Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Aquaculture Effluents as Fertilizer in Hydroponic Cultivation

A Case Study Comparing Nutritional and Microbiological Properties

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Självständigt arbete 15 hp
Hortonomprogrammet
Alnarp 2014

Aquaculture Effluents as Fertilizer in Hydroponic Cultivation: A Case Study Comparing Nutritional and Microbiological Properties

Fiskodlingsvatten som näringskälla i hydroponisk odling: En fallstudie som jämför näringsmässiga och mikrobiologiska egenskaper

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Omfattning: 15 hp
Nivå och fördjupning: G2E
Kurstitel: Kandidatarbete i trädgårdsvetenskap
Kurskod: EX0495

Program/utbildning: Hortonom
Examen: Kandidatarbete i Trädgårdsvetenskap
Ämne: Trädgårdsvetenskap (EX0495**)**

Utgivningsort: Alnarp
Utgivningsmånad och –år: Mars 2014
Omslagsbild: Författarens bearbetning av bilden http://www.flickr.com/photos/thart2009/5376510119/sizes/l/ av Tom Hart. Licens CC-BY-SA.
Elektronisk publicering: http://stud.epsilon.slu.se

Nyckelord: Organic hydroponic. Aquaponic. Aquaculture. Plant nutrition. Microbial horticulture.

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Sammanfattning

Detta arbete utvärderar möjligheterna att använda vattnet från fiskodlingar som näringskälla i ekologisk hydroponisk odling, så som är fallet i akvaponiska odlingssystem. Att ersätta syntetiska gödselmedel med organiska är avgörande för utvecklingen av ekologisk hydroponisk odling. Dessutom ingår etablering av en sjukdomsundertryckande mikroflora som en del av växtskyddsstrategin i moderna hydroponiska odlingar. Därför analyserades och jämfördes både näringsmässiga och mikrobiella egenskaper hos fiskodlingsvatten med de från en ekologisk hydroponisk näringslösning. Resultaten visade att både den hydroponiska näringslösningen och fiskodlingsvattnet hade brist på flertalet essentiella västnäringsämnen, dock var den ekologiska näringslösningen mest optimal. Den ekologiska näringslösningen hade högst densitet av aeroba bakterier, så väl som av fluorescerande pseudomonader. Nivån av svampar var likvärdig. Halten av fluorescerande pseudomonader var märkbart mindre efter att fiskodlingsvattnet passerat anläggningens biofilter.

En kvalitativ analys av mikrofloran i en akvaponisk odling skulle kunna öka förståelsen av mikroorganismers uppträdande i denna unika miljö samt potentiell inverkan på växtskydd och växtnäringscykeln.

Abstract

This paper evaluates the prospects for utilizing aquaculture effluents as a nutrient source in organic hydroponic, as is the case in aquaponics. The development of organic hydroponics is dependent on replacing synthetic fertilizers with organically derived nutrients, such as those found in aquaculture effluents. Also, in hydroponic cultivation the establishment of a plant pathogen suppressive micro flora is part of the plant protection strategy. Therefore, both nutritional and microbial qualities of aquaculture water and organic hydroponic nutrient solution were analyzed and compared. Results showed both aquaculture water and organic hydroponic solution to be deficient in a number of essential elements, although organic hydroponic solution was closer to recommendations. The organic nutrient solution had the highest densities of aerobic bacteria as well as fluorescent pseudomonades. Levels of fluorescent pseudomonades in aquaculture water were significantly lower after passing through the biofilter. Qualitative analysis of microorganisms in an actual aquaponic farm would help to better understand the composition of the micro flora in this unique environment and its implications for nutrient cycling as well as plant health.

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1 Introduction

Aquaculture is the fastest growing sector of all animal food production. From 2000 to 2008 production almost doubled. Nearly half of the fish consumed globally is provided by aquaculture, and a majority of this comes from freshwater systems (FAO, 2011). The discharge of aquaculture effluents and raised competition over the use of freshwater is identified as some of the main issues of environmental concern associated with open and flow-through aquaculture. (FAO, 2006) (FAO, 2011) Recirculating aquaculture systems on the other hand, is an example of water efficient food production (FAO, 2011). In recirculating aquaculture systems, great numbers of fish are cultured in minimal volumes of water. The same water is recirculated repeatedly and must be treated in a biological filter to avoid toxic levels of nitrogenous waste products. The process of reusing treated water results in accumulation of mineral nutrients and organic matter. If daily water exchange is less than two percent of the total volume, nutrients accumulate in concentrations close to levels found in hydroponic nutrient solutions (Rakocy et al., 2006).

