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GROWTH PERFORMANCE OF THREE FISHES AS COMPARED BETWEEN MONOCULTURE AND POLYCULTURE REARING SYSTEMS UNDER HIGH-ALTITUDE CONDITIONS IN RWANDA

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ABSTRACT

A 240-day experiment was conducted to compare the growth performance of common carp, Nile tilapia, and African catfish reared in monoculture and polyculture conditions at the Rwasave Fish Farming and Research Station, Rwanda. Fish juveniles of 67.00±1.90, 50.00±2.10 and 10.00±1.10 g respectively for common carp, Nile tilapia, and African catfish were randomly distributed and stocked at 400 fish per pond of 200 m^2. Seven experimental variants were undertaken as follows: T1, carp monoculture: T2, tilapia monoculture: T3, catfish monoculture: T4, carp-tilapia polyculture: T5, carp-catfish polyculture: T6, tilapia-catfish polyculture: T7, carp-tilapia-catfish polyculture. The total weight gain (TWG), daily weight gain (DWG), relative growth rate (RGR), specific growth rate (SGR), coefficient of condition (K_m) was calculated during the experimental period. Data were subjected to analysis of variance (ANOVA). Globally, treatment groups in the polyculture showed higher TWG, DWG, RGR, SGR but not significantly different ($p \geq 0.05$) from the monoculture groups. Nevertheless, T7 had higher TWG, DWG, RGR, SGR followed by T6 and T4. The African catfish followed by the common carp demonstrated a better growth performance than the Nile tilapia in T1, T3, T4, T6, T7. SGR and RGR for the African catfish in monoculture and polyculture groups were significantly different ($p \leq 0.05$) from the common carp and the Nile tilapia. The African catfish and the common carp suit to low temperature conditions of high altitude of Rwanda. The polyculture of carp-tilapia-catfish, tilapia-catfish and carp-tilapia can be recommended in the Rwandan aquaculture industry.

Key words: zootechnical parameters, common carp, Nile tilapia, African catfish, Rwandan aquaculture industry

INTRODUCTION

The need for public understanding of critical roles and undisputed values of managing and conserving freshwater and marine resources has become global issues in the face of continued human population growth and dwindling of natural resources (Mengistu and Ayano, 2021). Nowadays, one of the major issues of serious concern which affect most of the sub-Saharan African countries is to ensure food security to the population. The pertinent fact is that the basic needs of man are: food, clothing and shelter. Fisheries and aquaculture play global roles in sustainable balanced food diets; this niche of aquatic resources cannot be overemphasized in human consumptions. The high demand for rich amino acids which are domiciled in fisheries resources necessitated increased demand by the human population for harvesting aquatic food resources.

Rwanda being a landlocked country without lagoon and ocean has extremely low fish consumption; 2.6 kg capita^{-1} year^{-1} (RAB, 2019) in comparison to other countries in the region (East Africa Nations; 5 to 7 kg capita^{-1} year^{-1}). Low fish production in tropical Africa and particularly in Rwanda is the combination of several factors such as the regional overfishing and low level of production from aquaculture. Fish farming is still based on tilapia and African catfish without often much attention to environmental conditions such as low high-altitude temperature that can limit the performance of these species. Aquaculture development is limited by difficult to access seed and feed of high quality, poor technical knowledge, inappropriate production systems, few reared species, very little research, and the cultivation of the two thermophilic fish species; the Nile tilapia

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and the African catfish without much attention to the environmental conditions. Attempts to improve low fish production were made by introducing the rearing of the African catfish without taking into accounts its thermal requirements. In addition, the common carp was introduced a long time ago into certain water bodies but there are no studies on its adaptability to the environmental conditions.

Fish production in Rwanda slightly increased from 41,664 tonnes in 2021 to 43,560 tonnes in 2022, according to a report by the Ministry of Agriculture and Animal Resources. It shows that 4,000 tonnes of fish were produced from fish farming. Importation stands at 15,000 tons of fresh fish annually (RAB, 2019). Low production from aquaculture can be resolved by using fish species adapted to the environmental conditions and the practice of productive systems. The rearing of new species such as carps in this case would be an encouraging initiative and should contribute to the first try of specific diversification of aquaculture activities in Rwanda. The common carp (*Cyprinus carpio*) was introduced for aquaculture in 1960 from Israel (Welcomme, 1988). The species is now found in the Upper Akagera system (Lake Rweru) and is common in Lake Karago (a small highland lake North-East of Gisenyi (De Vos *et al*., 2001). The growth potential of common carp is enormous. In tropical climates, the common carp can reach more than 2.00 kg after one year of rearing. If the water temperature is suitable, its many forms and strains can attain an individual weight of about 0.20-0.30, 1.00-1.20 and 2.50-3.50 kg within about 2-3, 5-7, and 10-14 months, respectively (FAO, 2018). Moreover, in cold environments the common carp could supplant Nile tilapia and the African catfish because it offers ecological tolerances less stringent than these and may ensure better growth and reproduction capacities (FAO, 2006).

In regard to productive systems, the polyculture of compatible fish species is the most favoured fish culture practice which facilitates efficient utilization of all ecological niches within the pond environment enhancing the maximum standing crop. Several studies demonstrated that polyculture in aquaculture presents more advantages than monoculture in regard to productivity and economic profitability (El-Sagheer *et al*., 2008; Muhammad *et al*., 2013; Madhav *et al*., 2018). Hussain *et al*. (2013) stated that there are many fish culture technologies available of which composite fish culture system is the most sustainable fish culture practice. Most of the aquaculture production in Egypt is pond-based using polyculture farming techniques (GAFRD, 2010). Over the years, composite fish culture has been established as a proven technology aimed for obtaining higher yield and return from unit area (Hussein, 2012). Polyculture is one approach to developing aquaculture.

In aquaculture practice, the exotic fishes were introduced for utilization of vacant niche in the native ecosystem and increasing food production (Ma *et al*., 2003). The fish polyculture provides various fish species of different dietetic and organoleptic tests at a same harvest ensuring products comply with organizational and consumer requirements.

The present study was undertaken to determine the fish farming system, the monoculture or polyculture, that offers best growth performance among the common carp through characterization of its production performances and comparing it to the two thermophilic cultivated species' performances (Nile tilapia and African catfish) under the low temperature of high-altitude conditions of Rwanda. Therefore, this study will highlight the culture system and the fish species among the three selected to be recommended to Rwandan fish farmers for more productivity in the aquaculture sector.

