumulating in perlite receiving AE but few problems with irrigation and media clogging were observed. Future work should include nutrient supplementation and system scalability in relation to water exchange needs to maintain a specific nitrate concentration.

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Table 1. Fertilization schedule for greenhouse tomato production[Z].

Week # following transplanting	Days following	Oz of 3-13-29/ 100 gl	Oz of calcium nitrate/100	Times of irrigation per day	N ppm	K ppm
1	35	6	4	3	56	100
2	42	7	5	4	77	110
3	49	8	6	5	90	130
4	56	9	7	6	99	150
5	63	10	8	7	113	170
6	70	11	9	8	129	190
7	77	12	9	9	129	200
8	84	13	9	10	129	220
9	91	14	9	11	131	240
10	98	14	9	12	135	260

[Z]From Hanna 2013.

Table 2. Inputs and outputs of a 149 day tilapia crop in a 100 m^3 production system.

	Total used	per m^3 of fish production[Z]	per kg of fish
Final Biomass (kg)[Y]	1,502	15.0	-
Beginning biomass (kg)	470	4.7	-
Feed (kg)	2,010	20.1	1.9
Power Use (kwh)[X]	5,338	53.4	5.2
Water (m^3)	168	1.7	0.2
Base (kg)[W]	159	1.6	0.2

[Z]Calculated from 100 m^3 fish production unit.

[Y]Final biomass of Nile tilapia (Oreocrhromis niloticus)

[X]Power included energy consumption from reginerative blowers and greenhouse fans.

[W]Calcium hydroxide was used as base source.

Table 3. Water quality parameters as relates to fish health during 149 day production cycle in a minimum water exchange biofloc production system.

Parameter	Location	Mean[ZY]		Standard Deviation
Total Ammonia Nitrogen (mg/l)	Production Tank	2.3	±	0.95
	Exiting Clarifier	2.2	±	1.15
Nitrite (mg/l)	Production Tank	6.2	±	1.50
	Exiting Clarifier	6.1	±	1.30
Nitrate (mg/l)	Production Tank	330.6	±	99.70
	Exiting Clarifier	331.0	±	106.00
Total Hardness (mg/l)	Production Tank	1,216.9	±	368.00
	Exiting Clarifier	1,231.6	±	368.00
Total Suspended Solids (mg/l)	Production Tank	508.8	±	210.00
	Exiting Clarifier	463.6	±	170.60
Settable Solids (ml/l)	Production Tank	21.1	±	21.60
	Exiting Clarifier	11.6	±	15.90

[Z]Means were calculated from water samples taken weekly

[Y]Descriptive statistics analyzed using the StatPlus software package (AnalystSoft Inc., Alexandria, Virginia).

Table 4. Dailey water quality parameters as relates to fish health during 149 day production cycle in a minimum water exchange biofloc production

Parameter	Time Measure	Mean[ZY]		Standard Deviation
Dissolved Oxygen (mg/l)	AM	5.7	±	0.8
	PM	4.9	±	0.5
Temperature (C°)	AM	26.9	±	3.0
	PM	27.8	±	3.0
pH	AM	6.7	±	0.2
	PM	6.7	±	0.2

[Z]Means were calculated from water samples taken daily

[Y]Descriptive statistics analyzed using the StatPlus software package (AnalystSoft Inc., Alexandria, Virginia).

Table 5. Yield comparisons of cherry tomato cultivars 'Goldita' and 'Favorita' grown with conventional fertilizer or aquaculture effluent.

		Yield (kg/m2) for each harvest date[Z,X]											
Variety	Nutrient Source	11/29	12/7	12/13	12/20	12/28	1/7	1/14	1/25[Y]	2/8	2/19	2/28	3/7
Favorita	Conv. Fert[W]	0.28	1.02	1.32	0.78	1.20	2.66	1.83	2.39	3.23	2.83	2.32	2.28
	Aqua. Effluent[U]	0.26	0.99	1.22	0.73	1.41	2.80	1.90	1.50	1.93	1.60	1.90	1.50
	Significance	NS	NS	NS	NS	NS	NS	NS	*	*	*	NS	*
Goldita	Conv. Fert	0.00	0.21	1.26	0.63	1.44	2.06	2.19	3.01	3.45	2.64	1.86	1.94
	Aqua. Effluent	0.00	0.19	0.88	0.40	1.42	1.69	1.78	1.98	2.02	1.62	1.13	1.34
	Significance	N/A	NS	*	*	NS	NS	NS	*	*	*	*	*

[Z] Plant density was 3.2 plants/m^2.

[Y] Fish crop was harvested on 1/24/15.

[X] Means were analyzed using Proc Ttest(SAS Version 9.2 SAS Institute, Cary, NC). If variances were found to be equal the Pooled method was used to determine significance. If variances were unequal Satterthwaite method was used to determine significance. $P \leq 0.05$ (*); NS = nonsignificant.

[W] Conv. Fert = Conventional fertilizer treatment.

[U] Aqua Effluent = Aquaulture Effluent treatment.

Table 6. Yield of cherry tomato cultivars Goldita and Favorita grown with conventional fertilizer or aquaculture effluent at time of fish harvest and crop termination.

		Yield (kg/m^2)[Z] for each harvest date	
Variety	Nutrient Source	At Fish Harvest[Y]	At Crop Termination[X]
Favorita	Conventional Fertilizer	11.8[W]	23.1
	Aquaculture Effluent	11.1	18.8
	Significance	NS	*
Goldita	Conventional Fertilizer	10.8	20.5
	Aquaculture Effluent	8.3	14.4
	Significance	*	*

[Z] Plant density was 3.3 plants/m^2.

