Innovative Aquaponic Technologies for Water Reuse in Cyprinid Fish Farms

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Abstract
In the Western part of Europe aquaculture is represented by intensive and semi-intensive systems with mostly marine fish species, while in the Eastern countries traditional aquaculture is extensive, in ponds, with primarily freshwater fish species. Extensive aquaculture utilizes large amounts of freshwater and decomposition of wasted feed and fish excreta can lead to eutrophication in receiving waters. Alternative intensive aquaculture systems with recirculation are being developed in order to improve rational water use and lower the environmental impact. 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 increase. The aquaponic system was efficient in the removal of TSS, BOD_5, COD, NH_4-N and TP but not in the removal of NO_3-N, 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 presented could be useful for semi-natural fish farming.

Keywords: *Aquaponic; Constructed wetland; Fish farming; Recirculation; Ultrasound; Water treatment*

Introduction

Currently, the worldwide rising demand for fish, and the problem of overfishing are resulting in furious expansion of conventional aquaculture technologies. These have a detrimental effect on the aquatic environment by releasing excess nutrients contained in the fish faeces in the water (1).

An aquaponic system (a combination of fish and crop production) is a form of nutrient recycling for aquaculture. The nutrient rich water of the aquaculture is recirculated over trickling filters in which crop plants are grown. This special kind of constructed wetland provides the necessary nitrification rates for a recirculating aquaculture, and furthermore it reuses nutrients for marketable products like fruits, herbs and vegetables. Aquaponics are therefore a possible solution to reduce the water pollution and the water eutrophication of the aquaculture industry. And furthermore Aquaponics can give new economically possibilities for inland farmers. An Aquaponic system uses minimal amounts of freshwater (2).

This paper describes a monitored aquaponic pilot operation 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, in recirculating aquaculture systems biological wastewater treatment is commonly in use. However, due to the relatively high expense of those technologies and unstable operation, recirculation aquaculture systems are not widespread (3). According to Sindilariu (4) constructed wetlands (CW) could be sustainable cost effective alternatives (4) with the usage of various sand filters (5) or light expanded clay aggregate (2). The presented multi-functional integrated technology has all the benefits of physical water treatment without any use of chemicals, since US acts as disinfectant and algae inhibitor, while water circulation can contribute to water savings.

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

Material and Methods

Description of a pilot system

The research was carried out at the experimental fish farm located in Ajdovščina in Slovenia. The experiment was performed in two fish ponds (length 9 m, width 5 m, depth 1 m, volume 36 m^3) of which one served as an experimental (Pond A), and one as a control pond (Pond B). A commercially available US transducer (LG Sonic® Tank, range 70 m, energy consumption 13 W, 20-200 kHz) was installed, floating in the corner of Pond A. From Pond A the water was pumped by a bypass in a 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 inlet water was dripping across the CW surface and additional aeration was provided. As a filter material, light expanded clay (8/8 mm) was used and filled into standard vegetable boxes enabling aeration from the sides and at the bottom of the CW. CW effluent was passed back into the Pond A. Both ponds had constant aeration (disk diffuser). Beside aeration, Pond B did not receive any treatment. At the start of the experiment, both ponds were filled with the groundwater from the nearby source. Groundwater was also added in the ponds during the experiment when water conditions threatened fish population regarding threshold values (pH > 10, NO_2-N > 0.6 mg/L, dissolved oxygen (DO) < 3 mg/L) and to compensate evaporation losses. The groundwater was also consumed for maintenance of the TT and to clean the ponds during the time of fish weighing.