MATERIALS AND METHODS

Study Area

This study was conducted at the Rwasave Fish Farming and Research Station (RFFRS) in Huye District, Southern Province in Rwanda. The RFFRS is situated in Rwasave swamp through which a stream after which it is named runs. It is geographically situated at: Latitude: 2°40' South, Longitude: 29°45' East, Altitude: 1625 m above sea level (Figure 1). Annual temperatures of pond water vary from 20 to 25 ºC but sometimes fall and reach 15, even exceptionally 13 ºC at night during dry seasons. Precipitations on the RFFRS are estimated at 1200 mm per year (Bowman, 2000). Moreover, some data on physico-chemical characteristics of ponds of the region of Huye indicate night temperatures of 21.30 to 25 ºC in July and October. Soils at the Rwasave Station are quite acidic, with pH values reported prior to the beginning of experiments in 1995 ranging from 4.5-4.8. Organic matter contents ranged from 0.70-5.10 *t* ha^{-1}, and cation exchange capacity is ranged from 4.5-17.6 meq $100g^{-1}$ (Bowman, 2000).

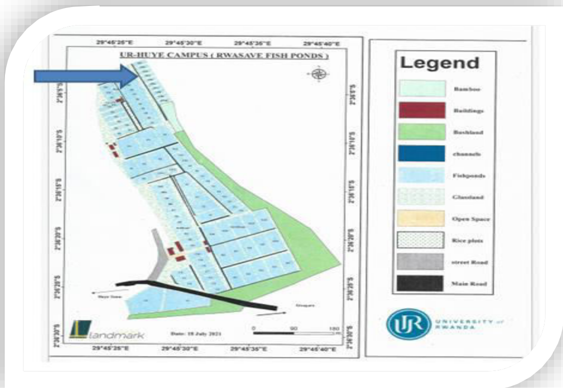

Figure1: Map showing the Rwasave Fish farming and Research Station

Supply of the Stock of Common Carp (*Cyprinus carpio*), Nile Tilapia (*Oreochromis niloticus*) and African Catfish (*Clarias gariepinus*)

To conduct this study, 1200 juvenile carps of 36.00±2.30 g were purchased at IPRC-Musanze Fish Farm in Northern Province of Rwanda. At the RFFRS, fish were acclimatized for two weeks where they reached 67.00±1.90 g before being stocked into the experimental ponds. The Nile tilapia and catfish were collected from pregrowing ponds of the RFFRS where juveniles weighting respectively 50.00±2.1 g and 10.00±1.10 g were collected in ponds.

Fertilization of Ponds

Prior to commencing the experiment, ponds of 200 m^2 each were drained, sun-dried and filled up to a depth of 80-90 cm with water from the peripheral canal. A water level was maintained weekly to compensate for evaporation and seepage losses. Each pond was fertilized with organic fertilizers. In the compost, the cow manure mixed with dried grass were deposited 10 kg are^{-1} at the beginning, and then added 2 kg are^{-1} fortnightly.

Fish Stocking

After the adaptation period, fish were collected, weighted and then randomly distributed and stocked at 400 fish per pond of 200 m^2 that means with the density corresponding to 2 fish m^{-2}. Seven experimental treatments were carried out in two replications. Fish species were reared in monoculture and in polyculture as shown in detail in the experimental design in Table 1.

Pond Fertilization and Feeding

Fish ponds were fertilized by organic fertilizers; cow manures mixed with dried grasses to stimulate the proliferation of phytoplankton. Also, a commercial pellet diet (28% protein content) purchased from HUYE FEEDS Company was supplemented. The diet was manually offered to fish twice daily at 9:00 am and 3:00 pm. The feeding rate varied in the beginning and at the end of the experiment from 2.5 to 1% of the biomass of fish in the pond, respectively.

Control of Physico-Chemical Parameters of Water

In situ: temperature (T°), dissolved oxygen (DO), pH, and turbidity were daily measured respectively with thermometer, oxygen meter, pH meter, and turbidimeter, respectively. In the laboratory every two and half months, the salinity and conductivity were measured by electromagnetic induction method, the total suspended solids (TSS) and total alkalinity (TA) were measured by gravimetric method. The PO_4^{3-}, total ammonia nitrogen (TAN), NO_2^-, and NO_3^- were measured by titrimetric method with spectro-photometry. These physico-chemical parameters were analyzed according to standard methods (APHA, 2017) in the College of Science and Technology Laboratory of the University of Rwanda.

Control of Zootechnical Parameters

Growth parameters

The total weight gain (TWG, g), relative growth rate (RGR, %), daily growth rate (DGR, g day^{-1}) and the specific growth rate (SGR, % day^{-1}) were calculated monthly. For that, 30 fish were randomly captured and their weight measured using a digital electronic weighting scale (IndiaMart, capacity 10 kg). The zootechnical parameters were calculated as follows:

$$\text{TWG (g)} = \text{fW} - \text{iW} \quad (1);$$

$$RGR\ (\%) = [\frac{fW-iW}{iW}] \times 100 \quad (2);$$

$$DGD\ (g\ day^{-1}) = (fW - iW)/\Delta t \quad (3);$$

$$SGR\ \%\ day^{-1} = \left[\frac{InfW-IniW}{\Delta t}\right] \times 100 \quad (4);$$

where *fW* is final and iW is initial body weight.

Coefficient of condition

The weight-length relationship was calculated to characterize the growth conditions. The condition coefficient is a coefficient indicating the physiological status of fish of the same species which points out, notably their health and reproductive capacity. So, the more a fish is heavy for a given length, the higher its condition coefficient. The coefficient of condition was calculated by dividing the weight of a fish by the cube of its total body length (Williams, 2000).

$$K_m = \left(\frac{W}{L^3}\right) \times 100 \quad (5);$$

where *W* is weight (g*) and L* is total length (cm*)*.

Survival rate (%)

Survival rate (SR) was calculated at the end of the 240-day experiment. This parameter was easily determined knowing the initial number of fish stocked in ponds and the number of fish harvested at the end of the experiment.

$$SR\ (\%) = (\frac{fN}{iN}) \times 100 \quad (6);$$

where *fN* is final number of fish stocked and *iN* is initial number of fish stocked.

Feed Utilization Parameters

Feed intake (FI), feed conversion efficiency (FCE) and feed conversion ratio (FCR) were determined to characterize the feed consumption. Feed utilization parameters were calculated as follow:

$$FI = dD \quad (7);$$

$$FCE = (fB - iB)/dD \quad (8);$$

$$FCR = dD/(fB - iB) \quad (9);$$

where *dD* is distributed diet (feed), *fB* is final biomass and *iB* is initial biomass.