[Y]Fish crop was harvested on 1/24/15.

[X]Tomato crop was terminated on 3/7/13.

[W]Means were analyzed using Proc Ttest(SAS Version 9.2 SAS Institute, Cary, NC). If variances were found to be equal the Pooled method was used to determine significance. If variances were unequal Satterthwaite method was used to determine significance. $P \leq 0.05$ (*); NS = nonsignificant.

Table 7. Water quality parameters as relates to plant health during 149 day production cycle in a minimum water exchange biofloc production system.

Parameter	Location	Mean[ZY]		Standard Deviation
Total Nitrogen	Production Tank	371.8	±	148.0
(mg/l)	Exiting Clarifier	405.0	±	157.0
Nitrate	Production Tank	330.6	±	99.7
(mg/l)	Exiting Clarifier	331.0	±	106.0
Dissolved Reactive	Production Tank	47.2	±	13.8
Phosphorus (mg/l)	Exiting Clarifier	42.7	±	15.4
Total Phosphorus	Production Tank	82.2	±	39.9
(mg/l)	Exiting Clarifier	73.6	±	24
Potassium	Production Tank	239.4	±	36.4
(mg/l)	Exiting Clarifier	235.8	±	32.3
Calcium	Production Tank	424.4	±	141.6
mg/l	Exiting Clarifier	431.0	±	138.8
Magnesium	Production Tank	44.4	±	4.0
(mg/l)	Exiting Clarifier	43.9	±	6.0

[Z]Means were calculated from water samples taken daily

[Y]Descriptive statistics analyzed using the StatPlus software package (AnalystSoft Inc., Alexandria, Virginia).

Table 8. Nutrient concentration of cherry tomato 'Favorita' fruit tissue grown with conventional fertilizer or aquaculture effluent.

	Percent macronutrient found in leaf tissue[Z]					
Treatment	Nitrogen	Phosphorous	Magnesium	Potassium	Calcium	Sulfur
Conv. Fert[Y]	2.40	0.61	0.17	4.56	0.11	0.20
Aqua. Effluent[X]	2.03	0.54	0.17	4.15	0.20	0.19
Significance	*	*	NS	*	NS	NS

	Concentration (mg/l) of micronutrient found in leaf tissue					
Treatment	Boron	Iron	Manganese	Copper	Zinc	Aluminum
Conv. Fert[Y]	11.20	52.23	35.30	7.90	20.17	134.87
Aqua. Effluent[X]	9.13	35.13	24.50	7.23	25.40	163.27
Significance	*	*	NS	NS	*	NS

[Z]Means were analyzed using Proc Ttest(SAS Version 9.2 SAS Institute, Cary, NC). If variances were found to be equal the Pooled method was used to determine significance. If variances were unequal Satterthwaite method was used to determine significance. $P \leq 0.05$

[Y]Conv. Fert = Conventional fertilizer treatment.

[X]Aqua Effluent = Aquaulture Effluent treatment.

Table 9. Nutrient concentration of cherry tomato 'Goldita' fruit tissue grown with conventional fertilizer or aquaculture effluent.

	Percent macronutrient found in leaf tissue[Z]					
Treatment	Nitrogen	Phosphorous	Magnesium	Potassium	Calcium	Sulfur
Conv. Fert[Y]	2.68	0.67	0.17	0.21	0.15	0.23
Aqua. Effluent[X]	2.57	0.61	0.17	0.20	0.20	0.22
Significance	NS	NS	NS	NS	NS	NS

	Concentration (mg/l) of micronutrient found in leaf tissue					
Treatment	Boron	Iron	Manganese	Copper	Zinc	Aluminum
Conv. Fert[Y]	11.47	56.43	27.40	9.97	25.90	184.07
Aqua. Effluent[X]	10.37	41.37	25.63	9.43	27.30	159.00
Significance	NS	NS	NS	NS	NS	NS

[Z]Means were analyzed using Proc Ttest(SAS Version 9.2 SAS Institute, Cary, NC). If variances were found to be equal the Pooled method was used to determine significance. If variances were unequal Satterthwaite method was used to determine significance. $P \leq 0.05$ (*); NS = nonsignificant.

[Y]Conv. Fert = Conventional fertilizer treatment.

[X]Aqua Effluent = Aquaulture Effluent treatment.

Table 10. Nutrient concentration of cherry tomato 'Favorita' leaf tissue grown with conventional fertilizer or aquaculture effluent.

	Percent macronutrient found in leaf tissue					
Treatment	Nitrogen	Phosphorous	Magnesium	Potassium	Calcium	Sulfur
Conv. Fert[Y]	2.77	0.44	0.51	4.48	3.89	1.92
Aqua. Effluent[X]	2.62	0.27	0.33	3.20	6.01	1.97
Significance	NS	*	*	*	*	NS

	Concentration (mg/l) of micronutrient found in leaf tissue					
Treatment	Boron	Iron	Manganese	Copper	Zinc	Aluminum
Conv. Fert[Y]	113.30	115.00	711.30	11.90	33.50	16.10
Aqua. Effluent[X]	49.67	73.00	243.00	6.07	38.13	21.33
Significance	*	*	*	*	NS	NS

[Z]Means were analyzed using Proc Ttest(SAS Version 9.2 SAS Institute, Cary, NC). If variances were found to be equal the Pooled method was used to determine significance. If variances were unequal Satterthwaite method was used to determine significance. $P \leq 0.05$ (*); NS = nonsignificant.

[Y]Conv. Fert = Conventional fertilizer treatment.

