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BALANCE OF PHOSPHORUS IN TWO DIFFERENT TYPES OF CYPRINIDS POLYCULTURE PONDS

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Abstract

In order to limit the impact of industrial aquaculture activity on the environment and therefore, to be able to compete with recirculating aquaculture systems, pond based production systems must improve their sustainability by implementing innovative technical and technological solutions. The present study aims to identify the balance of phosphorus in two cyprinid polyculture ponds based production systems, by applying different rearing technologies and technical solutions. The design of present experiment consists in two ponds (PCP and CP-PP), stocked with common carp (CC), silver carp (SC), bighead carp (BC) and grass carp (GC), where different fish rearing technologies were applied. Also, in case of CP-PP, split-pond technique, together with a particular hydraulic regime was used. The phosphorus input through administrated feed was 165% higher in the case of PCP, compared to the CP-PP. The results obtained by using Sankey diagram revealed higher percentages of phosphorus accumulation in water (> 1000%) and sediments (> 15%), in the case of PCP pond, compared to the CP-PP pond. However, higher percentages of phosphorus accumulation in fish biomass were registered at PCP pond (>8% in CC, 500% in SC, 150% in BC and >118% in GC). As a conclusion, by applying split-pond technique, together with a particular hydraulic regime and fish rearing technology, phosphorus footprint of cyprinid polyculture ponds can be reduced, by decreasing the concentration of this element in output water and sediments.

Key words: fish rearing technologies, phosphorus balance, phosphorus footprint, ponds cyprinid aquaculture, sustainability

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1. Introduction

Aquaculture sector struggles to face the new challenges regarding the minimizing of the environmental impact, together with production maximizing, productivity and economic efficiency. In this context, ensuring the sustainability of pond aquaculture by its environmental footprint is a priority. Considering that cyprinids are the most common fish species reared in ponds, the impact of cypriniculture on the ecosystems has been extensively studied in Central and Eastern Europe (Hrbacek et al., 1961; Korınek et al., 1987; Pechar et al., 2002).

The release of effluent loaded with nutrients into open waters, as a result of pond aquaculture industrial activity, leads to eutrophication and deterioration of water quality. As it was proved in a series of researches over the time, the cycling of nutrients is critical for the sustenance of pond ecosystems (Chapin et al., 2000; Costanza et al., 1997; DeAngelis, 1992; Vanni, 2002). Among nutrients, the concentrations of nitrogen and phosphorus in aquaculture ponds were always higher than those in the river, their primary water source, indicating that the aquaculture ponds are sources of nitrogen and phosphorus (Kawasaki et al., 2016; Kumar et al., 2018). High concentrations of phosphorus (P) in pond waters are the main reason for water quality deterioration, initial hyper-nitrification and subsequent eutrophication (increase of primary

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production) in these ecosystems. Reducing dissolved P output through better retention of nutrients has been considered a key element for long-term sustainability of aquaculture operations around the world (Boyd et al., 1998).

Phosphorus occurs in dissolved organic and inorganic forms or attached to sediment particles. When it remains in the sediments it is generally not available for use by algae; however, various chemical and biological processes can allow sediment phosphorus to be released back into the water (MPCA, 2008). Sediments in ponds may serve as a P source or sink, but the direction of P flux between sediments and overlying water have not been clearly identified or quantified (Reddy and Reddy, 1993). Soil with a low pH and high concentrations of iron and aluminium oxides are especially adsorptive (Egna and Boyd, 1997). The administrated fish feed is considered as being the main input of P in the ponds. According to Vanni (2002), freshwater fish can affect nutrient cycling direct (includes consumption of nutrients and their subsequent allocation to feces, growth, and nutrient excretion) and indirect (affects nutrient fluxes through impacts on their prey and/or on physical habitat structure). For the evaluation of P dynamics in fish pond effluents, it is necessary to identify the main accumulation rates of this chemical element in a series of key targets as follows: pond technological water, pond sediments and fish muscle tissues. However, it is very difficult to quantify the amount of fecal nutrients in pond production systems. Thus, sediment analysis may be an important indicator for the above mentioned quantification. The main factors which mediate nutrient excretion by fish are water temperature and fish body size.

The present study aims to identify the balance of phosphorus in two cyprinids polyculture ponds based production systems, by applying different rearing technologies and technical solutions.

2. Material and methods

The research was conducted at "Piscicola Iasi SC" fish farm, which is situated at 24 km from Iasi - Romania and, more exactly, in the Larga Jijia village. The water source is represented by Jijia River. Both inlet and outlet are made gravitationally, by using monk hydraulic constructions. For our research, two ponds with an area of 0.45 ha each and an average water depth of 1.5 m, were used (Fig. 1).

The PCP is stocked with 2500 common carp (CC) specimens (63.0±7.80 g/fish), 40 silver carp (SC) specimens (2006.3±213.80 g/ fish), 40 bighead carp (BC) specimens (1937.0±191.48 g/ fish) and 100 grass carp (GC) specimens (200.4±20.01 g/ fish). The CP-PP split-pond was divided by using a net, as follows: 1st part (CP - carp pond), with an area of 0.15 ha, and 2nd part (PP - polyculture pond), with an area of 0.30 ha.

