JFMSE, 33(3), pp. 569~576, 2021.
수산해양교육연구, 제33권 제3호, 통권111호, 2021.
www.ksfme.or.kr
https://doi.org/10.13000/JFMSE.2021.6.33.3.569

Effects of Mono and Polyculture on the Growth of Four Species Fishes in Recirculating Rearing System

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순환여과시스템에서 4개 어종의 단일 및 복합양식시 성장에 미치는 영향

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Abstract

In this study, the experiment was conducted for 100 days and all fish were reared in 36 ponds, divided into 3 groups: control group (four fish species monoculture); two species polyculture (*S .asotus* and *C. carassius*, *S. asotus* and *C. carpio*); three species polyculture (*S. asotus*, *C. carassius* and *O. niloticus*; *S. asotus, C. carpio* and *O. niloticus*). We have set three groups. Group A were control group, which was the monoculture of four species. Group B were two species polyculture, and group C were three species polyculture. All water quality parameters evaluated were within acceptable limits for fish culture. Considering the growth parameters, the combination of *S. asotus*, *C. carpio* and *O. niloticus* has the highest growth rate at a ratio of 25:50:25. *S. asotus* growth is obviously over the other species in all treatments. The growth of *C. carassius* has been inhibited a lot in polyculture. It's not a suitable species for polyculture in this experiment. The introduction of *O. niloticus* in three species polyculture had improved *C. carpio* growth a lot. There seemed to be a synergistic relationship between *C. carpio* and *O. niloticus*.

Key words : Polyculture; Growth; Recirculating rearing system

Ⅰ. Introduction

The polyculture of aquatic animal has a long history and started in China during A.D.618-907, now spread to world. The principle of polyculture is based on the fact that each fish species stocked has its own feeding niche that does not completely overlap with the feeding niches of other species. Therefore, a more complete use is made of the food resources and space available in polyculture than in monoculture. In some cases, one species enhances the food availability for other species and thus increases the total fish yield per unit area (Hepher et al., 1989; Miah et al., 1993; Azad et

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※ The author wishes to acknowledge the financial support of the Fisheries Science Institute of Kunsan National University made in the program year of 2020.

al., 2004; Wang et al., 2000; Gao et al., 2015; Ali et al., 2018; Mehrim et al., 2018).

Culturing different carp species in the same pond optimizes the utilization of the food available in the ecological niches of the pond ecosystem (Kestmont, 1995). In addition, the polyculture aims to increase productivity by a more efficient utilization of the ecological resources in the aquatic environment (Lutz, 2003). Thus, two species or more complimentary fish species can increase the maximum standing crop of the pond by allowing a wide range of available foods and ecological niches.

One of the major problems facing the polyculture in Korea involves the low acceptance, by consumers, of the species of fish utilized, e.g. common carp (*Cyprinus carpio*) and crucian carp (*Carassius carassius*). Thus, the introduction of other species with a higher market price and better acceptance by consumers seems to be the best alternative to improve fish productivity.

In this study, the species chosen to co-cultivate with the carp species were the far eastern catfish (*Silurus asotus*), a species spread widely in the East Asia, and the well known omnivorous and filtrating fish, the Nile tilapia (*Oreochromis niloticus*).

Ⅱ. Materials and methods

This experiment was conducted from June to September, 2014, lasted for 100 days, at the facilities of the fish farm, Kunsan National University (KSNU). All fishes were acquired from the fish farm of KSNU. Fishes used in the present study were *S. asotus* (13.4±0.4 g, 11.4±0.9 cm), *C. carassius* (23.4±3.0 g, 12.2±1.5 cm), *C. carpio* (21.9±1.2 g, 10.8±1.0 cm) and *O. niloticus* (16.8±0.6 g, 9.2±0.9 cm). Fishes were reared in 36 concrete recirculating tanks (2.5 × 2.5 × 0.9 m, water volume 4.5 ton) with different combinations and stocking ratios.