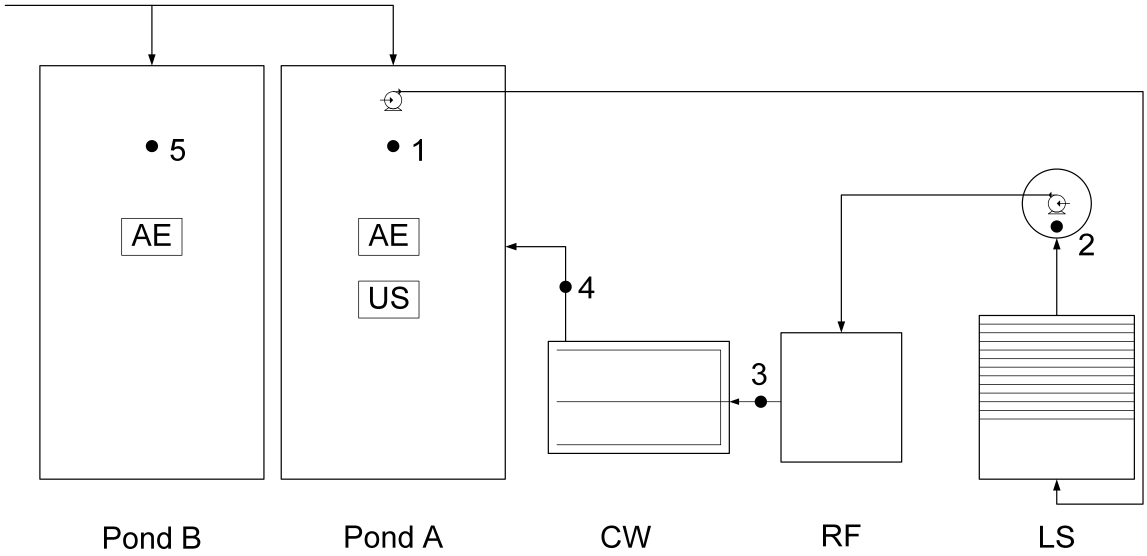

Figure 1: Experimental set up of the pilot system consisting of an experimental pond (Pond A), a control pond (Pond B), an aeration unit (AE), an ultrasound transducer (US), a lamellar settler (LS), a roughing filter (RF) and a vertical constructed wetland (CW). Black dots mark sampling points: 1-in 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.

Monitoring of the pilot system

The aquaponic system was monitored from June 2011 to September 2011. DO, pH, electric conductivity (EC), temperature and oxidation reduction potential (ORP) were measured twice a day (8 a.m. and 2 p.m.) in both ponds, using WTW Multiline/F portable meters, throughout the monitoring period. Water from both ponds, and effluents from the LS, the RF and the CW were sampled two to three times per month from June 2011 to September 2011 for 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) according to Standard Methods (6). The samples for chlorophyll *a* analyses were taken in both ponds once a month from June 2011 to September 2011. Due to the fact that planktonic algae live primarily near the surface of stagnant water bodies (7), chlorophyll *a* samples were collected just below the surface. Samples were collected near the middle of the pond, which was assumed to be adequate for a simple characterization of a possible trend in chlorophyll *a*. Extraction of the chlorophyll *a* was performed as follows: a 10 mL suspension was filtered using a Whatmann glass fibre filter (GF/F), diameter 47 mm, cat. No. 1825-047. The filtration was made using an apparatus made 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 a 90% acetone solution and incubated for 24 hours, at 6 °C in darkness to prevent the pigment denaturing. After incubation, the solution was placed 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) increase was measured at the beginning of the pilot operation in June 2011 and in October 2011. The fish were hand fed with GARANT Aqua fish food on average 0.7 kg once per day. The amount of fish food was the same for both ponds. In the case of fish mortality, the dead fish were registered, veterinary inspected, weighed and removed from the pilot system. 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.

Results

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 Pond A and Pond B 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 show the opposite pattern. Temperatures in Pond A and in Pond B were the highest in June and August with maximum of 25.4 °C and 25.8 °C, respectively, and the lowest in September with minimum 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, showing high fluctuation over time (Tab. 1). Chlorophyll *a* values were markedly lower in Pond A, compared to Pond B, 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 marked in bold.

			Pond A		Pond B		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).

Removal efficiency of the treatment train

The TT showed elimination 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.

