THE WASTE NUTRIENTS REUTILISATION CAPACITY OF COMBINED POND AQUACULTURE SYSTEMS

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Abstract

In the frame of the SustainAqua project two pilot scale experiments were implemented in order to investigate the potential of nutrient reusing capacity of integrated aquaculture: (1) combined intensive-extensive aquaculture system (IES) and (2) constructed wetland system (ACS). The IES was a combined pond fish production system operated in a close interaction of the intensive and extensive production units. The ACS was built for the water treatment of the effluents of an intensive flow-through African catfish production farm. Besides the water treatment the constructed wetland system was able to transform the waste nutrients into valuable by-products such as fish and energy plants. The aim of this study was to estimate the potential of nutrient recovery by additional production activities in combined systems.

Keyword: aquaculture, nutrient inputs, fish biomass

INTRODUCTION

Nutrient retention into fish biomass varies only between 20 and 30% of the introduced fish feed in various aquaculture practices (HARGRAVES, 1998; BRUNE et al., 2003). For the sustainability of aquaculture necessary steps needed to reduce the nutrient input. To make further sustainable increase of aquaculture production possible higher efficiency of nutrient conversion of input nutrients is needed.

In the frame of the SustainAqua project two pilot scale experiments were implemented in the HAKI in order to investigate the potential of nutrient reusing capacity of integrated aquaculture:

- combined intensive-extensive aquaculture system (IES),
- constructed wetland system (ACS).

The IES as a production system operated in a close interaction of the intensive and extensive production units. The fishponds could be an effective tool for water treatment since they are able to retain high amount of nutrients (KNÖSCHE et al., 2000; GÁL et al., 2008). The combination of the intensive fish production with extensive pond culture affords a possible solution for the improvement of the nutrient utilisation and for the diversification of fish species. The key element of the proper operation was the treatment capacity of the extensive unit; hence the investigations were focused on the periphyton application on the nutrient utilisation and water quality of the production system. The overall objective of the IES case study is helping for the traditional carp farmers to use their water more efficiently by producing valuable species in their reservoir or extensively used ponds in order to diversify their production and increase the economical performance of fish production.

The ACS was built for the water treatment of the effluents of an intensive flow-through African catfish production farm. Besides the water treatment the constructed wetland system was able to transform the waste nutrients into valuable by-products such as fish and energy plants. The aim of this study was to estimate the potential of nutrient recovery by additional production activities in combined systems. Constructed wetlands were applied firstly in environmental restoration preventing polluted inflow into protected wetlands, later for treatment of municipal and industrial waste waters. The utilisation of constructed wetlands for agricultural effluents and liquids has not a long tradition. Numerous constructed wetlands are reported for aquaculture waste treatment in North America (TILLEY et al., 2002.), and Europe (SCHULZ et al., 2003) Asia (LIN et al., 2005), however their application is not widespread. The objectives of the case study were to purify the intensive aquaculture effluent efficiently by retaining significant amounts of discharged nutrients and to use the wasted nutrients as resources for the production of economically valuable crop cultivation, which generates an additional income for the fish farmers.

MATERIAL AND METHODS

Combined intensive-extensive aquaculture system (IES)

The experiments of IES were carried out in three ponds (area 310m^2, depth 1m) served as extensive units, where to a cage was placed as an intensive unit (volume 10m^3) in each pond. The ponds were filled up with natural water from a river before a week of fish stocking. The water level was maintained by supplying river water regularly. A paddlewheel aerator (0.5 kW) was applied in the pond to provide sufficient oxygen concentration and maintain the water circulation between the intensive and extensive units (Figure 1).

