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Original article – Thematic Issue

Growth performance, nutrients and microbial dynamic in aquaponics systems as affected by water temperature

S. Khalil
Department of Biosystems and Technology, Swedish University of Agricultural Sciences, Alnarp, Sweden

Summary

Aquaponics is an integrated production of fish and hydroponic crops with recirculation of the nutrient solution in which fish wastes are used as plant fertilizers. Development towards bioeconomical based cultivation system using industrial symbioses makes application of aquaponics systems in areas with surpluses or excess heat of great interest. Within the frame of these surpluses a significant amount of energy leaves the processes as low-grade heat through flue gas stacks and cooling water. However, little knowledge is available about the effect of low water temperature on the growth and microbial parameters in an aquaponics system. Investigations in the current study were thus carried out to study the effect of water temperature of 11°C compared with 21°C on plant growth, nutrient and microbial dynamic in aquaponic systems. Two cultivation systems (treatments) were used, an aquaponic system consisted of a fish tank, a biofilter and a plant unit, and a hydroponic system (control) consisted of a water tank and a plant unit. Basil and trout were used as model organisms. The experiment was run for a period of eight weeks and repeated over time. The results indicated good fish growth and better plant growth in aquaponics systems compared with hydroponic systems at both water temperatures. The growth, as indicated by plant biomass, leaf length and width as well as nitrate content in the leaves, was better at water temperature of 21°C compared with 11°C. Low water temperature of 11°C indicated a negative effect on biofiltration, microbial dynamics and disease incidence in the system. Negative correlation between the total nitrogen removal rate and low water temperature was also indicated.

Keywords
resource use, excess heat, horticultural crops, aquaculture, nutrients, plant growth, biofiltration, hydroponics, nitrogen dynamic, sweet basil, trout

Significance of this study

What is already known on this subject?

- Aquaponics is an old concept but has received a big attention during the last years due to food security aspects, the need for production of more and sustainable food and to environmental problems related to aquaculture and fish industry. During these years the studies performed focused on the aquaculture system with less attention to the plant part in relation to growth, nutrients, quality and microbial aspects. Less attention is also paid to food safety and human health.

What are the new findings?

- The current study advocates for bioeconomy and industrial symbiosis in aquaponics system. It develops baselines for application of aquaponics systems in environments where surpluses and low temperate excess heat is a resource. The findings of this study form baselines considering the effect of low water temperature on plant growth as well as on nutrients dynamics. The study is the first to present information considering the microbial dynamics and disease incidence in aquaponics system using low water temperature.

What is the expected impact on horticulture?

- From the horticultural point of view, the study presents a future horticultural cultivation system that advocates for environmentally friendly techniques with efficient use of resources. The impact on horticulture is characterized by developing knowledge about the efficient reuse of excess heat in primary food production. This impact is also characterized by the baselines developed considering the parameters for the healthy system such as growth, microbial and plant pathological parameters.

Introduction

Food production world-wide needs to be increased substantially in order to satisfy the demands of a growing global population, but this has to be achieved in a sustainable way. Development and design of production systems that meet these requirements is therefore crucial. Several studies have shown that production of vegetables in hydroponics or soilless systems has a positive effect on both yield and product quality (Gruda, 2009). Hydroponics systems provide optimised conditions for growth with respect to supply of water and nutrients. From environmental point of view closed hydroponic systems are recommended to reduce discharge of nutrient-enriched water from greenhouses and thus prevent eutrophication of neighbouring waters.

Closed hydroponic systems can be integrated with aquaculture to create so-called aquaponics systems. Aquaponics is a concept for the combined production of healthy and nutritious products such as vegetables and high-protein food (fish). It is considered to be cheap and resource-efficient (Tyson et al., 2011). Fish waste products, especially nitrogen-rich compounds, are microbially converted to release nutrients for adjacent hydroponically grown crops (Rakocy,

1989), leading to a reduction in high ammonia levels in the fish tank, which can otherwise be harmful to fish. Through biofiltration, nitrifying bacteria convert ammonia into nitrite and nitrate, which are readily available to the growing crop (Rakocy et al., 2006). Furthermore, cultivation in an aquaponics system brings other advantages in terms of reductions in fertiliser and water consumption (Rakocy, 1989), as well as lowering nutrient release to the environment and thereby lowering the risk of eutrophication.

