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Akvaponika – orodje za sonaravno ribogojstvo

Tjaša Griessler Bulc
University of Ljubljana, Faculty of Health Sciences, Ljubljana, Slovenia,
tjasa.bulc@zf.uni-lj.si
University of Ljubljana, Faculty of Civil and Geodetic Engineering, Institute of Sanitary Engineering, Ljubljana, Slovenia

Aleksandra Krivograd Klemenčič
University of Ljubljana, Faculty of Health Sciences, Ljubljana, Slovenia,
Aleksandra.krivograd@zf.uni-lj.si
University of Ljubljana, Faculty of Civil and Geodetic Engineering, Institute of Sanitary Engineering, Ljubljana, Slovenia

Izvleček

Cilj raziskave je bil zmanjšati onesnaženje vode v majhnih ciprinidnih ribogojnicah s ponovno uporabo/recikliranjem vode v sistemu akvaponike. Pilotno ribogojnico sta sestavljala dva bazena, vsak s prostornino 36 m^3, od katerih je eden predstavljal poskusni, drugi pa kontrolni bazen. Začetna količina vloženih rib je bila 0,6 kg/m^3 krapov (*Cyprinus* c. *carpio* L.) na bazen. V poskusnem bazenu je bila nameščena ultrazvočna naprava za preprečevanje rasti alg. Iz poskusnega bazena smo črpali vodo v čistilni sistem sestavljen iz lamelnega usedalnika, peščenega filtra in vertikalne rastlinske čistilne naprave, zasajene s paradižnikom (*Lycopersicum esculentum* L.). V pilotni ribogojnici smo od junija do septembra 2011 spremljali vrednosti fizikalnih in kemijskih parametrov, koncentracijo klorofila-*a* in povečanje teže rib. Sistem akvaponike je bil uspešen za odstranjevanje TSS, BPK_5, KPK, NH_4-N in TP, ne pa tudi za odstranjevanje NO_3-N in NO_2-N. Ultrazvočna naprava je uspešno preprečevala rast alg v poskusnem bazenu. V slednjem smo zaradi boljših gojitvenih pogojev dosegli večjo proizvodnjo rib v primerjavi s kontrolnim bazenom. Predstavljen sistem zaprte zanke bi bil lahko uporaben v semi-naravnih ribogojnicah.

V letu 2012 smo pričeli z izvajanjem projekta AQUA-VET (Vseživljenjsko učenje, Prenos inovacij), katerega glavni cilj je vključiti akvaponiko v poklicno izobraževanje in razviti nov poklic »urbani kmetovalec - akvaponik«.

Ključne besede: akvaponika, rastlinska čistilna naprava, ribogojstvo, kroženje, ultrazvok, čiščenje vode

Aquaponic – a tool for sustainable fish farming

Abstract

The objective of this study was to reduce the water pollution in small-scale cyprinid fish farms with a diversion of recirculation water into aquaponic system. The experiment ran in two 36 m^3 fishponds, one as experimental and one as control pond with the starting fish load of 0.6 kg/m^3 of carp (*Cyprinus c. carpio* L.) per pond. Ultrasound device for inhibition of algae growth was installed in the experimental pond. From there the water was pumped by a bypass to the treatment train consisting of a lamellar settler, a roughing filter and a vertical constructed wetland planted with tomatoes (*Lycopersicum esculentum* L.). The pilot fish farm was monitored from June to September 2011 for physical and chemical parameters, chlorophyll-a concentration and fish body weight. The aquaponic system removed efficiently TSS, BOD_5, COD, NH_4-N, and TP but not NO_3-N and NO_2-N. The ultrasound successfully inhibited algae growth in experimental pond. A higher fish production was achieved compared to the control pond due to better rearing conditions. The closed-loop system as presented here could be useful for semi-natural fish farming.

In 2012 AQUA-VET project started (Lifelong Learning, Transfer of Innovation) which main goal is introducing aquaponic in vocational education (VET) and develop a new VET profession "Aquaponic Urban Farmer".

