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Rearing of European catfish (*Silurus glanis* L.) in earthen ponds in polyculture with common carp larvae (*Cyprinus carpio* L.)

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Abstract: The aim of the present study is the production of stocking material of European catfish (*Silurus glanis* L.) using common carp larvae (*Cyprinus carpio* L.) as natural food source. The experiment was carried out in two earthen ponds (№18 and №19). The stocking material was produced through semi-artificial reproduction of European catfish and natural reproduction of common carp in two stages. The main aquaculture production indicators of the stocking material of European catfish and common carp were calculated: growth (WG, g), survival (%), total yield (kg) and average yield (kg/1000 m^2). The obtained results show that the growth of European catfish in pond №19 is 69.67 g, while in pond №18 it is 58.91 g. Also, the survival rate in pond №19 is 2.8 times higher than in pond №18. After analyzing the obtained results, it can be concluded that the production indicators of the European catfish stocking material are higher in experimental pond №19.

Keywords: European catfish (*Silurus glanis* L.); ponds; polyculture; carp (*Cyprinus carpio* L.)

INTRODUCTION

European catfish (*Silurus glanis* Linnaeus, 1758) is one of the most valuable predatory fish species (Linhart et al., 2002). In fish farms, it can be used as an ameliorator as it willingly eats weed fish and unwanted offspring resulting from carp (*Cyprinus carpio*) rearing (Zaikov et al., 2008; Woynarovich et al., 2010; Pronina et al., 2022).

European catfish is also an important species for aquaculture in temperate climates. At present, its production relies mainly on pond aquaculture. However, European catfish could be a promising candidate for intensive aquaculture since it has a high growth rate on commercial diet, it is resistant to handling and has relatively low requirement for water quality (Szabó et al., 2015).

Polyculture is a potentially interesting rearing practice for future aquaculture developments. Nevertheless, it may result in beneficial as well as detrimental consequences for fish production. One way to maximize the benefits of polyculture is to combine species with high levels of compatibility and complementarity (Amoussou et al., 2022).

The efficiency of growing European catfish in polyculture, in particular with sturgeon has been established by several studies. Ulikowski et al. (2003) found that the weight gain when these fish are reared together is higher than in a monoculture of each species. Good results have been etsbalished also by Mihoc et al. (2021) when rearing sterlet (*Acipenser ruthenus*) fingerlings and European catfish in recirculating aquaculture systems (RAS).

Another interesting and important aspect to consider in European catfish aquaculture is the role of intestinal microbiota. The gut microbiota plays a vital role in nutrient digestion and absorption, immune system development, and the overall health of the fish. Recent studies have demonstrated the potential for manipulating the gut microbiota to improve fish growth, disease resistance, and overall performance (Barbacariu et al., 2023).

Very few studies have been conducted regarding the production parameters of *S. glanis* reared in polyculture with other fish species. The aim of the present experiment is to determine the main fish production parameters of European catfish reared in polyculture with common carp.

MATERIAL AND METHODS

European catfish larvae

Semi-artificial reproduction of European catfish was carried out in two stages. For the stimulated maturation of the sexual products, carp pituitary was used at doses of 3 mg/kg live weight for male fish and 6 mg/kg for female fish.

Semi-artificial reproduction of European catfish - Stage 1 and Stage 2

On 17th of May 2022, the female fish were injected and after 12 hours - the male fish. Afterwards, the fish were transferred for breeding in hatchery pond №3. On 19th of May 2022, 28-30 hours after the collection of the male and female catfish in the designated sectors, the pyramid nests were removed and the eggs stuck to the substrate were incubated in industrial tubs with a capacity of 3 m^3. The incubation lasted for 50-55 hours at an average water temperature of 23°C. On 21st of May 2022, the first hatched larvae were observed. On the second day, the larvae were fed with natural food from freshwater crustaceans of the species *Artemia salina* and cyclops from the family Cyclopidae, genus *Cyclops*.

The rearing of the European catfish larvae in the industrial tubs continued for 10 days, starting from 23rd of May to 1st of June 2022. Their biometric data is listed in Table. 1. On 2nd of June 2022, experimental pond №18 (area – 1 800 m^2) was stocked with European catfish larvae at a density of 3000 ind/1000 m^2 or a total of 5 400 larvae.

