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Impacts of magnetic water treatment on water quality, feeding efficiency and growth performance of common carp in integrated recirculating aquaculture systems

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ABSTRACT

An integrated recirculating aquaculture system (IRAS) is considered as an alternative solution for efficient utilization of available resources, nutrient recycling and maintaining ecological balance. The effects of using magnetized water on the growth performance of common carp (*Cyprinus carpio* L.) and water quality parameters were investigated in an IRAS. Six independent IRASs were designed; each system consisted of three tanks: a fish rearing tank, a waste-collection tank and a biological filter tank. An additional crop of macrophyte (*Lemna minor*) was used as a medium in the biological filter tanks in order to qualify as an IRAS. Two treatments with three replicates were set up in a randomized design. The experimental treatment was supplied with the magnetic field device, while there was no device in the control treatment. The fish growth, feeding efficiency and water quality parameters were measured in all systems. The results revealed that the use of magnetized water in the IRASs increased the specific growth rate of common carp and the growth rate of plants; while, decreased the feed conversion ratio. However, the magnetized water had no effects on the concentrations of ammonium nitrogen, nitrite nitrogen and nitrate nitrogen. The study suggested that the use of magnetized water in the IRASs could be beneficial as a cost-effective technique to increase the profitability of the system.

Keywords: common carp, growth, magnetic fields, magnetized water, water quality

INTRODUCTION

Recirculating aquaculture systems (RASs) offer many benefits in terms of reducing water requirements, nutrient recycling, improving waste management and better disease management (Timmons et al., 2002). The research and developments in the RASs tend to focus on: (1) technical improvements within the recirculation loop and (2) recycling of nutrients through integrated farming (Martins et al., 2010). Production systems that use plants to remove nutrients from wastewater have a promising future as an alternative technology for converting nutrients into valuable products and preventing nutrient overload in the environment (Schneider et al., 2005; Martins et al., 2010).

Recently, magnetized water is used successfully for improving water properties in different sectors such as farming and agriculture, wastewater treatment and scale elimination (Ali et al., 2014). Cai et al. (2009) reported that the magnetic field changes the physicochemical properties of water, and results in decreasing the surface tension and increasing the viscosity of water. Ali et al. (2014) stated that magnetized water improved irrigation water quality, water saving, and scale elimination. The positive effect of magnetized water also reported on the germination rates of the rice (Carbonell et al., 2000) and lettuce seeds (Reina and Pascual, 2001).

Moreover, it was shown that the magnetic field reorganizes the water molecules into tiny and homogeneous clusters easing their travel through the pathways in plant and animal cell membranes (Ali et al., 2014). Magnetic fields change osmotic processes, affect the permeability of the cellular membrane, and disturb the hydration ability of tissues in animals (Ibraheim and Khater, 2013) and plants (Reina and Pascual, 2001). Ali et al. (2014) reported that magnetized water improved the health of livestock as well as plant growth and crop yield.

Although the applications of magnetic water treatment have been successfully used in different fields, limited investigations have been done in aquaculture on different species. Some authors reported that the magnetic water treatment had positive effects on fish growth (Hassan et al., 2018a; Nofouzi et al., 2017), and water quality of the systems (Krzemieniewski et al., 2003; Hassan and Rahman, 2016; Hassan et al., 2018b). However, other authors revealed no effect of using the magnetic water treatment on fish growth (Krzemieniewski et al., 2004; Hassan et al., 2019), and water quality (Krzemieniewski et al., 2004; Hassan et al., 2019). It appears that there is still considerable debate regarding the effects of magnetic water treatment on the growth of cultured species and water quality of rearing systems. Besides that, there are currently no publications regarding the impacts of magnetic water treatment on common carp growth in an integrated recirculating aquaculture system. Therefore, the purpose of the present study was to evaluate the effects of using electromagnetic field (EMF) on water quality parameters, feed utilization efficiency and growth performance of common carp in an integrated recirculating aquaculture system (IRAS).