In the experiment we had set three groups. Group A was control group, which was the monoculture of four species. Group B was two species polyculture, B1, B2 and B3 were combinations of *S. asotus* and *C. carassius*; B4, B5 and B6 were combinations of *S. asotus* and *C. carpio*. Group C was three species polyculture, C1, C2, C3 and C4 were combinations of *S. asotus*, *C. carassius* and *O. niloticus*; C5, C6, C7 and C8 were combinations of *S. asotus*, *C. carpio* and *O. niloticus* (<Table 1>). The whole experiment was conducted in the summer season, water temperature (WT) ranged from 22.6-26.5℃. All tanks were equipped with airstone to ensure enough dissolved oxygen (DO). The productivity, water quality parameters were evaluated over 100 days. The pH, DO and WT were checked once a week, at a depth of 30 cm with a water quality checker WQC-22A(TOA-DKK, Japan). Every two weeks, COD, total hardness and alkalinity were measured with titration test and total ammonium-N, nitrite nitrogen, nitrate nitrogen were measured with colorimetric test.

For weight determination and feed adjustment, each species were collected periodically (every 4 weeks) with a pen net. The fishes were weighed, measured and immediately returned to the water. And then calculated and decided the feeding amount. At the end of the experiment, all fish were harvested and the total number, weight and size of each fish species were determined. Mortality and yield were then calculated.

The growth and yield indexes measured and calculated were: mean body weight by species (g), where fW is final weight, iW is initial weight,

<Table 1> Density and combination of all experiment groups

Groups	Fish species*			
	S. asotus	*C. carassius*	*C. carpio*	*O. niloticus*
A1	100	—	—	—
A2	—	100	—	—
A3	—	—	100	—
A4	—	—	—	100
B1	34	66	—	—
B2	50	50	—	—
B3	66	34	—	—
B4	34	—	66	—
B5	50	—	50	—
B6	66	—	34	—
C1	25	25	—	50
C2	25	50	—	25
C3	33	33	—	33
C4	50	25	—	25
C5	25	—	25	50
C6	25	—	50	25
C7	33	—	33	33
C8	50	—	25	25

*Total number of individual.

standard length (cm), specific growth rate (SGR=100×[Ln(fW)-Ln(iW)/t] and t is culturing days, as mentioned previously (Barcellos et al., 2004), feed conversion ratio (FCR= feed amount/weight gain), growth rate [GR=(fW-iW)/iW]. Fishes were fed twice a day (8:00 and 17:00 hours) to apparent satiation (feed was applied until fish appeared to be full or satiated) with a 43% protein floating commercial catfish feed. The experiment was performed in replicated and results are reported as means±standard deviation (all fish) unless otherwise stated. Data were analyzed by one-way ANOVA with the SPSS (SPSS 9.0, SPSS Inc., USA) statistical package. Means were separated by using Duncan's multiple range test and were considered significantly different if $P < 0.05$.

Ⅲ. Results

No difference of WT was observed among 18 tanks during the experiment period, since all tanks were adjacent and receive water from the same source, WT only varied a little within rearing time, during all experiment period WT ranged from 22.6 to 26.5℃ (<Table 2>). And DO ranged from 6.45 mg/L to 8.34 mg/L, all values were within an ideal range (above 5 mg/L), and had no obvious difference among treatments. The pH values were almost consistent during all experiment period, varied from 7.1 to 7.8 (optimum range 6.5-9.0). In this experiment, the alkalinity was within an ideal range for fish culture (50-200 mg $CaCO_3$/L), ensured a good production. But the hardness is some higher than the appropriate range (50-150 mg $CaCO_3$/L).

The initial body weight (IBW), final body weight (FBW), growth rate (GR), specific growth rate

<Table 2> Variations of water quality parameters during the experiment period

Items	Rearing days (week)							
	0	2	4	6	8	10	12	14
Alkalinity ($mgCaCO_3/L$)	70.6±0.9	60.3±0.9	57.7±0.5	53.0±0.5	56.9±0.7	58.6±0.5	64.7±0.9	59.7±0.6
Hardness ($mgCaCO_3/L$)	221.4±2.0	213.1±3.9	221.5±2.0	227.8±2.8	227.4±3.1	227.2±3.8	232.1±2.3	229.1±1.8
TAN-N (mg/L)	0.003±0.000^{a}	0.404±0.035^{b}	0.277±0.0024^{c}	0.207±0.033^{c}	0.160±0.025^{d}	0.162±0.025^{d}	0.206±0.016^{c}	0.143±0.012^{e}
Nitrite-N (mg/L)	0.067±0.003^{a}	0.300±0.008^{b}	0.095±0.008^{c}	0.128±0.005^{d}	0.037±0.003^{e}	0.060±0.003^{a}	0.070±0.003^{a}	0.072±0.004^{a}
Nitrate-N (mg/L)	4.948±1.556^{a}	6.803±0.060^{b}	6.275±0.409^{c}	6.619±0.250^{b}	5.343±0.579^{a}	4.345±0.361^{d}	3.233±0.187^{e}	4.877±0.472^{a}
COD (mg/L)	2.10±0.23^{a}	4.73±0.17^{b}	3.06±0.56^{cd}	3.45±0.21^{c}	2.59±0.19^{d}	2.06±0.24^{a}	2.88±0.90^{d}	3.37±0.72^{c}