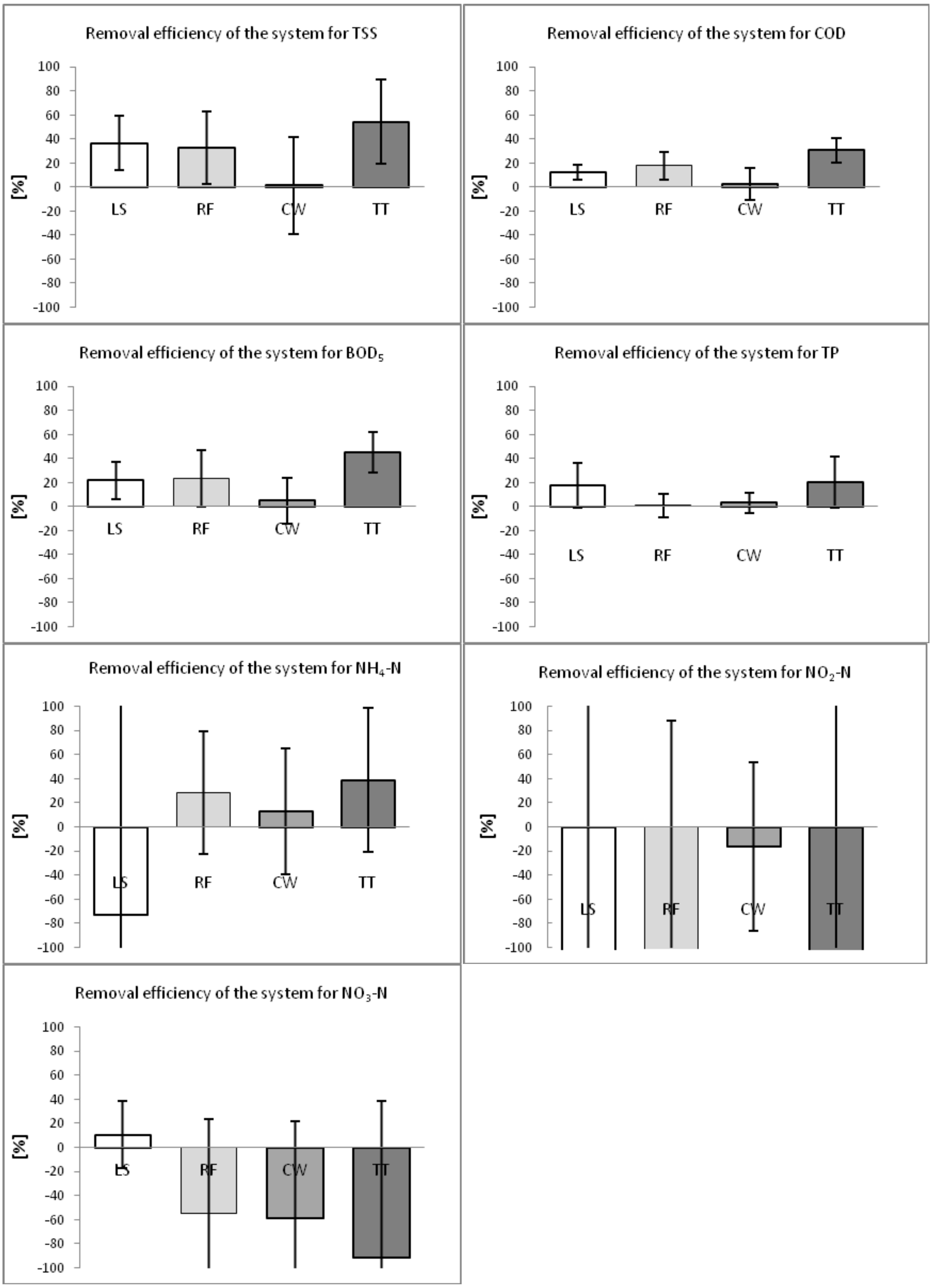

Figure 2: Removal efficiency of the treatment train (TT) for chemical parameters from June to September 2011. LS – Lamellar settler, RS – Roughing filter, CW – Vertical constructed wetland.