MATERIALS AND METHODS

Experimental systems

The experimental system was performed according to the prototype published by (Irhayyim and Fotedar, 2019; Ardiansyah and Fotedar, 2016). In brief, the trial comprised six independent experimental systems: each system consisted of three tanks: a rearing fish tank, a waste-collection tank and a biological filter tank. All three tanks were joined and operated under the theory of an IRAS. Water from the waste collection tank was pumped through a plastic tube to the biological filter tank by a submerged pump (RESUN, Model: P-1500, Guangdong Risheng Group Co. Ltd., China) and water from the biological filter tank was then circulated to the fish tank by gravity. Water from the bottom of the fish tank was drained back through a PVC pipe to the waste-collection tank (Figure 1). The volumes of water in the waste-collection and fish rearing tanks were kept at 36 and 55 litres respectively, while the volume of water in the biological filter tanks was kept at 60 litres. The rearing fish tanks were provided with one air stone and covered with a polyethylene mesh (1.0–1.5 cm in diameter) to prevent fish from jumping outside. The biological filter tanks were also aerated with one air stone. The light was provided by snow LED light bulbs (Aalite, 1430 lumen, E27, 15W, 3000 Kelvin; Monoki Péter E.V., Debrecen, Hungary), which were set on timers to a 12 h light: 12 h dark.

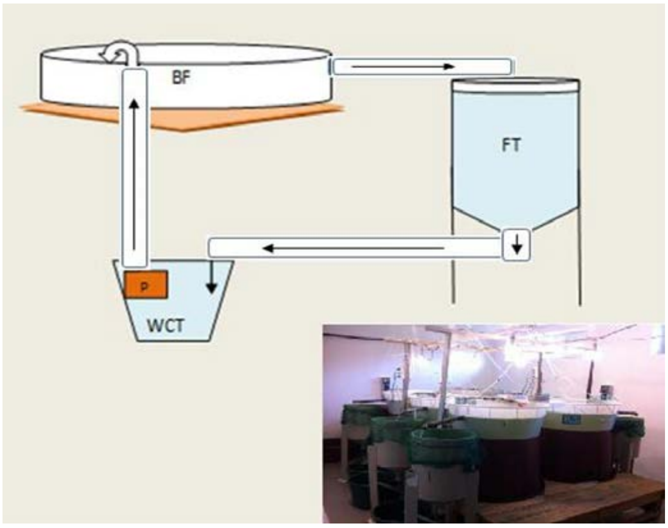

Figure 1. Diagram of experimental units (arrows show the direction of water flow), (FT): Fish tank (WCT): Waste collection tank, (BF): Biological filter, (P): Pump

Experimental biological filters

Six combined biological filters with the same surface area of 0.41 m^2 were designed to be used in this experiment. In order to qualify as an IRAS, each biological filter contains 0.0015 m^3 of plastic media and 70 g of duckweed (*Lemna minor*) as a biofilter medium (Figure 2).

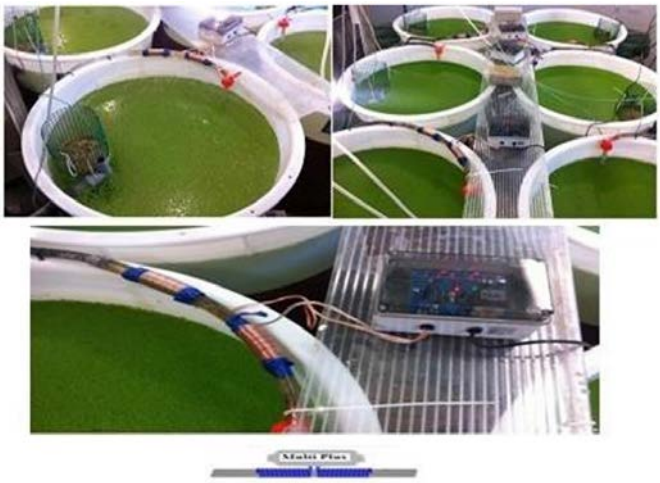

Figure 2. Magnetic field generator and the biological filters used in the experimental units

The plastic media in the form of bio-balls and a specific surface area of 400 m^2/m^3 were used to place in the biofilter tanks. The plastic media with established biofilms were obtained from an operating recirculating system in Georgikon Aquatic Research Laboratory (GARL), Keszthely, Hungary.