Keywords: aquaponic, Constructed wetland, Fish farming, Recirculation, Ultrasound, Water treatment

1 Introduction

Currently, the increasing worldwide demand for fish coupled to the problem of overfishing results in furious expansion of conventional aquaculture technologies. These have a detrimental effect on the aquatic environment by releasing nutrient rich effluent containing fish faeces and excess feeds into the water (1).

An aquaponic system (a combination of fish aquaculture and hydroponic crop production) is a technology that recycles the nutrient rich aquaculture effluent. The aquaculture effluent is recirculated over trickling filters or other suitable substrates in which crop plants are grown. This special kind of constructed wetland provides the necessary nitrification rates for a recirculating aquaculture, and furthermore reuses nutrients for marketable products like fruits, herbs and vegetables. Aquaponic is therefore a possible solution to reduce the water pollution and eutrophication due to the aquaculture industry. Furthermore, aquaponics can open new economic possibilities for inland farmers. An aquaponic system uses minimal amounts of freshwater (2).

This paper describes a monitored pilot operation of aquaponic under field conditions, i.e. a small-scale land-based cyprinid fish farm with a diversion of recirculating water into a closed-loop system with a treatment train (TT) consisting of a lamellar settler (LS), roughing filter (RF), vertical constructed wetland (CW) planted with tomatoes (*Lycopersicum esculentum* L.) and of an ultrasound device (US). Due to water recirculation, the closed-loop system presented was also expected to enable water savings in accordance with European water policy. In contrast to the investigated closed-loop system, other recirculating aquaculture systems usually apply a biological wastewater treatment. However, due to the relatively high cost and unstable operation, recirculation aquaculture systems are not widespread yet (3). Constructed wetlands (CW), using various sand filters (5) or light expanded clay aggregate (2) could provide a sustainable cost effective alternative to conventional biological treatment (4). The presented multi-functional integrated technology has all the benefits of physical water treatment without any use of chemicals, since ultrasound device acts as disinfectant and algae inhibitor, while water circulation can contribute to water savings.

The objective of this study was therefore to evaluate the treatment performance and fish production of a pilot aquaponic system for small-scale land-based cyprinid fish farms. Our hypothesis was that the system will restrain suspended solids as well as dissolved nutrients, counteract algae growth and act as a disinfectant.

2 Material and Methods

2.1 Description of the pilot system

The research was carried out at the experimental fish farm located in Ajdovščina, Slovenia. Of the two fish ponds (length 9 m, width 5 m, depth 1 m, volume 36 m^3) one served as an experimental (Pond A), and one as a control pond (Pond B) (Figure 1). Both ponds had constant aeration (disk diffuser). An US transducer (LG Sonic® Tank, range 70 m, energy consumption 13 W, 20-200 kHz) was deployed, floating in the corner of the Pond A. From the Pond A the water was pumped by a bypass into the treatment train (TT) consisting of the LS, the RF, and the CW. The TT with Pond A formed an aquaponic system, in which the water was treated first by the LS (length 2.5 m, width 1.9 m, depth 1.0 m) with lamellae positioned at an angle of 60º. Function of the LS was to retain organic mass from the Pond A. Efficient particle deposition was enabled by bottom-up inflow and a water flow rate of 4 m^3/h. From the LS the water was pumped through the shaft with submersible pump and then to the bottom of the RF. The RF (length 1.5 m, width 1.5 m, depth 1.1 m) was filled from the bottom up with gravel with the grain size of 4/8, 8/16 and 6/22 mm. The water in the RF was pumped bottom-up and from there it flew by gravity on the surface of the 2.25 m^2 vertical CW planted with tomatoes (*Lycopersicum esculentum* L.). Inflow to the CW was arranged in a network of pipes, which were installed approximately 5 cm above the substrate so that water was dripping across the CW surface, thus providing additional aeration. Light expanded clay (LECA, 8/8 mm) was used as filter material and filled into standard vegetable boxes enabling aeration from the sides and at the bottom of the CW. CW effluent was recirculated into the Pond A. Pond B did not receive any treatment.

At the start of the operation, both ponds were filled with the groundwater from the nearby source. Groundwater was also added to the ponds during the experiment whenever water conditions reached threshold values that were threatening to the fish (pH > 10, NO_2-N > 0.6 mg/L, dissolved oxygen (DO) < 3 mg/L), and to compensate evaporation losses. Groundwater was also consumed for maintenance of the TT and to clean the ponds during the time of fish weighing.