In addition to the fish and plant production units being connected in aquaponics, other cycles may also be integrated in an advanced production system to save more resources. For example, residual or surplus heat originating from manufacturing industries may be used, reducing energy costs and environmental impacts. At present, a large amount of low-temperature surplus heat (below 20°C) is still unexploited, and there is great interest in using this kind of surplus in greenhouse production to reduce the energy costs in the greenhouse industry. There is also interest in developing aquaculture systems for cold-water fish. In order to utilise low-temperature surplus heat in aquaponics systems, knowledge is needed about the effect of water temperatures below 20°C on basic parameters in the system regarding nutrient cycling and uptake, the nitrification process, the resident microflora, the choice of fish and plant species and the effect on their growth (Nimmermark and Nilsson, 2013).

The aim of the present study was to investigate the effect of water temperature of 11°C, in comparison to 21°C in aquaponics system on growth and yield of horticultural crops and fish, nutrient flow in the system, indigenous microflora as well as disease incidence on the plants. The results from this study can provide baselines for production of environmentally friendly and healthy horticultural crops in aquaponics systems.

Material and methods

Model organisms

Sweet basil (*Ocimum basilicum* 'Genovese') was used as a model crop and trout (*Salmo trutta*) was used as a model fish.

System description and experiment setup

The experiment was carried out in a climate chamber under controlled conditions for a period of eight weeks, and was repeated over time. In total two experiments were performed. Each experiment consisted of two treatments, an aquaponics system and a hydroponics (control) system. Three replicates were included in each treatment. The treatments were investigated at two different water temperatures, 11°C and 21°C. Each replicate in the aquaponics treatment consisted of one fish tank with a volume of 50 L and a cultivation gutter for the plant unit. An NFT system was used for crop irrigation, with a rotating biological contactor filter installed between the fish and crop units in the system. The water was circulated from the fish tank through the biofilter to the cultivation gutter and back to the fish tank.

In the control treatment with a hydroponics system, the same set-up as in aquaponic treatment was used but without the fish and without a biofilter. Three replicates of this treatment were also used.

In order to achieve the required water temperature, a cooler was placed in the water tanks and the temperature was regulated as appropriate to 11 or 21°C. In the climate chamber, the air temperature was maintained at 25°C during the day and 19°C at night. A photoperiod of 16 h per day with natural light supplemented using high-pressure sodium lamps (200 W m^{-2}) was applied. The lamps were switched on during the photoperiod of 16 h and the light intensity received by the plants at canopy level was 200 µmol m^{-2} s^{-1}.

Samples of trout (8 fish per tank) were obtained from a local trout producer. The fish were hand-fed once a day during the experiment with a commercial feed at a rate of 1% of fish body weight. In the crop unit part of the aquaponics system, 15 basil seedlings were placed in each gutter in small rockwool cubes (Grodan, The Netherlands) with a size of 2 × 2 × 4 cm. In the hydroponics system (control), the same number of seedlings was used and a standard nutrient solution for basil according to Hoagland and Arnon (1950) was applied with a pH value of 5.8 and electrical conductivity (EC) value of 2.2 dS m^{-1}. Daily monitoring and compensation of the solution composition was performed.

Growth parameters

After eight weeks of experimental duration measurements of the fresh weight (FW) and dry weight (DW) of plant roots and shoots (g $plant^{-1}$) were performed at the end of each experiment. The total body weight of the fish was measured at the beginning and at the end of each experiment.

Water quality parameters

For the analysis of nutrient content, water samples were collected every four weeks at three different sites in the aquaponics system: before and after the biofilter and after the plant unit. In the control system, water samples were collected every four weeks from the water tank. The amounts of total organic nitrogen, using Kjeldahl procedure, and of macronutrients and micronutrients in the systems, using spruce way analyses technique, were analysed at LMI Laboratory (Helsingborg, Sweden). Dissolved oxygen, pH, electrical conductivity and temperature were monitored daily throughout the experiment. To determine the nitrate content, basil leaves (FW) were analysed, at LMI Laboratory (Helsingborg, Sweden).