The hormonal stimulation of the catfish from the second round takes place on 25th and 26th of May, 2022. The methodology used for the semi-artificial reproduction of European catfish is the same as in the first round. On 11th of June 2022, experimental pond №19 (area – 1 600 m^2) was stocked with 10 day-old larvae of European catfish (Table 1) at a density of 3 000 ind/1 000 m^2 or a total of 4 800 larvae.

Natural reproduction of *Cyprinus carpio*

The natural reproduction of the common carp is synchronized with the semi-artificial reproduction of the European catfish. It is also performed in two stages, so that on the day of the injection of the female catfish, the carp broodstock is imported for natural reproduction in the corresponding experimental ponds. The female-to-male ratio is 1:2, with 8 female and 16 male fish introduced in pond №18, and 6 female and 12 male fish in pond №19. presents The biometric data of common carp larvae, in experimental ponds №18 and

Table 1. Initial body weight (BW, g) and initial total length (TL, cm) of European catfish larvae during their stocking in experimental ponds №18 and №19

Experimental pond №18 (02.06.2022)		
	BW, g	**TL, cm**
ave±sd	0.03±0.01	1.45±0.21
min - max	0.02-0.06	0.96-1.77
Experimental pond №19 (11.06.2022)		
ave±sd	0.06±0.02	1.52±0.13
min - max	0.03-0.09	1.24-1.74

Table 2. Initial body weight (BW, g) and initial total length (TL, cm) of common carp larvae from experimental ponds №18 and №19

Experimental pond №18 (02.06.2022)		
	BW, g	**TL, cm**
ave±sd	0.05±0.01	1.57±0.12
min – max	0.03-0.07	1.38-1.75
Experimental pond №19 (11.06.2022)		
ave±sd	0.06±0.03	1.63±0.19
min – max	0.02-0.17	1.34-2.03

pond №19 on the date of the stocking with European catfish larvae, is presented in Table 2.

Hydrochemical monitoring

The main physicochemical parameters temperature (T, °C), dissolved oxygen (O_2, mg/l^{-1}), pH and electrical conductivity (µS/cm) were measured every week in the two experimental ponds. The sampling started from the first week of the stocking of the ponds and continued until the final catch.

Water temperature (T,°C) – determined using a thermometric method with a microprocessor oximeter, type WTW 315 (SET (BSS 17.1.4.01-77));

Dissolved oxygen, mg.l^{-1} – electrochemical method with a microprocessor oximeter, type WTW 315 (SET (BSS EN 25814-2002));

pH – electrometric method with a pH meter, type WTW 315 (SET (BSS 3424-81, ISO 10523, 1994));

Electrical conductivity, µS.cm^{-1} – BSS EN 27888

Control and final catch of European catfish and common carp stocking material

On 13th of September 2022, a control catch was carried out in experimental ponds №18 and №19 with a net with a mesh size of 12 mm. 30 fish of each species from both experimental ponds were measured in the field After the measurements, the fish were released back into the ponds. Data from the control catch were used to calculate the absolute growth (WG, g; TL, cm) of the stocking material of European catfish and common carp to the specified date.

On 27th of October 2022, the final catch was held in experimental pond №18, and on 4th of November 2022 - in experimental pond №19. The stocking material of catfish and carp was sorted into two separate portable water containers. 50 fish from both stocking material were measured in the field.

Fish production parameters

The following basic fish farming parameters of European catfish and carp stocking material were determined:

Absolute weight gain (WG, g): WG $=\mathbf{Wt_2}$**-**$\mathbf{Wt_1}$ where:

Wt_1= average initial weight of the fish (g);

Wt_2 = average final weight of the fish (g);

Linear growth (TL, cm): TL = TL_2 – TL_1, where:

TL_2= initial total length of the fish (cm);

TL_1= final total length of the fish (cm);

Survival rate (SR, %): SR = $\frac{NF}{NI} \times 100$, where:

NF = final number of fish;

NI = initial number of fish;

Total yield (kg) = number of fish*average weight (kg)

Average yield (kg/1000 m²) = total yield (kg)/ pond area (m²)

RESULTS AND DISCUSSION

Absolute weight gain and linear growth (control catch)

The results from the control catch, for weight gain (WG, g) and linear growth (TL, cm) of European catfish and common carp, are presented in Fig. 1 and in Fig. 2, respectively.

