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GROWTH PERFORMANCE, SURVIVAL AND BREEDING OF *Oreochromis niloticus* AND *Oreochromis macrochir* REARED UNDER GREENHOUSE CONDITIONS

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ABSTRACT

The growth, survival and breeding performance of *Oreochromis niloticus* and *Oreochromis macrochir* was investigated in earthen ponds under greenhouse conditions at Henderson Research Institute. Six experimental ponds, three in open atmosphere and three under greenhouses were set up. Each pond was further subdivided by hapas to make 12 experimental units of which half were stocked with *Oreochromis niloticus* and the other *Oreochromis macrochir*. Fish weights and lengths were recorded fortnightly and feed intake was based on current biomass. Fish sex and breeding activities were noted. Results showed that mean weight gain for *O. niloticus* was significantly higher than *O. macrochir* both in greenhouse ponds and open ponds. Feed intake was also higher leading to greater weight gains in the greenhouse than in open ponds. Growth performance of both species improved significantly under greenhouse culture but *O. niloticus* was much superior compared to *O. macrochir*. Even *O. niloticus* cultured in open ponds had superior performance to *O. macrochir* cultured in greenhouse ponds. Turbidity, alkalinity and sulphates had positive correlation with the weight and length of *O. macrochir* in open ponds. The study results demonstrated that the greenhouse can enhance growth performance of *O. niloticus* and *O. macrochir* in climatic considered less favourable for tilapia culture.

Keywords: Greenhouse aquaculture, Temperature, Survival, Growth performance, Recruitment

Introduction

Tilapia fish are warm water species that have high growth rates and are highly adaptable to a wide range of environmental conditions. They can grow and breed in captivity as well as survive on relatively poor quality feed (FAO, 2010). Water temperatures and the level of protein in the diet are important parameters for fish growth (Gardeur, 2007; Mizanur et al., 2014). Fish growth is directly influenced by the temperature of their aquatic environment (Karadede & Unlu, 2007). Hence, water temperature has a major influence on aquaculture husbandry practices and it has a profound impact on overall metabolic activity (Gardeur, 2007). In fish as well other higher organisms, temperature is the major driver of all physiological processes particularly development, spawning, growth, reproductive capacity and metabolic scope (Kausar & Salim, 2006; Brander, 2007 and Xia 2010).

Under natural conditions, aquaculture production is restricted to the warmer months of the year when temperatures are favorable. Hence, the colder climate requires the additional or supplemental heat to increase the water temperature in order to increase the overall supply of fresh fish from aquaculture. *Oreochromis niloticus* can reach market size of 500-600 grams in 6 to 8 months under optimum temperature conditions of 28-35ºC (Lucas & Southgate, 2003). However, the use of *O. niloticus* is a very controversial issue within Zimbabwe and also within the region. According to Zimbabwean it is Sixth Schedule species and its propagation is illegal due to environmental concerns. Currently, authorities are turning a blind eye but in future legal issues on its use could arise. In Zambia, trials were carried out using *Oreochromis macrochir* instead, and fish attained maximum growth of 353g in 8 months (Nsonga, 2014). This growth performance is still less than that of *O. niloticus*, however it was recommended such indigenous species could still be viable alternatives for *O. niloticus*. The use of indigenous species has the advantage of minimizing genetic pollution from potentially invasive species such as *O. niloticus* and also enhance the propagation of indigenous species in natural ecosystems.

Sub-tropical regions of Africa have a well-defined seasonality unlike the more tropical regions, with a cold winters and very warm summers. It has been observed that tilapia fish species in Zimbabwe do not grow well or breed in winter due to low temperature of below 22ºC as compared to countries like Ethiopia where in certain regions, breeding is throughout the year (Hirpo, 2013). Even in the warm Zambezi Valley, the breeding season of most fish species is confined to the warm season which coincides with other environmental cues such as inflows of freshwater from the rains. Fish production in sub-tropical regions then tends to be very cyclical with episodes of high production in summer and very little production in winter. The major challenge has therefore been to maintain a constant supply of fresh fish throughout the year due to low temperatures in most parts of the country. There is also need to optimize production even in the summer months where water temperatures may not frequently be in the optimum range. For example, average temperatures in the Highveld region of Zimbabwe, range between 5º C to 18 ºC in winter and 20-27ºC in summer (Zimbabwe Department of Meteorology Services Report, 2007-2012). It is evident that these temperatures are not the most ideal for best tilapia growth performance. However in Zimbabwe and so is the case in other sub-tropical regions of Southern Africa, the warm regions also tend to be the most water scarce regions of the country. Both warm temperatures and a good supply of water are key elements to any successful aquaculture operation.