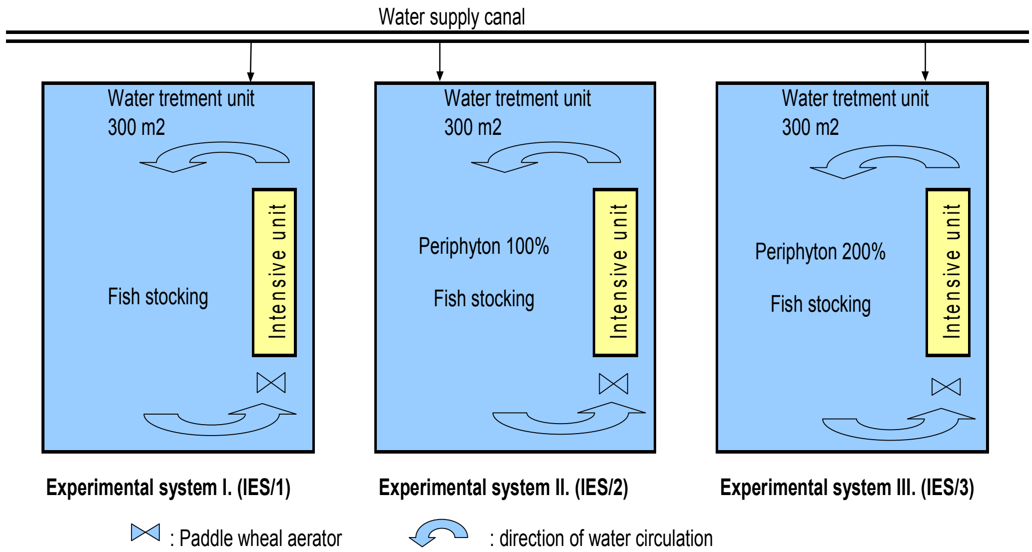

Fig. 1. Scheme of the IES experimental design

Three different setups of extensive ponds were studied: additional area for periphyton development equalled about 0, 100 and 200% of the pond surface area. Artificial plastic substrate was used for periphyton. The operation lasted 16 weeks from 21 May to 10 September of 2008. In the intensive units African catfish (*Clarias gariepinus*) were cultured and fed with pellet – initial stocking biomass was 200kg (20 kg/m^3) –, while 200kg common carp (*Cyprinus carpio*) and Nile tilapia (*Oreochromis niloticus*) were stocked in each extensive unit as well (in the ratio of 1:1) and were raised without any artificial feeding. All ponds were subjected to the same regime of feeding and fish stocking. A pelleted fish feed (45% crude protein, C:N ratio 6) was applied daily to the intensive ponds using an automatic feeder, but there was no feeding in the extensive fishponds. The only nutrient source of the system was the fish feed used in the intensive unit. The average feed loading was 0.9gN/m^2/day (maximum 1.8gN/m^2/day).

Constructed wetland system (ACS)

The African Catfish Site (ACS) is located at the Experimental Pond System of the Research Institute for Fisheries, Aquaculture and Irrigation (HAKI) in Szarvas, Hungary. The pilot-scale 1.1 ha (Subsystem 'A') and 0.4 ha (Subsystem 'B') wetland systems were constructed to treat effluent water of an intensive flow-through African catfish farm. The wetland systems were constructed by the combination of a stabilisation pond, a fishpond and macrophyte pond units. The ponds were filled up with stored freshwater originating from the nearby oxbow lake of River Körös at the beginning of the operation period (May in 2007, February in 2008).

The effluent from the African catfish farm was channelled into the aerated stabilisation pond, where a paddle wheel aerator was operated and supplemental river water was added. The water from the stabilisation pond was introduced into the fishpond unit, where a certain part of the nutrients was retained in fish biomass. The effluent from the fishpond unit was channelled into 4 surface-flow constructed wetlands planted with different energy plants: common reed (*Phragmites australis*), cattail (*Typha latifolia* and *T. angustifolia*), willow (*Salix viminalis*) and giant reed (*Arundo donax*). The scheme of this module is shown in Figure 2.
The calculated hydraulic retention time was 18 days in each wetland unit. The average water depth in the stabilisation and fishponds was 1.2 m, and 0.5 m in the macrophyte ponds. Fish were stocked in polyculture at a stocking density of 900 kg/ha: 35% common carp (*Cyprinus carpio*), 60% silver carp (*Hypophthalmichthys molitrix*) and 5% grass carp (*Ctenopharyngodon idella*) in April and May. This fish stocking composition was chosen to achieve the water treatment goals and to utilise the different natural food sources as effective as possible. There was no artificial feeding applied in fishponds. The fishponds were harvested in November, the water was drained and the bottom kept dry in winter (from November till February).
The effluent water of the African catfish farm is characterised by a high total dissolved solids content originating from the used geothermal water, and by high chemical oxygen demand (COD). The total nitrogen is composed of approximately 60% total ammonium nitrogen (TAN) and 40% organic nitrogen, other nitrogen forms were found in negligible amounts. The total phosphorus contained nearly 50% orthophosphate phosphorus, while the volatile suspended solids represented 90% of the total suspended solids (Table 1).