The absolute weight gain of catfish in pond №18 is 2.87 g higher than in pond №19. This result is due to the fact that pond №18 is stocked with European catfish larvae 8 days earlier than pond №19. At the same time the average initial weight of the European catfish larvae at the time of the stocking of pond №18 is 0.03 g, and in pond №19 – 0.06 g. The slightly lower initial weight of the European catfish larvae in pond №18 is compensated by the longer rearing period and probably by the better nutritional base at the time of the control catch.

Absolute weight gain and linear growth (final catch)

In contrast to the control catch, where the weight gain of European catfish in pond №18 is higher, during the final catch it is recorded that the weight gain in pond №19 is 10.76 g higher compared to pond №18 (Fig. 3). It is estimated that the European catfish from pond №19 fulfill

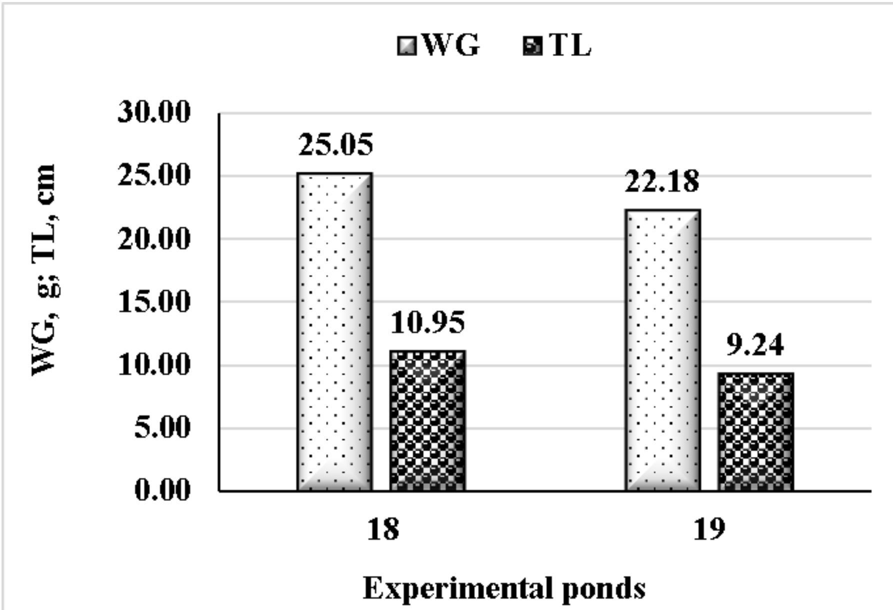

Figure 1. Absolute weight gain (WG) and linear growth (TL) of European catfish from experimental ponds №18 and №19.

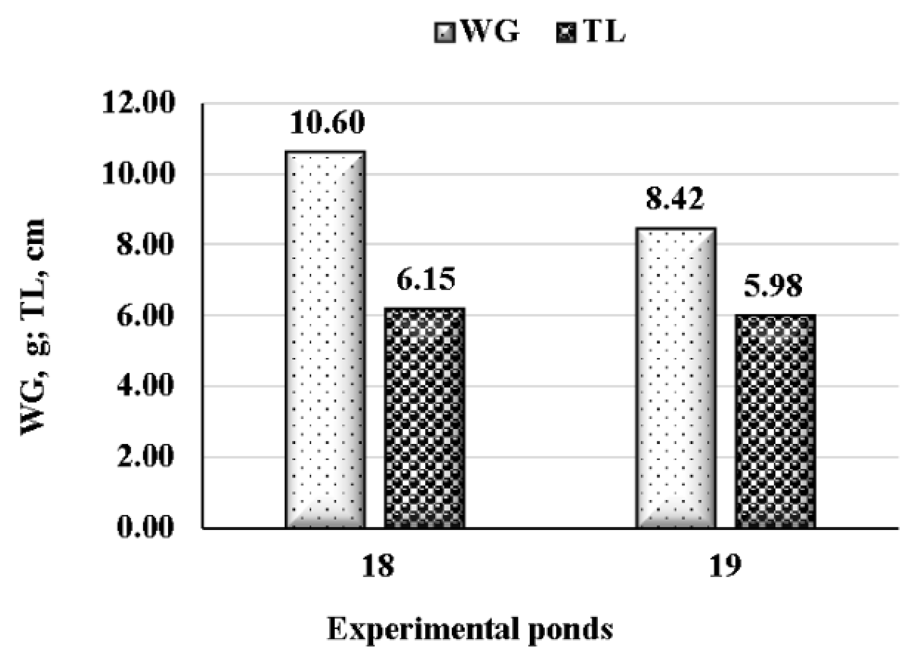

Figure 2. Absolute weight gain (WG) and linear growth (TL) of common carp from experimental ponds №18 and №19.