In order to address the problem of water temperatures, greenhouse technology has been put forward as a possible solution. Currently, there is intensive use of greenhouses for fish production in countries such as USA and in Asian countries such as China and also in Israel (Hulata & Simon 2011). In Africa, some work has been conducted in Kenya (Angienda et al. 2011) and South Africa (Food & Agriculture Organisation, 2012). No studies have been done in Zimbabwe and keeping water temperature within species optimal metabolic range requirements remains a challenge for most fish farmers in Zimbabwe. Some studies have shown that water temperature in a greenhouse could be increased by 3–9°C (Ghosal et al., 2005, Zhu et al., 1998). There is therefore need for more in depth of assessment and the testing of simple technologies to enhance aquaculture production. Adoption of simple technologies has the added benefit of reducing cost and hence increases profits to small scale rural fish farmers.

The main aim of this study was to investigate the growth performance, survival and recruitment of *O. niloticus* and *O. macrochir* under greenhouse conditions. The hypotheses being tested were that overall fish performance under greenhouse conditions would significantly supersede that of open ponds. Secondly, the growth of performance of *O. macrochir* can be improved to be at par with that of *O. niloticus* under greenhouse conditions. The research hypothesis is that utilization of greenhouses in aquaculture will solve the problem of low aquaculture productivity in natural agro regions I, II, & III, which are generally characterized by lower temperatures throughout the year.

Materials and Methods

Study Area

The study was carried out at Henderson Research Institute (Fisheries Section; 17º 35'S and 30º 58'E). The institute is situated about 32 km North of Harare, along the Harare – Bindura highway, in the Mazowe District. According to Zimbabwe's regional classifications, the Institute is in agro-ecological region 2b, which is characterized by mean annual rainfall range of 750-850 mm and annual average temperatures of 18.2°C (Zimbabwe Department of Meteorology Services Report, 2007-2012). Thus Henderson Research Institute therefore experiences cool temperatures for the greater period of the year (Meteorological Services Department, Harare, Zimbabwe). Water is supplied to the Fisheries section by canal from the perennial river, Dasura.

Experimental design

Six ponds each measuring 8.5m x 6m (56m^2) and 1m deep were set up in a completely randomized design with two treatments, open ponds and greenhouse ponds, replicated three times. The dimensions of the greenhouses were 20m x 10m x 2m constructed with 250 microns plastic sheath. Free circulation of air in the greenhouse was achieved by opening of the doors. Water samples were collected fortnightly from each pond using the improvised Ruttner sampler for chemical analysis whilst all physical variables were determined *in-situ*.

Earth ponds measuring were stocked at the end of July 2015 and trial ran until end of July 2016. Each pond was stocked with 100 fingerlings of *O. niloticus* obtained from Southcote Estates in Kariba of mean weight 1.7 ± 0.3g and 100 fingerlings of *O. macrochir* of mean weight 2.6 ± 0.3g, separated haps. Fish were fed on fish pellets at a rate of 5 % of body weight (BW) twice daily and sampling was carried out once in two weeks. A sample was made up of ten fish that were obtained from each pond, weighed using an electronic balance equipped with a high precision strain gauge sensor system to get the precise average fish weight for each species per pond. Total lengths were determined by measuring from the snout to the end of the caudal fin for each of the ten fish using a fish measuring board. New feed requirements were calculated using the new weights every fortnight. The level of water in the ponds was maintained by opening up water from the river through a canal, topping up once every week depending on the rate of evaporation.