The duckweed (*L. minor*) plant was also chosen because of its potential to convert nutrients into useful products as well as it has rapid growth and simplicity of harvest. The plants were obtained from the aquatic research laboratory of Debrecen University, Hungary. The plants were cleaned and put in a stock tank for two weeks as an acclimatization period until the start of the trial.

Experimental fish

Common carp (*Cyprinus carpio* L.) were originated from natural reproduction in a pond at H & H Carpio fish farming Ltd., Ócsárd, Baranya, Hungary. A total number of 72 common carp with an average weight of 10.59 ± 0.06 g were collected from the same stock pond and transported to GARL, Keszthely, Hungary. The experimental IRASs were operated with fish for 7 days before the commencement to acclimate fish to the experimental conditions. Fish were fed a commercially extruded feed that declared by the manufactured company as, Nutra MP (50% crude protein, 18% crude fat, 1% crude fibre, 11% crude ash, 0.5% Na, 2% Ca and 1.5% P) (Skretting a Nutreco Co., Mozzecane, Italy).

Experimental design and rearing conditions

The trial was conducted over 28 days in GARL and designed as two treatments with three replicates in a random arrangement. The first treatment was supplied with a magnetic field device, which was placed before the biofilter tank, while the control treatment was set up without the device. The Electromagnetic field (EMF) was generated in a coil by currents using a commercial magnetic field generator with a frequency of 25 kilohertz (kHz) and an intensity of 0.8 millitesla (mT) (Magnetic Field Generator Multi Plus; manufactured by IVT Innovative Versorgungs-Technik GmbH, Hirschau, Germany) (Figure 2).

Fish were initially stocked at a density of 12 fish per tank (mean biomass: 127 g per tank, equal to 2.3 kg/m^3). All fish were fed by hands twice a day at 09:00 and 16:00 hours with a commercial diet (pellet size 1.5 mm) and the feeding rate was 3.5% of body weight per day. The uneaten feed was collected one hour after feeding, while faeces were removed daily before the feeding commenced through a filter net with a mesh size of 100 µm and the remaining water returned back into the waste-collection tank of the same experimental unit. The water flow rate was set at 3 litres per minute, and approximately 30% of the system water was siphoned out weekly and replaced with new water. Every four days, 20% of the surface area of the duckweed biofilter was harvested from each system and the weight of the harvested plants was recorded.

Sample collection and analysis

Dissolved oxygen (DO), temperature and pH of water in the fish tanks were measured once a day before feeding commenced. Dissolved oxygen and temperature were measured by using the OxyGuard Handy Polaris meter (OxyGuard International A/S, Denmark), while pH was measured by using the Milwaukee MW100 meter (Milwaukee Instruments, Romania). The concentrations of ammonium nitrogen (NH_4-N), nitrite nitrogen (NO_2-N) and nitrate nitrogen (NO_3-N) in all fish tanks were measured weekly using a Lovibond photometer Multi Direct (Tintometer Group, Germany), following the methods in the instruction manual.

Survival and growth rates of the fish were recorded at the end of the trial for each tank. Specific growth rates (SGR), fish weight gain (WG), feed conversion ratio (FCR) and survival rates were calculated using the following formulas:

$$SGR\ (\%/day) = 100 \times (lnW_f - lnW_i)/t$$

$$WG = W_f - W_i$$

$$FCR = WF\ (g) / WG\ (g)$$

$$Survival\ rate\ (\%): S = 100 \times (n_f / n_i)$$

where W_f and W_i are the weight of fish at the end and the start of the trial respectively, while (t) is the number of rearing days. The WF is the weight of feed given to the fish (g) and WG is the weight gain (g). The n_f and n_i are the number of fish at the end and the start of the trial respectively.

At the end of the experiment, the plants were harvested from the biofilter tanks and the weight of plants was recorded. The final biomass and specific growth rates of plants (SGR) were calculated using the equations:

Final biomass of plants = Biomass of plants in biofilter tank at the end of the trial (g) + harvested biomass throughout the trial (g)

$$SGR\ of\ plant\ (\%/day) = 100 \times (lnB_f - lnB_i)/t;$$

where: B_f and B_i are the final biomass of the plant and the initial stocked biomass respectively, while (t) is the number of rearing days.