In hydroponic growing systems plants are cultivated in small containers, gutters or mats with a majority of the nutrients supplied by a liquid medium (Savvas, 2003). Closed hydroponic systems waste very little water and fertilizer. Despite the advantages of recycling nutrients and water, most growers worldwide use open systems to reduce the risk of disease (Carruthers, 2007). When growers first adopted the hydroponic technology the ideal was a sterile system, free from microorganisms. This proved impossible. New pathogens emerged, thriving in the liquid medium with little competition from other microorganisms (Postma et al., 2008). The modern approach in closed hydroponic systems is to use biological control methods to fight and prevent disease (Atkin & Nichols, 2004).

Consumers and governments push for food that is safe, nutritious and sustainable (Carruthers, 2007). Organic hydroponics can offer products that might meet these

criteria. With respect to efficient resource use and biological pest management, hydroponic systems are already well developed. If soilless cultivation can be accepted in the organic standards, the major challenge for organic hydroponic is to replace synthetic fertilizers with those derived from organic sources (Atkin & Nichols, 2004). This paper compares the nutritional and microbiological properties of the nutrient solution from a closed organic hydroponic with those of water from a recirculating aquaculture facility to evaluate the suitability of aquaculture effluents as a source of organic fertilizer for hydroponic systems, as is the case in aquaponic systems. Aquaponic culture integrates fish and hydroponic plant production into one recirculating system. Most plant nutrients are provided by effluents from the aquaculture subsystem. Aquaculture effluents are removed of nitrogenous waste products in the hydroponic component and then returned. The same culture water may be continuously recirculated for years (Rakocy et al., 2004). Successful and sustainable integration requires optimizing growth of three integrated biological components: fish, plant and nitrification bacteria. The challenge is to maximize production and minimize release of nutrient loaded wastewater to the environment (Tyson et al., 2011).

1.1 Purpose of study

The purpose of this study was to evaluate recirculated aquaculture water as a nutrient source for organic hydroponics.

1.2 Hypothesises

1. Water from the recirculating aquaculture system contains the highest density of cultivable microorganisms, compared to the recirculating biosolid nutrient solution in the hydroponic facility.
2. The biosolid based nutrient solution used in the hydroponic facility is more nutritionally optimized as lettuce fertilizer, than is water from the recirculating aquaculture system.

2 Background

2.1 Aquaculture effluents as a nutrient source for hydroponic cultivation systems

In this paper effluents from a recycling aquaculture system are compared to nutrient solution from an organic hydroponic. Although this comparison can provide useful information, utilizing aquaculture effluents in hydroponics is not feasible with the two being separate systems. The real benefits first emerge when hydroponics and aquaculture are fused into one closed system; an aquaponic system. A well functioning system has to balance the needs of fish, plants and microorganisms to maximize production outputs and minimize pollution (Tyson et al., 2011). Great advantages with aquaponic are that fish effluents become a resource for plants, and plants treat the water (Rakocy et al., 2006). A challenge is that nitrification and plant growth cannot be optimized simultaneously (Savidov, 2004) (Tyson, 2011). Table 1 displays the relationships between important environmental parameters and the biological components of an aquaponic system.

Table 1. *Relation between environmental parameters and biological components in aquaponic systems.*

Parameters	Fish	Nitrification bacteria	Plant
pH 5.5- 6.5		Below optimal levels of performance. [1]	Optimal for plant growth and mineral nutrient solubility.[1]
pH 7.5 -8.0		Optimal performance.[1]	Essential mineral nutrients less available.[2]
Ammonia	Excreted by fish, toxic at low concentrations.[3]	Remove ammonia by nitrification. [3]	Plants absorbing ammonium reduce levels of ammonia in water. Source of nitrogen for plants.[1]

Nitrate	Relatively non – toxic for fish.[3]	Final product from the full bacterial nitrification of ammonia. Process that demands oxygen [3]	Main source of nitrogen for plants.[1]
Mineral nutrients	Excreted by fish, accumulate in recirculating water.[2]		Absorbed by plants, essential for growth and development. [2]

[1.] Tyson et al (2011).