Water temperatures (Tw), ambient air (Ta) for both inside and outside the greenhouse ponds were measured every two hours by calibrated mercury filled, glass-bulb thermometer daily and temperature regulated as desired. Once the temperature readings in the greenhouse reached 35°C, curtains were opened to avoid overheating of water that could result in oxygen depletion. Once every fortnight, 24 hour data collection was done to determine the variability of temperature and other essential water quality parameters such as pH, conductivity, total dissolved solids, dissolved oxygen after every two hours for both greenhouse and the open ponds

EXPERIMENTAL OBSERVATIONS

Growth Parameters

Growth rate was analysed for the fish both from the greenhouse ponds and open ponds.

The following parameters and formulas were used to evaluate the two tilapia species' growth performance:

1. Weight gain (W) = Final Weight (F_w) – Initial Weight (W_0) (g)
2. Individual Weight Gain (IWG) (g/ex) = (Final Weight (F_w) – Initial Weight (W_0)/t
3. Food Conversion Ratio (FCR) = Total feed (F)/Total Weight Gain (W) (g/g)
4. Specific Growth Rate (SGR) = 100 × ($\ln W_t - \ln W_0$)/t (%BW/day)

Survival and Breeding

Fish were counted at the beginning of the trial and at the end of the trial in order to determine the survival rate, which was calculated by deducting the number of *O. niloticus* and *O. macrochir* that were in the ponds in the greenhouse and in open ponds at the end of the trial. The onset of breeding was assessed by observing for the presence of fry in the ponds.

Feed and Feeding

Feed accounts for 40-60% of the total production costs in fish farming and 35-40% of the feed consumed by the fish is assimilated and turned into fish flesh while the rest (60-65%) is excreted into the water. Fish were fed on a maintenance ration of 5% body mass.

Statistical Data Analysis

Statistical analysis was performed using the program (SAS) Version 9.3, (SAS, 2010). The *t*-test was used to test whether the means of various parameters were statistically different. The coefficient of variation (CV) was calculated as the ratio of the standard deviation to the mean in order to have a measure of dispersion.

Data on fish weight and length were analysed using a model in the first stage. In stage two. a regression analysis was carried out for each site and fish species to investigate the association between the biological parameters (fish length and weight) and the physical and chemical parameters. The following model was used:

Stage 1: Factors affecting fish length and weight

$$y_{ijkl} = \mu + w_i + s_j + (ws)_{ij} + e_{ijkl}$$

y_{ijkl} is the observation of fish weight or length

μ is overall mean due to conditions common to all fish

w_i is effect of the i^th^ week of sampling (I = 1,2,3,...40)

sj is effect of j^th^ site (greenhouse ponds and open ponds) (j =1,2)

$(ws)_{ij}$ is the effect of week by site interaction

e_{ijkl} are random residuals {assumed to be normally distributed in a mean of zero and variance of r^2_{e}}

Means were separated using the adjusted Tukey's method.

Stage 2: Regression analysis

This was carried out for each site (greenhouse ponds and open ponds) and fish species to investigate the association between the biological parameters (fish length and weight) and the physical and chemical parameters.

i. Regression of physical water parameters on biological parameters was carried out with the following model

$$y = b_0 + b_1x_1 + b_2x_2 + b_3x_3 + b_4x_4 + b_5x_5 + \varepsilon$$

y is the dependent variable (weight or fish length)

b_0 is the intercept

b_1 **to** b_5 are partial linear regression coefficients relating the water physical parameters (independent) to the biological (dependent) parameters

x_1 **to** x_5 are the physical water parameters (pH, conductivity, total dissolved salts, temperature and dissolved oxygen)

Results and Discussion

Table 1 contains the summary statistics of the water physical and chemical parameters in greenhouse and open air ponds. Table 2 shows the overall fish length and fish weight for fish from the greenhouse ponds and those from open ponds at the end of the trial period. Overall, *O. niloticus* attained a greater weight than the *O. macrochir* in both greenhouse and open ponds. Similarly, fish cultured under greenhouse conditions also attained a greater weight than those in the open ponds for both species at the end of the trial. Notably, *O. niloticus* cultures in open ponds attained a greater weight than *O. macrochir* cultured under greenhouse conditions. Weekly weight gain trends showed the differences in the treatments during the course of the trial (Figure 1).