Statistical analyses

All statistical analyses were performed using the SPSS version 22.0 for Windows package. All of the data obtained were tested for normality of distribution and homogeneity of variance. The independent t-test was conducted to determine any significant differences between treatment means, and the Mann-Whitney test was used to test the differences if the data did not have a normal distribution or homogeneous variance. The 5% level of probability was considered to be the significance level.

RESULTS AND DISCUSSION

Plant growth performance

The results indicated that the SGR of plants in the electromagnetic field systems of 0.8 mT and 25 kHz was significantly higher (P<0.05) than in the control systems (Table 1). Previous studies revealed that the exposure of plants to continuous electromagnetic field induces different biological responses such as changes in enzyme activity, growth rate and gene expression (Vian et al., 2016; Tkalec et al., 2005). The results obtained in this study are comparable with the results of Yaycili and Alikamanoglu (2005), who found that the weight, length, number of leaves and chlorophyll content of *Paulownia tomentosa* and *Paulownia fortune* were positively affected by the magnetic field. The positive effect of the magnetic field also reported on the germination rates of the rice (Carbonell et al., 2000) and lettuce seeds (Reina and Pascual, 2001) exposed to the magnetic field. One explanation suggests that the ionic currents in the plant cell membrane can interact with the magnetic field, and this can change the ionic concentrations and osmotic pressure of the plant membrane which helps to regulate the water flow into the cell (Reina and Pascual, 2001). In contrast to the results obtained in this study, Tkalec et al. (2005) found the growth of duckweed (*Lemna minor*) significantly decreased after the exposure to the electromagnetic field of 900000 kHz. The low frequency (25 kHz) used in the present study could be one of the explanations for the higher SGR of the plants compared to the results by Tkalec et al. (2005), who concluded that the effects of electromagnetic fields vary between different plants species according to the frequencies applied and field strength.

Water quality parameters in fish tanks

There were no significant differences (P>0.05) in the means of DO, pH and temperature between the treatments over the entire period of the study (Table 2). The temperature, pH and DO concentrations in the fish tanks of all systems remained within the tolerance range for common carp growth and survival (Horváth et al., 2002).

Table 1. Growth of *Lemna minor* under the exposure of electromagnetic field in an integrated recirculating aquaculture system

	EMF	Control
Initial plant biomass (g per biofilter tank)	70±0.00[a]	70±0.00[a]
Final plant biomass (g per biofilter tank)	709.060±4.287[a]	612.483±11.41[b]
Plant biomass gain (g per biofilter tank)	639.060±4.29[a]	542.483±11.41[b]
SGR of plant (%/day)	8.27±0.021[a]	7.74±0.065[b]

Values (means ± SE) having the same superscript letters are not significantly different

EMF: electromagnetic field system

However, DO in both treatments showed a slight decline as the trial progressed from 8.40 to 7.61 mg/L, and this could be related to an increase in the total biomass of fish and a consequent rise in the oxygen consumption rates (Jørgensen et al., 1993). The pH values remained relatively constant (ranged from 7.2 to 7.4), and did not change in any of the systems during the study period. Cahill et al. (2010) suggested that a lack of change in pH between systems may be attributed to the systems being maintained under good aeration. Water temperature in the fish tanks was around the average of 24°C, which is within the optimum temperature of common carp foraging and growth (24 and 28 °C) reported by Oyugi, et al. (2012).

The overall means of NH_4-N, NO_2-N and NO_3-N concentrations in fish tanks did not differ significantly (P>0.05) between the electromagnetic field system and the control system (Table 2). The results of the present study are comparable with the findings of various authors (Krzemieniewski et al., 2004; Hassan et al., 2018a; Hassan et al., 2019) who found no changes in ammonium concentrations between the magnetic field system and the control system. However, the results of this study were in contrast with the findings obtained by Hassan and Rahman (2016), and Hassan et al. (2018b) who found a reduction in the ammonium concentrations of the magnetic treatments. The different findings could be related to the exposure time and/or lower magnetic intensity (0.8 mT) used in this study, compared to those (100-200 mT) used by Hassan and Rahman (2016), and Hassan et al. (2018b). Tang et al. (2015) reported that the effect of the magnetic field is influenced by the exposure duration, field intensity and sensitivity of different species. Hassan et al. (2018a) suggested that the ammonium concentration in water from fish tanks could be reduced by increasing the magnetic intensity from 100 to 200 mT.