Microbial parameters

Water samples from the control treatment and from the aquaponics system before and after the biofilter and after the plant unit were also analysed for general bacterial and fungal flora according to Khalil and Alsanius (2001). For this a dilution series was prepared, where 1 mL of water sample was serially diluted and then 200 µL aliquots were spread, in duplicate, on the following media: i) R2A Agar (DIFCO 218-26-3) complemented with cycloheximide (100 µL mL^{-1}) for enumeration of the general bacterial flora; ii) 0.5% malt extract agar (MA, DIFCO 0186-17-7) for enumeration of the general fungal flora; and iii) King Agar B (KB) with cycloheximide (100 µg mL^{-1}) for enumeration of fluorescent pseudomonads. The R2A and MA plates were incubated at room temperature, for 72 h and 7 days, respectively. The KB plates were incubated for 24 h at 27°C.

The incidence of disease on the whole root system of basil was measured at harvest. Seedlings were sorted into five symptom classes: 0 = healthy plants; 1 = necrotic root tip; 2 = necrotic area above the root tip; 3 = partly necrotic root with reduced development of cotyledons; and 4 = severe necrosis. The mean disease index (DI) was then calculated according to the formula: DI = (S*Np) Nt^{-1}, where S = symptom severity, Np = number of infected plants, and Nt = total number of plants, according to Khalil and Alsanius (2001).

Table 1. Mean plant and fish biomass (g) in the hydroponics (control) and aquaponics system at two water temperatures, 11°C and 21°C. Values within rows followed by different lower-case letters are significantly different with $p < 0.05$. Values shown are mean ± standard error. $n = 13$ for plants, $n = 8$ for fish.

Biomass (g)	Hydroponics	Aquaponics	Hydroponics	Aquaponics
	11°C		21°C	
Plant				
Fresh biomass	154.6 ± 0.4a	208.6 ± 0.3b	205.2 ± 0.5a	235.7 ± 0.4b
Dry biomass	101.1 ± 0.2a	164.2 ± 0.3b	172.6 ± 0.4a	192.4 ± 0.3b
Fish				
Total biomass at start		68.6 ± 0.5a		70.2 ± 0.4b
Total biomass at harvest		149.4 ± 0.5a		197.5 ± 0.3b

Statistical analyses

All statistical analyses were performed using Minitab statistical software for Windows (release 15; Minitab Inc., State College, PA, USA). The population densities of the resident microflora were subjected to $\log_{10}$ transformations. The data on population densities, nutrient content and growth measurements were analysed using analysis of variance (ANOVA). Means were separated by a least significant difference (LSD) test, with $P < 0.05$ considered significant. The data on disease incidence were subjected to the Kruskal-Wallis test, a non-parametric ranking procedure. For analysis of growth parameters, data on 13 of the 15 plants used in the plant unite were available.

Results

Analysing the data from the two repetitions (experiments) indicated no significant differences between these repetitions. Therefore, the results from the first repetition are only presented.

Plant growth

Plant growth, in terms of both fresh and dry weight, was higher in the aquaponics system than the hydroponics system (control) at both 11°C and 21°C (Table 1). The best plant growth was observed in the aquaponics system at 21°C. Plants grown in the hydroponics (control) system showed also better growth at 21°C compared with their counterparts grown at 11°C ($P < 0.05$). Thus, a water temperature of 11°C gave lower plant growth in both systems. Fish total weight increased over eight weeks of cultivation in the aquaponics system, and again was better at 21°C than at 11°C (Table 1).

Analyses of plant growth in terms of leaf length and width indicated greater length (Figure 1) and width (Figure 2) at 21°C compared with 11°C in both the hydroponics and aquaponics systems. Plants cultivated in the aquaponics system at a water temperature of 21°C showed the greatest leaf length and width.

Analysis of nitrate content in the leaves revealed a higher content in plants cultivated at a water temperature of 11°C compared with 21°C in both the hydroponics and aquaponics systems (Figure 3). At a water temperature of 21°C, the nitrate content was lower in plants cultivated in the hydroponic system compared with those in the aquaponics system.

Water quality parameters

The total nitrogen content in the system varied depending on water temperature. In general, the nitrogen content was higher in the aquaponics system compared with the hydroponics system (Figure 4). The highest nitrogen content was found at a water temperature of 11°C on the second sampling occasion. On the other hand, a lower nitrogen content was found at a water temperature of 21°C on both sampling occasions. The lowest amount was recorded on the second sampling occasion, at the sampling point after the plant unit (Figure 3).

Table 2. Content of macronutrients and micronutrients in the returned water to the fish tank from the plant unit in the aquaponics system at a water temperature of 11°C. Samples were collected every four weeks during the eight-week experiment. Analysis of variance was applied. Treatment means were separated using Tukey's HSD, with $P < 0.05$ considered significant. Values in the same column followed by different lower-case letters are significantly different. Each value is a mean of $n = 3$.