68% of their growth in the period from the control catch to the final catch or for a period of a month and a half.

For the entire study period the established weight gain of carp stocking material is higher in experimental pond №18 compared to experimental pond №19. The common carp in pond №18 registered an increase of 19.73 g, which is 7.26 g more compared to pond №19.

Survival rate, % (experimental pond №18)

Survival rate is one of the most important indicators in European catfish rearing, especially in the initial stages of its development. It directly affects not only the other fish farming results, but also the economic efficiency. Its values depend on many factors, such as natural food base, diseases, hydrochemical regime, cannibalism, feeding difficulties, etc. This metric varies widely and often the results are contradictory.

Common carp stocking material

With the natural reproduction of carp in the hatching ponds, no survival rate can be determined, because the initial data on the number of

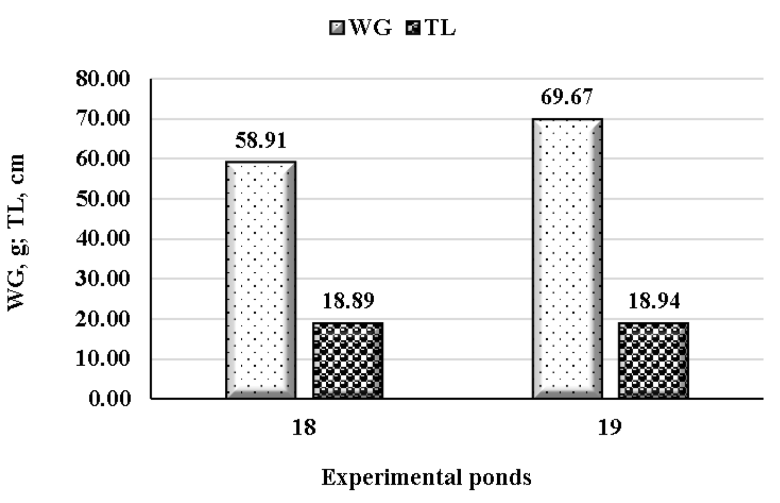

Figure 3. Absolute weight gain (WG, g) and linear growth (TL, cm) of European catfish for the entire rearing period in experimental ponds №18 and №19.

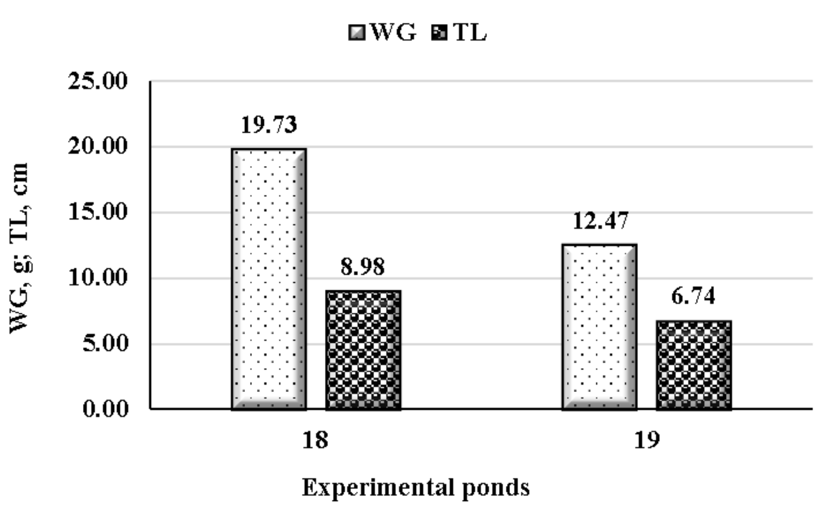

Figure 4. Absolute weight gain (WG, g) and linear growth (TL, cm) of common carp for the entire rearing period in experimental ponds №18 and №19.

hatched carp is unknown, which is why just the final number of carp is taken into account.