Table 2. Overall mean water quality parameters in the electromagnetic field and control systems

	EMF	Control
NH_4-N (mg/L)	0.351±0.011[a]	0.379±0.008[a]
NO_2-N (mg/L)	0.148±0.046[a]	0.149±0.050[a]
NO_3-N (mg/L)	5.88±0.90[a]	6.69±1.01[a]
DO (mg/L)	7.97±0.066[a]	7.96±0.070[a]
pH	7.28±0.021[a]	7.29±0.020[a]
Temperature (°C)	23.97±0.28[a]	23.94±0.28[a]

Values (means ± SE) having the same superscript letters are not significantly different

EMF: electromagnetic field system

The concentrations of NH_4-N, NO_2-N and NO_3-N in the fish tanks of both treatments were maintained at the levels recommended for common carp aquaculture (Horváth et al., 2002; Timmons et al., 2002), and this was due to the functions of different mechanisms to convert nutrients such as nitrification process and plants uptake. The means NH_4-N in both systems increased during the first 2 weeks and decreased after that (Figure 3). The decreasing trend in the NH_4-N concentrations in the later stages of the experiment could be related to the increase in the growth rate of plants, since the potential rate of nutrient uptake by plants is limited by their growth rate (Vymazal, 2007). Another explanation for this decreasing trend could be due to the increase in the number of nitrifying bacteria (*Nitrosomonas*) in response to the rise in ammonia concentrations as a consequence of increasing fish biomass (Brazil, 2006). The mean NO_2-N in both systems remained relatively constant during the course of the experiment (Figure 4). This may be attributed to the second step of the nitrification process and the increase in the number of nitrite-oxidizing bacteria (*Nitrobacter*) (Timmons et al., 2002).

In the same line, the mean NO_3-N in both systems increased in the first week and decreased thereafter (Figure 5). The decreasing trend may provide further evidence that ammonium and nitrate are directly taken up from the water culture by macrophytes as a nitrogen source and are incorporated into the plant biomass (Fang et al., 2007).

Growth and survival rates of fish

The magnetized water had significant effects ($P<0.05$) on the SGR and weight gain of common carp compared to the control system (Table 3). The lowest mean of FCR was also recorded with the fish reared in the electromagnetic field system, which was a significant difference ($P<0.05$) than the control system (Table 3). The differences in growth performance of fish in the present study are more likely to be related to differences in the food consumption and feed utilization efficiency by fish; because the best FCR in this study was achieved at the magnetic field group (Table 3). Previous studies revealed that the magnetic field has the ability to change the surface tension, density, viscosity, hardness and conductivity of water as well as the solubility of solid matter; and these changes in water properties can affect the biological activities of the organisms (Gabrielli et al., 2001; Krzemieniewski et al., 2003; Krzemieniewski et al., 2004). The additional magnetic field can bring effect to the living organisms namely the magnetic biologic effect, which is related to biomass metabolism, enzyme activity, and cell membrane permeability (Liu et al., 2008). In all animals, there is no common mechanism has been implicated regarding the effect of the magnetic field on the growth performance of the animals. Brizhik (2014) suggested that the magnetic field can cause a hierarchy of modifications from the primary effect on the dynamics of electrosolitons, to the modifications of the macromolecules state, to the effects on the respiration rate and, finally, to the effect on the whole metabolism of the system. Another mechanism reported by Rodriguez et al. (2002) in the dairy cattle, is related to the increase in the level of insulin-like growth factor-I that plays an essential function in the regulation of growth hormone actions in every cell in the body.