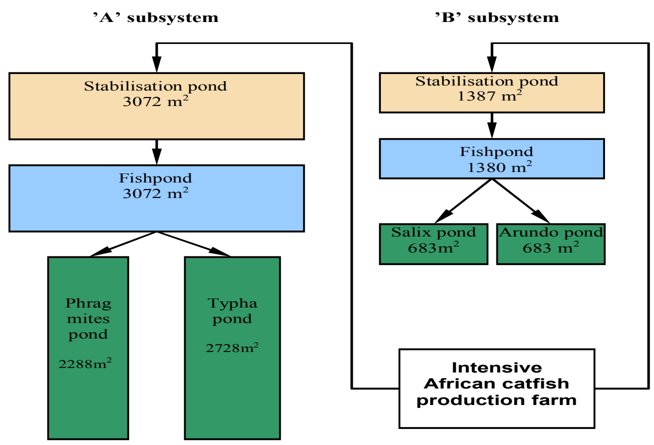

Fig. 2. Schematic picture of the ACS design

Table 1

Average values of the water chemistry parameters of the effluent water (n=38) (STD: standard deviation

Parameter	$C_{Effluent}$	**STD**
	mg/l	
Total dissolved solids	714	62.5
COD	200	89.0
TAN	18.7	5.84
Total organic N	11.6	11.8
Total N	29.7	11.4
Orthophosphate P	1.37	1.07
Total P	2.90	0.92
Volatile suspended solids	114	57.6

RESULTS AND DISCUSSION

Combined intensive-extensive aquaculture system (IES)

The fish yields and data of growth performances are summarised in Table 2. The growth rate (SGR 1.0%) and feed conversion (FCR 1.6%) were similar in all intensive units. There was no significant difference in the fish growth performances between the intensive units. Therefore the net fish yield of the whole system (intensive and extensive unit together) was the highest in those ponds, where the periphyton area was 100% of the pond surface.

Table 2

Fish growth performance in IES (SF: shellfish)

	IES/1	**IES/2**	**IES/3**
Intensive unit			
Stocked fish	African catfish	African catfish	African catfish
Stocked total weight	200 kg	200 kg	200 kg
Stocked avg. weight	612 g/ind	606 g/ind	618 g/ind
Added feed amount	613 kg	613 kg	613 kg
Average feeding rate	1.55%	1.57%	1.57%
Harvested total weight	613 kg	599 kg	600 kg
Harvested avg. weight	1890 g/ind	1872 g/ind	1916 g/ind
Specific growth rate	1.02%	1.00%	1.00%
Food conversion ratio	1.53	1.58	1.58
Mortality	2%	3%	5%
Net yield	13.2 t/ha	12.8 t/ha	12.8 t/ha
Extensive unit			
Stocking	C carp/Tilapia	C carp/Tilapia	C carp/Tilapia
Stocked total weight	100 kg/100 kg	100 kg/100 kg	100 kg/100 kg
Stocked avg. weight	140/500 g/ind	140/500 g/ind	140/500 g/ind
Feeding rate	no feeding	no feeding	no feeding
Harvested total weight	173/115 kg	206/152 kg	163/122 kg
Net yield	2.79 t/ha	5.05 t/ha	2.72 t/ha
Combined			
Food conversion ratio	0.90	0.83	0.92
Gross yield	28.9 t/ha	30.7 t/ha	28.4 t/ha
Net yield	16.0 t/ha	17.8 t/ha	15.5 t/ha

The total nutrient inputs (stocked fish, inlet water, fish feed) and outputs (harvested fish and drainage water) are summarised in Table 3. The main nutrient source was the fish feed, which represented 80% of the total input of nitrogen, 75% of phosphorus and 85% of carbon. The nutrient retention was 6,300 kg/ha for organic carbon, 1,000 kg/ha for nitrogen and 180 kg/ha for phosphorus. The retained nutrients represented 57% of the nitrogen and 58% of the phosphorus and 64% of the organic carbon introduced into the system in average. The combined system was able to process 1,400 kg/ha of fish feed-origin nitrogen.

Table 3

Partial nutrient budget of the IES

	IES/1			**IES/2**			**IES/3**		
	N	**P**	**C**	**N**	**P**	**C**	**N**	**P**	**C**
Input (kg/ha)	1790	310	9700	1800	320	9700	1800	310	9700
Output (kg/ha)	760	130	3100	840	140	3900	720	130	3200
Retention (%)	58	60	67	53	55	59	60	60	67

The nutrient utilisation of fish production in IES expressed in the percentage of the total introduced nutrients is summarised in Table 4. There were only negligible differences in the nutrient accumulation between the intensive units. The nutrient reuse by the additional fish production in the extensive unit was the highest where the periphyton area was 100% of the pond surface. The combined fish production resulted in higher protein utilisation by 26%; with periphyton application this ratio can be increased by 40%. This indicates that the 100% periphyton ratio was sufficient to utilise the metabolites of the feed loading of 1.8 g N/m^2/day. The average FCR was 1.5 in the intensive unit. By the combined production the FCR was improved by 44% (to 1.6 and 0.9) due to the additional fish yield of the extensive unit.