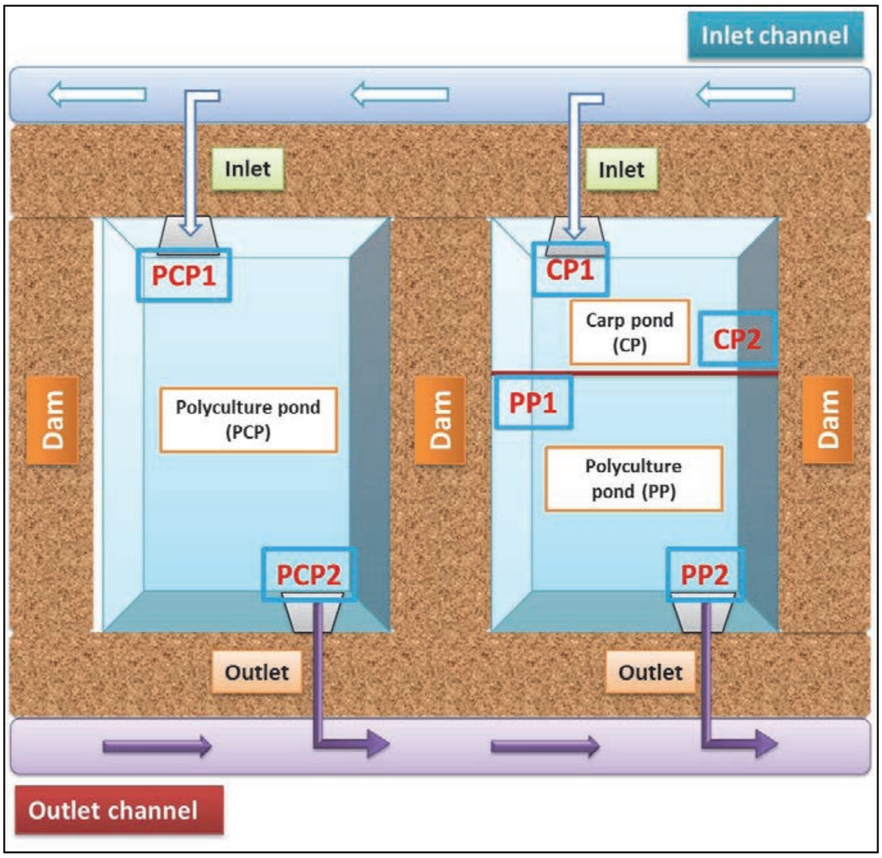

Fig. 1. Experimental design: 1st pond (PCP) – polyculture pond; 2nd pond (CP-PP: CP – carp pond, PP – polyculture pond) and sampling areas: PCP1 – PCP pond inlet, CP1 – CP-PP pond inlet, PCP2 – PCP - pond outlet, PP2 – CP-PP pond outlet; CP2 and PP1 - -net area sampling points in CP-PP pond

The CP part was stocked with 2000 CC specimens (61.2±11.60 g/ fish), while in PP part 500 CC specimens (60.0±10.45 g/ fish), 40 SC specimens (2044.0±289.80 g/fish), 40 BC specimens (1824.1±182.59 g/ fish) and 100 GC specimens (199.4±20.00 g/fish) were stocked. Considering the above stocking formulas, the following stocking densities had resulted: 949 kg/ha – CC PCP, 1705 kg/ha – CC CP, 265kg/ha – CC PP; 237 kg/ha – SC PCP, 299 kg/ha – SC PP; 248 kg/ha – BC PCP, 397 kg/ha – BC PP; 281 kg/ha – GC PCP, 343 kg/ha – GC PP.

The experimental research lasted 83 days, from 15 June to 5 September 2016. During this experimental period, outside the initial (15 June 2016) and final sampling (5 September 2016), three other samplings were performed, in intermediary stages, as follows: intermediary 1 (Int.1: 6 July 2016), intermediary 2 (Int.2: 25 July 2016) and intermediary 3 (Int.3: 5 August 2016). Water samples were collected at a 25-30 cm depth. From each pond, the water temperature (°C), dissolved oxygen (DO; mg/L) and pH (upH) were analyzed daily, using the HQ40d Portable pH and dissolved oxygen multi-parameter (HACH) devices. The chemical oxygen demand (COD-Cr; mg/L), percentage removal of BOD_5 in water (%), electrical conductivity (EC; µs/cm) and total suspended solids (TSS; mg/L) were determined monthly, as follows: COD - Merck kits for Spectroquant photometer Nova 400 equipment, BOD_5 - Velp IP54 analyzer, EC - WTW MultiLab® TetraCon® 325 sensor device, TSS – water filtration at pre-weighed glass fiber filter, followed by constant heating the filter at 104 ± 1° C. For total phosphorus (TP) determination in water, the samples were acidified with ultrapure nitric acid (1–5 mL HNO_3 / L H_2O) (Biziuk et al., 2010) and values were determined by using a continuous flow analyser. After each intermediary harvesting activity, fish samples from CP, PP and PCP ponds were taken for analysis. Fish selection for the biochemical determinations was performed, as follows: selected fish should have their individual biomass closer to the individual biomass average value of the batch; the fish specimens visual exam should prove that they are healthy. In order to determine the P concentration, fish meat samples were homogenized, dried, weighed (350 – 500 mg) and digested with nitric acid 65% ultrapure (Merck) and hydrogen peroxide (Merck) in a closed Teflon (^{TM}) digestion vessels, using a microwave digestion system. After completion of the digestion process, the samples were diluted with 50 mL deionized water. The results were expressed in mg/100 g wet weight (ww). A rectangular metal tube with a side of 20 cm was used to take randomLy sediment samples from the upper 10 cm sediment layers. Five individual samples were taken in a 2m^2 imaginary square surface, then mixed and carefully homogenized for analysis._The same method was applied for all 7 sampling locations. The sediment samples were initially dried at 105°C and then were gently homogenized, removing rough material and gravel, organic fibers and shell fragments. The digestion of sediment samples (500 mg) was performed by using Teflon digestion vessels in which were added 10 mL of nitric acid (65%), in a microwave digestion system. After cooling, the samples were filtered through cellulose nitrate filters into a 100 mL volumetric flask, with deionized water (Jitar et al., 2014). The results were expressed in mg/100 g dry weight (dw). After digestion process, the P concentration from fish meat and sediments was determined by using the flame module of an atomic absorption spectrometer system.

Calibration of the equipment was made by using a single element standard solution from Merck. Feed was manually administered twice/day, only in PCP and CP, for five days/week, which makes a total of 59 days of feeding during the entire experimental period. A total quantity of feed of 285.41 kg at CP-PP pond and 756.82 kg at PCP pond was administrated among the experimental period. The administered feed had a phosphorous concentration of 0.9% and it was represented by a mix of cereals (wheat lees, dry maize dregs and sunflower groats) in equal amounts. Therefore, due to the feeding management applied, the P inputs by administrated feed are almost three times higher in case of polyculture pond PCP, compared to the CP-PP pond (Table 1). Thus, while at polyculture pond (PCP) the feeding ratio was calculated relative to the entire fish biomass from the pond, in case of CP-PP pond, the feeding ratio was calculated relative only to common carp biomass, stocked in CP pond part, while the rest of fish biomass stocked in PP part was not fed during the entire experimental period

Table 1. Ponds P inputs from administrated feed

Experimental period	***Phosphorus input from administrated feed (kg)***	
	PCP	***CP***
Initial - Int.1	2.01	0.73
Int.1 - Int.2	3.08	1.25
Int.2 - Int. 3	1.15	0.48
Int.3 - Harvesting	3.83	1.21