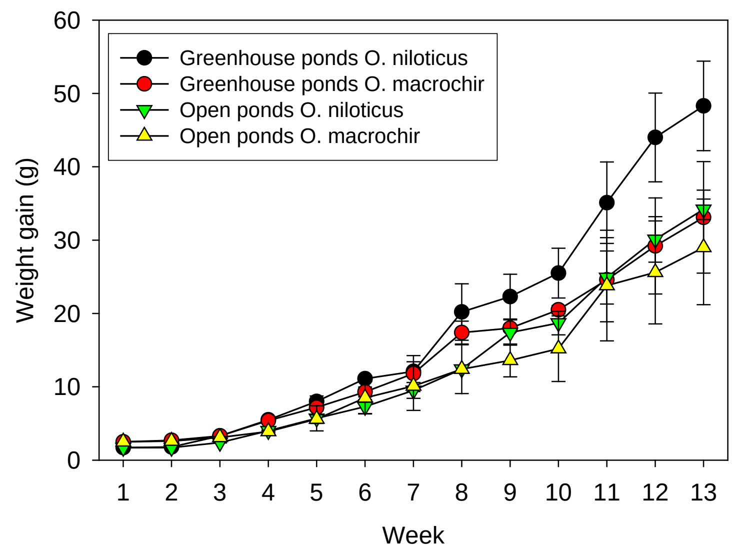

Figure 1. Weekly mean weight gain of *O. niloticus* and *O. macrochir* cultured under greenhouse and open conditions at Henderson Research Station

Factors Influencing Fish Length and Weight

There were significant differences ($p<0.05$) in mean lengths and weights of *O. niloticus* cultured in greenhouse and open ponds, with fish cultured in greenhouses attaining a significantly greater size. However, *O. macrochir* showed significant differences in mean lengths between fish cultured in greenhouse and open ponds, within a narrow margin (Table 3). Fish in the greenhouse ponds preformed significantly better than those in the open ponds in relation to growth rate. The mean lengths of both *O. niloticus* and *O. macrochir* were significantly influenced ($p<0.05$) by date of sampling and site. With regard to fish weight, significant interactions ($p<0.05$) were observed for weight of *O. niloticus* in the greenhouse ponds.

Table 1. Summary statistics of the physical parameters of greenhouse pond water (n = 420) and open pond water (n = 419)

Variable	Greenhouse ponds		Open ponds	
	Mean	SD	Mean	SD
Physical parameters				
Water temperature (ºC)	25.92	3.10	22.82	3.12
Conductivity (microS/cm)	405.28	39.52	412.56	44.08
Total dissolved solids (mg/L)	262.79	26.98	271.85	33.68
Dissolved oxygen (mg/L)	3.05	1.83	3.25	1.75
pH	7.94	0.57	7.98	0.56
Chemical parameters				
Biological oxygen demand (mg/L)	1.51	1.25	1.59	0.83
Chemical oxygen demand (mg/L)	38.52	50.97	30.74	22.43
Turbidity (NTU)	24.86	18.45	29.08	18.44
Total suspended solids (mg/L)	15.33	11.43	16.74	12.49
Alkalinity (meq/L)	1.06	0.45	1.14	0.58
Chlorides (mg/L)	0.32	0.11	0.32	0.09
Chlorophyll a (µg/mL)	1.74	2.81	1.28	1.42
Total nitrates (mg/L)	0.44	0.60	0.16	0.18
Total phosphorus (mg/L)	0.10	0.15	0.11	0.18
Reactive phosphorus (mg/L)	0.01	0.02	0.02	0.01
Ammonia (mg/L)	0.52	0.49	0.32	0.35
Sulphates (mg/L)	0.18	0.14	0.21	0.18

Table 2. Fish weights and lengths (Mean (SD) of *O. niloticus* and *O. macrochir* cultured in greenhouse and open ponds from at Henderson Research Station