Although there are no published studies about the effect of magnetized water on common carp growth, the results of the current study were in agreement with the findings obtained by Hassan et al. (2018a) with red hybrid tilapia (*Oreochromis* sp.) in RAS and Nofouzi et al. (2017) with rainbow trout (*Oncorhynchus mykiss*). However, the results were in contrast with the findings obtained by Krzemieniewski et al. (2004) who found no significant difference between the growth of European sheatfish *Silurus glanis* L. larvae reared in the system modified by the constant magnetic field and the control group. In the present study, the SGRs of 1.82 and 1.61%/day were calculated for common carp reared in the electromagnetic field and the control systems respectively, which are lower than those (6.22-6.32%/day) achieved by Hassan et al. (2018a) for red hybrid tilapia (*Oreochromis* sp.) reared in a RAS under the exposure of different magnetic field intensities. The lower SGR was probably due to the higher initial stocking rate (2.3 kg/m^3) and/or the lower magnetic intensity (0.8 mT) used in the present study compared to those (0.213 kg/m^3 and 100-200 mT) used by Hassan et al. (2018a). However, the SGRs of fish in the present study were higher than the 1.28-1.52%/day reported by Nofouzi et al. (2017) for rainbow trout (*Oncorhynchus mykiss*) and the 1.60%/day obtained by Hassan et al. (2019) for Jade Perch *Scortum barcoo* juveniles reared in a RAS under the exposure of different magnetic field intensities. Furthermore, the SGR of fish in the present study was also higher than the 1.03-1.06%/day and 0.9-1.21%/day reported for common carp reared in the RASs without magnetic treatment by Karakatsouli et al. (2010) and Velichkova and Sirakov (2013) respectively.

In the present study, no fish mortality was recorded in both treatments (Table 3), and this could be related to the low magnetic intensity used. Moreover, the stocking density of fish was probably below the carrying capacity of these systems and did not reach the threshold at which survival rates would be affected. The survival rates of fish in the present study (100%) were higher than the 80.9% survival rate reported by Krzemieniewski et al. (2004) for the larval of European sheatfish Silurus glanis treated with the magnetized water in a RAS and the 88.89-95.83%

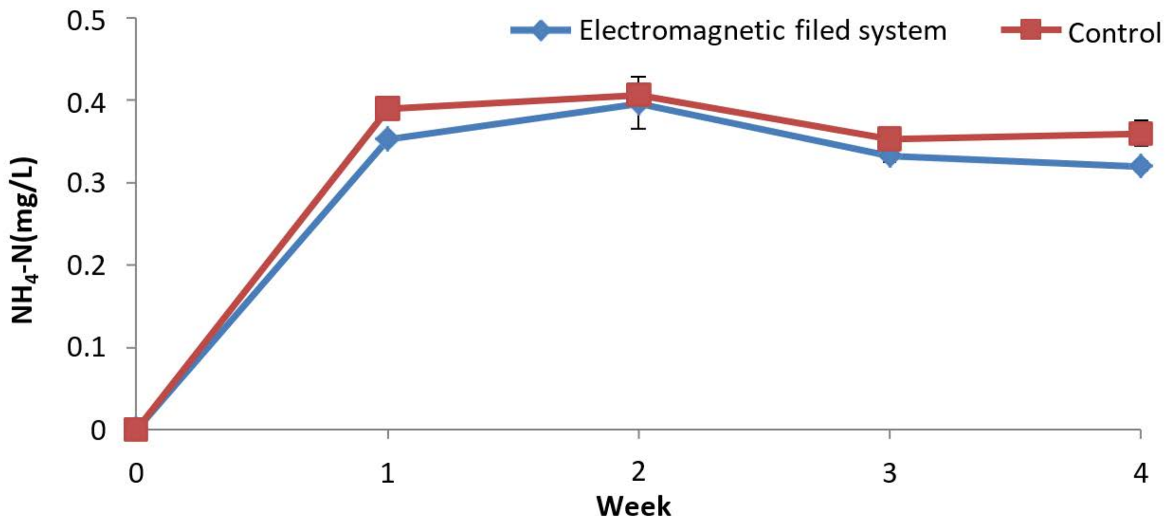

Figure 3. Weekly mean concentrations of ammonium nitrogen in fish tanks under the exposure of electromagnetic filed (error bars indicate the standard error)