In order to present the phosphorus balance, Sankey diagram, by Sankey MATIC, was used. The sediments and fish biomass meat phosphorus concentrations are presented in Sankey diagram, as inputs (the initial results, at the beginning of the experimental period) and outputs (results registered at the end of the experimental period) data. Since, for both ponds, a water exchange rate of 1.2% per day was applied, the inputs and outputs of phosphorus concentration in water, presented in Sankey diagram, are calculated as follows (Eqs. 1-2):

$$P_{input} = P_{initial} + P^{*}_{1.2\% inlet} \quad (1)$$

$$P_{output} = P_{end} + P^{*}_{1.2 outlet} \quad (2)$$

where: "*" represent intermediary results for P concentration in inlet/outlet water are used, $P_{initial}$ –

average P concentration in pond water, at the beginning of the experimental period; $P_{1.2\%\ inlet}$ – P concentration in pond water inlet, by applying a 1.2% daily water exchange rate; P_{end} – average P concentration in pond water, at the end of the experimental period; $P_{1.2\%\ outlet}$ – P concentration in pond water outlet, by applying a 1.2% daily water exchange rate.

The results obtained in this research were statistically analysed using IBM SPSS Statistics 20.0. The homogeneity of variance was tested by using Levene's test (F value). Both t-test and ANOVA test were used in order to examine whether group means differ from one another. However, the t-test was used when two variables groups were compared, while ANOVA was applied when comparing more than two groups of variables.

3. Results and discussion

3.1. The dynamics of water quality parameters for each of the experimental ponds sampling points

The water temperature average values registered an upward evolution at the end of the experimental period (Table 2). The pond water pH values, recorded at the end of the experimental period, are lower in the case of CP-PP inlet sampling point (CP1), compared to the outlet sampling point (PP2) Table 2). This can be explained by the high CC stocking density, applied in CP part of this pond, as well as due to the feeding management – no feed was administrated in PP pond area. In the case of PCP, lower pH values are recorded at the outlet sampling point (PCP2), compared to the inlet sampling point (PCP1) (Table 2). The DO revealed higher differences between inlet and outlet in the case of CP-PP, compared to the PCP pond (Table 2).

This context can be due to better conditions existing in the case of CP-PP for algae biomass growth, in the pond outlet area. The high CC stocking density, applied in the case of CP pond area, together with the feeding management and CC bioturbation activity, might cause the higher TSS concentrations, recorded in the inlet of CP-PP, compared to the concentrations registered in the outlet area of this pond (table 2). Also, the TSS concentration registered at pond outlet is lower in the case of CP-PP, compared to the PCP. Better results for percentage removal of BOD were found in the case of CP-PP pond outlet, compared to the PCP outlet, while both ponds have a higher COD accumulation tendency (Table 2).

3.2. The dynamics of TP in water, for each of the experimental ponds sampling points

The higher phosphorus values were found in the case of PCP outlet sampling point (4.22 mg/L). Significant higher ($p<0.05$) P concentration registered for CP-PP pond inlet, compared to the PCP inlet can contribute to this results, together with the feeding management applied (Fig. 2).

Table 2. The dynamics of water physico-chemical parameters

Parameters	***Exp. stages***	***Sampling points***					
		CP1	***CP2***	***PP1***	***PP2***	***PCP1***	***PCP2***
Temperature (°C)	Int. 1	19.80	19.60	19.90	19.40	21.10	20.60
	Int. 2	22.92	22.46	22.74	22.78	22.96	23.30
	Int. 3	21.86	22.02	21.28	21.62	22.14	21.66
	Final	16.46	16.34	16.36	16.52	16.88	16.78
pH (upH)	Int. 1	8.22	8.24	8.31	8.31	8.01	8.02
	Int. 2	9.15	9.13	9.16	9.22	8.72	8.87
	Int. 3	9.20	9.11	9.16	9.07	9.10	9.07
	Final	8.98	9.18	9.12	9.06	9.21	8.98
DO (mg/L)	Int. 1	9.78	8.26	8.91	9.23	7.61	8.07
	Int. 2	13.54	12.79	15.41	16.29	6.53	9.89
	Int. 3	8.78	8.72	8.49	9.28	8.136	9.59
	Final	11.18	13.16	12.92	13.78	12.22	13.65
TSS (mg/L)	Int. 1	687.00	567.00	486.00	567.00	230.00	652.00
	Int. 2	1267.20	840.80	892.80	1088.00	629.60	827.20
	Int. 3	916.80	549.60	634.40	496.00	725.60	823.20
	Final	2116.80	2076.80	2125.60	2273.60	2924.00	2554.40
Percentage removal of BOD5 in Watter (%)	Int. 1	85.20	89.30	84.50	82.80	91.60	88.60
	Int. 2	100.00	99.35	98.75	97.65	100.00	100.00
	Int. 3	100.00	99.65	99.05	98.80	100.00	100.00
	Final	100.00	99.90	99.30	99.25	100.00	100.00
COD (mg/L)	Int. 1	103.00	88.00	75.00	63.00	121.00	82.00
	Int. 2	134.40	133.80	136.20	120.00	152.40	148.60
	Int. 3	163.60	152.20	152.40	152.68	175.94	191.60
	Final	150.00	156.60	158.80	173.20	177.60	193.20
EC (µs/cm)	Int. 1	1087.00	1087.00	1081.00	1085.00	1274.00	1292.00
	Int. 2	1137.60	1141.20	1139.60	1147.00	1497.80	1401.40
	Int. 3	1311.40	1305.80	1312.60	1307.20	1477.00	1488.80
	Final	1325.00	1367.00	1371.60	1390.40	1444.20	1462.20

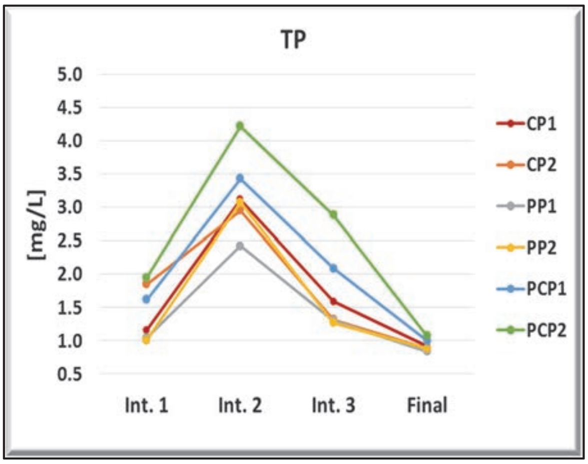

Fig. 2. The dynamics of water TP concentration in both ponds

However, when compared the P concentration registered at inlet and outlet areas of each pond, it can be concluded that CP-PP pond had a better average P retention, compared to the PCP pond. The dynamics of both pond water P concentrations have a downward tendency from Int.2, until the end of the experimental period, revealing a better utilization of this nutrient by various consumers, as phytoplankton, thus, limiting the TP footprint of the ponds cyprinids aquaculture economic activity.