Table 1: Experimental design

Culture system	Treatments	Fish species	Ratios T:C:Ca
Mono-culture	T1	400 Carp of 67 g	1
	T2	400 Tilapia of 50 g	1
	T3	400 Catfish of 10 g	1
Poly-culture	T4	80 Carps of 67 g + 320 Tilapia of 50 g	1:4
	T5	80 Carps of 67 g + 320 Catfish of 10 g	1:4
	T6	320 Tilapia of 50 g + 80 Catfish of 10 g	4:1
	T7	40 Carps of 67 g + 320 Tilapia of 50 g + 40 Catfish of 10 g	1:8:1

Table 2: Proximate composition of the diet

Ingredients	Composition (100 g)
Fish meal	4.3
Corn meal	16
Corn bran	20
Soya bean meal	35
Soya full fat	4
Wheat pollard	16
Rice bran	3
Di calcium phosphate (DCP)	0.4
Sodium chloride	0.3
Vitamin premix	1
Crude protein (%)	28.08
Fat (%)	5.18
Gross energy (kCal:100g dry matter)	482.4

Statistical Analyses

Data were analyzed using the stratigraphic package software IBM SPSS Statistics 29.0.1.0. The obtained data on the zootechnical performance parameters, and feed utilization parameters were subjected to two-way analysis of variance (ANOVA 2) to quantify biological interaction between species in polyculture to monoculture. Means of these parameters were compared for statistical significance ($p \leq 0.05$) using Tukey's range test to compare the culture systems (monoculture and polyculture) and the three selected fish species that offered improved growth performance. Physico-chemical parameters were subjected to one-way analysis of variance (ANOVA 1) and means of these parameters were compared for statistical significance ($p \leq 0.05$) using Tukey's range test to compare the different treatments in the monoculture and polyculture systems.

RESULTS

Weight Gain Dynamics

Generally, polyculture treatment groups showed higher monthly weight gains compared to the monoculture ones, specifically from the 5th month onwards ($p \leq 0.05$); except for tilapia T7 groups, carp T5 fish and catfish T5 ones (Figures 2-4).

Growth Rate Related Parameters

The total weight gain (TWG) values were relatively higher in polyculture than in monoculture without a significant difference ($p \geq 0.05$). As expected, DWG values were higher in big-sized species; the African catfish and common carp were significantly different ($p \leq 0.05$) compared to Nile tilapia (Table 3). The DWG values were also higher in polyculture than in monoculture with significant difference ($p \leq 0.05$) for some treatments except for Nile tilapia groups. The RGR and SGR values did not significantly differ between polyculture fish groups and monoculture ones, whatever the fish species. Values were bigger for the African catfish and significantly different ($p \leq 0.05$) compared to common carp and Nile tilapia.

The coefficient of condition (K_m) for the fish species was bigger in polyculture than in monoculture ($p \leq 0.05$). Common carp and Nile tilapia showed better K_m values which differed significantly ($p \leq 0.05$) from those of African catfish (Table 3).

No significant difference ($p \geq 0.05$) was observed between polyculture and monoculture for the survival rate SR for all fish species. SR values was higher for common carp and Nile tilapia and significantly different ($p \leq 0.05$) to the African catfish (Table 3).

Zootechnical Performances of The Three Selected Fish Species in Different Treatments of Monoculture and Polyculture

Common carp

Higher zootechnical parameters for common carp were observed in treatment groups where the species was in polyculture than in its monoculture. However, TWG, DWG, SGR, and RGR were not significantly different ($p \geq 0.05$) between all treatments (T1, T4, T5, and T7) that involved this species. Better K_m was observed in T7 (carp-tilapia-catfish polyculture) and T5 (carp-catfish polyculture) with significant different ($p \leq 0.05$) than in T1 (monoculture of carp) and T4 (carp-tilapia polyculture). The SR was higher in monoculture as well in all polyculture without significant difference ($p \geq 0.05$) between all treatments involving the species. The T7 (carp-tilapia-catfish polyculture) followed by T4 (carp-tilapia polyculture) displayed bigger zootechnical parameters. The T1 (monoculture of carp) showed the lowest zootechnical parameters compared to all treatment groups where this species was in polyculture system.

Nile tilapia

TWG and DWG were not significantly ($p \geq 0.05$) different between monoculture T1 compared to polyculture T4 (carp-tilapia) and T7 (carp-tilapia-catfish). A significant difference ($p \leq 0.05$) for these two parameters was observed between T6 (tilapia-catfish polyculture) and T1 (monoculture of tilapia). Mostly, no significant difference ($p \geq 0.05$) was displayed for the RGR, SGR, K_m and SR to all treatments (T1, T4, T6, T7) involving the species. Treatment T6 (tilapia-catfish polyculture) presented better zootechnical parameters followed by treatment T4 (carp-tilapia polyculture). Treatment T2 (monoculture of tilapia) showed the lowest zootechnical parameters compared to treatment groups where this species was in polyculture conditions.

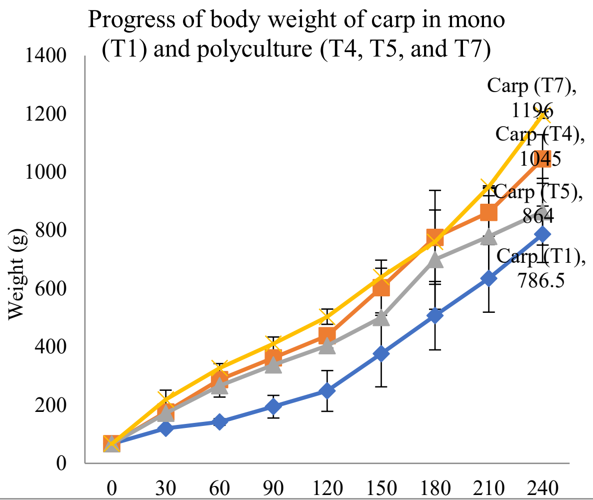

Figure 2: Growth curves of Carp in monoculture and polyculture for 240-day study period in the conditions of high altitude of Rwanda

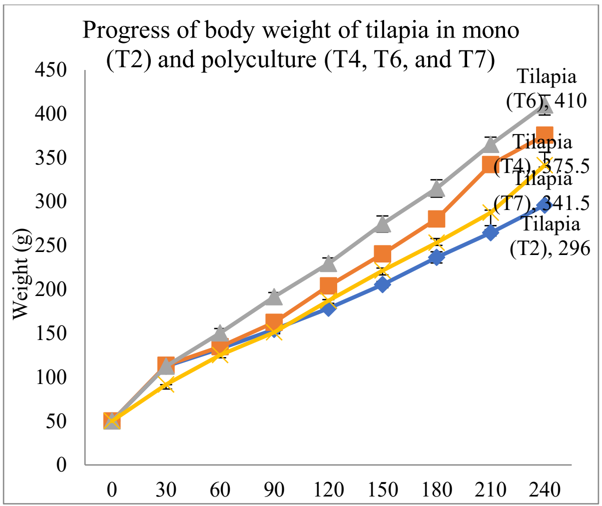

Figure 3: Growth curves of Tilapia in monoculture and polyculture for 240-day study period in the conditions of high altitude of Rwanda