Nutrient content (mM)	Hydroponic system	Fish tank at start	Collection after plant unit	Fish tank at start	Collection after plant unit
		Sampling 1		Sampling 2	
P	2^{c}	4.3^{b}	5.6^{a}	6.1^{d}	5.9^{a}
K	11^{a}	10.4^{a}	10.6^{a}	10.9^{a}	10.3^{a}
Mg	1^{c}	0.9^{c}	1.8^{b}	1.9^{b}	2.1^{a}
S	1.13^{c}	1.1^{c}	2.4^{b}	3.2^{a}	3.7^{a}
Ca	4.5^{c}	9.1^{b}	10.9^{a}	9.3^{b}	10.4^{a}
Mn	0.005^{b}	0.005^{b}	0.006^{a}	0.006^{a}	0.005^{b}
B	0.03^{c}	0.03^{c}	0.03^{c}	0.04^{b}	0.005^{a}
Cu	0.00075^{b}	0.0008^{b}	0.0008^{b}	0.001^{a}	0.001^{a}
Fe	0.04^{d}	0.05^{c}	0.06^{b}	0.07^{b}	0.008^{a}
Zn	0.004^{c}	0.004^{c}	0.005^{b}	0.006^{a}	0.005^{b}
Mo	0.0005^{b}	0.0004^{c}	0.0005^{b}	0.0006^{a}	0.0005^{b}

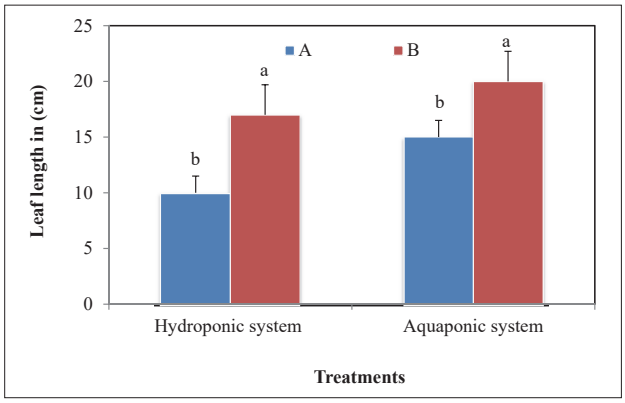


FIGURE 1. Effect of water temperature A = 11°C or B = 21°C in the hydroponics (control) system and the aquaponics system on leaf length (in cm) of sweet basil. Treatment means were separated using Tukey's HSD, with $P < 0.05$ considered significant. Each bar represents mean ± standard error. $n = 13$.

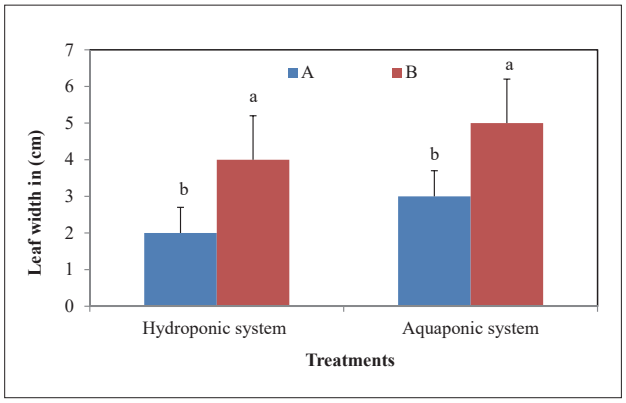


FIGURE 2. Effect of water temperature A = 11°C or B = 21°C in the hydroponics (control) system and the aquaponics system on leaf width (in cm) of sweet basil. Treatment means were separated using Tukey's HSD, with $P < 0.05$ considered significant. Each bar represents mean ± standard error. $n = 13$.