Fish monitoring

Table 2 summarizes results of fish monitoring during the experimental period. The BW increased from June to September by 134.6% (26.4 kg) in Pond A and by 98.6% (19.4 kg) in Pond B at 69.3 kg of total feed load per pond. The SGR was in Pond A 0.23 %/day and in Pond B 0.19 %/day. The FCR was in Pond A 2.63 and in Pond B 3.57. In Pond A there was no fish mortality while in Pond B 2.18 % of the fish died during the experimental period.

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

	Unit	Pond A	Pond B
Fish load	kg/m3	0.54-1.28	0.55-1.10
Fish biomass	kg	19.61-46.00	19.69-39.10
Fish biomass growth	kg	26.39	19.41
Average fish weight	kg	0.45-1.05	0.39-0.80
Body weight increase	%	134.57	98.58
Specific growth rate	%/day	0.23	0.19
Food conversion rate	-	2.63	3.57
Feed load total	kg	69.3	69.3
Mortality	%	-	2.18

Discussion

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 algal flora in middle summer. In general, morning oxygen conditions were better in Pond A compared to Pond B, while afternoon oxygen values were slightly higher in Pond B compared to Pond A due to intensive algae growth in Pond B. Daily pH values varied in both ponds but none of the measured pH values 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 compared to Pond A, indicating that the TT contributed to the mitigation of pH values due to its buffering capacity and algae inhibition. All of the NO_2-N values measured were below the threshold value of 0.6 mg/L. When DO values in the ponds exceeded threshold values, groundwater was added in order to prevent fish mortality. The measured 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 show 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 were in the range of 0.63-0.87 mg NO_2-N/L and 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 the uptake of NO_3-N was in Pond A noticeable lower and concentrations of NO_3-N noticeable higher. One third NO_2-N concentrations in Pond A and almost 60% NO_2-N concentrations in Pond B exceeded the legislation value of 0.01 mg NO_2-N/L. Mean NO_2-N concentrations were similar in Pond A compared to Pond B. Exceeded limit NO_2-N values in the ponds can be explained with the reduction of the nitrification processes in the summer season due to the lack of oxygen at nights, higher feeding load, high temperature and agricultural pollution. Vymazal (13) reported that nitrification processes will continue 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). At the time the threshold values in ponds were exceeded, groundwater was added to the pond to prevent fish mortality. Phosphate levels also differed markedly between the ponds. Mean TP in both ponds exceeded legislation limit of 0.4 mg/L. TP was lower in Pond A compared to Pond B probably due to sedimentation of planktonic algae by US. Also Chlorophyll *a* values were markedly lower in Pond A in comparison to Pond B showing efficiently reduction of alge by US. .

The comparison of measured parameters with legal requirements

Slovenian legislation only refers to 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, in single measurements in Pond B DO and pH values exceeded the legislation limit of 5 mg/L for DO and of 9 pH. In Pond A the mean values of DO and pH met the legislation requirements. 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 while in Pond A were below the limits. According to the legislation limits, the aquaponic system met the legislation requirements more often and consistently compared to Pond B.

Fish biomass

The experiment presented 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. However, 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 the experiment presented fish were overfed mostly due to quick hand feeding. The results showed that Pond B occasionally exceeded the threshold values regarding DO values in experimental period which never occurred in Pond A. Pond A was efficient at a stocking density of 0.5 - 1.3 kg fish/m^3, although a higher fish load could lead to conditions that threaten fish population regarding Jana (16) who found that carp are more sensitive to low levels of DO and high levels of ammonia than some other fish species (tilapia or catfishes) 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.