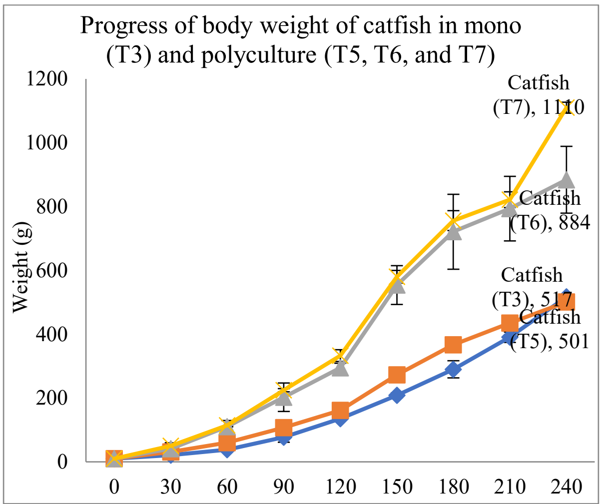

Figure 4: Growth curves of the African catfish in monoculture and polyculture for 240-day study period in the conditions of high altitude of Rwanda

African catfish

Higher zootechnical efficiency of the African catfish was observed in polyculture than in monoculture. The TWG was not significantly different ($p \geq 0.05$) between T3 (monoculture of catfish), T6 (tilapia-catfish polyculture) and T7 (carp-tilapia-catfish polyculture). There was a significant difference ($p \leq 0.05$) in DWG between T7 (carp-tilapia-catfish polyculture) and T6 (tilapia-catfish polyculture) compared to T3 (monoculture of catfish). The RGR was bigger in polyculture T7 and T6 and significantly different ($p \leq 0.05$) from monoculture T3. No significant difference ($p \geq 0.05$) was displayed for the SGR, K_m and SR between polyculture involving this species and its monoculture. The T7 (carp-tilapia-catfish) and T6 (tilapia-catfish) showed better zootechnical parameters where the catfish was cultivated. The T3 (monoculture of catfish) showed the lowest zootechnical parameters compared to all treatment groups where this species was in polyculture conditions.

Taking into account the relative zootechnical parameters, SGR and RGR, polyculture treatment groups tended to display better values than monoculture. Of the three selected fish species, the African catfish showed better performances in both monoculture and polyculture with values that differed significantly ($p \leq 0.05$) from common carp and Nile tilapia. Common carp displayed better growth performance than Nile tilapia (Figures 5 and 6).

Feed Utilization

Generally, no clear difference was pointed out between monoculture and polyculture in concern of feed utilization parameters. However, a trend of decrease was observed in FCE and FCR values for carp and catfish in polyculture fish groups compared to monoculture ones, while an increase appeared in for Nile tilapia. The African catfish and common carp demonstrated better FCE and FCR in monoculture that was significantly different ($p \leq 0.05$) compared to Nile tilapia (Table 4).

Water Quality

Temperature, dissolved oxygen, acidity, turbidity, salinity, alkalinity, conductivity, hardness, total gas pressure, nitrogen compounds and water soil interactions are the basic physico-chemical properties because these affect the growth and health of fish. Based on the standard values of water quality in aquaculture (Table 6), all physico-chemical parameters showed values that were on their allowable range. Globally, no significant difference ($p \geq 0.05$) was observed between the monoculture and the polyculture in regard to physico-chemical parameters variations. However, for some parameters, significant differences ($p \leq 0.05$) were observed between treatment groups (Table 5). There was a negligible correlation (r = 0.10-0.19) between the weight gains and the water temperature variation, the dissolved oxygen level as well as between the NO_2^-, NO_3^- concentration and the RGR.

Table 3: Growth zootechnical parameters of carp, tilapia and catfish in mono and polyculture

Culture System	Ttms	Fish species	TWG (g)	DWG (g/d)	RGR (%)	SGR (%/d)	K_m	SR (%)
Monoculture	T1	Carp	719.5±96.9^{a}	3.0±0.4^{b}	1073.9±144.6^{c}	1.0±0.1^{b}	1.8±0.4^{b}	78.8±1.1^{ab}
	T2	Tilapia	256±2.8^{c}	1.1±0.0^{c}	512±5.7^{d}	0.8±0.0^{b}	1.8±0.1^{b}	87.3±1.1^{a}
	T3	Catfish	507±12.7^{a}	2.1±0.1^{b}	5070±127.3^{b}	1.6±0.0^{a}	1.1±0.1^{c}	75.1±0.5^{b}
Polyculture	T4	Carp	978.0±83.4^{a}	4.1±0.3^{a}	1459.7±124.5^{c}	1.1±0.0^{b}	1.8±0.2^{b}	84.4±2.7^{a}
		Tilapia	325.5±4.9^{b}	1.4±0.0^{c}	651.0±9.9^{d}	0.8±0.0^{b}	2.2±0.6^{a}	87.5±2.7^{a}
	T5	Carp	797.0±114.6^{a}	3.3±0.5^{ab}	1189.6±171.0^{c}	1.1±0.1^{b}	2.0±0.0^{ab}	89.4±4.4^{a}
		Catfish	491.0±4.2^{b}	2.0±0.0^{b}	4910.0±42.4^{b}	1.6±0.0^{a}	0.9±0.1^{c}	75.0±2.7^{b}
	T6	Tilapia	360.0±11.3^{b}	1.5±0.0^{c}	720.0±22.6^{d}	0.9±0.0^{b}	2.8±0.1^{a}	91.3±2.2^{a}
		Catfish	874.0±104.7^{a}	3.6±0.4^{a}	8740.0±1046.5^{a}	1.9±0.0^{a}	0.8±0.0^{c}	74.4±2.7^{b}
	T7	Carp	1129.0±11.3^{a}	4.7±0.0^{a}	1685.1±16.9^{c}	1.2±0.0^{ab}	2.7±0.0^{a}	81.3±5.3^{a}
		Tilapia	291.5±2.1^{c}	1.2±0.0^{c}	583.0±4.2^{d}	0.8±0.0^{b}	2.3±0.3^{a}	89.4±1.3^{a}
		Catfish	1100.0±17.0^{a}	4.6±0.1^{a}	11000.0±169.7^{a}	2.0±0.0^{a}	1.1±0.1^{c}	73.8±5.3^{b}

TWG - total weight gain, DWG - daily weight gain, RGR - relative growth rate, SGR - specific growth rate, K_m - coefficient of condition, SR - survival rate. The values express the means and the standard deviation between replicates. In the column, values with different superscripts are significantly different ($p \leq 0.05$).