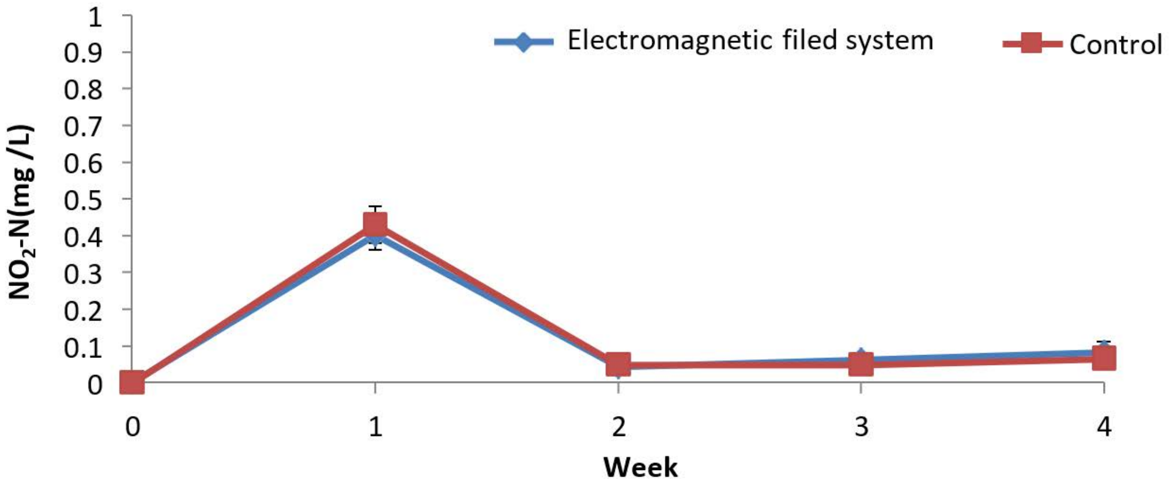

Figure 4. Weekly mean concentrations of nitrite nitrogen in fish tanks under the exposure of electromagnetic filed (error bars indicate the standard error)

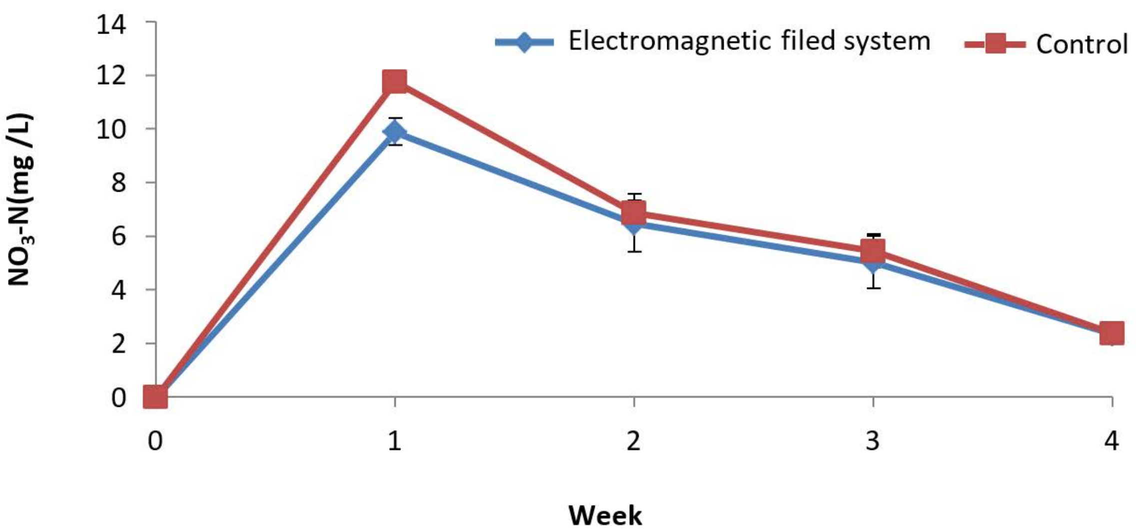

Figure 5. Weekly mean concentrations of nitrate nitrogen in fish tanks under the exposure of electromagnetic filed (error bars indicate the standard error)

Table 3. Growth, feeding efficiency and survival rates of *Cyprinus carpio* L. under the exposure of electromagnetic field in an integrated recirculating aquaculture system