[2.] Rakocy et al. (2006).

[3]. Hagopian & Riley (1998).

Nitrogen is vital for plant growth and the mineral nutrient required in largest amount (Taiz & Zeiger, 2006). Sixty to ninety percent of nitrogenous waste in aquaculture are in the form of ammonia (NH_3) and ammonium (NH_4), originating from the gills of the fish. Urine, feces, gill cation exchange and uneaten feed also contributes to total nitrogenous waste loading in aquaculture. In the case of tank reared fish, very small amounts of feed remain uneaten (Hagopian & Riley, 1998) Part of the ammonia excreted is ionized into ammonium and these two forms together make up the total ammonia nitrogen, abbreviated TAN (Figure 1) (Tyson et al., 2011).

$$NH_4^+ \leftrightarrow NH_3 \ + H^+$$

Figur 1. Total ammonia nitrogen (TAN) equilibrium in water (Tyson et al., 2011).

Unionized ammonia is toxic to fish even at low concentrations and must not accumulate in the recirculating water. The same applies to nitrite, but lethal concentrations vary substantially between species and stages in the life cycle of fish. Nitrate on the other hand, in some cases, can exceed the toxic levels of ammonia a million times before reaching lethal concentrations. Thus the full nitrification of ammonia and nitrite is an essential part of the recirculating aquaculture system (Hagopian & Riley, 1998). In the aquaponic system, potentially toxic ammonia is removed both by microbial activities and by phytoremediation (Tyson et al., 2011).

In general, all mineral plant nutrients except calcium, potassium and iron are present in adequate amounts in aquaculture effluents, according to Rakocy et al.

(2004). Minimizing daily water exchange is important to achieve accumulation of mineral nutrients (Rakocy et al., 2006). Keeping pH above 7.0 is the key to effective nitrification, but the process itself lowers pH. To compensate for the low pH, and at the same time raise levels of calcium and potassium, Rakocy et al. (2004) continuously added $Ca(OH)_2$ and KOH to their aquaponic system. Iron deficiency was avoided by adding iron chelate. Fish waste provided all other nutrients in this experiment. Tyson et al. (2011) also emphasized the importance of effective nitrification, suggesting pH 7.5-8.0 rather than at optimum for plant mineral nutrient solubility in the range pH 5.5-6.5, for water quality to remain high. Savidov (2004) argued for another strategy in which pH is decreased to 6.2. At this level mineral nutrients are more soluble and plant growth is favored. Savidov (2004) showed that plants are very effective as the main nutrient control mechanism in aquaponics, absorbing ammonium very fast. As well, at acidic pH the TAN equilibrium is weighted towards ammonium, decreasing levels of free ammonia (Savidov, 2004). Ammonium is a source of nitrogen, but in high levels it is toxic to plants. Ammonium also affects the plant indirectly. When assimilated by the roots, a lot of oxygen is consumed. A well aerated root environment, such as in soilless cultivation, facilitates assimilation of ammonium. (Silber & Bar-Tal, 2008:307-310). Also, ammonium depresses the uptake of potassium, calcium and magnesium. (Marschner, 1995: 38-39)

By regulating pH with phosphoric acid, potassium can be supplemented to meet plant demand without affecting pH (Savidov, 2004). Calcium and magnesium were abundant in the local water and available in adequate amounts at the lower pH. Fe was supplemented (Savidov, 2004). Savidov (2004) identifies imbalanced fish feed as the source of deficiency in aquaponics and suggests developing plant based fish feed with higher levels of potassium.

2.2 The role of microbes in hydroponic cultivation systems.

It has become evident that a soilless growing system free of microbes is unrealistic and emphasis has been shifted towards establishing a micro flora that suppresses plant pathogens (Postma, 2004). A lot of research has been done to quantify and identify microorganisms and their influence on suppressing plant pathogens and plant disease attacks in different hydroponic systems (Vallace et al., 2010). Microorganisms in soilless culture can inhabit growing media, nutrient solution and rhizosphere. Diversity and density of microbes in the respective habitat is affected by growing media, nutrient solution and age and cultivar of plant species (Vallace

et al., 2010). The micro flora can act to suppress pathogens by competition, parasitism, antibiosis and systemic induced resistance in the plant (Vallace et al., 2010). Studies of the micro flora in aquaponics have so far focused on nitrifiers and their role in nitrification (Tyson et al., 2011). But establishment of plant pathogens should be of no less concern in aquaponics than in hydroponics. Patterns of microbial diversity and density in the aquaponic system could be expected to differ from those in hydroponic cultures. Therefore the micro floras of aquaponic cultures need to be studied from the perspective of disease suppression as well as nitrification.