[X]Aqua Effluent = Aquaulture Effluent treatment.

Table 11. Nutrient concentration of cherry tomato 'Goldita' leaf tissue grown with conventional fertilizer or aquaculture effluent.

	Percent macronutrient found in leaf tissue					
Treatment	Nitrogen	Phosphorous	Magnesium	Potassium	Calcium	Sulfur
Conv. Fert[Y]	2.93	0.31	0.78	4.87	4.35	1.99
Aqua. Effluent[X]	2.63	0.23	0.47	3.33	6.41	1.61
Significance	*	*	*	*	*	*

	Concentration (mg/l) of micronutrient found in leaf tissue					
Treatment	Boron	Iron	Manganese	Copper	Zinc	Aluminum
Conv. Fert[Y]	145.67	126.67	736.33	10.63	28.80	22.13
Aqua. Effluent[X]	38.43	56.87	179.33	5.20	65.23	14.33
Significance	*	*	*	*	*	*

[Z]Means were analyzed using Proc Ttest(SAS Version 9.2 SAS Institute, Cary, NC). If variances were found to be equal the Pooled method was used to determine significance. If variances were unequal Satterthwaite method was used to determine significance. $P \leq 0.05$ (*); NS = nonsignificant.

[Y]Conv. Fert = Conventional fertilizer treatment.

[X]Aqua Effluent = Aquaulture Effluent treatment.

Table 12. Optimum levels of nutrient elements in greenhouse tomato leaf tissue[Z].

Percent macronutrient found in leaf tissue						
%	N	P	K	Ca	Mg	
	4.0-5.5	0.3-1.0	4.0-7.0	1.0-5.0	0.4-1.5	
Concentration (mg/l) of micronutrient found in leaf tissue						
ppm	Fe	Zn	Mn	Cu	B	Mo
	100-250	30-150	40-300	5-25	35-100	0.15-5.0

[Z]From Snyder (1992).

Chapter IV

Economics and Input Efficiencies Associated with Integrating Biolfoc Tilapia Production with Cherry Tomato Production

Abstract

Little information exists quantifying cost savings when integrating fish production with greenhouse vegetable production systems. The objective of this research was to critically investigate the economic changes associated with integrating a biofloc tilapia (*Oreochromis niloticus*) production system with greenhouse cherry tomato *(Solanum lycopersicum* var. *cerasiforme)* production. Production data from an experiment investigating the integration of biofloc tilapia production with greenhouse cherry tomatoes was used to develop the economic analysis. Data was extrapolated from cherry tomato production to cover 267 m^3 of 100% cherry tomato production. In order to evaluate economic and resource changes associated with integration, an integrated system was compared to a tilapia only production and greenhouse tomato only production. When fertilizer savings associated with integration was applied to the tilapia production variable cost(as a negative cost), the return above variable cost increased by 12% for tilapia when compared to tilapia grown in the non-integrated scenario. Through integration where fertilizer savings were applied to tilapia variable costs, the break-even price per kg of fish was reduced by 7%. An opportunity cost to land was observed when independent tomato production was chosen over the integrated scenario. Water use was

reduced by 50% in the integrated approach. The conversion of nitrogen to sellable products was improved by 68% in the integrated approach. This analysis makes a strong case for an economic and resource saving advantage to existing fish production facilities to integrate, providing a market for the plant product is available. The benefits to existing greenhouse cherry tomato producers to integrate with tilapia production is limited. Water and nitrogen use efficiency improvements may outweigh these opportunity cost in areas where water is limited or nitrogen pollution are a concern.

Introduction

While fish as a production crop is efficient in feed conversion compared to other livestock animals a great deal of waste is still produced. Fish waste containing nutrients can have negative environmental impacts to encompassing or nearby water bodies (Cao et al., 2007; Herbeck et al., 2014; Farmaki et al., 2014). As feed is a major expense in fish production. Conversion of as much feed into sellable product as possible is desirable. Improving feed conversion and nutrient use efficiency (NUE) can increase both the economic and environmental sustainability of an aquaculture system.

In traditional RAS, nitrate concentrations can cost effectively be reduced by two methods; water exchange (dilution) or through denitrification. Denitrification involves treating culture water by recirculation in an anaerobic vessel where bacteria are able to use nitrate or nitrite in anaerobic respiration (Van Rijn et al., 2006). The end result of denitrification is the conversion of nitrate and/or nitrite into nitrogen gas resulting in loss through vitalization (Van Rijn et al., 2006; Lee et al., 2000). Both dilution and denitrification result in lowering NUE as nitrogen is lost from the system.

Aquaponics is the integration of fish and plant culture (Rakocy et al., 2006). Aquaponic systems have been shown to improve NUE, decrease water consumption and improve water quality over conventional RAS systems (Rakocy, 1988; Al-Hafedh et al., 2008; Clarkson and Lane 1991; Takeda et al., 1997). The impact integration has on water quality and NUE varies depending on plant and fish species and RAS design. Quiller et al., (1995) reported that 60 % of applied nitrogen was recovered with 28% being assimilated into plant biomass and 31% being assimilated into fish biomass when fish production was integrated with hydroponic tomato production. Chaves et al., (2000) compared an integrated system to both monoculture fish system and monoculture plant system and observed 13 to 14% reduction in nitrates and 14 to 19% reduction in PO_4 when compared to an identical fish production. Mariscal-Largarda reported a 97 to 98% reduction in water usage per kg of shrimp when comparing to traditional monoculture systems in Mexico and a 93 to 96% reduction accounting for water used for tomato production.