Different letters on the same row represent significant differences between groups at equivalent days (P < 0.05).

(SGR), feed conversion ratio (FCR) and survival were expressed in <Tables 3~7>.

At the beginning of the experiment, the average weights of *C. carassius* and *C. carpio* were some heavier than *O. niloticus* and *S. asotus*, and in the end, there were statistical difference for different species in different treatments, with a combination effect on growth. *S. asotus* final average weights varied from 160.6 g (B3 group) to 289.0 g (C6 group) (<Table 3>). In control group (A1-4 groups), *S. asotus* got a final average weight of 183.5 g, which was higher than treatment in combination with *C. carassius* (160.6-181.5 g), but lower than the left polyculture treatments (206.7-289.0 g). Final average weight of *C. carassius* varied from 42.1 g (C3 group) to 69.6 g (A2 group) (P < 0.05), the highest final average weight was got in monoculture treatment. Final average weight of *C. carpio* in three species polyculture were some higher than in two species polyculture, and ranged from 125.2 g (B5

<Table 3> Growth results of initial (IBW) and final body weight (FBW) in mono and polyculture of four species

Fish species		Groups																	
		A1	A2	A3	A4	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4	C5	C6	C7	C8
S. asotus	IBW	13.1±1.6^{a}				13.4±1.3^{a}	13.6±1.7^{a}	12.5±0.9^{a}	12.9±1.2^{a}	13.3±1.6^{a}	13.8±1.1^{a}	12.9±0.8^{a}	13.6±1.3^{a}	13.2±1.0^{a}	13.2±1.1^{a}	13.9±0.9^{a}	13.8±1.7^{a}	13.9±1.2^{a}	13.9±1.3^{a}
	FBW	183.5±33.5^{a}				177.3±43.2^{a}	181.5±32.8^{a}	160.6±23.5^{b}	221.1±41.2^{ac}	244.1±24.8^{c}	206.7±36.4^{ac}	255.9±25.7^{c}	247.5±32.5^{c}	222.3±31.4^{ac}	212.6±45.6^{ac}	239.0±27.1^{c}	289.0±41.5^{d}	220.2±26.8^{ac}	240.5±36.9^{c}
C. carassius	IBW		22.2±2.1^{a}			21.3±3.0^{a}	27.8±2.2^{b}	27.0±3.1^{b}				21.3±1.9^{a}	26.0±2.9^{b}	21.1±2.2^{a}	20.6±1.1^{a}				
	FBW		69.6±14.8^{a}			48.0±15.1^{b}	53.3±14.1^{b}	54.2±14.7^{b}				49.3±21.6^{b}	53.0±22.2^{b}	42.1±11.4^{b}	45.3±11.8^{b}				
C. carpio	IBW			23.0±1.6^{a}					22.08±2.8^{a}	20.61±1.6^{a}	22.76±2.6^{a}					22.7±2.2^{a}	19.5±1.9^{a}	22.1±2.8^{a}	22.4±2.6^{a}
	FBW			139.1±28.2^{a}					138.4±23.8^{a}	125.2±15.6^{a}	141.0±33.6^{a}					175.9±21.5^{b}	153.3±32.1^{ab}	168.6±33.4^{ab}	166.5±27.2^{ab}
O. niloticus	IBW				17.5±1.2^{a}							17.2±0.8^{a}	16.5±1.6^{a}	15.9±1.2^{a}	16.5±1.1^{a}	16.7±0.9^{a}	16.3±1.0^{a}	17.5±1.0^{a}	17.4±1.2^{a}
	FBW				132.6±18.4^{a}							117.6±20.9^{ab}	113.4±31.6^{ab}	122.5±24.0^{ab}	110.4±21.7^{b}	119.7±28.7^{ab}	129.2±19.5^{ab}	126.8±23.1^{ab}	113.0±21.2^{ab}

Different letters on the same row represent significant differences between groups at equivalent days (P < 0.05).