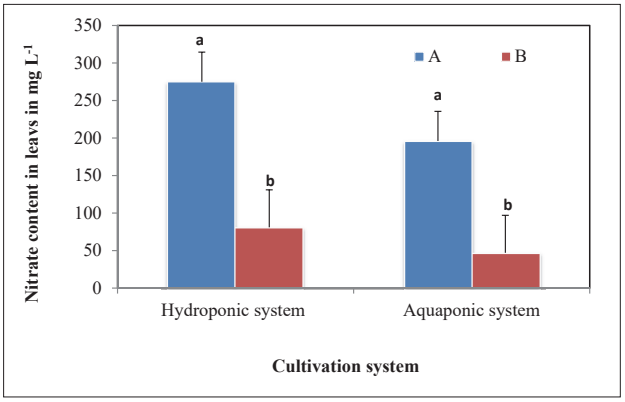


FIGURE 3. Effect of water temperature A = 11°C or B = 21°C in the hydroponics (control) system and the aquaponics system on nitrate content in sweet basil leaves. Treatment means were separated using Tukey's HSD, with $P < 0.05$ considered significant. Each bar represents mean ± standard error. $n = 13$.

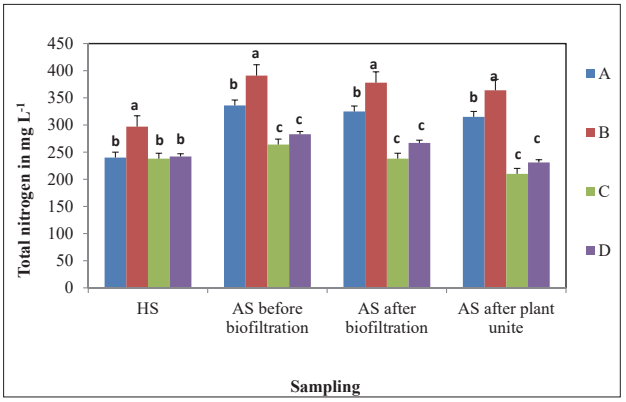


FIGURE 4. Effect of water temperature of 11°C or 21°C on total nitrogen content in the hydroponics system (HS) and the aquaponics system (AS) before biofiltration, after biofiltration, and after the plant unit. A = sampling 1 at 11°C, B = sampling 2 at 11°C, C = sampling 1 at 21°C, and D = sampling 2 at 21°C. Analysis of variance (ANOVA) was applied. Treatment means were separated using Tukey's HSD, with $P < 0.05$ considered significant. Each bar represents mean ± standard error. $n = 3$.

TABLE 3. Content of macronutrients and micronutrients in the returned water to the fish tank from the plant unit in the aquaponics system at a water temperature of 21°C. Samples were collected every four weeks during the eight-week experiment. Analysis of variance was applied. Treatment means were separated using Tukey's HSD, with $P < 0.05$ considered significant. Values in the same column followed by different lower-case letters are significantly different. Each value is a mean of $n = 3$.

Nutrient content (mM)	Hydroponic system	Fish tank at start	Collection after plant unit	Fish tank at start	Collection after plant unit
		Sampling 1		Sampling 2	
P	2^{c}	4.3^{a}	3.9^{b}	4.1^{a}	3.2^{b}
K	11^{a}	11.2^{a}	7.3^{b}	10.8^{a}	6.5^{b}
Mg	1^{a}	1.2^{a}	0.8^{a}	0.9^{a}	0.5^{a}
S	1.13^{a}	1.2^{a}	0.9^{a}	1.2^{a}	0.7^{a}
Ca	4.5^{b}	10.3^{a}	9.5^{a}	9.8^{a}	8.4^{b}
Mn	0.005^{a}	0.005^{a}	0.004^{b}	0.005^{a}	0.003^{c}
B	0.03^{b}	0.04^{a}	0.03^{b}	0.04^{a}	0.002^{c}
Cu	0.00075^{d}	0.0007^{b}	0.0006^{c}	0.0008^{d}	0.005^{a}
Fe	0.04^{b}	0.05^{a}	0.04^{b}	0.05^{a}	0.03^{c}
Zn	0.004^{b}	0.005^{a}	0.003^{c}	0.005^{a}	0.002^{c}
Mo	0.0005^{a}	0.0004^{b}	0.0003^{c}	0.0005^{a}	0.0003^{c}

Table 4. Microbial density in the hydroponics (control) system and in the aquaponics system before and after the biofilter, analysed using viable counts. Values within rows followed by different letters are significantly different according to Tukey's test ($p < 0.05$).