Greenhouse production of vegetables utilizing hydroponic and soilless culture techniques improves nutrient and water use efficiency (WUE) over conventional open field production (Grewal et al., 2011, El-Behairy, 2003). Jovicich et al., (2007) demonstrated a 33% reduction in water and a 28% reduction in a nitrogen per kg of cucumber fruit when comparing greenhouse grown to conventional field grown cucumbers. Greenhouse vegetable growers commonly use soilless culture to discharge irrigation without recycling that nutrient laden water. This is commonly referred to as “drip to waste”. This leachate solution is not recycled for biosecurity reasons and associated difficulty related to managing nutrient concentrations in recycled solutions.

Drip to waste soilless systems typically allow a 20 to 25% leaching fraction to prevent the buildup of fertilizer salts in the media that would otherwise cause damage to the crop (Resh, 2013)

Previous experiments have suggested that integrating fish production with soilless greenhouse vegetable production is possible. Little research has documented the economic impact integration has on both fish and plant production. This purpose of this project is to investigate the economic implications of a biofloc system integrated with soilless culture of greenhouse cherry tomato production and the effects on nitrogen and WUE.

Materials and methods

Economic analysis for this study is derived from a previous study on the feasibility of utilizing aquaculture effluent from a biofloc system to irrigate and fertilize greenhouse grown cherry tomatoes (Chapter 3). Production parameters for each crop is outlined in Table 1. Tilapia (*Oreochromis niloticus*) (157 g) were stocked in a 100 m^3 biofloc system at a density of 30 fish/m^3. Cherry tomatoes 'Favorita'were transplanted 32 days after fish stocking in an adjacent greenhouse (Table 1). Two irrigation/fertilization treatments were applied, aquaculture effluent or a commercial fertilizer. The plants were arranged in a complete randomized design with a planting density of 3.2 plants/m^2, with 10 replicates per treatment.

Plants were grown in perlite with a conventional irrigation system that has been previously described (Chapter 3). Plants were trained with conventional cultural techniques (Snyder, 2007). Fertilization of plants receiving fertilizer loosely followed the

fertigation regime presented by Hanna (2013). This economic analysis is based off data collected from stocking until fish harvest for both the tomato and tilapia crop and includes 147 days of tilapia production and 117 days of cherry tomato production. Plant yield is an important component in this analysis. Yield is highly variable in greenhouse production and can be influenced by cultivar, crop duration, light intensity and plant health. Little information is available on verified yields of cherry tomato production and yields can be significantly impacted by geographical area, associated weather and light levels. Cherry tomato production data was extrapolated to a 267.5 m^2 greenhouse in full production. Economic analysis and presentation was modeled after Brown et al., 2014.

Nitrogen conversion ratio (NCR) was calculated using the following:

$$NCR = \frac{(\%\ nitrogen\ in\ feed\ x\ feed\ fed\ (kg))}{Net\ Fish\ biomass\ produced\ (kg)}$$

(Adapted from Boyd et al 2007).

Boyd (2005) has suggested using a water index that would allow systems to be evaluated based on water use.

$$Water\ use\ index\ (m^3/kg) = \frac{\text{Total water used in production } (m^3)}{Production\ (kg)}$$

(Adapted from water use indices proposed by Boyd (2005)).

In order to quantify savings three scenarios were compared, consisting of the following: 1) tilapia and cherry tomato produced independently and no savings applied; 2) tilapia and cherry tomato integrated where fertilizer savings were applied to variable cost in cherry tomato production; and 3) tilapia and cherry tomato integrated where fertilizer value was applied to receipts in tilapia production.

Assumptions

Labor cost was based on an average of 25 man hours per week of production (Snyder et al., 2007). Data was not available for actual greenhouse heating cost, so propane cost was assumed to be $3,000 for the winter production of the tomato crop. This assumption was based off previous experience and average cost reported by local growers. Prices associated with greenhouse developmental cost was based on prices from greenhouse manufacturers and greenhouse construction contractors. Energy cost for both the fish and tomato systems were from actual power meter records for those crops. Water use for fish production was derived from actual water use data collected during production. Management, transportation and marketing cost were not included. Tilapia prices were assumed to be $6.00 per kg and cherry tomato prices were assumed to be $10.00 per kg with the assumption that 100% of the product for both crops were sold. Straight line depreciation method was used to calculate depreciation. After the tomato crop that provided this data was harvested, for an additional 36 days and 12 more kg of tomatoes were harvested from plants grown with conventional fertilizer and 7 kg for plants grown from aquaculture effluent grown plants.

Results

The gross returns for the tilapia crop production and tomato crop was $9,102 and $22,269, respectively (Table 2). The total variable cost for fish production was $5,662 compared to $8,799 associated with tomato production (Table 2). When total variable costs were reduced to cost per square meter the fish and tomato were $14.5 and $28.6 per m^2, respectively. Income above variable cost for tilapia was $3,350 and $13,470 for tomato.

The capital cost to develop the fish greenhouse (267.5 m^2) and production system was $56,874 or $213/$m^2$ (Table 3). It is important to note that this analysis includes only the 149 day tilapia crop discussed in Chapter 3 and only represents only 16% of the total annual capacity of the fish system. Variable cost and fixed cost have been adjusted to reflect the only 16% of the total annual variable and fixed cost (Table 3). The greenhouse and production system responsible for the cherry tomato production was $42,910 or 160/$m^2$ (Table 4).

The variable cost associated with both the tilapia and cherry tomato production systems were calculated (Table 5). The tilapia crop was similar to most aquaculture systems, where feed (35%) and fingerlings (29%) make up the majority of the variable cost (Table 5). The majority of the variable cost associated with the cherry tomato production was in labor (18%) and heat energy (13%).