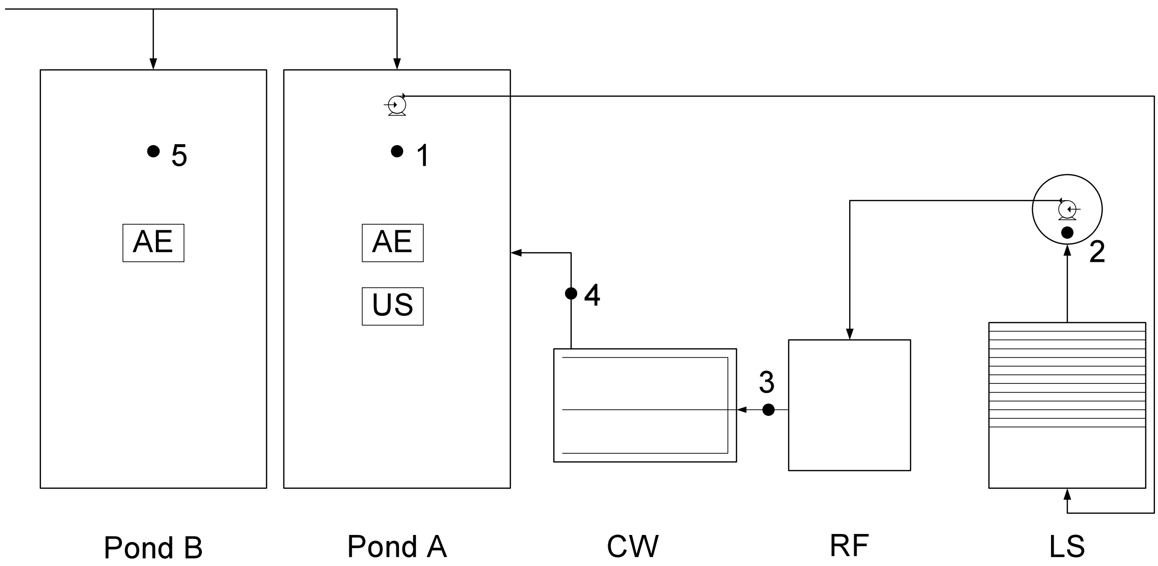


Figure 1: Experimental set up of the pilot system consisting of an experimental pond (Pond A), a control pond (Pond B), an aeration unit (AE), an ultrasound transducer (US), a lamellar settler (LS), a roughing filter (RF) and a vertical constructed wetland (CW). Black dots mark sampling points: 1-in Pond A, 2-after the LS, 3-after the RF, 4-after the CW which coincides with the effluent from the treatment train and 5-in Pond B.

2.2 Monitoring of the pilot system

The system was monitored from June through September 2011. Dissolved oxygen (DO), pH, electric conductivity (EC), temperature and oxidation reduction potential (ORP) were measured twice a day (8 a.m. and 2 p.m.) , using WTW Multiline/F portable meters. . Water from both ponds, and effluents from the LS, the RF and the CW were sampled two to three times per month, and total suspended solids (TSS), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), ammonium nitrogen (NH_4-N), nitrate nitrogen (NO_3-N), nitrite nitrogen (NO_2-N), orto-phosphate (PO_4-P) and total phosphorous (TP) were determined according to Standard Methods (6). The samples for chlorophyll *a* analysis were taken monthly from both ponds. As planktonic algae are suspended mostly near the surface of stagnant water bodies (7), chlorophyll *a* samples were collected just below the surface, near the middle of the pond, which was assumed to be adequate for a simple characterization of a possible trend in chlorophyll *a*. Chlorophyll *a* was extracted by filtering a 10 mL suspension through a Whatmann glass fibre filter (GF/F), diameter 47 mm, cat. No. 1825-047. The filtration apparatus consisted of a filter holder, a Buchner flask, and a vacuum pump. Five replicates were performed for each sample. For determination of chlorophyll *a*, the GF/F were ground up in 10 mL of 90% acetone solution and incubated for 24 hours at 6 °C in darkness to prevent the pigment denaturing. After incubation, the solution was transferred in a 3.5 mL glass cuvette and the optical density (OD) of the supernatant was measured at three wavelengths: 663, 645, and 630 nm. A solution of acetone at 90% was used as a blank. The chlorophyll *a* concentrations were calculated according to the equation of Scor/Unesco (8): chlorophyll *a* concentration (mg m^{-3}) = (11.64 OD_{663} – 2.16 OD_{645} – 0.1 OD_{630}) * (volume of acetone (mL)/volume of sample (L)).