Conclusions

Aquaponic is a promising tool to support the sustainable aquaculture industry without excessive water demands and chemical use. The study evaluated the performance efficiency and fish production of the aquaponic system for small-scale cyprinid fish farms. Our hypothesis that combination of a lamellar settler (LS), a roughing filter (RF), a vertical constructed wetland (CW) and an ultrasound (US) device can restrain suspended solids as well as dissolved nutrients and counteract algae growth was partially confirmed. The results showed that the aquaponic system was efficient in removal of total suspended solids, biochemical oxygen demand, chemical oxygen demand, ammonium and total phosphorus, but the removal of nitrate and nitrite was not efficient. The majority of pollutant removal took place in the pre-treatment unit of 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 better rearing conditions. The aquaponic system presented could be useful for semi-natural fish farming with fish load of 0-5-1.3 kg/m^3. The system presented can be an efficient alternative chemical-free solution for the removal and inactivation of algal cells and the linked harmful potential in fish farms.

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References

(1) Gál, D., Szabó, P., Pekár, F., Váradi, L., 2003. Experiments on the nutrient removal and retention of a pond recirculation system. Hydrobiol. 506–509, 767–772.

(2) Graber, A., Junge, R., 2009. Aquaponic Systems: Nutrient recycling from fish wastewater by vegetable production. Desalination 246, 147-156.

(3) Wik, T.E.I., Linden, B.T., Wramner, P.I., 2009. Integrated dynamic aquaculture and wastewater treatment modelling for recirculating aquaculture systems. Aquac. 287, 361-370.

(4) Sindilariu, P.D., Brinker, A., Reiter, R., 2009. Factors influencing the efficiency of constructed wetlands used for the treatment of intensive trout farm effluent. Ecol. Eng. 35, 711-722.

(5) Brovelli, A., Malaguerra, F., Barry, D.A., 2009. Bioclogging in porous media: Model development and sensitivity to initial conditions. Environ. Model. Softw. 24, 511-25.

(6) American Public Health Association (APHA), American Water Works Association (AWWA), Water Environment Federation (WEF), 2005. Standard methods for the examination of water and wastewater, twenty-first ed. American Public Health Association, Washington, D.C.

(7) Wetzel, R.G., 2001. Limnology, Lake and River Ecosystems, third ed. Academic press, San Diego.

(8) UNESCO, 1969. Determinations of photosynthetic pigments in seawater, Rep. SCOR/UNESCO WG 17, UNESCO Monogr. Oceanogr. Methodol., 1, Paris.

(9) Chao, K.P., Chen, C.S., Wang, E.I.C., Su, Y.C., 2005. Aquacultural characteristics of *Rhizoclonium riparium* and an evaluation of its biomass growth potential. J. Appl. Phycol. 17, 67-73.

(10)Krivograd-Klemenčič, A., Toman, M.J., 2010. Influence of environmental variables on benthic algal associations from selected extreme environments in Slovenia in relation to the species identification. Period. Biol. 112, 179-191.

(11)Alam, A., Al-Hafedh, Y.S., 2006. Diurnal dynamics of water quality parameters in an aquaculture system based on recirculating green water technology. J. Appl. Sci. Environ. Mgt. 10, 19 – 21.

(12)Yang, L., Chou, L.S., Shieh, W.K., 2001. Biofilter treatment of aquaculture water for reuse applications. Water Res. 35, 3097-3108.

(13)Vymazal, J., 2001. Removal of Phosphorus in Constructed Wetlands with Horizontal Sub-Surface Flow in the Czech Republic. Water, air, soil pollut. 4, 657-670.

(14)Kalin, B., 1984. Ribogojstvo. ČZP Kmečki glas, Ljubljana. (in Slovene)

(15)Bravničar, D., 2003. Sladkovodno ribogojstvo, in: Janc, M., Šušteršič, M. (Eds.), Priročnik za gospodarje in čuvaje ribiških družin. Ribiška zveza Slovenije, Ljubljana, pp. 119-136. (in Slovene).

(16)Jana, B.B., 1998. Sewage-fed aquaculture: The Calcutta model. Ecol. Eng. 11, 73-85.