The differences, in terms of TP concentration in water, between CP-PP inlet and outlet sampling points, are not significant ($p>0.05$). Regarding net area sampling points, significant differences ($p<0.05$) are recorded between both points (higher TP concentrations at CP2, compared to the PP1), only during the first half of the experimental period, probably due to pond hydraulic regime, together with draining channel diagonal positions, between water inlet structure and water outlet monk.

The concentrations of TP in water, recorded in the present study, are relatively similar with those reported by Gurung et al. (2013) who tested four variants of pond polyculture for six species of cyprinids, together with tilapia (*Oreochromis niloticus*) and sahar (*Tor putitora*) and registered TP concentration in water between 1.3 – 3.3 mg/L. Hlavac et al. (2016a) tested two types of feed, respectively four types of feed (Hlavac et al., 2016b) for common carp reared in ponds, in monoculture, and registered lower TP concentrations in water (0.14 – 0.16 mg/L, respectively 0.18 – 0.21 mg/L).

3.3 Dynamics of fish meat P concentration for each of the experimental ponds

Fish generally occupies a relatively high trophic position in aquatic ecosystems and play an important role in nutrient cycles of the ecosystem (McIntyre and Flecker, 2010). In the present study, TP concentration from each of the four cultured fish species (common carp – CC, silver carp – SC, bighead carp- BC, grass carp – GC), were identified both at the beginning and at the end of the production cycle, but also in the intermediary points of the experiment, when partial harvesting for control were made (Fig. 3). During those partial harvestings, prussian carp (*Carassius gibelio*) - PrC specimens have been found in both PCP and CP-PP ponds and were categorized as unwanted species. As at the beginning of the experiment it was stocked in neither of the ponds, the prussian carp may have entered into both ponds through the water inlet screen holes. However, those unwanted specimens were also analysed in terms of TP concentration in meat.

3.3.1. Common carp

The results indicate significant differences ($p<0.05$) between CC-CP vs. CC-PP vs. CC-PCP meat TP concentration in Int.2, Int.3 and at final harvesting (Fig. 3a). The highest concentration of TP in CC meat was recorded at CP pond area (445.66±44.17 mg/100g ww), followed by PCP pond (297.79±39.84 mg/100g ww) and PP pond area (124.41±41.57 mg/100g ww). However, better fish growth performances are found in the case of PCP pond (213.55±57.30 g/fish), followed by PP (184.90±65.50 g/fish) and respectively CP pond (175.10±63.90 g/fish). The differences between CC individual biomass at the end of experimental period are statistically significant ($p<0.05$), when PCP pond is compared to CP, respectively to PP pond area (Fig. 4a). Therefore, although CC recorded better growth performances at PCP, the highest TP concentration in CC meat were found at CP biomass.

The CC stocking density, applied at CP (1705 kg/ha), was almost two times higher, compared to CC from PCP (949 kg/ha) stocking density, fact that can affect welfare status and therefore, can reduce fish growth. Also, the feed competition manifested between all four cyprinids species, reared in polyculture at PCP, can reduce the access to feed of CC, encouraging them to take advantage of natural food availability, thus benefiting from a higher P input. Also, the higher individual biomass of SC and BC can increase the above mentioned feed competition.

This can explain the TP higher concentrations recorded in CC meat, at PCP pond, compared to CP pond. The CC reared at PCP pond stirs up the sediments, in the tentative of natural food valorisation, process that can contribute to high TP concentrations in water, recorded at PCP pond (Fig. 2). The decrease of meat TP concentration in CC stocked at PP pond area can be explained by the evolution of water temperature and natural food availability. Guo et al. (2018) used ecological stoichiometry in order to study how the accumulation of nutrients in fish varies with growth. Therefore, he obtained higher TP concentration for common carp (Table 3) compared to the values found in present study.

According to Watanabe et al. (1999), in common carp, the TP loading calculated based on P retention in whole body was 13.6 kg P/t produced. This value is higher than those from other fish species like salmons, which discharge less than 3 kg P/t produced (Cho and Bureau, 1997). Also, as Jahan et al. (2002) stated, P retention is also directly affected by growth rate, and higher values were obtained when growth performances were good. Carp are capable of having a strong effect on aquatic habitats through regulation of the freshwater ecosystem structure (Hrbacek et al., 1961).

Table 3. The individual average biomass and average P concentration in common carp meat (Guo et al., 2018)

Individual average biomass (g/fish)	TP concentration (mg/100g)
372.67±76.50	1670±50
438.33±88.00	1710±70
849.00±126.37	1820±80
989.00±178.68	1920±40
1253.00±58.40	2060±50
1478.00±66.14	2030±50