The starting fish load in both ponds was 0.6 kg/m^3 or 55 carp in Pond A and 58 carp in Pond B (*Cyprinus c. carpio* Linnaeus 1758). The fish body weight (BW) was measured at the beginning of the pilot operation in June 2011, and in October 2011. The fish were hand fed once per day with GARANT Aqua fish food. The amount of fish food was on average 0.7 kg, thus using totally 69.3 kg per pond for the entire period. All the dead fish were registered, veterinary inspected, weighed and removed from the pond. The specific growth rate (SGR) according to Chao et al. (9) and food conversion rate (FCR) were calculated. In the calculations the mortality was adequately considered.

3 Results

3.1 Water quality of the aquaponic system

Table 1 summarizes physical and chemical quality of the water in both ponds, and of the effluent from the TT. There was no obvious difference in the mean values of pH and EC between the ponds, while mean values of DO and ORP were higher in Pond A compared to Pond B. Morning DO, pH and ORP values were higher in Pond A compared to Pond B, while EC values showed the opposite pattern. Temperatures in Pond A and in Pond B were highest in June and August with maxima of 25.4 °C and 25.8 °C, respectively, and lowest in September with minima of 17.8 °C and 17.7 °C, respectively.

Mean values of TSS, BOD_5, COD, NH_4-N, NO_2-N, PO_4-P and TP were lower in Pond A compared to Pond B; however, mean values of NO_3-N were lower in Pond B (Tab. 1). Mean values of TSS, BOD_5, COD, NH_4-N and TP were lower in the effluent from the TT compared to the Pond A, while the concentrations of NO_3-N, NO_2-N and PO_4-P were slightly lower in Pond A, indicating an accumulation of nitrates, nitrites and phosphates in the TT. Standard deviations for all parameters were in the same range as the mean values, reflecting high fluctuations over time (Tab. 1). Chlorophyll *a* values were markedly lower in Pond A, compared to Pond B, probably due to the algae inhibition by US in Pond A (Tab. 1).

Table 1: Mean (± 1 standard deviation) and range for measured parameters in the experimental pond (Pond A), in the control pond (Pond B) and after the treatment train (TT) of Pond A in comparison with Slovene legal requirements. Exceeded legislation values are underlined.