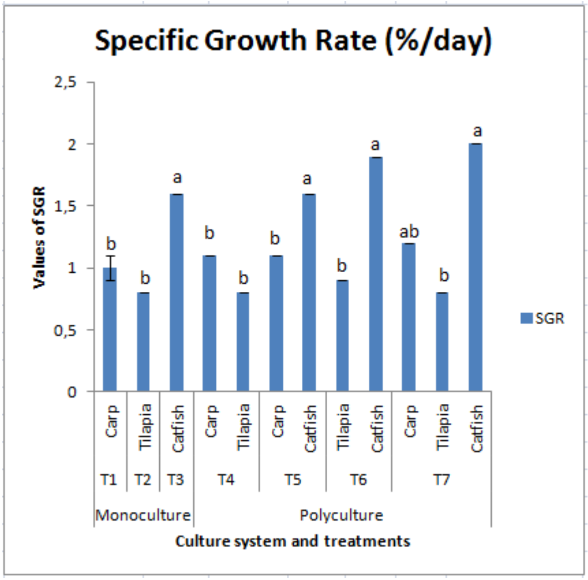

Figure 5: Specific growth rate of fish species in mono and polyculture

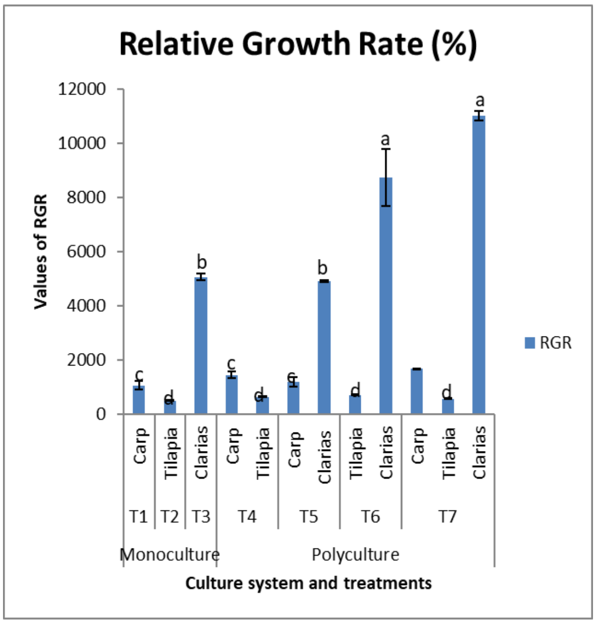

Figure 6: Relative growth rate of fish species in mono and polyculture

Optimum Range of Water Physico-Chemical Parameters

As shown in Table 6, water quality in fish culture has to be ranged in the standard values (Nathan and Hugh, 1977; Boyd and Claude, 1990; Wurts and Durborow, 1992; Boyd and Tucker, 1998; Ronald *et al*., 1999).

DISCUSSION

Fish Growth

Nutrition, including the quality and quantity of food, plays a significant role in growth regulation. A number of environmental factors, such as temperature, oxygen concentration, salinity and photoperiod, influence the rate of growth. The rate of growth differs from species to species and sometimes it differs even within the species also, as well as being affected by many factors such as seasonality, fish species, availability of food and oxygen, stocking density, aquaculture system, and age (Dutta, 1994; Viadero, 2005). Recent data suggest that genotypes, hormones and physiological conditions of the individual are also equally important endogenous regulators of growth (Dutta, 1994). In the present study, the African catfish showed better growth performance than common carp and Nile tilapia, especially in polyculture. Under good farming practices *C. gariepinus* can be grown from 1 g fingerlings to approximately 1 kg in 10 months at temperatures ranging between 26-29 °C. The optimal growth temperature is around 28 °C (Hecht *et al*., 1988). For this study, the African catfish passed from 10 g to a maximum of 1110 g. Despite the low protein content (28%) of distributed feed and mid temperature (23.7-24.6 ºC), the growth of the African catfish was in accordance with other previous findings. The African catfish seems to suit the environmental conditions of the rearing area. The common carp demonstrated better growth progress than Nile tilapia. Indeed, in cold environments common carp could supplant Nile tilapia because it offers ecological tolerances less stringent than these to ensure better growth and reproduction (FAO, 2018). If the water temperature is suitable, its many forms and strains can attain an

Table 4: Feed utilization of carp, tilapia and catfish in mono and polyculture

Culture system	Treatments	Fish combination	FI (kg)	FCE	FCR
	T1	Carp	771,7	$0,63\pm0,03^{a}$	$1,60\pm0,07^{ab}$
	T2	Tilapia	441,1	$0,42\pm0,00^{c}$	$2,41\pm0,02^{a}$
Monoculture	T3	Catfish	400,8	$0,76\pm0,01^{a}$	$1,32\pm0,02^{b}$
	T4	Carp Tilapia	623,8	$0,50\pm0,01^{b}$	$2,02\pm0,02^{a}$
	T5	Carp Catfish	587	$0,59\pm0,02^{a}$	$1,69\pm0,04^{ab}$
	T6	Tilapia Catfish	608,3	$0,51\pm0,01^{b}$	$1,96\pm0,05^{a}$
Polyculture	T7	Carp Tilapia Catfish	582,2	$0,52\pm0,00^{b}$	$1,94\pm0,02^{a}$

FI - feed intake, FCE - feed conversion efficiency, FCR - feed conversion ratio. The values express the means and the standard deviation between replicates. In the column, values with different superscripts are significantly different ($p \leq 0.05$).

Table 5: Physico-chemical parameters of water in fish ponds of different treatments