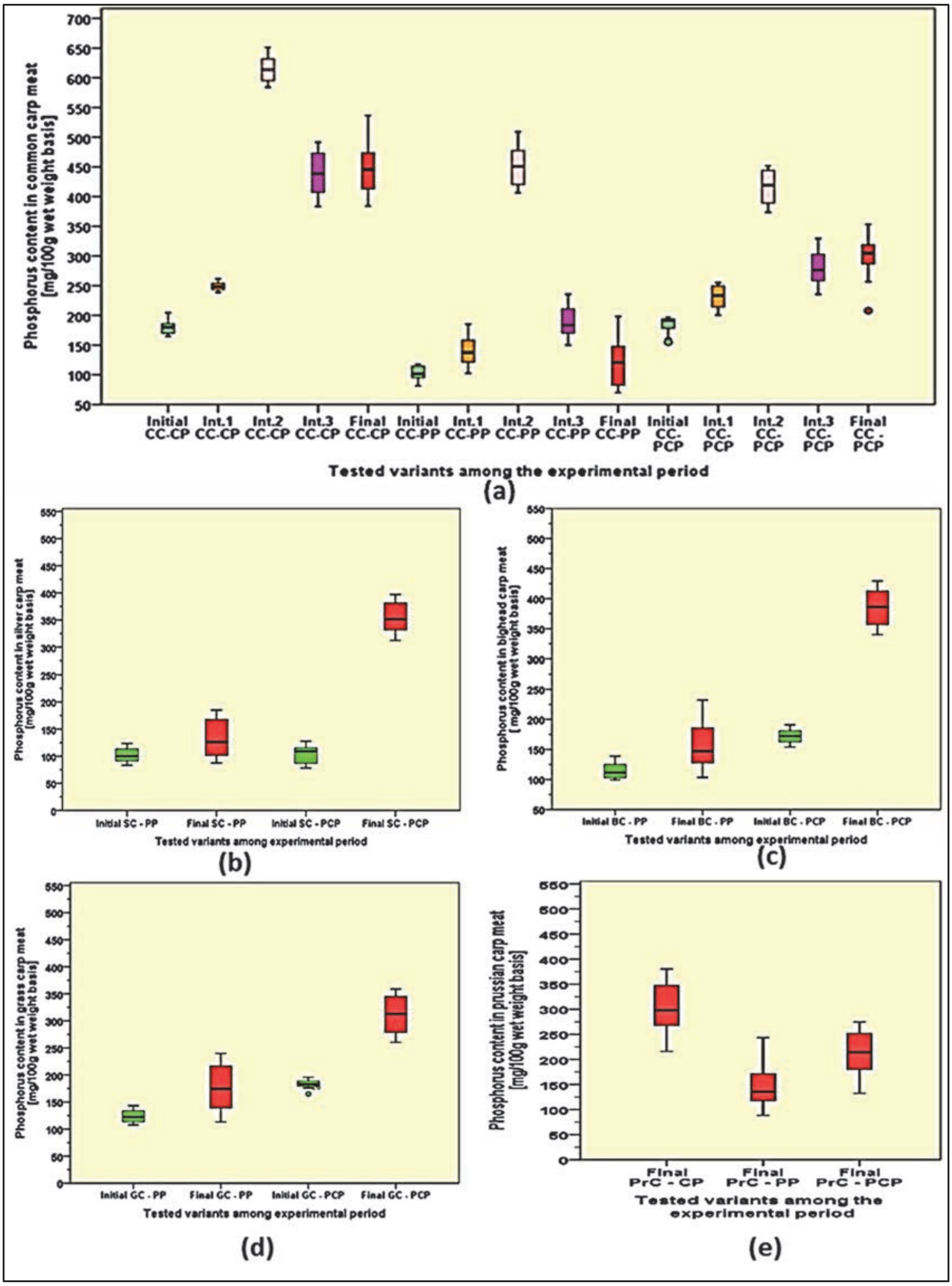

Fig. 3. The TP concentration in common carp (CC) meat – (a) silver carp (SC) meat; (b) bighead carp (BG) meat; (c) grass carp (GC) meat; (d) and in prussian carp (PrC) meat; (e) from each experimental variant

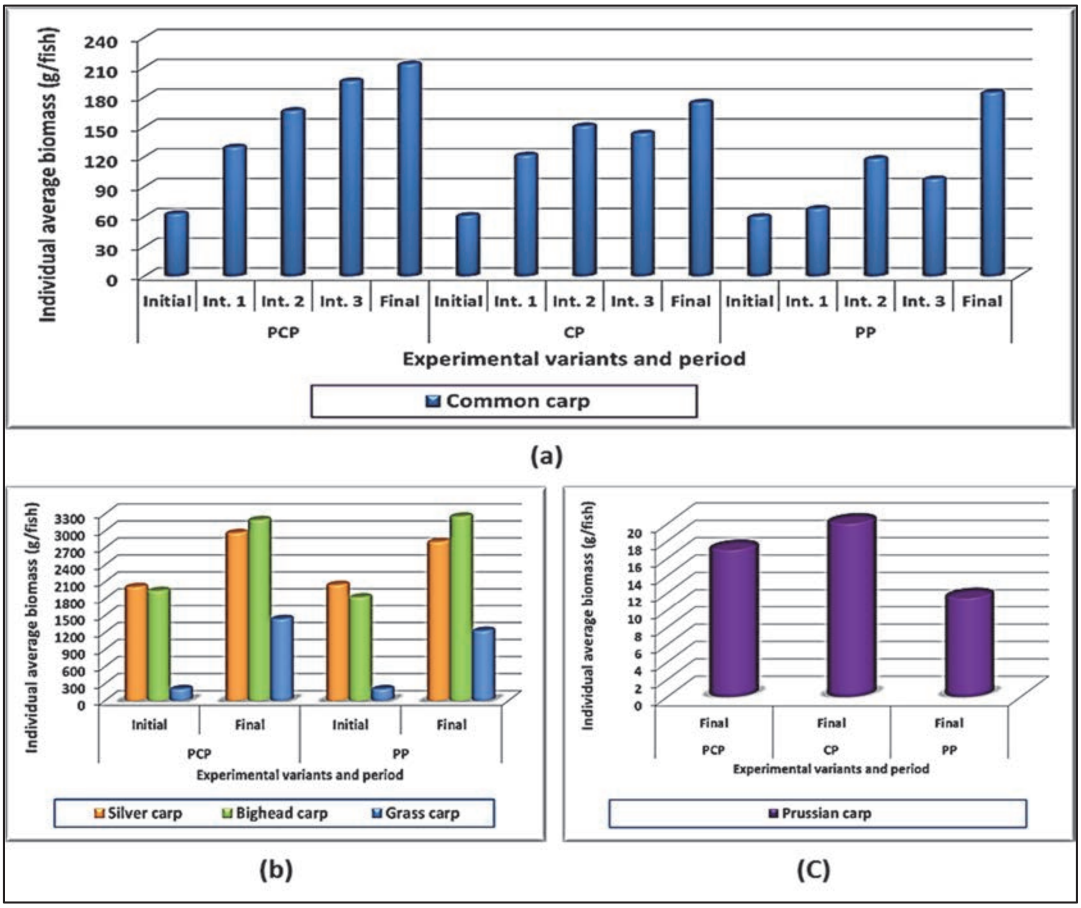

Fig. 4. The individual average biomass for common carp (a), silver carp, bighead carp and grass carp (b) and prussian carp (c)

Carp do this in two ways: through feeding activity and nutrient recycling via physical resuspension - bioturbation (Adamek and Marsalek, 2013), and through predation on large zooplankton such as Daphnia (Angeler et al., 2002). By stirring up sediments, carp can enhance the nutrient concentration, which in turn increases natural food availability in ponds (Milstein et al., 2002).