Site	Species	Variable	Mean	SD	Min.	Max.
Greenhouse	***O. niloticus***	Fish weight (g)	43.95	6.05	37.90	50.00
		Fish length (cm)	10.23	0.59	9.80	10.90
	O. macrochir	Fish weight (g)	29.23	6.55	22.60	35.70
		Fish length (cm)	9.10	0.60	8.50	9.70
Open ponds	***O. niloticus***	Fish weight (g)	30.01	3.10	27.00	33.20
		Fish length (cm)	10.67	1.27	9.30	11.80
	O. macrochir	Fish weight (g)	25.60	7.02	17.50	29.90
		Fish length (cm)	8.60	1.23	7.70	10.00

Table 3. LS mean (s.e) fish weight and length for the greenhouse and open ponds at Henderson Research Station

Species	Variable	Greenhouse	Open pond
O. niloticus	Weight (g)	20.85 (0.64)^{a}	14.53 (0.64)^{b}
	Length (cm)	7.80 (0.24)^{a}	6.84 (0.24)^{b}
O. macrochir	Weight (g)	15.88 (0.84)^{a}	13.33 (0.84)^{b}
	Length (cm)	6.98 (0.12)^{a}	6.83 (0.12)^{a}

NB: Means with different superscripts are significantly different (p<0.05)

Relationship Between Biological Parameters and Physical-Chemical Water Parameters

There were significant relationships between the length of *O. macrochir* and pH, turbidity, ammonia as well as the BOD (Table 4). Similarly, there were significant relationships between the weight of *O. macrochir* in the greenhouse ponds and alkalinity, turbidity, TSS, sulphates and chlorophyll *a*. In the open ponds, the length of *O. macrochir* was significantly related (p<0.05) pH, nitrates and temperature (Table 4). With regards to *O. macrochir* weight, only temperature and nitrates were significantly related in the open ponds (Table 4).

Table 4. Regression analysis results of the relationship between environmental factors and growth parameters (weight and length) of *O. macrochir* cultured in greenhouse and open ponds at Henderson Research Station

Site (M)	Variable	Weight		Length	
		b_i	P-value	b_i	*p*-value
Greenhouse ponds	Intercept	6.19	0.2295	3.81	0.004*
	Nitrates	3.17	0.1208	-0.05	0.889
	Total phosphorus	-6.16	0.2276	-1.58	0.129
	Reactive phosphorus	47.53	0.4087	23.09	0.065
	Alkalinity	-5.65	0.0210*	-0.59	0.172
	Turbidity	0.07	0.0002*	0.01	0.006*
	TSS	-0.25	0.0337*	-0.03	0.204
	Chlorides	6.88	0.4291	2.76	0.130
	Ammonium	5.33	0.0145	1.31	0.005*
	Sulphates	40.41	0.0493*	5.03	0.184
	COD	-0.03	0.0893	-0.001	0.815
	BOD	1.79	0.0893	0.68	0.006*
	Chlorophyll *a*	0.74	0.0316*	0.08	0.201
	pH	-0.41	0.1514	-0.15	0.006*
	Conductivity	0.10	0.4987	0.03	0.186
	Total dissolved salts	0.06	0.8445	-0.01	0.833
	Temperature	0.91	0.4730	-0.06	0.781
	Dissolved oxygen	1.65	0.2415	0.39	0.111
Open ponds	Intercept	7.13	0.5430	5.71	0.0479*
	Nitrates	20.37	0.0358*	2.42	0.2064
	Total phosphorus	17.43	0.2274	4.81	0.1362
	Reactive phosphorus	-108.21	0.7907	-21.58	0.8080
	Alkalinity	-2.61	0.5524	-0.77	0.4269
	Turbidity	-0.01	0.1624	-0.001	0.4600
	TSS	0.14	0.4047	0.004	0.9047
	Chlorides	4.03	0.8929	1.27	0.8457
	Ammonia	-3.65	0.6872	-0.95	0.6313
	Sulphates	-36.04	0.4250	-1.79	0.8527
	COD	-0.03	0.7377	-0.01	0.7140
	BOD	4.68	0.2198	1.22	0.1508
	Chlorophyll *a*	0.13	0.9390	-0.25	0.5133
	pH	2.39	0.6196	-2.21	0.005*
	Conductivity	-0.10	0.1141	-0.01	0.215
	Total dissolved salts	0.05	0.5781	-0.003	0.779
	Temperature	3.96	0.0012*	0.30	0.047*
	Dissolved oxygen	-0.82	0.4066	0.082	0.552
	pH	2.39	0.6196	-2.21	0.005*