		Monoculture			Polyculture			
Parameters	Units	T1	T2	T3	T4	T5	T6	T7
Temperature	ºC	24.4 ± 0.28^{a}	23.7 ± 0.14^{a}	24.6 ± 0.28^{a}	24.3 ± 0.21^{a}	24.1 ± 0.71^{a}	23.8 ± 0.21^{a}	24.2 ± 0.14^{a}
DO	mg l^{-1}	5.9 ± 0.42^{b}	6.4 ± 0.28^{a}	6.6 ± 0.28^{a}	6.0 ± 0.21^{b}	6.4 ± 1.2^{a}	6.3 ± 0.21^{a}	6.1 ± 0.35^{ab}
pH		7.9 ± 0.21^{a}	7.7 ± 0.35^{a}	8.0 ± 0.14^{a}	7.7 ± 0.14^{a}	7.8 ± 0.21^{a}	7.8 ± 0.42^{a}	7.8 ± 0.14^{a}
Transp	cm	21.5 ± 5.6^{b}	25.5 ± 0.9^{a}	22.3 ± 5.4^{b}	22.6 ± 3.9^{ab}	21.3 ± 5.9^{b}	21.5 ± 4.7^{b}	20.9 ± 6.0^{b}
Turbid	NTU	138.9 ± 2.2^{a}	117.2 ± 6.2^{ab}	130.1 ± 7.8^{a}	90.3 ± 2.2^{b}	128.1 ± 6.5^{a}	136.5 ± 6.2^{a}	120.7 ± 4.6^{a}
TAN	mg l^{-1}	0.19 ± 0.05^{a}	0.19 ± 0.01^{a}	0.15 ± 0.02^{a}	0.21 ± 0.05^{a}	0.24 ± 0.06^{a}	0.20 ± 0.08^{a}	0.20 ± 0.04^{a}
NO_2^{-}	mg l^{-1}	0.75 ± 0.56^{a}	0.46 ± 0.28^{b}	0.94 ± 0.52^{a}	0.72 ± 0.51^{a}	0.46 ± 0.35^{b}	0.25 ± 0.03^{c}	0.54 ± 0.37^{b}
NO_3^{-}	mg l^{-1}	1.27 ± 0.31^{a}	1.33 ± 0.43^{a}	0.76 ± 0.68^{b}	0.68 ± 0.15^{b}	1.03 ± 0.02^{ab}	1.04 ± 0.10^{ab}	0.70 ± 0.44^{b}
PO_4^{3-}	mg l^{-1}	0.19 ± 0.25^{b}	0.22 ± 0.31^{b}	0.24 ± 0.27^{b}	0.22 ± 0.16^{b}	0.19 ± 0.27^{b}	0.53 ± 0.75^{a}	0.16 ± 0.18^{b}
TA	mg l^{-1}	25.8 ± 0.35^{a}	20.3 ± 2.47^{b}	22.8 ± 2.12^{ab}	23.0 ± 4.95^{ab}	22.2 ± 3.18^{ab}	20.5 ± 0.35^{b}	21.4 ± 3.54^{ab}
Salinity	‰	0.04 ± 0.00^{a}	0.04 ± 0.01^{a}	0.03 ± 0.00^{a}	0.04 ± 0.00^{a}	0.03 ± 0.00^{a}	0.04 ± 0.00^{a}	0.04 ± 0.01^{a}
TSS	mg l^{-1}	240.8 ± 88.7^{b}	81.8 ± 41.4^{d}	270.0 ± 235^{b}	178.5 ± 67.2^{c}	305.0 ± 213^{a}	228.3 ± 145^{b}	276.3 ± 122^{b}
Conductivity	µs cm^{-1}	85.6 ± 3.15^{a}	74.7 ± 6.72^{b}	69.2 ± 5.83^{b}	87.5 ± 0.28^{a}	69.5 ± 8.03^{b}	61.8 ± 5.13^{c}	74.4 ± 13.4^{b}

DO - dissolved oxygen, TAN - total ammonia nitrogen, TA - total alkalinity, TSS - total suspended solids, NTU - nephelometric turbidity unit. Values are means ± standard deviation between replicates. In the row, values with different superscripts are significantly different ($p \leq 0.05$).

Table 6: Standard values of water quality in aquaculture

Parameters	Desirables values	Acceptable values
Temperature	29-30 ºC (Optimal growth)	20-32 ºC
(tropical species)	< 26-28 ºC (Low growth rates)	< 10-15 ºC (Lethal limit)
pH	6.5-9.5	5.5-10.0
Salinity	< 0.5 ppm	-
TAN	0-0.2 mg l^{-1}	Less than 4 mg l^{-1}
NH_3-N (un-ionized)	0 mg l^{-1}	Less than 0.4 mg l^{-1}
NO_2^{-}	0-1 mg l^{-1}	Less than 4 mg l^{-1}
NO_3^{-}	< 100 mg l^{-1}	-
Alkalinity, Total	50-150 mg l^{-1} as $CaCO_3$	Above 20 mg l^{-1} and less than 400 mg l^{-1}
Hardness, Total	50-150 mg l^{-1} as $CaCO_3$	Above 10 mg l^{-1} as $CaCO_3$
PO_4^{3-}	0.005-0.05 mg l^{-1}	-
TSS	< 300 mg l^{-1}	-
DO	> 4.0 mg l^{-1}	1-10 mg l^{-1}
Turbidity	< 10NTU in streams and rivers while < 30NTU in lakes and ponds	-
Conductivity	100-2000µs cm^{-1}	30-5000 µs cm^{-1}

TAN - total ammonia nitrogen, TSS - total suspended solids, DO - dissolved oxygen, NTU - nephelometric turbidity unit

individual weight of about 0.20-0.30, 1.00-1.20 and 2.50-3.50 kg within about 2-3, 5-7, and 10-14 months, respectively (FAO, 2018). For 240-day study period, the common carp body weight passed from 67 g to a maximum of 1196 g. The difference between these two findings may be due to low protein content of feed distributed in this experiment but not to the temperature since the optimal growth of the common carp ranges 23-25 ºC (Boyd and Claude, 1990) values recorded during this experiment. The Nile tilapia did not show better growth performance. From an initial body weight of 50 g it passed to a maximum of 410 g. This situation may be explained by the inconvenient temperature recorded during the experiment. In fact, the average temperature during the experimental period ranged from 23.7-24.6 ºC which is far to the preferendum growth temperature of the Nile tilapia: 30-32 ºC (Nivelle *et al*., 2019).

In regard of culture system, the polyculture (T4: carp-tilapia, T5: carp-catfish, T6: tilapia-catfish, and T7: carp-tilapia-catfish) is the system where all fish species displayed better growth performance compared to the monoculture system (T1, T2, and T3) as showed in the figures 2, 3, and 4. Several studies demonstrated that polyculture in aquaculture presents more advantages than the monoculture in growth performance, productivity and economic profitability (El-Dahhar *et al*., 2006; El-Sagheer *et al*., 2008). Natural food in ponds (increased by fertilization) and supplemental feeds are not completely consumed if only one species is cultured in the pond and better growth and yields are obtained with polyculture (Schmidt and Vincke, 1981). Not only in earthen ponds but also in floating cages, net happas, raceways, concrete tanks and the recirculating aquaculture system, the polyculture provides better growth performance than the monoculture. In cohabitation in the same rearing medium some interactions exist between fish species which has a reciprocal benefit in growth development. In earthen ponds, polyculture of compatible fish species is the most favoured fish culture practice which facilitates efficient utilization of all ecological zones within the pond environment enhancing the maximum standing crop. For instance, in composite culture of Nile tilapia and common carp, the later species stirs the pond bottom for feeding purpose and this behavior resuspends and aerates the sediment, oxidizes organic matter and improves the recycling of nutrients that stimulates the production of natural food such phytoplankton that Nile tilapia feeds on and consequently boosting its growth. Al-Azab *et al.* (2013) carried out an experiment in 12 ponds (3,000 m^2 $pond^{-1}$) for 180 days to evaluate the effect of stocking different ratios of Nile tilapia; *Oreochromis niloticus*, striped mullet; *Mugil cephalus*, thinlip grey mullet; *Lisa ramada* and found better growth performance and good economic return in polyculture. A study conducted in concrete tanks by Olele and Tighiri (2010) showed higher growth performance and survival rates in the polyculture of Nile tilapia and African catfish than in their respective monoculture. Sofronios *et al.* (1992) have experimented the rearing in two monocultures (100% *Cyprinus carpio* and 100% *Oreochromis aureus*) and in two polycultures (60 % carp – 40% tilapia and 60% tilapia – 40% carp) using a recirculating system, for 291 days and found that the polyculture populations of both species showed the highest specific growth rates than the monocultures. In India, Hussain *et al.* (2013) stated that there are many fish culture technologies available of which the polyculture or composite fish culture system is the most sustainable fish culture practice.