	EMF	Control
Mean stocked fish biomass per tank (g)	125.37±0.363[a]	128.166± 1.026[a]
Number of fish per tank	12	12
Mean initial weight of fish (g)	10.44±0.030[a]	10.68±0.084[a]
Mean final fish biomass per tank (g)	209.223± 1.88[a]	201.413± 0.69[b]
Number of surviving fish	12	12
Mean final weight of fish (g)	17.44±0.15[a]	16.78±0.058[b]
Biomass gain per tank (g)	83.85± 2.04[a]	73.24±0.98[b]
Mean fish weight gain (g/fish/28 days)	7.00±0.17[a]	6.10±0.08[b]
SGR (%/day)	1.82±0.037[a]	1.61±0.026[b]
Feed consumption (g/fish/28days)	10.24±0.03[a]	10.46±0.08[a]
FCR	1.46±0.037[b]	1.71±0.034[a]
Survival rate (%)	100±0.00[a]	100±0.00[a]

Values (means ± SE) having the same superscript letters are not significantly different

EMF: electromagnetic field system

Table 4. Economic analysis of different production techniques (for five m^2 area of the biofilter and five m^3 water volume of the fish tank)

	EMF	Control
	IRAS with EMF	IRAS
Investment cost:	All other investments are same	
The price of the device (Euro)	86.38	0.00
Operation cost:	All other costs are same	
Initial stocking density of fish (kg/5 m^3)	11.40	11.65
Cost of fish (Farm gate price=1.91 Euro/kg)	21.77	22.25
Initial plant biomass (g/5 m^2)	853.66	853.66
Cost of plants (1 Euro for each 40 g of plants)	21.34	21.34
Operation cost for the magnetic device (Euro)	0.50	0.00
Total cost of the system (Euro)	**43.61**	**43.60**
Cash flow:		
Final stocking density of fish (kg/5 m^3)	19.02	18.31
sale of fish (Farm gate price=1.91 Euro/kg)	36.33	34.97
Final plant biomass (g/5 m^2)	8647.07	7469.30
sale of plants (1 Euro for each 40 g of plants)	216.18	186.73
Total sale of the system (Euro)	**252.51**	**221.71**
Profitability of the system /Euro (Total sale -Total cost)	**208.9**	**178.1**

IRAS is the integrated recirculating aquaculture system, and EMF is the electromagnetic field
The price of fish was according to the Hungarian Research Institute of Agricultural Economics
The capacity of the magnetic field device = 5 m^3/h, (according to the supplier)
The price of plants was according to the company (Interaqua-Flora Ltd., Hungary)

reported by Hassan et al. (2019) for Jade Perch *Scortum barcoo* juveniles reared in a RAS under the exposure of different magnetic field intensities. The higher survival rate was achieved in the present study might be related to the duration of exposure, the field intensity and the variation in the sensitivity of different species.

Economic assessment

The economic assessment is essential to find out the benefits of the systems designed in the present study. It should be mentioned that the plants in IRASs are usually more than just biofilters to remove nutrients and maintain water quality in the culture systems; they are harvestable products. Duckweed (*L. minor*) is capable of recovering nutrients into high protein-enriched products that can be used as an organic feed for animals and many species of fish (Mukherjee et al., 2010). Table 4 shows the profit of applying the magnetic water technique in the IRASs. It is clear that the IRAS supplied with the magnetic water technique had higher profitability compared to those of the IRAS without the magnetic water technique. The higher profitability in these systems results from the increase in the growth rates of both fish and plants, as well as the improvement in the feed utilization efficiency of fish. From an economic point of view, these improvements in the growth and feed utilization efficiency when using the magnetic water technique in the IRASs would reduce the production cost and make these systems more cost-effective to be used.

CONCLUSIONS

The results of this paper revealed that the growth of common carp and feed utilization efficiency improved after the exposure to the electromagnetic field of 0.8 mT in IRASs. The growth of plants that used as a biofilter medium in the IRASs also improved when they exposed to the electromagnetic field of 0.8 mT. However, the electromagnetic field had no significant effect on water quality parameters in this study. According to these improvements, the use of the magnetic water technique and plant based biofilters in the IRAS can be valuable for increasing the profitability of these systems.

Further investigations are necessary to determine the ideal intensity of the magnetic field, which can positively affect the water quality and the growth performance of cultured species since the responses of different species of fish differ under the exposure of the magnetic fields.

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