Table 4

Nutrient accumulation in fish biomass in the percentage of the total input (%)

	PA 0%			PA 100%			PA 200%		
	N	P	C	N	P	C	N	P	C
Intensive	23	23	16	22	22	15	22	22	15
Extensive	6.1	3.3	4.4	10	8.9	7.3	5.9	3.3	4.2
Total	29	26	20	33	31	22	28	25	19

PA: Periphyton area

Between the treatments there were no significant differences in the measured water quality parameters ($p>0.05$). The water quality parameters are summarised in Table 5.

Table 5

Water quality of the IES in mg/l

	IES/1	IES/2	IES/3
TAN	0.322±0.235	0.207±0.323	0.087±0.057
NO_2-N	0.464±0.570	0.189±0263	0.135±0.200
NO_3-N	1.45±1.86	1.65±2.09	1.66±2.12
Total inorganic N	2.23±2.35	2.05±2.33	1.88±2.24
Total N	5.62±3.48	7.71±4.84	6.57±4.03
PO_4-P	0.116±0.184	0.218±0.362	0.248±0.472
Total P	0.510±0.156	0.748±0.278	0.619±0.345
COD	89.0±40.4	128±84.0	95.0±77.0
Chlorophyll-a	506±224	752±510	426±232

From the experimental ponds 2.6-5.8 g nitrogen, 0.20-0.53 g phosphorus and 16-46 g organic carbon were discharged during the production of 1 kg fish biomass. There was no effect of the periphyton application and feed loading on the nutrient content of effluents. Only the nitrogen concentration was lower in the effluent in case of 200% periphyton ratio.

In the operation of water treatment systems besides algae nutrient uptake and bacterial decomposition, consumption of heterotrophic organisms and denitrification processes have a significant role. Hence, the regulation of oxygen regime, to provide aerobic condition by artificial aeration is important for the efficient nutrient removal during water treatment.

The pilot scale experimental combination of an intensive fish production unit and an extensive fishpond proved the applicability of such systems. The combined system could process a significant part of surplus nutrients from the intensive fish production. The efficiency of the extensive unit was improved by periphyton developed on artificial substrates, as the periphyton can provide special foods for fish. The dry matter content of periphyton developed on different layers was significantly higher in the samples, which were collected from the top parts of poles than samples were taken from lower parts. Comparing the annual average amounts of periphyton dry matter, there was no significant difference between the ponds. However, the higher amount of periphyton consumption by fish resulted in a higher fish yield in the extensive unit. By following the quantitative and qualitative changes of the periphyton, we get more detailed knowledge on functioning of the system, nutrient cycling and energy flow in the aquatic ecosystem and possibilities of increasing the system efficiency, which can then be applied to the operation and further development of the technology.

Investigations on the nutrient budget of the system demonstrated that an adequate size of the extensive fish pond could treat the effluent from intensive fish culture efficiently and make possible the reuse of water for intensive fish production. Results proved that combination of intensive and extensive fish farming systems is an efficient tool to reduce environmental pollution of intensive fish farming and to increase extensive fish production as co-product. The general fish yields are around 1 t/ha in traditional ponds, but in combined systems it can be increased up to 20 t/ha. However, the nutrient discharge from the traditional fishponds is very low because of the improved nutrient utilisation efficiency.

Constructed wetland system (ACS)

The total nitrogen output was amounted to 116 kg during the operational period in 2008, which corresponded to 0.48 kg/day discharge of the whole treatment system. In the output water less than 6% of the nitrogen amount was detected than in the input water sources. The total phosphorus output was 37.1 kg and the daily discharge was 0.15 kg, in the output water 16% of the input phosphorus amount was found. The total organic carbon output was 4,812 kg during the operation corresponding to 19.7 kg daily output. In the output water, less than 5% of the total organic carbon input was detected (Table 6).