Zootechnical Parameters Analysis

Globally, most of the zootechnical parameters were higher in polyculture groups than in monoculture. Higher growth performances in polyculture results on synergistic interactions among fish species which are explained on the basis of two interrelated processes: increase of available food resources and improvement of the environmental conditions. For this study, the TWG were higher for the African catfish and the common carp and were significantly different compared to the Nile tilapia. This observation can be explained by the fact that the African catfish and the common carp are naturally big-sized fish species. The common carp showed higher DWG followed by the African catfish which were significantly different to the Nile tilapia. Nevertheless, DWG for the Nile tilapia recorded in the polyculture was better compared to results obtained by Kohinoor *et al.* (1999) where values ranged from 0.37-1.20 g day^{-1}. Better RGR and SGR were shown by the African catfish which were significantly different compared to the common carp and the Nile tilapia. However, K_m and SR were higher for the Nile tilapia and the common carp which were generally significantly different compared to the African catfish. Although, the experimental conditions were not similar, zootechnical parameters recorded in this study for the three selected fish species are near to results obtained in monoculture and polyculture carried out in earthen ponds by different researches (Abdelghany and Mohammed, 2002; Abdel-Hakim *et al.*, 2006; Olele and Tighiri, 2010). It is assumed that, zootechnical values of this study could be higher if the feed provided to the fish had protein content that responded to the required exigencies of these fish species and the feeding ratio ranged from 5 to 2%. Indeed, Abdelghany and Mohammed (2002) recorded higher TWG and SRG in feeding ratio at 5% and satiation than 0.5-1%.

Common carp showed better growth performance in polyculture than in monoculture. Higher TWG, DWG, RGR, SGR, K_m and SR were observed in T7 (carp-tilapia-catfish), T4 (carp-tilapia), and T5 (carp-catfish). The T7 and T4 stand out as a rearing system which offers best growth performance for the common carp. Low growth performance recorded in T5 (carp-catfish polyculture) may be explained by the fact that both species occupy the same ecological niche and are bottom feeders. Several experiments demonstrated in polyculture the common carp presented higher zootechnical parameters than Nile tilapia and catfishes. Abdel-Hakim *et al.* (2006) noted higher growth performance of the common carp than the Nile tilapia stocked at different rates in earthen ponds. The growth performance of the common carp can result from the fact that the species is a flexible and opportunistic feeder that can switch from preferred to alternative diets according to the food availability (Hoole *et al.*, 2011). Being a bottom feeder, the common carp drew advantages and consumed various benthic invertebrates and also supplemented feed. Besides, the water temperature was on the preferendum of a suitable growth for the common carp than the Nile tilapia and the African catfish. Indeed, the average temperature during the experimental period was in the range of 23.7-24.6 °C which is favourable to the optimal growth of the common carp than to Nile tilapia; 30-32 °C (Nivelle *et al.*, 2019) and the African catfish; 28-30 °C (Hogendoorn *et al.*, 1983). Although the ecological spectrum of common carp is obvious; however, the optimum growth rate can be obtained when water temperature ranges between 24 and 28 °C (Song-bo *et al.*, 2012).

Nile tilapia presented better growth performance in polyculture groups than in monoculture. Higher TWG, DWG, RGR, SGR, K_m and SR were observed in T6 (tilapia-catfish) and T4 (carp-tilapia). The T6 and T4 stand out as rearing systems that offer best growth performance for the Nile tilapia. In fact, polyculture increases productivity by a more efficient utilization of the ecological resources in the pond (Lutz, 2003). Stocking two or more complementary species can increase the maximum standing crop of a pond by taking advantage of a wider range of available foods and ecological niches. Nile tilapia had better growth performance in polyculture with the African catfish than with common carp. The explanation of this observation can result in the fact that Nile tilapia and common carp may have near feeding habits than with the African catfish and consequently should compete somehow for the same natural food resources in the pond. Although the rearing conditions were not similar, the growth performance of Nile tilapia was relatively low in polyculture with common carp experimented by Abdelghany and Mohammed (2002) compared to polyculture of Nile tilapia with the African catfish conducted by Ibrahim and El-Naggar (2010). In regard to low growth performance of Nile tilapia in T7 (carp-tilapia-catfish), this can stem from higher competition of two bottom feeder fishes; the common carp and the African catfish exerted on the Nile tilapia.

African catfish also showed better growth performance in polyculture groups than in monoculture. Higher TWG, DWG, RGR, SGR, K_m and SR were observed in T7 (carp-tilapia-catfish) and T6 (tilapia-catfish). Polyculture T5 (carp-catfish) and the monoculture (T3) presented near growth performance at the end of the experiment. The T7 and T6 stand out as rearing systems that offer best growth performance for the African catfish. It is paradoxical that both bottom feeders; the African catfish and the common carp displayed better zootechnical parameters in T7 whereas the growth was relatively low in T5 where the two species were in polyculture condition. The cohabitation and interactions with Nile tilapia in T7 may provide some benefit on the growth of the African catfish and the common carp.