Count (log CFU mL^{-1})	Hydroponics system		Aquaponics system before biofilter		Aquaponics system after biofilter	
	11°C	21°C	11°C	21°C	11°C	21°C
Sampling 1						
General bacterial flora	3.5^{b}	4.6^{a}	2.5^{a}	2.8^{a}	3.1^{b}	5.5^{a}
General fungal flora	2.2^{b}	3.5^{a}	1.9^{b}	2.6^{a}	2.8^{b}	3.4^{a}
Fluorescent pseudomonads	2.8^{b}	3.6^{a}	2.2^{a}	2.8^{a}	2.6^{b}	3.9^{a}
Sampling 2						
General bacterial flora	4.3^{b}	5.8^{a}	3.2^{a}	3.9^{a}	4.3^{b}	5.7^{a}
General fungal flora	2.1^{b}	3.7^{a}	1.6^{b}	2.5^{a}	2.3^{b}	3.3^{a}
Fluorescent pseudomonads	2.9^{b}	4.5^{a}	3.1^{b}	4.2^{a}	3.1^{b}	5.1^{a}

Table 5. Disease incidence[1] in the hydroponics (control) system and in the aquaponics system before and after the biofilter.

	Hydroponics system		Aquaponics system before biofilter		Aquaponics system after biofilter	
	11°C	21°C	11°C	21°C	11°C	21°C
Sampling 1	2^{a}	0^{b}	3^{a}	1^{b}	3^{a}	1^{b}
Sampling 2	3^{a}	0^{b}	4^{a}	2^{b}	4^{a}	0^{b}

[1] Disease symptoms were evaluated on a scale from 0 (healthy plants) to 4 (severe necrosis). Values within rows followed by different letters are significantly different according to Kruskal test.

At both temperatures, the pH value in the fish tank was within the range 7.1–7.5 and was adjusted daily after biofiltration, by the addition of acid, to a value around 6.0. Analyses of macronutrient and micronutrients at the beginning of the experiment showed a low content of potassium, iron, boron, zinc, copper, manganese and molybdenum in fish water at both water temperatures tested, compared with the standard nutrient solution for basil used in hydroponic system (Table 2). On the other hand, the content of phosphorus and calcium in the fish tank was higher than that in the standard solution in the hydroponic system. Analyses of water samples collected on two sampling occasions showed that at a water temperature of 11°C, the content of all these elements increased after the plant unit in the aquaponics system (Table 3). However, the content was markedly lower at this sampling site at a water temperature of 21°C (Table 4).

Microbial analysis

Analyses of the microflora indicated lower density of microorganisms at a water temperature of 11°C compared with 21°C in both the hydroponics and aquaponics system (Table 4). The lowest density of microorganisms was found in the aquaponics system, at the sampling point before the biofilter, at a water temperature of both 11 and 21°C. After biofiltration, an increased density of microorganisms was observed.

Evaluation of disease incidence indicated higher levels in both the hydroponics and aquaponics system at water temperature of 11°C compared with 21°C (Table 5). At water temperature of 21°C, disease incidence in the aquaponics system was also higher before the biofilter compared with after.

Discussion

Growth parameters

The results obtained in this study indicate that the temperature of the surplus water used in the system plays an important role for cultivation in both aquaponics and hydroponics. The weight measurements indicated that plants and fish performed better at 21°C than at 11°C. At a water temperature of 21°C, plant growth performance, indicated by measurements of biomass (Table 1), leaf length (Figure 1) and width (Figure 2), and nitrate content in the leaves (Figure 3) was better in the aquaponics compared with the hydroponics (control) system. At a water temperature of 11°C, growth was slower in both systems. The results obtained indicate that it is better to use a higher temperature, here 21°C, in aquaponics systems to achieve positive effects on plant and fish growth. This means that temperature of 11°C of surplus water or heat from different industrial processes should be increased to a higher temperature before its use in aquaponics making this temperature unsustainable solution in such cultivation systems. The results also indicate new pathways for crop fertilisation and the possibility of using fish feed, and ultimately excreta, as an organic fertiliser in hydroponics systems. The longer, wider leaves and lower nitrate content in the leaves in the aquaponics system at 21°C in this study are in line with results reported by Liu et al. (2014) in a study which showed that application of organic fertiliser increased the length and width of lettuce leaves and reduced their nitrate content compared with inorganic fertiliser.

The choice of plant species to cultivate at low water or air temperatures has been examined by Nilsson and Nimmermark (2013), who suggest herbs and lettuce as candidate crops to be cultivated in aquaponics systems under cold con-

ditions. According to the growth parameters investigated in the present study, sweet basil is a good candidate to be cultivated in aquaponics systems at a water temperature of 21°C.