Table 6

Nutrient input, output and the nutrient removal of the pond units in ACS (in brackets: removal calculated for the pond input)

	N			P			C		
Unit	**Input**	**Output**	**Removal**	**Input**	**Output**	**Removal**	**Input**	**Output**	**Removal**
	kg	kg	%	kg	kg	%	kg	kg	%
A_ST	1 352	865	36.0	152	95.9	37.0	2 646	1 304	50.7
A_FI	865	376	36.1 (56.5)	95.9	48.0	31.5 (49.9)	1 304	1 143	6.07 (12.3)
A_PH	184	41.9	10.5 (77.3)	23.7	15.5	5.36 (34.4)	562	161	15.2 (71.4)
A_TY	198	37.1	11.9 (81.2)	23.3	14.7	5.66 (36.9)	522	166	13.4 (68.1)
A_Total	**1 352**	**79.0**	**94.2**	**152**	**30.2**	**80.1**	**2 646**	**327**	**87.6**
B_ST	717	361	49.6	78.9	40.4	48.7	1 351	554	59.0
B_FI	361	184	24.7 (49.0)	40.4	19.3	26.7 (52.2)	554	503	3.78 (9.22)
B_SA	88.3	17.3	9.90 (80.4)	9.21	2.96	7.93 (67.9)	238	68.3	12.5 (71.3)
B_AR	99.0	19.5	11.1 (80.3)	9.78	3.97	7.36 (59.4)	257	80.1	13.1 (68.8)
B_Total	**717**	**36.8**	**94.9**	**78.9**	**6.93**	**91.2**	**1 351**	**148**	**89.0**
Total	**2 069**	**116**	**94.4**	**231**	**37.1**	**83.9**	**3 997**	**475**	**88.1**

(A_ST : A subsystem stabilisation pond, A_FP: A subsystem fishpond, A_PH: A subsystem *Phragmites* pond, A_ TY: A subsystem *Typha* pond, B_ST: B subsystem stabilisation pond, B_FP: B subsystem fishpond, B_SA: B subsystem *Salix* pond, B_AR: B subsystem *Arundo* pond)

The nutrient removal capacity of the wetland system was 1,300, 180 and 3,000kg ha/year for nitrogen, phosphorus and organic carbon, respectively. The efficiency of water treatment exceeded the 90% removal rate for nitrogen and organic carbon, and 84% was found for phosphorus. On average, 4% of the total input of nitrogen and 6% of the phosphorus input were reutilised in the by-products (including fish and plants as well; Table 7). The wetland plant species (*Phragmites* and *Typha*) resulted in higher nutrient accumulation, while low growth rate was characteristic for the terrestric *Salix* and *Arundo*.

Table 7

The potentiality of the nutrient accumulation in different by-products (%)

	Nitrogen	Phosphorus	Organic carbon
Fish	0.8	1.4	1.9
Phragmites australis	1.7	1.9	n.c.*
Typha sp.	3.2	7.1	n.c.*
Salix viminalis	0.7	0.5	n.c.*
Arundo donax	0.2	0.2	n.c.*

* no calculation because of the non accounted atmospheric CO_2 uptake of the plants

Based on the data of a temperature-dependent loading experiment in 2008, the retention capacities were calculated for 5 ºC intervals. The nitrogen removal showed the highest sensitivity, and the COD removal also improved when the water temperature increased. The phosphorus retention and volatilise suspended solids (VSS) removal were more efficient only in the highest temperature range (Table 8). During the planning of the system, the lowest removal efficiency should be considered, and the sizing of the area of different wetland types is recommended to be done with parallel pond units, which can be attached or detached depending on the necessity.

Table 8

The specific removal of the constructed wetland system at different temperature intervals

Water temperature interval	N removal	P removal	VSS removal	COD removal
	kg/ha/day			
10-15 ºC	2.96	0.36	19.48	18.99
15-20 ºC	5.71	0.37	18.68	30.92
20-25 ºC	7.41	0.75	37.66	44.46

The operation of the constructed wetland system was characterized by effective nutrient removal efficiency, positive energy budget and possibilities for diversification of income sources. The application of the examined treatment system decreased the amount of discharged nutrients of the intensive aquaculture by 1,300 kg N/ha, 130 kg P/ha and 7,500 kg COD/ha. The ecological sustainability was enhanced by the production of 40,900 kg plant biomass; as potential renewable energy source. It could offset the burning of fossil gas, the savings of CO_2 emission would be 11,250 kg yearly.

CONCLUSIONS

Results of the study proved that combination of intensive aquaculture with extensive fishponds enhances the nutrient utilisation efficiency and fish production in IES. The combined fish production resulted in higher protein utilisation by 26%; even this ratio can be increased by 40% with periphyton application. The operation of the constructed wetland system was characterized by effective nutrient removal efficiency and additional revenue possibilities. Besides the adequate treatment capacity the constructed wetlands have a remarkable potential in energy crop production, as well.

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