3 Materials and Methods

3.1 Samples

Samples were collected in two separate facilities, a closed hydroponic greenhouse system and a recirculating aquaculture system. Sampling occurred at three occasions, every other week, in January and February 2012.

In the hydroponic greenhouse facility organically certified lettuce was produced. Nutrient solution was circulated and based on bio-solids. Growing medium was peat and production staggered. Solution samples were collected in 3 sterile glass bottles (2L) from the nutrient solution tank and immediately placed in cool bags.

Water from recirculating aquaculture facility producing tilapia was collected at two cardinal points: fish rearing tank outflow and from biofilter outflow. Three sterile glass bottles (2L) where filled with water from each cardinal point and immediately placed in cooler.

2 liter samples were collected for microbiological analysis and transferred to a cool storage when arriving at the research facility. For each two liters of sample a 50 ml sample was collected as well, to be used for chemical analysis. These samples were stored in a freezer. Temperature was measured on site with infrared thermometer.

3.2 Microbiological analyses

3.2.1 Treatments

The following three groups of heterotrophic microorganisms were analyzed: general bacterial flora, general fungal flora and fluorescent pseudomonades. Groups

of microbes were distinguished by different treatments (medium, incubation time, incubation temperature) (Table 2).
To determine the density of cultivable microbes, each group was analyzed quantitatively with regard to colony forming units (cfu) per volume (ml) of sample.

Table 2. *Treatments for analysis of colony forming units(cfu).*

Group to be analyzed	Medium	Incubation temperature (°C)	Incubation time (h)	Analysis
General bacterial flora in water samples.	R2A	25	48	Visual standardized count of bacterial cfu.
General fungal flora	0.5 malt extract (MA)	22	96	Visual standardized count of fungal cfu.
Fluorescent pseudomonades	King agar B (KB)	25	24	Visual standardized count of fluorescent colonies under UV light.

3.2.2 Preparations, dilutions and plating

Samples of water and nutrient solution were serially diluted in 0.85 NaCl. From each dilution step, 50µl were spread in duplicates using a spiral plater. Plating was performed mechanically using a WASP 2 apparatus (Whitley Automated Spiral Plater 2, Don Whitley Scientific Limited, Shirley, UK).

3.2.3 Analysis

Colony forming units were quantified with a standardized counting procedure, using a circular grid specially designed for manual counting of spiral plates. The grid showed areas representing a dispersed volume of sample solution and was placed over the petri dish for the counting of colony forming units. Starting from the outside and working towards the center, the smallest area containing 30 cfu was chosen for calculating density of viable microbes in the dispersed solution (cfu ml^{-1}). Each area was duplicated radially opposite and together represent a specified dispersed volume. Once the appropriate area for calculation was determined, a count of cfu in complementary areas was performed. If the largest designated area contained less than 30 cfu, total count of colony forming units was performed. Three dilution levels were chosen to be plated for each sample and medi-

um. The two replicates easiest to count, of the three dilutions of each sample, was used for calculating density of viable cultivable microorganisms.

3.2.4 Sources of error

Samples collected were to be analyzed within 48 hours and kept cool during all times. During the first cycle of sampling and analysis the spiral plater was malfunctioning and no results were obtained at the first sampling. This means analysis could not be performed within 48 hours. Water samples were used for additional analyses, other than comprised in this paper, therefore sample bottles were used a lot in the lab and not always kept cool.

An error occurred during plating in the second cycle. All petri dishes went in the spiral plater before it was realized that the vacuum pump was not turned on, with the effect that no volumes were sucked up and dispersed. Since the suction tube is dipped in ethanol and rinsed twice during the plating procedure, it was decided to use the same plates again. This increase the risk of contamination, but all plates were exposed to the same treatment.