Therefore, in the present study, the application of CP-PP fish stocking structure and feeding strategy generated lower concentration of TP in meat in case of BC, GC and SC stocked in PP, compared with similar species reared in PCP, while CC reared in PCP recorded higher TP concentrations in meat, compared with the specimens reared in PCP and respectively, stocked in PP.

3.3.2. Silver carp

The P concentration in silver carp meat had an upward dynamic during the experimental period. The results (Fig. 3b) indicate significant differences ($p<0.05$) between SC-PP vs. SC-PCP meat TP concentration, at final harvesting. Also, SC reared at PCP had a higher growth rate, compared to the specimens stocked at PP pond area (Fig. 4b). No results are available during the experimental period, at intermediary stages, because no specimens of silver carp were harvested. The higher values, both in terms of biomass growth and meat TP concentrations, registered at SC reared in PCP (2958.8±417.5 g/fish, respectively 355.19±236.52 mg P/100g ww) could be due to the applied feeding ratio, since in PP pond are no feed was administrated.

3.3.3. Bighead carp

The TP concentration in bighead carp meat had an upward dynamic during the experimental period. The results (Fig. 3c) indicate significant higher differences ($p<0.05$) at BC-PCP (383.06±28.81 mg/100gww), compared to the BC-PP meat TP concentration (132.56±32.68 mg/100gww), at final harvesting. No significant differences ($p>0.05$) were found between BC reared at PCP and the specimens stocked in PP pond area, in terms of growth performance (Fig. 4b). No results are available during the experimental period, at intermediary stages, because no specimens of bighead carp were harvested. The higher values, in terms of biomass growth and meat TP concentrations, registered at BC reared in PCP, could be due to applied feeding management. It must be mentioned that planktivorous bighead carp mainly prey on phytoplankton and indirectly uptake TP, while bait-eating common carp refer utilizing fish diet as food and directly consume P (Rai, 2000).

3.3.4. Grass carp

Currently, P requirements have been confirmed in juvenile grass carp (Liang et al., 2012) and young grass carp (Wen et al., 2015), which is mainly based on growth performance. However, the nutrient requirements of fish may vary with different indices. Hlavac et al. (2016b) stated that, for maximum efficiency of feed utilization in carp pond aquaculture, grass carp probably represents the only option, both in terms of economic effects and the importance of sustainable water quality in ponds.

The TP concentration in grass carp meat had an upward dynamic during the experimental period. The results (Fig. 3d) indicate significant higher differences ($p<0.05$) at GC-PCP (310.73±32.52 mg/100g ww), compared to the GC-PP (176.98±42.10 mg/100g ww), in terms of meat TP concentration, recorded at final harvesting. Also, GC reared at PCP had a higher growth rate, compared to the specimens stocked at PP pond area (Fig. 4b). The higher values, both in terms of biomass growth and meat TP concentrations, registered at GC reared in PCP, could be due to feeding management applied. Guo et al. (2018) obtained a higher P concentration for grass carp compared to the values found in present study (Table 4).

Table 4. The individual average biomass and average of TP concentration in grass carp meat (Guo et al., 2018)

Individual average biomass (g/fish)	*TP concentration (mg/100g)*
505.33±103.37	1930±80
681.00±22.61	1970±100
1033.67±3.05	2030±40
1348.00±83.35	2060±40
2159.33±50.62	2050±100
2503.67±85.01	2030±50

3.3.5. Prussian carp

The TP concentration in PrC meat indicate significant differences ($p<0.05$) between Pr.C-PP vs. Pr.C-PCP vs. Pr.C - CP meat TP concentration, at final harvesting (Fig. 3.e). Also, Pr.C found in CP pond area had the highest individual biomass (79.8.±35.4g/fish), compared to the specimens found in PP pond area and in PCP pond. (Fig. 4.c). The higher values, both in terms of individual biomass and meat TP concentrations, registered for Pr. C found in CP, compared to the specimens found at PP and PCP could be due to easier access to feed and lack of feed competitor, outside CC. Also, Pr.C found in PP registered the lowest individual biomass (11.39±3.63g/fish) and meat TP concentrations (148.45±46.43 mgP/100gww), since no feed was administrated in this pond area.

Gurung et al. (2013) analyzed the dynamics of meat P concentration for six species of cyprinids (common carp, bighead carp, grass carp, silver carp, rohu and mrigal), reared in polyculture conditions, in ponds, during a 270 days experimental period. An upward dynamic of meat P concentration was registered only in case of bighead carp, from 920mg/100g ww to 1050 mg/100g ww. Regarding common carp, grass carp and silver carp, an downward dynamic of meat P concentration was recorded, as follows: from 650mg/100g ww to 470mg/100g ww; from 930mg/100g ww to 780mg/100g ww and respectively, from 860mg/100g ww to 790mg/100g ww. Hlavac et al. (2016a, 2016b) reported an increase of P meat concentration of common carp reared in ponds, in monoculture, as follows: from 510mg/100g ww to 670mg/100g ww, respectively from 480mg/100g ww to 560mg/100g ww. Wudtisin and Boyd (2006) reported a value of 108.5 mg/100 g ww for P meat concentration of common carp reared in ponds. Stanek et al. (2013) analyzed the P meat concentration of lake prussian carp and found a value of 238 mg/100g ww. Also, Çiçek et al. (2013) analyzed the values of meat P concentration of lake common carp and mirror carp, registering values of 316mg/100g ww, respectively 385mg/100g ww.

The lower concentration of P registered in present study, compared with the concentrations reported by other authors (Guo et al., 2018) can be due to concentration of P in administrated feed. Also, another explanation can be related with the biomass differences in case of common carp. Therefore, as large carp are known to retain more P per unit weight than smaller fish (Vanni, 1996). However, fish body chemical content is species-specific (Griffiths, 2006) and varies greatly throughout the year depending on a range of factors, including fish length and mass (Torres and Vanni, 2007).

3.4. P accumulation in ponds sediments

As an essential part of water bodies, sediments act as the sinks and sources of pollutants (such as metals, nitrogen and P) in aquatic environments (Chon et al., 2012). Nutrients from ponds, tend to transfer from water to sediments through biochemical and physical reactions (Zhu et al., 2013).