Water quality parameters

In addition to plant growth, the nitrogen cycle and nutrient balance in aquaponics systems are crucial factors from a horticultural point of view. Earlier studies have focused on these factors (Sfectu et al., 2008; Blidariu et al., 2013; Petrea et al., 2013), but not in relation to low water temperature. Here, the choice of plant species again plays an important role in managing the high nitrogen content in aquaponics systems. Some plants require more nutrients than others (Diver, 2006) and react differently to different nutrients (Hu et al., 1997). The low nitrate level in the aquaponics system studied here after the plant unit (Figure 4) shows the effectiveness of basil plants in taking up nitrate and reducing the amount of nitrogen in the cultivation system. This makes basil a good choice to be grown in aquaponics systems.

Low nitrogen content after biofiltration also indicates good efficiency of the nitrification process in the biofilter. On the other hand, the high nitrate content at a water temperature of 11°C after the biofilter and the plant unit indicates that low temperatures may affect nitrate uptake in the plants and by the microorganisms involved in the biofilter and the nitrification process. This is in line with findings by Zhu and Chen (1999) that the rate of nitrification in the biofilter decreases at lower temperatures. Thus, in general, there are some drawbacks in cultivation of crops at low temperature, since these conditions could have negative effects on plant growth, yield and nutrient uptake (Stoltzfus et al., 1998).

As regards other water quality parameters, the fish tank had a pH of 7.5, a value that is recommended in the aquaculture sector to achieve efficient biofiltration (Tyson et al., 2011). However, this high pH is not suitable for most plant species and needs to be adjusted in order to achieve optimal uptake of nutrients. Most nutrients are taken up by plants within the pH range 5.0–6.5 (Marschner, 2011). In the present study, the pH at both temperatures investigated was adjusted daily to a value of 5.6, according to the recommendation by Hoagland and Arnon (1950), before the nutrient solution was circulated to the plant unit.

The results showed that a water temperature of 21°C had a positive effect in lowering the nutrient content in the aquaponics system. The low contents of macronutrients and micronutrients at 21°C after the plant unit indicates good uptake of these nutrients by the plants, which on the other hand did not perform well at a water temperature of 11°C (Table 2). As regards individual macronutrients and micronutrients, the results showed low contents of potassium, iron, boron, zinc, copper, manganese and molybdenum and high contents of phosphorus and calcium in fish water at both water temperatures compared with the standard nutrient solution for the crop (Table 2). This may indicate that the fish feed used in aquaponics results in a nutrient imbalance in the plant unit, an issue that should be taken into consideration. In this study we used a plant-to-fish ratio of 15:8 (plant:fish); there the number of plants used was 15 plants to 8 fish. The results confirm findings by Racoky et al. (2006) and Graber and Jung (2009), who reported nutrient deficiency with the fish feed used in their studies.

Microbial parameters

Microorganisms in the root environment are dependent on root exudates and are affected by root growth. In the present study, the lower plant growth at a water temperature of 11°C resulted in low microbial density on roots compared with plants grown at 21°C. The microbial groups analysed were also affected by the biofiltration process, as higher amounts of microorganisms were detected in water after biofiltration compared with before.

Disease incidence in the system was also affected by the water temperature and the biofiltration process. This could be connected to the stress conditions that plants experience during cultivation at a low water temperature and also to microbial growth, since higher numbers of microorganisms were found after biofiltration, i.e., before the water entered the plant unit.

Conclusions

This study examined the effect of a low water temperature of 11°C, compared with 21°C, on nutrient flow, plant and fish growth and microbial dynamics in an aquaponics system producing brown trout and sweet basil. The results showed that water temperature has a significant effect on plant and fish growth in aquaponics systems. Use of surplus heat from water at 21°C proved to be more suitable for cultivation in the aquaponics system studied, as growth of fish and plants was higher at that temperature. A water temperature of 11°C had a negative effect on nutrient uptake, biofilter efficiency and microbial parameters in the system. Basil was shown to be a suitable horticultural crop for cultivation in an aquaponics system. The results also indicated that choice of fish feed and optimisation of nutrients need to match plant requirements at low water temperatures. Here we used a plant-to-fish ratio of 15:8, but other ratios in relation to nutrients need to be investigated. The quality of the plants and fish produced is another aspect of great importance.

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Address of author:
S. Khalil
Department of Biosystems and Technology, Swedish University of Agricultural Sciences, Alnarp, Sweden