Data was not available for the actual fertilizer usage for the cherry tomato crop, so fertilizer use was calculated from the recommended fertilization and irrigation schedule outlined by (Hanna, 2013) (Table 6). It is assumed that one crop of fish could provide

adequate nutrition to one greenhouse (267m^2) of cherry tomatoes, a ratio that will vary between systems. The stocking density used in this study would be considered low density especially for the amount of inputs associated with tilapia production. More advanced, higher density systems may allow a higher ratio of plants to fish.

For tomatoes, savings in fertilizer was the only savings identified in this analysis. Savings from reduced fertilizer cost amounted to $478 per greenhouse of cherry tomato production where fertilizer could be 100% augmented by aquaculture effluent. The income above variable cost was increased by 3.4% when the savings associated with fertilizer were applied to the tomato variable cost when compared to the nonintegrated system, but when the savings were applied to tilapia production the incomve above variable cost increased by 12.5% (Table 5). Savings in variable cost had a more dramatic effect on the income above variable cost when compared to the scenario in which savings were applied to tomato production variable cost (Table 2). This is due to the higher degree of impact that variable cost has per unit of product when compared to the tomato production. This difference in savings was similar for net returns above all expenses, where savings provided a 20% increase in net returns to the non-integrated system for savings applied to fish (Table 2). Difference in savings was due to fertilizer being a minor component of greenhouse plant production. Fertilizer was approximately 5% of the variable cost associated with this crop of cherry tomatoes (Table 5).

An advantage of integrated systems that has not been documented is the ability to lower the selling price of a product as a result of the savings associated with integration. The breakeven price above all cost for cherry tomatoes was reduced by 3% (Table 2). When the savings was applied to the fish variable cost, the savings were 7% (Table 2).

When fertilizer savings from plant production was applied to fish variable cost a marketing advantage can occur by lowering the break-even price which could allow a reduced fish selling price. The live fish market is highly competitive in the U.S due to the limited amount of available markets. Reducing the price per unit of fish product could give integrated producers an advantage over nonintegrated producers.

Economic analysis revealed opportunity cost to land. In the non-integrated scenario the net returns above variable cost per m^2 was $25.00 for fish production and $50.00 for cherry tomato production (Table 5). For income above variable cost the return per m^2 increased by 42% when compared to fish alone but decreased by 14% when compared to cherry tomato production. These results suggest a potential opportunity cost of an integrated system over that of producing cherry tomatoes alone. This cost would be negated if integrating an already existing fish production system. Integrating an already existing cherry tomato production enterprise would result in less return per area.

In this study 2,010 kg of nitrogen and 168 m^3 of water was used to produce a net biomass of 1,032 kg of tilapia. The nitrogen conversion ratio (NCR) for feed to fish biomass was 0.10 for the non-integrated scenario. The actual amount of nitrogen applied to the cherry tomato crop was not recorded but loosely followed the irrigation and fertilization schedule recommended by Hanna (2013) (Table 6). Using these recommendations the total amount of nitrogen to produce 2,227 kg of cherry tomatoes in a 267.5 m^2 greenhouse was 15 kg. This represents a NCR of 0.01 kg of nitrogen for cherry tomatoes produced. In order to demonstrate the improvement of the NCR, only nitrogen applied to tilapia was used to calculate the NCR of the integrated scenario where nitrogen from feed was applied to both fish and tomatoes. The NCR for the integrated

scenario of tilapia and cherry tomatoes was 0.03. This improved the nitrogen conversion by 68% when compared to fish alone.

Similarly to the NCR, integration improved the water use index. Tilapia production required 168 m^3 of water to produce 1,032 kg of net fish biomass. This calculated to a water use index (WUI) for tilapia production of 0.16 m^3/kg. Data was not available for water use in the cherry tomato production and was calculated based on the fertilization and irrigation schedule recommended by Hanna (2013). Cherry tomato production was very efficient in converting water to fruit biomass with a WUI of 0.05. WUI for the integrated system was calculated in the same manner as the NCR where 100% of water was considered consumed by both fish and plants. The WUI for the integrated system was also 0.05 and improved WCR by 50% over fish production alone. The system evaluated in this study was an open system and leachate from plant production was not recycled back to fish production. It is recommended that 20 to 25% of irrigation applied should be leached from the plant production containers at each irrigation event to reduce fertilizer salt buildup (Resh, 2013). Utilizing this information calculations are that recirculating would improve WUI by 8% over an open system. This increase in WUI may outweigh the biosecurity risks associated with recycling the plant leachate.

Conclusions

This study is composed of both calculated and actual data. System design, stocking rates, feeding rates and plant crop can all have a profound impact on the practicality of integration. In more conventional RAS systems with higher densities and feed inputs, more water must be exchanged to control nitrates and therefor more plant

area could be irrigated. Increasing plant area can have a positive effect on net returns when savings from fertilizer is applied to the variable cost in fish production, as was demonstrated when comparing the different scenarios in this economic analysis. Through this analysis it was apparent that fertilizer cost is not a major variable cost in cherry tomato production and this can be assumed for most other greenhouse vegetable crops. The savings produced from the reduction of fertilizer can have a more significant impact when the savings is applied to fish production cost, since fish production has a higher ratio of variable cost to net returns compared to that of the cherry tomato production. Specific to this scenario, the savings can reduce the break-even price point per kg of fish allowing a more competitive market price or an increase in profit margin for integrated fish production compared to the non-integrated scenario.