<Table 4> Results of growth rate (%) in mono and polyculture of four species

Fish species	Groups																	
	A1	A2	A3	A4	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4	C5	C6	C7	C8
S. asotus	1302.4± 154.5^{a}				1225.5± 172.4^{ab}	1239.6± 163.4^{ab}	1182.4± 127.6^{b}	1610.8± 173.6^{c}	1732.9± 111.4^{cd}	1394.7± 136.2^{a}	1886.8± 117.7^{de}	1722.4± 119.8^{cd}	1580.3± 113.3^{c}	1509.3± 171.9^{ac}	1624.1± 127.1^{c}	1997.1± 136.6^{e}	1482.9± 109.6^{a}	1631.2± 199.2^{c}
C. carassius		213.6± 42.1^{a}			125.7± 30.7^{b}	91.5± 20.7^{c}	100.5± 24.6^{bc}				131.5± 31.4^{b}	104.1± 23.1^{bc}	99.7± 24.2^{bc}	120.4± 17.6^{b}				
C. carpio			504.4± 43.4^{a}					526.7± 52.9^{a}	507.6± 42.7^{a}	519.4± 57.9^{a}					676.2± 40.1^{b}	684.6± 32.2^{b}	664.2± 44.0^{b}	644.8± 45.7^{b}
O. niloticus				658.1± 57.0^{a}							583.2± 46.6^{b}	586.4± 42.6^{b}	669.9± 39.1^{a}	569.9± 53.2^{b}	615.5± 48.9^{ab}	693.5± 33.8^{a}	626.2± 55.6^{a}	549.2± 45.3^{b}

Different letters on the same row represent significant differences between groups at equivalent days ($P < 0.05$).

<Table 5> Results of specific growth rate (SGR) in mono and polyculture of four species

Fish species	Groups																	
	A1	A2	A3	A4	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4	C5	C6	C7	C8
S. asotus	2.6± 0.4				2.5± 0.3	2.5± 0.3	2.5± 0.4	2.8± 0.3	2.8± 0.4	2.7± 0.3	3.0± 0.3	2.9± 0.3	2.8± 0.5	2.7± 0.3	2.8± 0.5	3.0± 0.3	2.7± 0.4	2.8± 0.4
C. carassius		1.1± 0.4			0.8± 0.4	0.7± 0.3	0.7± 0.3				0.8± 0.3	0.7± 0.4	0.7± 0.3	0.8± 0.3				
C. carpio			1.8± 0.4					1.8± 0.3	1.8± 0.3	1.8± 0.2					2.1± 0.3	2.1± 0.4	2.0± 0.3	2.0± 0.4
O. niloticus				1.9± 0.4							1.8± 0.4	1.8± 0.4	2.0± 0.4	1.8± 0.4	1.9± 0.4	2.0± 0.4	1.9± 0.4	1.9± 0.4

Different letters on the same row represent significant differences between groups at equivalent days ($P < 0.05$).

group) to 175.9 g (C5 group) ($P > 0.05$). *O. niloticus* had higher final average weight in combination with *S. asotus* and *C. carpio* than those in combination with *C. carassius* and *S. asotus*.

Considering the GR (<Table 4>), for *S. asotus* the growth rate of control group was lower than the polyculture groups. The highest GR was got in C6 group, and the final average weight was about 20 times the initial average weight. But for *C. carassius* the situation was reverse, the GR of control group was higher than polyculture groups. And among different polyculture treatments there were no significant difference ($P > 0.05$). For *C. carpio* the GR of three species polyculture was obviously higher than two species polyculture and monoculture ($P < 0.05$), and there was no difference between monoculture and two species polyculture and among different treatments in two species polyculture ($P > 0.05$). *C. carpio* got the highest GR in C6 group. There were no significant difference for *O. niloticus* in different treatments ($P > 0.05$), however, the highest GR was got in C6 group.