Nevertheless, due to shifts in physical-chemical factors and frequent hydrodynamic disturbances, nutrients accumulated in the sediments can be released into the overlying water (Zhu et al., 2013), thus leading to water pollution and eutrophication. P absorption at the sediment-water interface is an important process that has a direct effect on nutrient concentrations in the sediments, as well as their transport and bioavailability in aquatic systems (Yang et al., 2015).

Sediments P concentration is a subject of the great importance, especially at the cyprinids pond farms. This status is due especially to common carp bioturbation process, which according to Dekun et al. (2013) has larger effects in the nutrient concentration than does the input of nutrients through cereals. At the beginning of the experiment, before stocking, the P concentration in sediments was lower at CP-PP pond, compared to the PCP pond (Fig. 5a).

The TP dynamics in sediments was influence by pond hydraulic regime generated by daily water exchange rate of 1.2% (Fig. 5a-e). Therefore, during the experimental period, the highest concentration of TP was accumulated at the level of CP pond area (91.80±12.76 mg/100gdw), most probably due to feeding management.

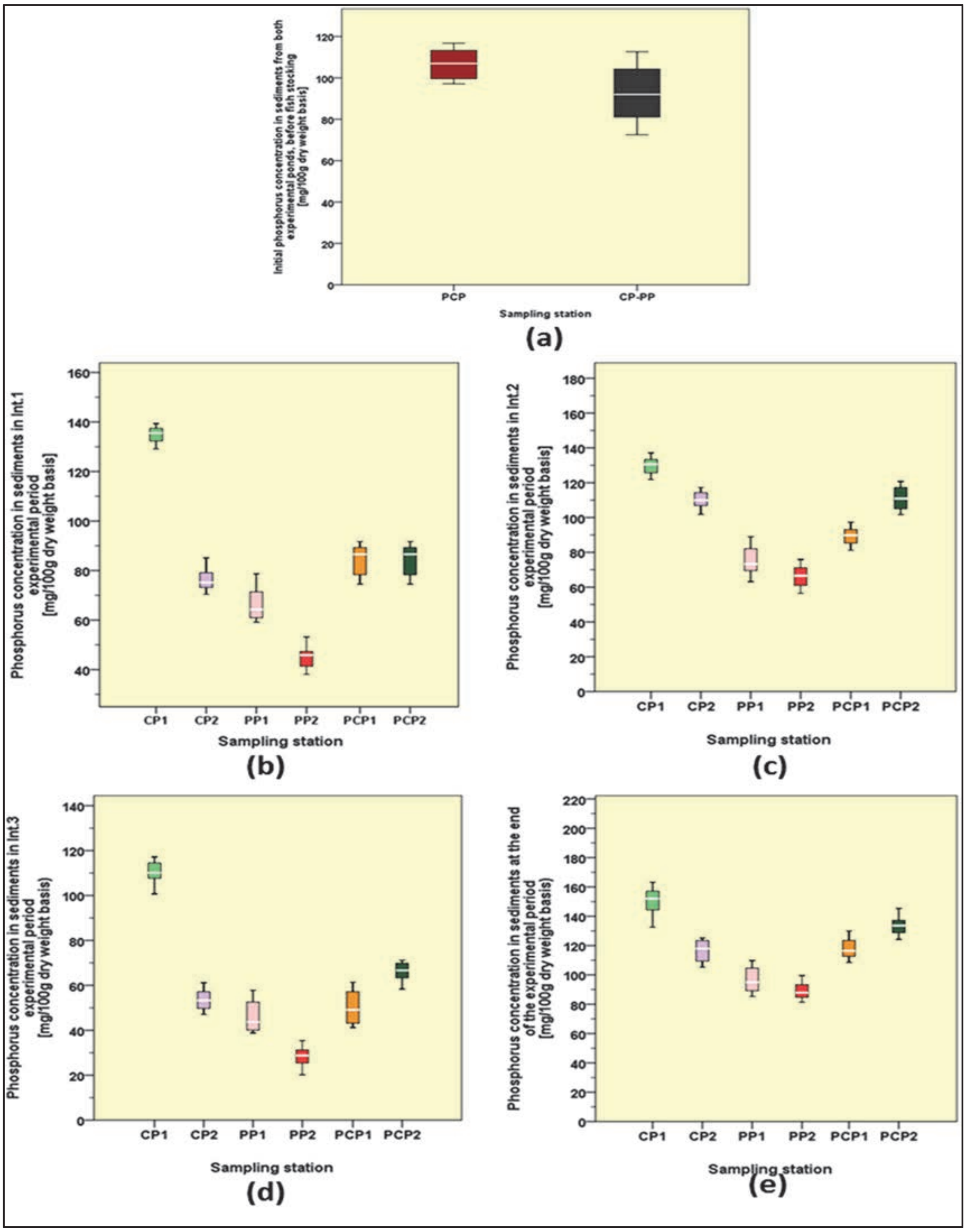

Fig. 5. The TP concentration in sediments at the beginning (a), intermediary 1 (b), intermediary 2 (c), intermediary 3 (d) and at the end of the experiment (e)

Since in CP pond area, the highest CC stocking density was applied and feeding competition was manifested only intraspecific, the bioturbation generated by the CC search for natural food was lower, therefore the transfer process of a TP accumulated in sediments, into the overlying water, decreased. Also, the dynamics of TP concentration in sediments reveals an accumulation tendency of this nutrient, manifested in the last part of experimental period (Int.3-Final) (Fig. 5d-e). However, in the CP-PP pond output area (PP2 – 88.98±5.36 mg/100g dw), the TP concentration in sediments is lower, comparing with the values recorded in the input area (CP1 – 150.72±9.16 mg/100g dw), fact that could be explained by the feeding management applied. The situation is opposite in the case of PCP pond, where TP concentration in sediments is higher in PCP1 (117.64±6.38 mg/100g dw) water inlet area, comparing with PCP2 (134.09±6.24 mg/100g dw) water outlet area. Also, the dynamics of TP concentration in sediments reveals the capacity of self-regulation in case of both experimental ponds, situation made possible especially through the process of nutrients transfer, ensured by the difference of water level, between the inlet and outlet sector of the ponds, fact assured by the presence of monk concrete structure, situated at the pond outlet.