Both water and nitrogen conversion into sellable product was improved through integration. This study suggests a clear advantage for RAS producers who integrated compared to non-integrates systems. This same advantage may not be present for already existing greenhouse companies as the net return per m^2 for greenhouse production was lowered through integration. This analysis is specific to these specific scenarios. Greenhouse tomato production in the Southeastern US is seasonally limited to winter and spring when field tomatoes are unavailable. Savings observed through this analysis would decrease if the savings were spread out over two more fish crops.

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Table 1. Production parameters for a tilapia crop integrated with cherry tomato production in greenhouses in Auburn, AL.

Item	Units	Amount
Tilapia production		
Total growing volume per crop[Z]	m^3	50
Biomass at stocking	kg	470
Fingerling weight	g	156
Days to reach market weight	days	149
Percent survival	%	96%
Final Final biomass	kg/m^3	30
Final biomass	kg	1,502
Market weight	kg	1
Total amount of feed fed	kg	2,010
Total amount of water used	m^3	168
FCR	kg/kg	2
Cherry tomato production		
Plant Density	plants/m^2	3.2
Yield	kg	27
Growing area dedicated to crop	m^2	268
Space utilization	%	75%
Days of production	days/crop	117
Cherry tomato plants per crop cycle	no.	660

[Z]Total growing volume represents 1/6 of yearly production capacity of fish growing system

Table 2. Enterprise budget summaries (US$) for tilapia and cherry tomato production with savings resulting from integration applied in different scenarios.

Variable	Not integrated[Z]	Integrated savings to tomato	Integrated savings to tilapia
Receipts, $			
Tilapia	9,012	9,012	9,012
Cherry tomato	22,269	22,269	22,269
Tilapia + cherry tomato	31,281	31,281	31,281
Variable cost, $			
Tilapia	5,662	5,662	5,184
Cherry tomato	8,799	8,321	8,799
Tilapia + cherry tomato	14,461	13,983	13,983
Income above variable cost, $			
Tilapia	3,350	3,350	3,828
Cherry tomato	13,470	13,948	13,470
Tilapia + cherry tomato	16,820	17,298	17,298
Fixed cost, $			
Tilapia	1,406	1,406	1,406
Cherry tomato	5,823	5,823	5,823
Tilapia + cherry tomato	7,229	7,229	7,229
Total Costs, $			
Tilapia	7,067	7,067	6,589
Cherry tomato	14,623	14,145	14,623
Tilapia + cherry tomato	21,690	21,212	21,212
Net returns to land and owner, $			
Overall			
Tilapia	1,945	1,945	2,423
Cherry tomato	7,647	8,125	7,647
Tilapia + cherry tomato	9,591	10,069	10,069
Per m^2, $/$m^2$			
Tilapia	14.5	14.5	18.1
Cherry tomato	28.6	30.4	28.6
Tilapia + cherry tomato	23.9	25.1	25.1
Break-even price[V], $/kg			
Variable cost (fish)	3.8	3.8	3.5
Total cost (fish)	4.7	4.7	4.4
Variable cost (tomato)	4.0	3.7	4.0
Total cost (tomato)	6.6	6.4	6.6

[Z] The not integrated scenerio represents where both tilapia and cherry tomatoes are treated as two separate enterprises and no economic benefits associated with interation are applied.

[Y] Indicates the scenerio where savings associated with integration was applied to tomato variable cost.

[X] Indicates the scenerio where savings associated with integration was applied to tilapia variable cost.

Table 3. Investment Cost/ Developmental Cost for one greenhouse in tilapia production (267.5 m^2 production area).

Item	Cost/Unit	Quantity	Cost	Useful life (years)	Average on investment	Annual depreciation[z]	Interest on investment
Greenhouse framing	9,362	1	9,362	20	4,681	468	374
Greenhouse covering	985	1	985	4	493	246	39
Covering locking system	0.75	928	696	20	348	35	28
Inflation system	99	1	99	5	50	20	4
Ventilation (fans and vents)	3,180	1	3,180	10	1,590	318	127
Shade 80%	1,014	1	1,014	5	507	203	41
Gravel walkways	500	1	500	20	250	25	20
Electrical	1,500	1	1,500	20	750	75	60
Construction	15,000	1	15,000	20	7,500	750	600
Clarifier and airlift system	1,676	1	1,676	6	838	279	67
Fish tank construction	6,144	1	6,144	6	3,072	1,024	246
Fish production air systems	4,964	1	4,964	6	2,482	827	199
Corn boiler and accessories	7,000	1	7,000	6	3,500	1,167	280
Generator	3,000	1	3,000	10	1,500	300	120
Dissolved oxygen meter	831	1	831	3	416	277	33
Water quality test kit	197	1	197	1	99	197	8
Dip nets	23	3	69	1	35	69	3
Baskets	24	3	72	2	36	36	3
Scale	585	1	585	3	293	195	23
Total investment costs			56,874		28,437	6,511	2,275
Per fish crop (16% of total capacity)			9,100		4,550	1,042	364

[z]Calculated with straight-line depreciation method with no salvage value for depreciable items

Table 4. Initial Investment cost for one 267.5 m^3 greenhouse in cherry tomato production.