When performing the final catch of the experimental pond №18 on 27th of October, 2022, 3 580 carp larvae are established.

European catfish stocking material

The established survival rate of European catfish stocking material in experimental pond №18 is 1.3% or 70 specimens in stocking of 5 400 larvae on 2nd of June 2022 with stocking density 3 000 ind/1 000 m^2.

Survival rate, % (experimental pond №19)

Common carp stocking material

During the final catch of experimental pond №19, 1 420 carp stocking material was recorded. A reason for the greater final number of carp in pond №18 (3 580) is also the fact that there are more broodstocks than in pond №19.

European catfish stocking material

The established survival rate of European catfish stocking material in experimental pond №19 is 3.6% or 172 specimens, with 4 800 larvae stocked on 11th of June, 2022, at 3000 ind/1000 m^2 stocking density.

The survival rate of European catfish stocking material in pond №19 is almost 3 times higher than in pond №18, which is due to the lower final number of carp. This is because the catfish consumed more carp, resulting in higher growth and survival of the former compared to pond №18. In pond №18, the final number of carp was higher by 2 162 individuals, and the survivability of catfish is 2.7 times lower compared to pond №19. These results show that the conditions in pond №18 are more favorable for the stocking material of carp, which developed faster than the population of European catfish stocking material.

Total yield (kg) and average yield (kg/1000 m²)

The total yield of carp in experimental pond №18 is 71.13 kg, while in pond №19 it is only 17.79 kg, with this indicator depending on the final number of fish, which in pond №18 is 2.5 times more. The total yield of catfish in pond №19 is three times more compared to the total yield of catfish in pond №18, which is also related to their higher survival rate in pond №19 – 3.6% compared to 1.3% in pond №18 (Table 3).

The average yield is determined by the total yield and the pond area and it is following the same trend as the total yield results. The average yield of carp stocking material in pond №18 is 3.6 times higher compared to pond №19. The average yield of European catfish stocking material in experimental pond №19 is three times higher compared to pond №18. The total yield of stocking material from experimental pond №19 is 29.78 kg, while from pond №18 it is 2.5 times higher - 75.26 kg. The higher total yield of catfish in the pond №19 is due to the lower total yield of carp. This is because the latter served as a natural food source for the European catfish stocking material.

The data on production parameters of *S. glanis* reared in ponds in polyculture is scarce as most studies involve rearing of the species in RAS.

Zoltán et al. (2020) investigated the effect of two different rearing technologies (monoculture (M), intensive-extensive pond system (I-E)) on the production traits, water and sediment quality in case of European catfish. During a 153 days long trial two years old European

Table 3. Total yield (kg) and average yield (kg/1000 m²) of European catfish and common carp stocking material from experimental ponds №18 and №19

Experimental pond №18, area 1 800m²		
Stocking material	**Total yield (kg)**	**Average yield (kg/1000 m²)**
Common carp (K0)	71.13	39.52
European catfish (C0)	4.13	2.29
Total (K0+C0)	75.26	41.81
Experimental pond №19, area 1 600 m²		
Stocking material	**Total yield (kg)**	**Average yield (kg/1000 m²)**
Common carp (K0)	17.79	11.12
European catfish (C0)	11.99	7.50
Total (K0+C0)	29.78	18.62

catfish (mean individual weight of 485.7±3.4 g) and common carp (mean individual weight of 348.9±2.5 g) were stocked into the experimental system. Final mean weight of the fish were as follows: 1932.9±194.5 g (European catfish) and 2266.9±87.56 g (common carp). No significant differences were observed in the production traits. Specific growth rate (SGR) was lower (0.9±0.1%/day) than expected. Significant differences were found in nitrate-N, nitrite-N, orthophosphate and total suspended solids content. Significant decrease was observed in the Kjeldahl-N and phosphate content of sediment in the extensive-intensive combined system. These results suggest that transformation of the nutrients in the combined system exceeds that of monoculture; significant amount of organic N and P compounds were removed and accumulated in the additional common carp yield.