NB: * significant at $p<0.05$

For the greenhouse ponds, total phosphorus, ammonia and chlorophyll *a* showed a significant relationship with *O. niloticus* length only (Table 5). On the other hand, only ammonia showed a significant relationship with fish weight in greenhouse ponds. All the other chemical water parameters had no significant relationship (Table 5). In the open ponds, a significant relationship ($p<0.05$) was observed between the growths parameters (length & weight), water temperature and dissolved oxygen (Table 5). Fish length only had a significant relationship ($p<0.05$) with nitrates in the open ponds.

Table 5. Regression analysis results of the relationship between environmental factors and growth parameters (weight and length) of *O. niloticus* cultured in greenhouse and open ponds at Henderson Research Station

Site	**Variable**	**Weight**		**Length**	
		b_i	**P-value**	**b_i**	***p*-value**
Greenhouse ponds	Intercept	-2.22	0.8353	4.36	0.0106
	Nitrates	8.93	0.0538	0.08	0.8739
	Total phosphorus	-21.45	0.0690	-3.77	0.0201*
	Reactive phosphorus	150.96	0.2372	18.82	0.2467
	Alkalinity	-2.18	0.6248	0.10	0.8639
	Turbidity	0.03	0.2371	0.005	0.1224
	TSS	-0.16	0.4670	-0.02	0.5141
	Chlorides	41.20	0.0503	4.27	0.0980
	Ammonium	10.78	0.0199*	1.36	0.0208*
	Sulphates	-26.82	0.4986	-6.73	0.2001
	COD	0.01	0.8079	0.01	0.2044
	BOD	1.49	0.4790	0.28	0.2986
	Chlorophyll *a*	1.07	0.1177	0.67	<.0001*
	pH	-0.63	0.1391	-0.19	0.0807
	Conductivity	0.20	0.3767	0.05	0.3990
	Total dissolved salts	-0.10	0.8122	-0.03	0.7626
	Temperature	2.13	0.2586	-0.001	0.9980
	Dissolved oxygen	1.39	0.4961	0.20	0.7002
	pH	-0.63	0.1391	-0.19	0.0807
Open ponds	Intercept	8.27	0.5254	6.04	0.0337*
	Nitrates	16.99	0.0946	4.58	0.0274*
	Total phosphorus	10.88	0.4833	3.69	0.2244
	Reactive phosphorus	15.08	0.9733	-43.87	0.6112
	Alkalinity	-1.58	0.7445	-0.46	0.6173
	Turbidity	-0.01	0.3716	-0.002	0.2067
	TSS	0.03	0.8560	0.014	0.6633
	Chlorides	8.45	0.7994	1.34	0.8312
	Ammonium	3.04	0.7617	0.43	0.8217
	Sulphates	-39.48	0.4306	-10.48	0.2786
	COD	-0.04	0.6160	-0.002	0.8575
	BOD	3.09	0.4506	0.88	0.2703
	Chlorophyll *a*	0.15	0.9355	-0.12	0.7450
	pH	-1.92	0.5927	-0.19	0.7650
	Conductivity	-0.09	0.0679	-0.02	0.0589
	Total dissolved salts	0.08	0.2066	0.02	0.1570
	Temperature	4.42	<0.0001*	1.06	<0.0001*
	Dissolved oxygen	-1.74	0.0277*	-0.34	0.0186*

NB: * significant at $p<0.05$

Survival and Onset of Reproduction of Fish Species

There were variation in the growth of the fish in the greenhouse ponds and those in open ponds. Sex of fish was determined every time sampling was carried out. Onset of reproductive activities were noted in the greenhouse ponds one and two in October and in open ponds the same activities were noted towards the end of November. At the end of the trial there were recruits from both the greenhouse and the open ponds, however due to the limited numbers and unplanned breeding statistical analysis could not be carried out on this.