The results recorded in present study, in terms of P concentration in sediments are similar with those reported by Brzozowska et al. (2007) (200-623.2mg P/100g dw) and lower than those reported by Hart and Harding (2015) (500mg P/100g dw). Gal et al. (2003) made a series of researches on both monoculture and polyculture of cyprinids, in ponds. Therefore, he reported values of P in monoculture common carp pond sediments between 760 - 800mg/100g dw and an average of 960mg/100g dw in case of polyculture (common carp, bighead carp and silver carp) pond sediments. However, the presence of common carp biomass generates physical disturbance of sediments during feeding activity, process which remobilizes and recycles the nutrients and therefore decreases the sediments nutrients concentration and reduces water quality. The intensity of these effects appears to be related, in part, to individual body size (Weber and Brown, 2009). Therefore, no certain correlation can be done in terms of quantity of nutrients inputs by feed and nutrients concentration in sediments without taking into consideration the fish stocking formula.

3.5 Phosphorus mass balance

In order to elaborate the mass balance, the inputs and outputs of TP in both experimental ponds (CP-PP and PCP) were quantified. The concentration of TP in feed, fish biomass, sediments and water were considered as dependent variables. Thus, the initial TP concentration in sediments (before fish stocking), water (inlet water during the experimental period and water already existed in the ponds before fish stocking), fish meat (the fish biomass stocked in ponds, at the beginning of the experimental period) and administrated feed quantity were taken as inputs. The outputs that were introduced in the mass balance include TP concentrations in sediments (at the end of the experimental period, after final harvesting), in water (water outlet during the experimental period and water existed in ponds after final harvesting) and in fish meat (harvested fish biomass, at the end of the experimental period). The difference between inputs and outputs is considered as unrecorded P.

Therefore, by analysing Sankey diagrams (Fig. 6), it can be noticed that TP inputs by administrated feed, recorded at PCP pond a value 165% higher, compared to the CP-PP, due to feeding management applied.

However, in terms of TP concentration accumulated in water and sediments, in case of the PCP pond, values were 1095%, respectively 15.76% greater than those recorded at CP-PP pond. Also, PCP pond recorded values 8.14%, 500%, 150% and 118.75% greater, in case of CC, SC, BC and GC, than those corresponding to cyprinids harvested from CP-PP pond.

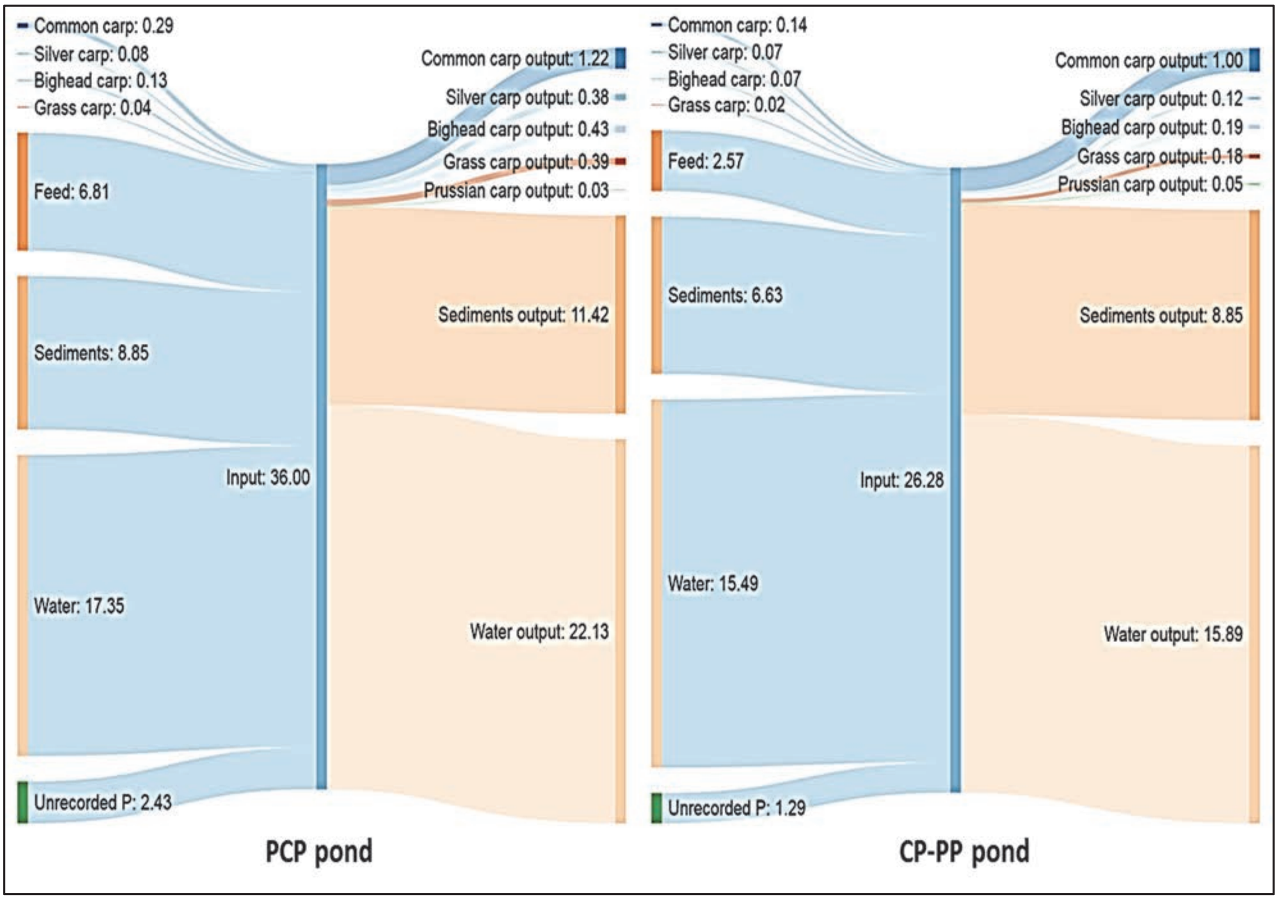

Fig. 6. The Sankey diagram of P quantity (kg/ha) in the both ponds (input and output)

4. Conclusions

It can be concluded that the CP-PP feeding management, together with the tested technical solution (split-pond and hydraulic regime) improved the sustainability of pond cyprinids polyculture by limiting the TP released into the environment through water outlets. Thus, the CP-PP production strategy improves sustainability, productivity and, therefore, profitability, by applying strategies that involves efficient utilization of natural food in ponds.

However, it is recommended that a slight change should be made in CC stocking structure, which consists in moving the entire CC biomass, from PP into the CP pond area, in order to improve the P recovery in fish biomass, as well as fish production capacity.

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