Ulikowski et al. (2003) conducted an experiment on intensive monoculture and polyculture of wels catfish and sturgeon in ponds. The initial average body weight of the fish in monoculture and polyculture was similar - wels catfish approximately 100 g; sturgeon - approximately 720 g, and the biomass was equal in each pond (approximately 30.7 kg). The fish were fed trout granulate for two months. The final survival rate was the same in both the monoculture and polyculture (wels catfish - 99.5%; sturgeon - 100%). Statistically significant differences ($p < 0.05$) were observed between the fish growth in monoculture and polyculture. Wels catfish grew faster in polyculture, with an average body weight of 349.1 g and a specific growth rate (SGR) of 2.0 % day^{-1} . In monoculture these figures were 276.1 g and 1.6% day^{-1} , respectively. Sturgeon grew faster in monoculture, with an average body weight of 1229.2 g, and an SGR of 0.86 % day^{-1}, while in polyculture these values were 854.2 g and 0.28 % day^{-1}, respectively. The intensive cultivation of wels catfish with sturgeon in pond polyculture influenced their growth, but not survival rates.

Mihoc et al. (2021) evaluated the effects of polyculture of the sterlet (*Acipenser ruthenus*) fingerlings with european catfish (*Silurus glanis*) (20 – 30%) into recirculating aquaculture system on growth dynamic of the fish and tank's bioproductivity. Two variants of polyculture have been tested during a period of 42 days in duplicate: V1-sterlet with 20% catfish (600 sterlets and 120 catfish); V2-sterlet with 30% catfish (600 sterlets and 180 catfish). The control group (C) contains sterlet in monoculture (600 sterlets). After 42 days of polyculture of the sterlet fingerlings with catfish 20% (V1) or 30% (V2) there were no significant differences ($p>0.05$) in sterlets' growth dynamic among the three variants. The bioproductive indices were better in the polyculture variant where sterlets were farmed with 30% catfish. The authors state that polyculture of catfish and sterlet could be a good way to positively influence the fingerling sterlet farming in RAS, having a beneficial impact on tank's bioproductivity. A significant plus of fish biomass (catfish) resulted by means of valorisation of the unconsumed food by the sterlet, was obtained in both polyculture variants.

Mihailov et al. (2017) studied two polyculture variants of the pikeperch, with European catfish and with sterlet, in order to emphasize the best candidate species for polyculture in RAS. The pikeperch and sterlet fingerlings used in our study have been obtained in RAS, in the spring of the year 2017, from broodfish exclusively reared in RAS. When the study starts, the fish were 6 months and 5 months old, for pikeperch and sterlet, respectively. The European catfish fingerlings have been obtained through artificial method using broodfish from ponds, and reared in RAS until the age of 4 months, when our study starts. The RAS used for the fish rearing had four tanks, with 1 cubic meter of water each. Two variants of polyculture have been tested in 2 replicates: pikeperch with sterlet, and pikeperch with European catfish. The fish biomass of the additional species represented about 21% from the pikeperch biomass in each variant. The fish were fed with dry feed SUPREME-10, size 3mm (Coppens International, Nederland). The main body traits (total length, standard length, maximum high and body weight) were measured and based on the data obtained after the them, the main bio productive indices were calculated. The authors established that weight gain (WG), specific growth rate (SGR) and daily growth rate (DGR) reveal superior values in pikeperch fingerlings from V1 (in polyculture with European catfish) comparing with V2 (in polyculture with sterlet). The catfish juveniles in V1 significantly increased ($p \leq 0.001$) their individual BW becoming almost double in 4 weeks, better than sterlet fingerlings in V2, with a BW growing of about 41% in the same period. The authors established better growing of the European catfish in polyculture with pikeperch has been reflected by the fish biomass too, this being higher in V1 than in V2. Mihailov et al. (2017) conclude that polyculture of the pikeperch with European catfish seems to be more advantageous than the polyculture of the pikeperch with starlet.

CONCLUSIONS

In experimental pond №19, the weight gain of European catfish stocking material was 69.67 g, while in pond №18 it was 58.91 g. The survival rate in pond №19 was 3.6% compared to 1.3% in pond №18. The total yield of European catfish in pond №19 is 11.99 kg, while in pond №18 it is 4.13 kg.

After analyzing the obtained results, we can summarize that fish production parameters of European catfish from experimental pond №19 are higher compared to pond №18. The conditions in experimental pond №18 favored the development of the stocking material of common carp, as a result a total yield of 71.13 kg was obtained or 3 580 fish.

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