Item	Cost/unit	No.	Cost	Useful life (years)	Avg on investment	Annual depreciation[z]	Interest on investment
Greenhouse framing (30' x 96' x 8'	9362	1	9362	20	4681	468	37
Greenhouse Covering	985	1	985	4	493	246	20
Covering locking system	1	928	696	20	348	35	3
Inflation System	99	1	99	5	50	20	2
Ventalation	3180	1	3180	10	1590	318	25
Cooling Pad	2575	1	2575	5	1288	515	41
Gravel Cover	1	1	1000	20	500	50	4
Heater	2671	1	2671	5	1336	534	43
6x6 post	34	6	204	8	102	26	2
6x6x12	8	16	121	8	61	15	1
Cable	92	1	92	8	46	12	1
Hardware	200	1	200	8	100	25	2
Construction Cost	12000	1	12000	20	6000	600	48
Electrical	1500	1	1500	20	750	75	6
Pots	4	660	2640	5	1320	528	42

[z]Calculated with straight-line depreciation method with no salvage value for depreciable items

Table 4. Cont. Initial Investment cost for one 267.5 m^3 greenhouse in cherry tomato production.

Item	Cost/unit	No.	Cost	Useful life (years)	Avg on investment	Annual depreciation[z]	Interest on investment
Pipe	0	500	155	5	78	31	2
Irrigation Controller	480	1	480	3	240	160	13
Irrigation Pump	235	1	235	2	118	118	9
Pump Start Relay	75	1	75	2	38	38	3
Emitters	1	1500	765	3	383	255	20
Main Line Drip	40	2	80	3	40	27	2
Solenoid valve	20	10	200	3	100	67	5
Box of sod staples	50	2	100	3	50	33	3
Fertilizer Injectors	180	4	720	5	360	144	12
Back Pack Sprayer	600	1	600	4	300	150	12
Cardy Nitrate Meter	450	1	450	2	225	225	18
Cardy Potassium Meter	365	1	365	2	183	183	15
Injector pumps	550	2	1100	3	550	367	29
PH EC Meter	260	1	260	2	130	130	10
Total Investment cost for plant production			42910		21455.1	5392.1	431.4

[z]Calculated with straight-line depreciation method with no salvage value for depreciable items

Table 5. Enterprise budget comparing integrated and non integrated tilapia and greenhouse cherry tomato production for one crop each.

		Unit	Cost	Quantity	Not integrated[Z]	Integrated savings to tomato[Y]	Integrated savings to tilapia[X]
I. Gross receipts							
	Fish Sales	kg	6	1,502	9,012	9,012	9,012
	Cherry Tomato Sales	kg	10	2,227	22,269	22,269	22,269
	Tilapia + cherry tomato			3,729	31,281	31,281	31,281
II. Variable Costs							
Tilapia	Fingerlings	per	0.55	3,000	1,650	1,650	1,650
	Feed	ton	880	2	1,962	1,962	1,962
	Electricity	kw	0.10	5,338	534	534	534
	Hydrated lime	bags	4	30	60	60	60
	Labor	MH	10	103	515	515	515
	Wood pellets	tons	155	4	620	620	620
	Interest on OC		0.08	5,341	320	320	320
	Synergistic savings				-	-	(478)
	Total variable cost (tilapia)				5,662	5,662	5,184
Cherry Tomatoes	Seedlings	per	1.00	700	700	700	700
	Electricity	$/kwh	0.10	2,943	294	294	294
	Tomato growing supplies		-	-		629	629
	Tomato clips (9000/box)	box	1	79	79	79	79
	Tomato hangers	box	700	1	350	350	350
	Chemicals	total	200	1	200	200	200
	Fertilizer 3-13-29	kg	450	1	478	478	478
	Labor	MH	10	320	3,200	3,200	3,200
	Liquid propane heat	gal	1.00	3,000	3,000	3,000	3,000
	Interest on OC	%	0.08	8,301	498	498	498
	Synergistic savings				-	(478)	-
	Total variable cost (tomato)				8,799	8,321	8,799
	Total Variable Cost (fish + tomato)				14,461	13,983	13,983

Table 5. Cont. Enterprise budget comparing integrated and non integrated tilapia and greenhouse cherry tomato production for one crop each.

	Not integrated[Z]	Integrated savings to tomato[Y]	Integrated savings to tilapia[X]
III. Income above Variable Cost			
Tilapia	3,350	3,350	3,828
Cherry Tomato	13,470	13,948	13,470
Total	16,820	17,298	17,298
IV. Fixed Cost		-	-
Equipment depreciation (tilapia)	1,042	1,042	1,042
Interest on equipment and construction	364	364	364
Total fixed cost (tilapia)	1,406	1,406	1,406
Equipment depreciation (tomato)	5,392	5,392	5,392
Interest on equipment and construction (tomato)	431	431	431
Total fixed cost (tomato)	5,823	5,823	5,823
Total Fixed Cost (tilapia+tomato)	7,229	7,229	7,229
V. Total varialbe and fixed costs		-	-
Tilapia	7,067	7,067	6,589
Tomato	14,623	14,145	14,623
Total	21,690	21,212	21,212
VI. Net Returns Above All Specified Expenses		-	-
Tilapia	1,945	1,945	2,423
Tomato	7,647	8,125	7,647
Total	9,591	10,069	10,069

Table 5. Cont. Enterprise budget comparing integrated and non integrated tilapia and greenhouse cherry tomato production for one crop each.

	Not integrated[Z]	Integrated savings to tomato[Y]	Integrated savings to tilapia[X]
VII. Net returns per square meter of greenhouse			
Above specified variable cost (tilapia)	25.05	25.05	28.62
Above specified total cost (tilapia)	14.54	14.54	18.11
Above specified variable cost (tomato)	50.36	52.14	50.36
Above specified total cost (tomato)	28.59	30.37	28.59
Above specified variable cost (tilapia+tomato)	41.92	43.11	43.11
Above specified total cost (tilapia+tomato)	23.90	25.09	25.09
VIII. Break-even price per unit of product		-	-
Above specified variable cost (tilapia)	3.77	3.77	3.45
Above specified total cost (tilapia)	4.71	4.71	4.39
Above specified variable cost (tomato)	3.95	3.74	3.95
Above specified total cost (tomato)	6.57	6.35	6.57

[Z] The not integrated scenerio represents where both tilapia and cherry tomatoes are treated as two separate enterprises and no economic benefits associated with interation are applied.