3.3 Chemical Analyses

Chemical parameters such as pH, electrical conductivity (EC) and mineral elements where analyzed externally (LMI, Sweden). Samples were sent to the laboratory for analysis as soon as possible after collection.

Total nitrogen (TN), ammonium, nitrite, nitrate and total organic carbon (TOC) analysis was performed by using Lange Cuvette Tests (LCK) (Hach-Lange, USA) (Products and equipment specified in Table 4.). The instructions on how to use the individual kits for each parameter where followed and the designated cuvettes where analyzed in a fully automated photo spectrometer, the LANGE XION$^{\Sigma}$500 (Hach-Lange, USA), calculating the results automatically. See Hach –LANGE manual for more information (Hach –Lange, [online] 2012 -05 -28).

Table 3. *Hach –Lange (USA) products used to analyze chemical parameters.*

Analyzed Parameter	Product name	Additional apparatus used for preparing sample
Total Nitrogen (TN)	LCK 338 Total Nitrogen	LANGE LT200 (Thermostat)
Ammonium	LCK 303	None

	Ammonia (2.5 -60.0 mg l^{-1})	
Nitrate	LCK 340 Nitrate (22 -155 mg l^{-1})	None
Nitrite	LCK 342 Nitrite (0.05 -20 mg l^{-1})	None
Total Organic Carbon (TOC)	LCK 385 TOC (3 -30 mg l^{-1})	LANGE TOC-X5 (Shaker) LANGE LT200 (Thermostat)

The timing of the sampling occasions should have been more carefully selected with respect to fertilization and feeding cycles. Information on the last time nutrients where added to the nutrient solution or when fish was last fed was not noticed for any of the sampling occasions.

3.4 Statistical Analyses

3.4.1 Analysis of microbiological parameters

Differences in microbial density between hydroponic nutrient solution, fish rearing tank water and biofilter effluent in relation to sampling occasion were tested using ANOVA General Linear Model. Nutrient solution and aquaculture water were compared on all shared parameters (19 chemical and physical, 3 microbiological) using ANOVA General Linear Model. This model makes comparisons on three levels: Sample site, sample occasion and selected parameter. Sample site was set as a fixed factor and sampling occasion as a random factor. All sample sites were categorized as independent. The Tukey method was used, on a 95.0 % confidence level, to calculate significance between sample site means on all shared parameters and to obtain grouping information. Minitab 16 (Minitab Inc, Pennsylvania, USA) statistical software was used for statistical calculations.

4 Results

4.1 Results from Chemical Analysis

Aquaponic showed low values on all parameters compared to standard nutrient solution, except for manganese. The pH was corresponding better to the requirements of crop cultivation in aquaculture water than in the nutrient solution. Nitrate levels were very low in all sampling sites, but were highest in nutrient solution. Levels of ammonium were low as well, but closer to optimum in nutrient solution than in water. The ratio of nitrate -ammonium was closer to recommendations for plant cultivation in aquaculture water, but low in all samples (Table 4).

Table 4. *Inorganic nitrogen, total organic carbon, pH and electrical conductivity (EC) of samples compared to recommended hydroponic nutrient solution for cultivation of lettuce (Sonneveld & Straver, 1994). Results obtained from LCK –test when not specified otherwise. Different letters on results means significant difference.*

					Δ		
(mmol l^{-1})	Hydroponic	Fish tank	Biofilter effluent.	Standard nutrient solution (25 °C)	Hydroponic	Fish tank	Biofilter
pH[1]	7.20 a	6.17 b	5.83 b	NA			
EC[1] (mS/cm)	2.24 a	0.78 b	0.76 b	2.6	-0.36	-1.82	-1.84
TOC	3.16 a	1.58 b	1.07 c	NA			
TN	11.16 a	4.89 b	5.05 c	NA			
Ammonia (NH_4)	0.79 a	0.40 b	0.34 b	1.25	-0.46	-0.85	-0.91
Nitrite (NO_2)	0.29 a	0.00 b	0.00 b	NA			
Nitrate (NO_3)	1.73 a	0.96 b	0.97 b	19	-17.27	-18.04	-18.03
NO_3/NH_4	2.20	2.40	2.87	15.20	-13.00	-12.80	-12.33

[1] Results from external analysis (LMI, Sweden)

Water from the the sample sites in the aquaculture system was deficient in all macronutrients and very low on phosporous and potassium. The nutrient solution showed abundance of magnesium, sulfur and calcium, but deficiency of phosphorous, potassium and silicon. (Table 5).