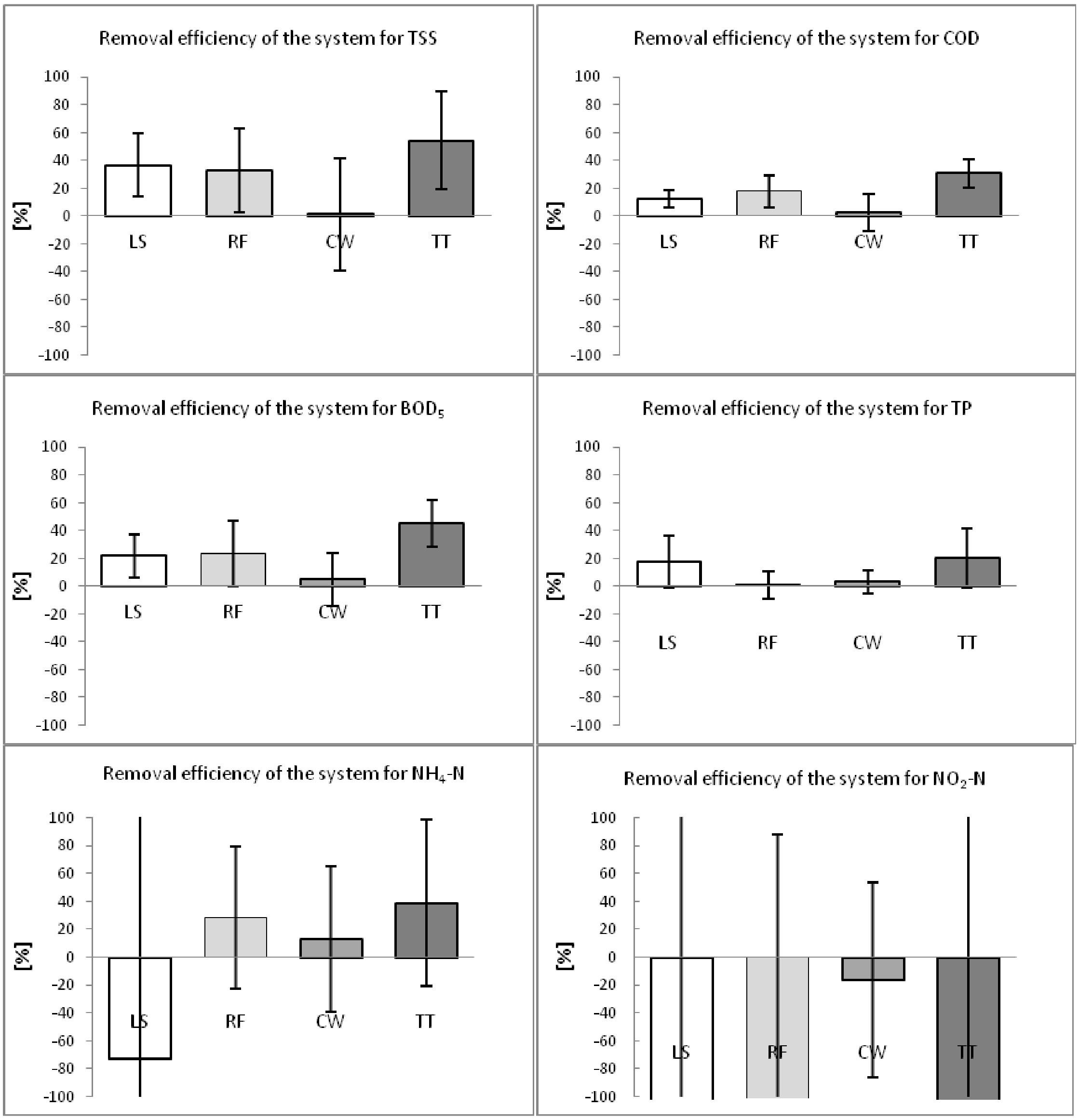
			Pond A (experiment)		Pond B (control)		TT		Limit value according to Slovene legislation (1)
	Unit	n	Mean ± stand. dev.	range	Mean ± stand. dev.	range	Mean ± stand. dev.	range	
Disolved oxygen	mg/L								
8 am		69	7.9±0.9	5.9-9.8	5.1±2.4	0.8-13.8	7.6±0.6	6.8-8.7	≥ 5
2 pm		69	10.6±1.1	8.2-13.5	11.8±3.8	5.5-21.8	-	-	≥ 5
pH									
8 am		69	7.6±0.2	7.2-8.4	7.5±0.4	6.8-8.6	7.8±0.2	7.6-8.1	6-9
2 pm		69	8.0±0.3	7.2-8.8	8.1±0.5	7.1-9.7	-	-	6-9
Electric conductivity	µS/cm								
8 am		69	346±58	279-514	383±118	214-574	321±23	286-355	-
2 pm		69	344±60	278-506	375±119	208-561	-	-	-
Temperature	°C								
8 am		69	21.9±2.3	17.0-26.1	22.2±2.4	17.3-27.3	22.6±2.4	17.6-25.8	-
2 pm		69	23.8±2.6	18.0-28.5	24.5±2.8	18.3-29.7	-	-	-
Redox potential	mV								
8 am		69	114.4±21.7	77-170	106.2±22.1	53-157	110±17.9	82-139	-
2 pm		69	99.5±23.1	21-157	88.8±24.7	22-144	-	-	
TSS	mg/L	12	15.2±10.8	2.3-35.0	61.1±53.2	10.1-199	5.6±5.1	1.3-15.7	≤ 25
BOD_5	mg/L	12	13.7±6.1	5.8-25.7	49.2±43.0	16.5-169	7.2±3.2	2.9-13.2	≤ 6
COD	mg/L	12	43.7±17.5	20.0-70.0	147.3±90.5	43.0-376.0	29.3±9.9	14.0-43.0	-
NH_4-N	mg/L	12	0.05±0.03	0.01-0.11	2.89±4.47	0.02-13.27	0.02±0.01	0.01-0.04	≤ 0.16
NO_3-N	mg/L	12	0.44±0.66	0.01-2.26	0.09±0.09	0.02-0.27	0.61±0.90	0.01-3.13	-