The SGR for *S. asotus*, *C. carassius*, *C. carpio* and *O. niloticus* varied from 2.6-3.0, 0.7-1.1, 1.8-2.1 and 1.9-2.1, respectively (<Table 5>). The SGR of *S. asotus* in C6 was obviously higher than in monoculture and polyculture with *C. carassius* ($P < 0.05$). There was no obvious difference between monoculture and two species polyculture ($P < 0.05$). However in three species polyculture especially in group C6, the SGR was higher than that in monoculture and two species polyculture ($P < 0.05$). There was no obvious difference for the SGR of *O. niloticus* in monoculture and different polyculture treatments ($P > 0.05$).

The FCR of A1 group was significantly lower than all the other treatments (<Table 6>). But for the other three monoculture groups A2, A3 and A4, the FCR were higher than polyculture groups, ranged 1.6, 1.3 and 1.1 respectively. No significant differences were found among different polyculture treatments ($P > 0.05$), and the values ranged from 0.9 to 1.1.

In relation to survival (<Table 7>), *C. carpio* had a lower survival in all treatments than the other species, ranged from 76.0% (C8 group) to 98.0% (A3 group), showed an obvious variability among different treatments, the average survival was lower in three species combination than that in two species combination. The reason of the low survival was not very clear now. Survival of the other species showed acceptable results. *S. asotus* and *C. carassius* survival varied from 92.4-100.0%, 88.5-98.1%, respectively. And for *O. niloticus* the survival rate was especially high, there's no death in most treatments except in A4 and C6 group.

Ⅳ. Discussion

Ammonia is another factor that may affect fish production. Deterioration of water quality restricts the amount of feed that can be applied and the rate of fish production in many aquaculture production systems. At high feeding rates, fish production maybe limited by unionized ammonia concentration if the assimilative capacity of the culture system for nitrogen is exceeded (Knud-Hansen et al., 1991). Exposure of fish to sublethal ammonia concentrations induces physiological, biochemical and behavioral

<Table 6> Results of feed conversion ratio (FCR) in mono and polyculture of four species

<table>
<tr><th rowspan="2">Fish species</th><th colspan="18">Groups</th></tr>
<tr><th>A1</th><th>A2</th><th>A3</th><th>A4</th><th>B1</th><th>B2</th><th>B3</th><th>B4</th><th>B5</th><th>B6</th><th>C1</th><th>C2</th><th>C3</th><th>C4</th><th>C5</th><th>C6</th><th>C7</th><th>C8</th></tr>
<tr><td>S. asotus</td><td>0.8± 0.2^{a}</td><td></td><td></td><td></td><td rowspan="4">1.1± 0.2^{a}</td><td rowspan="4">0.9± 0.1^{a}</td><td rowspan="4">0.9± 0.2^{a}</td><td rowspan="4">1.0± 0.1^{a}</td><td rowspan="4">0.9± 0.1^{a}</td><td rowspan="4">0.9± 0.2^{a}</td><td rowspan="4">0.9± 0.2^{a}</td><td rowspan="4">1.0± 0.1^{a}</td><td rowspan="4">0.9± 0.1^{a}</td><td rowspan="4">0.8± 0.2^{a}</td><td rowspan="4">1.0± 0.2^{a}</td><td rowspan="4">1.0± 0.1^{a}</td><td rowspan="4">1.0± 0.2^{a}</td><td rowspan="4">0.9± 0.2^{a}</td></tr>
<tr><td>C. carassius</td><td></td><td>1.6± 0.3^{b}</td><td></td><td></td></tr>
<tr><td>C. carpio</td><td></td><td></td><td>1.3± 0.2^{ab}</td><td></td></tr>
<tr><td>O. niloticus</td><td></td><td></td><td></td><td>1.1± 0.1^{a}</td></tr>
</table>

Different letters on the same row represent significant differences between groups at equivalent days ($P < 0.05$).