Table 5. *Essential macro elements from sample sites compared to recommended hydroponic nutrient solution (Sonneveld & Straver, 1994).¨*

Essential elements (mmol/l)	Hydroponic mean	Fishtank mean	Biofilter mean	Standard hydroponic solution.	ΔHydroponic	Δfish rearing tank	Δbiofilter effluent
P	0,38 a	0,08 b	0,08 b	2,0	-1,62	-1,92	-1,92
K	5,39 a	0,42 b	0,42 b	11,0	-5,61	-10,58	-10,58
Mg	1,36 a	0,37 b	0,37 b	1,0	0,36	-0,63	-0,63
S	2,22 b	0,43 b	0,42 b	1,125	1,10	-0,70	-0,70
Ca	5,07 a	2,02 b	2,01 b	4,5	0,57	-2,48	-2,49
Si	0,38 a	0,16 b	0,16 b	0,5	-0,12	-0,34	-0,34

Of all essential elements in nutrient solution and aquaculture water that showed deficiency compared to standard nutrient solution, nutrient solution was closer to optimum. Aquaculture samples were deficient in all microelements except manganese, with levels of molybdenum and iron to be considered very low. Nutrient solution was deficient in boron and zinc, but abundant in microelements manganese, copper, iron and molybdenum. Levels of manganese was abundant in all samples, but highest in hydroponic medium (Table 6).

Table 6. *Essential microelements from sample sites compared to recommended hydroponic nutrient solution for lettuce cultivation (Sonneveld & Straver, 1994). Results obtained from external analysis (LMI, Sweden)*

Essential elements (µmol/l)	Hydroponic	Fishtank	Biofilter	Standard nutrient solution.	ΔHydroponic	Δfish rearing tank	Δbiofilter outflow
Mn	4.75 a	2.12 b	2.12 b	0.0	4.75	2.12	2.12
B	17.10 a	3.37 b	3.34 b	30	-12.90	-26.6	-26.7
Cu	2.41 a	0.26 b	0.23 b	0.75	1.66	-0.49	-0.52
Fe	59.86 a	0.60 b	0.75 b	40	19.86	-39.40	-39.25
Zn	2.68 a	2.10 a	2.08 a	4	-1.32	-1.904	-1.92
Mo	3.94 a	0.06 b	0.08 b	0.5	3.44	-0.44	-0,42

4.2 Results from Microbiological Analysis

Total density of microorganisms was highest in the nutrient solution. Counts of the general bacterial flora showed significant differences between the nutrient solution and the aquaculture water, with highest numbers in the nutrient solution. No significant difference was found between fungal counts in any sample site. The occurrence of fluorescent pseudomonades was significantly different between all sample sites and most abundant in nutrient solution (Table 7).

Table 7. *Microbial density of hydroponic and aquacultural water based on viable count. Values within the same row followed by different letters are statistically different according to Tukey´s-test ($p < 0.05$).*

log cfu ml^{-1}	Cultured microbial groups	Hydroponic	Fish tank	Biofilter
MA	Fungi	4.9a	5.3a	4.5a
R2A	General bacterial flora	6.5a	5.2b	4.8b
KB	Fluorescent pseudomonades	3.9a	2.3b	0.9c

5 Discussion

5.1 Nutritional qualities of aquaculture water compared to organically derived nutrient solution.

In reference to recommended standard solution for the hydroponic cultivation of lettuce (Sonnenveld & Straver, 1994) neither the organic nutrient solution nor the aquaculture effluents provided the complete range of nutrients in sufficient amounts. In comparison between the two locations, the nutrient solution was better adapted to plant requirements on all parameters. The acidic pH suggests that bacterial nitrification in aquaculture biofilter was not working at the full potential.