Feed Utilization

Better FCE and FCR were observed in T3 (monoculture of the African catfish) which was significantly different compared to all treatments. Indeed, catfish seem to provide better feed utilization even if the diets are made from plant products. Abu *et al*. (2010) recorded better FCR on hybrid catfish fed with whole cassava root meal as a replacement for maize, and inclusion of whole cassava root meal in the diet of hybrid catfish enhanced growth and survival of the fish. Poor feed utilization was observed in T2; monoculture of Nile tilapia and in all fish combinations with Nile tilapia. Lower FCR values indicate higher efficiency. Typical FCRs in fish are between around 1.00 to 2.40 (Fry *et al*., 2018) or 1.20 to about 2.20 (FCE values of 0.83–0.45) depending upon the type of feed, the species, the size of the animals, feeding practices and water quality conditions in culture systems (Boyd, 2021). Sometimes, FCRs of 1.00 or less are reported, especially in Salmonid culture. The values of FCE and FCR recorded in this study ranged in values reported by Fry *et al*. (2018). Nevertheless, recorded FCRs were relatively higher probably due to low protein content (28%) of distributed feed. In fact, as the amount of protein in the diet increases, the FCR gets smaller. Saeed *et al*. (2005) observed the growth response and feed conversion in *Labeo rohita* at varying dietary protein levels. The FCRs decreased with increasing dietary protein. The required level of protein for growing-out phase of common carp, Nile tilapia and the African catfish are respectively: 30-35% (Watanabe, 1982), 30-32% (Jauncey, 2000; Lim and Webster, 2006) and 40-43% (Ali, 2001). Shahabuddin *et al*. (2007) found that 40% protein, 1-2% lipid, and 30% carbohydrate are required for normal growth and development of common carp. It emerges that the required values of protein levels of the three selected fish species are higher than 28% protein content for feed used in this research. In addition, the feed provided to fish was purchased at HUYE FEEDS Company where the main ingredient source of protein is soybean meal but less fish meal (Table 2). The snag is that feed made from plant products contain many anti-nutritional factors (such as, gossypol, glucosinolates, saponins, phytic acids, etc.) which limit efficient feed utilization compared to feed made from fish meal that have high protein content, excellent amino acid profile, high protein or amino acid digestibility, and excellent palatability (Vikas *et al*., 2012; Amrutha *et al*., 2020).

Water Quality

Based on the standard values of water quality in aquaculture (Nathan and Hugh, 1977; Boyd and Claude, 1990; Wurts and Durborow,1992; Boyd and Tucker, 1998; Ronald *et al*., 1999), the results obtained for all physico-chemical parameters showed that the values were found on their allowable range in all treatments. Monoculture and polyculture of the selected fish species did not affect the water quality. No significant differences in temperature, pH, TAN, and salinity were observed among the treatments (Table 5). For a 240-day period, temperature ranged from 23.7 to 24.6 ºC. This recorded temperature was in thermal preferendum of common carp being 23-25 ºC (Boyd and Claude, 1990) but not for Nile tilapia and the African catfish, respectively with optimal growth temperature 30-32 ºC (Nivelle *et al*., 2019) and 28 °C (Hecht *et al*., 1988). Low growth performance for Nile tilapia could result in low temperature of the rearing condition of high-altitude of Rwanda far from its preferendum. However, the African catfish showed higher growth performance even with the recorded prevailing temperature being outside the range of its thermal requirements.

The DO levels were in desirable range but treatments T1 (carp monoculture) and T4 (carp-tilapia polyculture), respectively with 5.90±0.42 and 6.00±0.21 mg l^{-1} had low values and were significantly different compared to others. This observation is probably due to high exigencies in DO by Nile tilapia or common carp for which a level of DO > 5.00 mg l^{-1} is required than the African catfish with DO = 3.00 mg l^{-1} (Ronald *et al*., 1999; Lloyd, 1992). Indeed, the African catfish equipped with suprabranchial organs emerges sometimes from the water column and absorbs the atmospheric air. Moderated temperatures recorded during the experimental period and low fish density in ponds may explain the DO levels maintained in desirable range. Water transparency measured in Secchi disk in T2 (tilapia monoculture) with 21.50±5.60 cm was significantly different to all treatments where the African catfish or the common carp were stocked. In fact, being bottom feeders, these fish species, especially the common carp, is very active, when it is feeding, it can stir mud and increase water turbidity (King and Hunt, 1967). Turbidity and TSS were higher in T1 (carp monoculture), T3 (catfish monoculture), T5 (carp-catfish polyculture), T6 (tilapia-catfish polyculture) and T7 (carp-tilapia-catfish polyculture) and significantly different to other treatments.

Phosphorus and nitrogenous waste values remained within the desirable range as described by Boyd and Claude (1990). The PO_4^{3-}, TAN, NO_3^-, and NO_2^- values were low in all treatments but for a given parameter some significant differences were observed between treatments. Low phosphorus and nitrogenous compound values recorded in this study should be explained by low fish density in ponds and low protein content in the distributed feed. In fish culture, the nitrogenous wastes found in the rearing mediums principally result from fish faeces, urine, the degradation of feed and the organic fertilizers (Green and Boyd, 1995; Green and Hardy, 2008). Nitrogen (N) and Phosphorus (P) are the main end-products of fish loading, and can affect not only the rearing water, but also the environment as a whole (Lazzari and Baldisseroto, 2008). The TA (mg l^{-1}) and conductivity (µS cm^{-1}) were found in the allowable range. Significant differences were observed between some treatments and this should be due to the soil structure of different experimental ponds. In monoculture as well as in polyculture, the water quality was not affected as various parameters: nitrogenous compounds (TAN, NO_2^-, and NO_3^-, pH, DO, etc.) were found on their allowable range in all treatments. These parameters had not influenced fish growth performance as they were not significantly different. Thus, differences observed on zootechnical parameters among some treatments might be due to the positive effect of fish species interactions in composite culture.

CONCLUSION

Polyculture groups showed higher zootechnical parameters than monoculture but were not often significantly different. T7 (carp-tilapia-catfish polyculture) had higher zootechnical parameters followed by T6 (tilapia-catfish polyculture) and T4 (carp-tilapia polyculture). In regard to the three cultivated fish species, the African catfish followed by common carp, demonstrated a better growth performance than Nile tilapia in most treatments. The African catfish and also the common carp seem to suit earthen pond-based cultivation with the low temperature of high-altitude conditions of Rwanda. In view of findings observed in this study, polyculture of carp-tilapia-catfish, tilapia-catfish and carp-tilapia can be recommended in the Rwandan Aquaculture industry. Nevertheless, for further studies, the stocking density and species combinations and ratios in polyculture should be readjusted and investigated as these factors have impact on fish growth, feed utilization and gross fish yield. The feed utilization parameters were relatively weak probably due to low protein content (28%) of distributed feed. For further studies it is suggested to provide feed corresponding to the required exigencies of the experimented fish species and the feeding ratio has to vary from 5 to 2% so as to improve different zootechnical parameters. In monoculture as well as in polyculture of these selected fish species, water quality was not affected as various parameters were found on their allowable range in all treatments.

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CONFLICT OF INTEREST

No conflict interest that could have influenced the work reported in this paper. All co-authors have accepted the authorship order.

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