NO_2-N	mg/L	12	0.04±0.07	0.00-0.21	0.05±0.08	0.00-0.24	0.06±0.11	0.00-0.41	≤ 0.01
PO_4-P	mg/L	12	0.26±0.32	0.01-1.01	1.38±1.57	0.02-4.60	0.34±0.40	0.02-1.29	-
TP	mg/L	12	0.50±0.35	0.16-1.33	2.25±2.34	0.24-8.31	0.42±0.36	0.09-1.23	≤ 0.4
Chorophyll a	mg/m^3	12	170.3±149.3	12.2-506,0	379.7±296.4	13.3-1104.2	-	-	-

(1) According to Slovenian standards for cyprinid surface waters concentrations presented in Decree on the quality required of surface waters supporting fresh-water fish life (Official Gazette of Slovenia, No 46/2002).

3.2 Removal efficiency of the treatment train

The TT eliminated varying fractions of TSS, COD, BOD_5, TP and NH_4-N (Fig. 2). The mean removal percentages for listed parameters were from 20% for TP to 54% for TSS. The majority of COD, BOD_5 and NH_4-N removal took place in the RF. The majority of TSS and TP removal took place in the LS. There was no elimination of NO_2-N and NO_3-N in the TT.



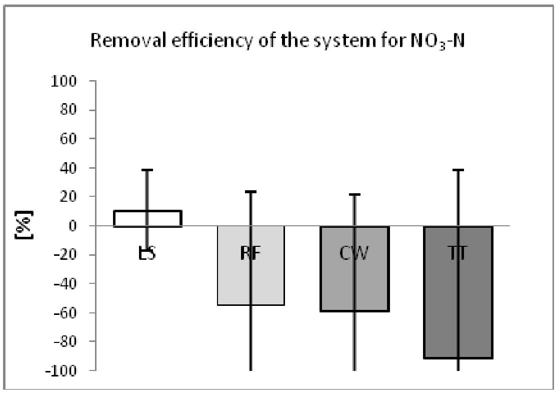


Figure 2: Removal efficiency of the treatment train (TT) for chemical parameters from June to September 2011. LS – Lamellar settler, RS – Roughing filter, CW – Vertical constructed wetland.

3.3 Fish monitoring

Table 2 summarizes results of fish monitoring during the experimental period. The fish thrived better in Pond A as compared to Pond B. This is indicated by better growth (higher total fish biomass, and average weight of fish), and the lower mortality in Pond A. Also, the food conversion rate was better in Pond A.

Table 2: Results of fish monitoring from June through September 2011 in the experimental pond (Pond A) and in the control pond (Pond B).

	Unit	Pond A	Pond B
Fish load (start - end)	kg/m3	0.6-1.3	0.6-1.1
Fish biomass (start - end)	kg	19.6-46.0	19.7-39.1
Fish biomass growth	kg	26.4	19.4
Average weight of fish specimens (start - end)	kg	0.45-1.05	0.39-0.80
Body weight increase	%	134.6	98.6
Specific growth rate	%/day	0.23	0.19
Food conversion rate	-	2.63	3.57
Mortality	%	-	2.18