Levels of essential elements deviate from recommended values and both aquaculture water and organic nutrient solution might seem inadequate as nutrient sources for hydroponic cultivation. But in organic hydroponic the liquid medium is not the only nutrient source. According to the Swedish certification body for organic farming (KRAV, 2012) short time cultivars such as lettuce must have a minimum pot size of 0.2 L, with a majority of nutrients coming from the growing medium. This would mean that the organic nutrient solution is merely a complementary nutrient source. And although organic nutrient solution showed better values than aquaculture water, they were not that far apart. Pantanella et al. (2012) found that a balanced aquaponic system can accumulate minerals in amounts that are on the same levels as those in conventional hydroponic nutrient solution, and produce the same yields and quality of lettuce as conventional hydroponic cultures. This means an aquaculture balanced to provide plant nutrients should be more than adequate as a complementary nutrient source for organic hydroponic.
Of course the use of aquaculture effluents must also be accepted by organic standards for this resource to be utilized in certified organic cultures. KRAV (2012), representing the Swedish certification body for organic farming, does not allow

any feces or urine as fertilizer. This might rule out aquaculture effluents. The larger volume of growing medium per pot in KRAV–certified greenhouse production (KRAV, 2012) can also be an obstacle for adapting aquaponic cultures to this standard. Optimizing the irrigation frequency can compensate for deficiencies in the nutrient solution. The use of this tool can be restricted if container size and growing medium do not allow good drainage and oxygenation. The important task of ammonia assimilation and nitrification in the root environment will be depressed by oxygen depletion. (Silber & Bar-Tal, 2008) Organic aquaponic cultivation is therefore dependent on a growing medium that fulfills the organic standards, supply adequate nutrients and allows for excellent drainage and aeration to optimize nitrification and assimilation of nitrogenous waste and essential elements by plants.

The low nutrient levels in the sampled aquaculture water could be explained by high water exchange rate in combination with fish feed low on plant nutrients. Levels of ammonia seemed to be very low, but still there were no indication of nitrification process in the biofilter. But if nutrients were added as fish feed in the main pools, and water removed during filtration process, chemical analysis should have revealed significantly lower levels of essential elements after filtration. This was not the case for any of the analyzed essential elements. One explanation could be that the aquaculture facility was not recirculating water at all, or exchanging it at high rates. In that case the sampling point that should have been after biofilter is instead straight from the water source. This could explain why levels of fluorescent pseudomonades are higher in the rearing tank than in the inflowing water. They grow faster in the rearing tank than the other analyzed microbial groups, in contrast to being selectively removed by filtration. Sampling of the aquaculture water source would have helped to reveal the actual circumstances.

5.2 Microbial densities

Because aquaculture water is polluted by fish waste, cfu was suspected to be higher than in the organic hydroponic. This proved to be false. The organic hydroponic had higher density of aerobic bacteria and fluorescent pseudomonades, but similar levels of fungi compared to aquaculture water. Density of fluorescent pseudomonades varies between sample sites, being much lower at the biofilter outflow. This

is interesting considering the importance of fluorescent pseudomonades in suppressing plant pathogens (Haas & Défago, 2005). Only fluorescent pseudomonades were significantly lower, no changes in general bacteria or fungal cfu could be found. One explanation for the reduced levels of pseudomonades could be if this bacterial group was more abundant, compared to general bacteria and fungi, on suspended solids than in free water. The significantly lower levels of organic carbon support the idea that suspended solids were removed by mechanical filtration and sedimentation during the filtering process. But, as discussed above, the overall impression from chemical analysis is that the sampled aquaculture facility does not show the properties one could expect from a recirculating aquaculture system. In that case total organic carbon is not removed by filtration; it was just added by fish and feed in the rearing tank.

Qualitative analysis of microorganisms in an actual aquaponic farm would help to better understand the composition of the micro flora in this unique environment and its implications for nutrient cycling as well as plant health.

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6 Conclusion

1. Occurrence of aerobic bacteria was significantly higher in biosolid based nutrient solution than in aquaculture water. Levels of fluorescent pseudomonades were significantly different between all samples. Highest numbers were found in the lettuce fertigator and least in biofilter effluents. No significant differences in regard to fungal cfu where found between any of the sampling sites.

2. The biosolid based nutrient solution was more nutritionally optimized than aquaculture water. Aquaculture water from the sampling site was far from optimal as nutrient source for lettuce cultivation, but so was the biosolid based nutrient solution. Recirculated aquaculture water should be more than adequate, compared to sampled organic nutrient solution, as a complementary nutrient source in organic hydroponic.

7 References

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