<Table 7> Results of survival(%) in mono and polyculture of four species

Fish species	Groups																	
	A1	A2	A3	A4	B1	B2	B3	B4	B5	B6	C1	C2	C3	C4	C5	C6	C7	C8
S. asotus	97.1± 1.2^{a}				97.1± 1.6^{a}	100.0± 0.0^{a}	92.4± 2.6^{b}	100.0± 0.0^{a}	96.1± 1.8^{a}	97.0± 1.2^{a}	100.0± 0.0^{a}	100.0± 0.1^{a}	93.9± 1.3^{b}	96.5± 1.6^{a}	100.0± 0.1^{a}	96.2± 1.0^{a}	97.2± 1.6^{a}	98.2± 2.6^{a}
C. carassius		100.0± 0.0^{a}			93.9± 2.6^{ab}	96.3± 1.2^{a}	94.1± 2.1^{ab}				96.1± 1.3^{a}	98.1± 1.1^{a}	93.9± 1.0^{ab}	88.5± 2.0^{b}				
C. carpio			98.2± 0.6^{a}					92.4± 1.3^{a}	86.6± 2.3^{ab}	91.2± 1.3^{a}					96.2± 1.5^{a}	82.6± 1.5^{b}	90.9± 2.1^{a}	76.1± 3.1^{b}
O. niloticus				98± 0.5							100.0± 0.0	100.0± 0.0	100.0± 0.1	100.0± 0.1	100.0± 0.1	96.0± 1.1	100.0± 0.1	100.0± 0.1

Different letters on the same row represent significant differences between groups at equivalent days ($P < 0.05$).

responses (Rand and Petrocelli, 1985). Collectively, these responses are more likely to suppress growth and immuno-competence rather than cause mortality. The 96-hour LC_{50} for un-ionized ammonia nitrogen to various species of fish range about 0.4-3.1 mg/L (Sampath et al., 1991).

During three months growing time, the GR of *S. asotu*s was especially high, and had the lowest feed conversion ratio. This was in relation to its fast growth characteristic, greedy and competitive. Though treatment A1 (monoculture of *S. asotus*) had the highest yield, the GR, SGR and final average weights were lower compared to polyculture treatments (except in combination with *C. carassius*). That's maybe because in monoculture the intraspecific competition was more fiercely than the interspecific competition in polyculture. In fact, *S. asotus* can affect the fish communities considerably, it was usually used as a controller of other fishes' overbreeding when introduced into polyculture, e.g, in Japan it has been used as a potential biological control of bluegill, *Lepomis macrochirus Rafinesque* (Osamu et al., 2003). But when it fed enough, it was not threaten to other species. And the growth was better in polyculture than in monoculture except in combination with *C. carassius*.

The growth of *C. carpio* was better in three species polyculture than that in two species polyculture and monoculture. And there was no obvious difference between two species polyculture and monoculture. The introduction of *O. niloticus* seems had improved *C. carpio*'s growth (compare the growth rate of *C. carpio* in B4~6 and C5~8 of Table 4). This was consistent with the report that *C. carpio* achieved best performance in the presence of *O. niloticus* (Papoutsoglou et al., 1991), also verified that *C. carpio* and *O. niloticus* achieved better results when cultured together than when cultivated in monoculture system. As reviewed by Kestmont (1995), the association of *C. carpio* and *O. niloticus* may increase the growth of *C. carpio*. In polyculture systems, only a proper combination of ecologically different species, at adequate densities, will utilize the available resources efficiently due to the maximization of synergistic fish-fish relationships and minimization of antagonistic ones (Milstein, 1992).

In this study, the growth of *C. carassius* was very slow. The biggest final average weight was 69.6 g, gained in monoculture treatment, much lower than the other species, this maybe relating to its high feed conversion ratio. And the growth was especially bad in polyculture. Considering the stocking ratio and combinations, C6 group (*C. carpio* 50, *S. asotus* 25, *O. niloticus* 25) had the best growth parameters. The three species all got the highest SGR and GR value in this treatment, but the mortality was some high. Therefore it still needs further verification whether it really can improve growth.

Ⅴ. Conclusions

In this study, the growth of *C. carassius* was very slow. The biggest final average weight was 69.6 g, gained in monoculture treatment, much lower than the other species, this maybe relating to its high feed conversion ratio. And the growth was especially bad in polyculture. The combination with other species inhibited its growth seriously. This maybe because C. carassius was inward a growing slowly and mild species, it couldn't compete with the other species for food. It was not an appropriate species for polyculture in this experiment. The introduction of *O. niloticus* in three species polyculture had improved *C. carpio* growth a lot. There seemed to be a synergistic relationship between *C. carpio* and *O. niloticus*.

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• Received : 03 February, 2021
• Revised : 30 March, 2021
• Accepted : 21 April, 2021