[Y] Indicates the scenerio where savings associated with integration was applied to tomato variable cost.

[X] Indicates the scenerio where savings associated with integration was applied to tilapia variable cost.

Table 6. Fertilization schedule for greenhouse cherry tomato production[Z].

Week # following transplanting	Days following seeding	Oz of 3-13-29/ 100 gal	Oz of calcium nitrate/100 gl.	Times of irrigation per day	N ppm	K ppm
1	35	6	4	3	56	100
2	42	7	5	4	77	110
3	49	8	6	5	90	130
4	56	9	7	6	99	150
5	63	10	8	7	113	170
6	70	11	9	8	129	190
7	77	12	9	9	129	200
8	84	13	9	10	129	220
9	91	14	9	11	131	240
10	98	14	9	12	135	260

[Z]From Hanna, 2013.

Table 7. Comparison of input conversions for greenhouse tilapia, greenhouse cherry tomato production and their integration.

Production system (kg)	Nitrogen conversion ratio (kg)[Z]	Water use index (kg)
Fish	0.10	0.16
Cherry tomato	0.01	0.05
Fish + cherry tomato	0.03	0.05

[Z]Nitrogen convesion equals the amount of nitrogen (kg) applied to yield one unit (kg) of product. With fish production, the amount of biomass gained was used in the calculation and 100% of the nitrogen applied was calculated as being consumed by the crop.

[Y]Water conversion equals the amount of water (m^3) applied to yield one unit (kg) of product. With fish production, the amount of biomass gained was used in the calculation and 100% of the water applied was calculated as being consumed by the crop.

Conclusions

Integration of intensive aquaculture systems with greenhouse plant production has been shown to improve aquaculture water quality conditions and improve plant nutrient use efficiency. The majority of research on integrated systems has involved raft culture or true hydroponics. Little work has been done on soilless culture utilizing drip irrigation. These studies demonstrate that greenhouse cherry tomato and greenhouse cucumber production utilizing soilless growing techniques can be successfully integrated with aquaculture effluent (AE) from a tilapia biofloc production system. Past research has excluded soilless production systems utilizing drip irrigation due to fouling of drip irrigation components. The system used to filter and deliver AE to plants has been in place for some time after these experiments and has shown little problems handling solids/sediment in the AE.

Yields for plants grown with AE in both of these experiments were less than yields produced when plants were grown with the fertilizer control by 20 to 30%. Previous experiments have shown yields that were the same or better than controls (data not shown), demonstrating a high degree of variability resulting from factors associated with fish production. Balancing fish, bacteria and plants to produce a consistent growing environment from crop to crop is difficult, however any reduction in yields may be outweighed by the potential benefits associated with water and nutrient savings. Work demonstrated in these studies show an increase in nutrient and water use efficiency.

Water savings in Alabama is not currently considered a major concern in due to the abundance of water in the state. Reducing nutrient pollution may not justify the risk associated with integration with current waste water regulations. However, the author has observed situations in the Southeastern U.S. were a reduction in water pollutants through integration would be of great benefit. One scenario involved a large aquaculture facility where effluent nitrogen concentrations and volume posed immense environmental concern. A second scenario involved an industrial plant located in an area that required the municipal water system to treat effluent. This treatment became a significant cost of production. Alabama has an abundance of water and is less concerned with pollution, other parts of the world where arid conditions exist and food security is an issue, increasing water and nutrient use efficiency would more than outweigh any reduction in yield.

The economic analysis in Chapter 4, demonstrates several synergistic benefits in regards to integration. An opportunity cost to land was observed when comparing the scenario of only growing tomatoes in the integrated scenario but a positive effect were observed when integrated production was compared to only tilapia production. There was also benefits observed in lowering the breakeven price of both products as a result of reducing production cost. This reduction in breakeven price would be of more benefit to an aquaculture producer than to an existing tomato producer due to tighter margins associated with intensive fish systems.

This analysis demonstrated that fertilizer cost is not a major variable cost in cherry tomato production, a result that is reasonable to assume for most other greenhouse vegetable crops. The savings produced from the reduction of fertilizer can have a more

significant impact when the savings is applied to fish production cost, since fish production has a higher ratio of variable cost to net returns compared to that of the cherry tomato production. Specific to this scenario, the savings can reduce the break-even point per kg of fish, allowing a more competitive price or an increase in profit margin for integrated fish production compared to the non-integrated scenario.

This study suggests an advantage for RAS producers who integrate compared to non-integrated systems. This same advantage may not be present for already existing greenhouse vegetable growers as the net return per m^2 for greenhouse production was lowered through integration. This analysis is specific to the systems and crops used in this study and is highly variable from system to system. Demand for greenhouse tomato production in the Southeastern U.S. is seasonally limited to winter and spring when field tomatoes are unavailable. Savings observed through this analysis would decrease if the savings were spread out over 2 more fish crops, however if the plant to fish ratio was increased the savings associated with fertilizer cost would increase resulting in an even lower breakeven price and net return.

Future work should attempt to better understand system sizing capacity as relates to amount of feed fed to plant growing area. Acid injection and nutrient supplementation should also be investigated to increase plant crop yields and give the grower more flexibility over the system.

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