4 Discussion

4.1 Performance efficiency of the pilot system

DO values below the threshold of 3 mg/L were present only in Pond B in 26% of measured values, all of which were measured in the morning. Low morning DO values indicate a lack of oxygen at nights, most probably because of the respiration of algae. In general, morning oxygen conditions were better in Pond A, while afternoon oxygen values were slightly higher in Pond B due to intensive algae growth in Pond B. Daily pH values varied in both ponds but never exceeded the threshold value of 10 pH. The highest pH value of 9.67 was measured in Pond B. pH values were in general slightly higher in Pond B, indicating that the TT contributed to the mitigation of pH values due to its buffering capacity and algae inhibition. All NO_2-N values measured were below the threshold value of 0.6 mg/L. The EC values in both ponds were in the typical range for natural water bodies in Slovenia (10); the difference in EC between the ponds was negligible. Temperatures in both ponds showed normal daily dynamics, with lower morning temperatures and higher afternoon temperatures due to direct exposure of the ponds to solar radiation. The average ORP values were slightly higher in Pond A compared to Pond B. Morning ORP values were higher in both ponds compared to afternoon ORP values.

The TT was significantly efficient in the removal of TSS, BOD_5, COD, NH_4-N and TP. The removal of the TT for NO_3-N and NO_2-N was negative. Besides the efficient elimination of TSS, BOD_5, and COD with the TT, we assume that US device contributed to the lower concentrations of listed parameters in the aquaponic system, namely by efficient algae control. Mean NH_4-N levels were markedly lower in Pond A, compared to Pond B. More than 41% of NH_4-N values measured in Pond B exceeded legislation value of 0.16 mg NH_4-N/L, of which the highest measured value was 13.27 mg NH_4-N/L (measured on 21.9.2011). Total ammonia nitrogen (TAN) consists of un-ionized ammonia (NH_3) and ionized ammonia (NH_4^+); the former of which is highly toxic to fish. The proportion of TAN in the un-ionized form is dependent upon the pH and temperature of the water. At higher pH and water temperatures, the percentage of toxic unionized ammonia could be high (11); however, in the end of September 2011 the measured pH value in Pond B was near neutral and the water temperature was below 20 °C. For this reason, we assume that NH_3 could not threaten fish health. Lower NH_4-N concentrations and higher NO_3-N concentrations in Pond A compared to Pond B, and higher concentrations of NO_3-N in the effluent from the TT compared to Pond A are most probably the consequence of nitrification occurring in the TT, while denitrification was negligible due to aerobic condition. This was also confirmed by negative removal for NO_3-N through the TT. However, NH_4-N concentrations entering the TT (i.e. from 0.01 to 0.11 mg NH_4-N/L) might be too low to support a significant growth of nitrifying bacteria in the RF, as stated by Yang et al. (12) that values below 0.5 mg NH_4-N/L are limiting for abundant bacterial growth. Despite this, our results indicate that some nitrification was still carried out in the TT. Aquatic species can tolerate high concentrations of NO_3-N (>100 mg/L), while NO_2-N can be harmful to them. However, the concentrations of NO_2-N and NO_3-N were lower in both ponds than observed by Alam and Al-Hafedh (11) in green water fish tanks, which ranged from 0.63-0.87 mg NO_2-N/L and from 31.51-61.04 mg NO_3-N/L. The groundwater used to replenish the ponds was polluted by agriculture and presented an additional source of NO_3-N for both ponds. The mean values of NO_3-N in groundwater (0.99±0.40 mg NO_3-N/L) were higher than the mean values of NO_3-N in both ponds, revealing NO_3-N uptake by algae in the ponds. However, due to depletion of algae by US in the pond A the uptake of NO_3-N was lower and concentrations of NO_3-N noticeable higher. One third of NO_2-N concentrations in Pond A and almost two thirds of NO_2-N concentrations in Pond B exceeded the legal limit of 0.01 mg NO_2-N/L. Mean NO_2-N concentrations were similar in Pond A compared to Pond B. This can be explained with the reduction of the nitrification processes in the summer due to the lack of oxygen at nights, higher feeding load, high temperature and agricultural pollution. Vymazal (13) reported that nitrification continues until concentrations of DO decline under 2 mg O_2/L. Below this concentration, diffusion rates of oxygen to the bacteria becomes critical. During the day, DO levels in both ponds increased (Tab. 1). Phosphate levels differed markedly between the ponds. Mean TP in both ponds exceeded legal limit of 0.4 mg/L. The lower TP in Pond A was probably due to sedimentation of planktonic algae caused by US. Also Chlorophyll *a* values were markedly lower in Pond A showing efficient reduction of algae by US.

4.2 The comparison of measured parameters with legal requirements

Slovenian legislation only defines the fresh water quality for cyprinid species. According to the legislation values presented in Table 1, the mean values of DO and pH in both ponds met the limits; however, several single measurements of DO and pH in Pond B exceeded the legislation limit of 5 mg/L for DO and of 9 pH. According to Slovenian standards for cyprinid surface waters, the concentration limits for nitrites, TP and BOD_5 were exceeded in both ponds. Mean values of TSS and ammonium were exceeded only in Pond B. According to the legislation limits the aquaponic system met the legislation requirements more often and consistently as compared to Pond B.

4.3 Fish biomass

The experiment was performed during the summer which is the most relevant period for fish farming. The BW increase was higher in Pond A than in Pond B, 134.6% and 98.6%, respectively. SGR was for Pond A on average higher (0.23 %/day) than in Pond B (0.19 %/day) indicating better rearing conditions in Pond A. Fish showed poor food conversion efficiency in both ponds. Based on the Slovene data from semi-natural fish farms with 1.5 food conversion rate on average (14, 15), it can be concluded that in our study fish were overfed, which is mostly due to quick hand feeding. DO values below the legal threshold were maintained in Pond A at stocking densities of 0.5 - 1.3 kg fish/m^3. A higher fish load could further reduce the DO and thus lead to conditions that threaten fish population. Jana (16) found that carp are more sensitive to low DO and high ammonia levels than some other fish species (tilapia or catfish) and need a larger water area for growth. Within the experimental period no fish died in Pond A and 2.18% of the fish died in Pond B due to the heron attack. The attacked fishes got severe wounds and were then more easily infected by parasites in the water. Against further heron attacks the ponds were protected with a net.

5 Conclusions

The study evaluated the performance of the aquaponic system for small-scale cyprinid fish farms. Our hypothesis that the combination of a lamellar settler (LS), a roughing filter (RF), a vertical constructed wetland (CW) and an ultrasound (US) device can reduce suspended solids and dissolved nutrients, and counteract algae growth was partially confirmed. The aquaponic system removed efficiently total suspended solids, biochemical oxygen demand, chemical oxygen demand, ammonium and total phosphorus, but did not remove nitrate and nitrite. The majority of pollutant removal took place in the roughing filter and lamellar settler. Legislation limits in the aquaponic system were met for all the measured parameters except biochemical oxygen demand, nitrites and total phosphorous. In the experimental pond higher fish production was achieved compared to the control pond due to generally better conditions. The aquaponic system as presented here could be useful for semi-natural fish farming with fish loads between 0.5-1.3 kg/m^3. The system offers an alternative chemical-free solution for the removal and inactivation of algal cells and the linked harmful potential in fish farms.

Aquaponic is a promising technology which could contribute to improving the aquaculture industry towards more sustainability by reducing the water demands, use of chemicals, and nutrient losses.

In order to promote and establish this technology, skilled operators will be needed. In 2012, a consortium with ten partners from three countries (CH, SI, IT) started the AQUA-VET project within the European Lifelong Learning Programme (LEONARDO). The project aims to (i) develop a new profession “Aquaponic Farmer”, (ii) transfer the aquaponic technology and corresponding teaching units into vocational educational (VET), (iii) adapt training resources to support the use of Aquaponic in VET curricula, and (iv) support the training of VET teachers and trainers for future training of emerging green jobs. In each participating country one VET centre is flanked by an institution of the forefront of research and development (R&D), and by a representative of the world of work interested in employing skilled operators. This clustering allows efficient transfer of innovation from R&D through feedback from economy into educational practice. As teaching “laboratory”, a model aquaponic farm will be used combining the production of plants and fish with an ideal environment for VET. The focus is on practical applications: VET training for “green jobs”. This forward thinking education will enable teachers to equip their students with special skills needed for emerging occupational chances in the field of urban farming and in modern agriculture.

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