Survival varied with species and site, and the results are presented in Table 6. There was significantly higher survival for both species in greenhouse ponds than open ponds. *O. niloticus* had the highest survival rate (85%) and *O. macrochir* had a survival rate of 77.7% in the greenhouse ponds. The mortality rate of *O. niloticus* was 15% and that of *O. macrochir was* 22.3% in the greenhouse ponds. The open ponds had very low survival with the mortalities as high as 51.3% for *O. niloticus* and 54% for *O. macrochir*. Because of sample size limitations, statistical analysis was not carried out for the survival data

Growth Performance Indicators

Growth performance indicators were determined to compare the fish cultured in greenhouse and open ponds. For *O. niloticus*, the final weight gain (FWG) of 48.3g was almost double that of similar fish cultured in open ponds (Table 7). In the case of *O. macrochir*, fish in greenhouse ponds had a greater a FWG of 24.23g compared to a FWG of 18.70g in the open ponds (Table 7). The difference in FWG for *O. macrochir* in the two culture systems was not as great as that of *O. niloticus*. The FWG for *O. niloticus* in open ponds was still greater than that of *O. macrochir* cultured in greenhouse ponds. A similar trend was observed for the Individual Weight Gain (IWG), where O. niloticus in greenhouse ponds far outperformed all the other fish in other experimental units (Table 7). *O. niloticus* in greenhouse ponds had the highest Food Conversion Ratio (FCR) of 11.68g/g while *O. macrochir* in open ponds had the lowest FCR of 19.73g/g (Table 7). Again *O. niloticus* had better FCR compared to all *O. macrochir* treatments. Finally, *O. niloticus* in greenhouse pond shad a Specific Growth Rate (SGR) of 7.2% which was 3-fold greater than that of *O. niloticus* cultured in open ponds (Table 7).

Table 6. Survival and reproductive data for *O. niloticus* and *O. macrochir* cultured in greenhouse and open ponds at Henderson Research Station

Site	Species	Birth rate/1000 fish	Death rate/1000 fish
Greenhouse ponds	***O. niloticus***	59	150
	O. macrochir	70	223
Open ponds	***O. niloticus***	371	513
	O. macrochir	262	540

The study was carried out to investigate optimum temperature ideal for the survival, growth, and reproductive activities of *O. niloticus* and *O. macrochir* reared in earth ponds under the greenhouse controlled environments in the cool eco-region of the country. The results showed significantly better growth for fish cultured in greenhouse conditions than in open ponds. The improved growth for the *Oreochromis niloticus* and *Oreochromis macrochir* in the greenhouses was certainly due to a higher metabolism. Temperatures recorded in the greenhouse were elevated probably due to the greenhouse effect and could be maintained between 25°C and 32°C. Such temperatures are ideal for tilapia culture and simulate water temperatures in much warmer aquaculture regions such as the Lake Kariba basin. The other water quality parameters measurements were within the range for normal growth of *O. niloticus* and *O. macrochir*. Within the greenhouse, it is important to ensure that water temperatures do not exceed 35°C (Pandit and Nakamura, 2010). *Oreochromis niloticus* had reduced growth performance at 35°C and 37°C which was attributed to decreased food intake and high rate of gastric evacuation at such elevated temperatures.

Table 7. Growth performance indicators for *O. niloticus* and *O. macrochir* cultured in greenhouse and open ponds at Henderson Research Station

Final Weight Gain (FWG)	**Experiment**	**Final Weight (F_w) (g)**	**Initial Weight (W_0) (g)**	**(F_w - W_0) (g)**
	O. niloticus (greenhouse)	50.00	1.7	48.30g
	O. niloticus (open ponds)	28.40	1.7	26.6g
	O. macrochir (greenhouse)	26.73	2.4	24.2g
	O. macrochir (open ponds)	21.20	2.5	18.7g
Individual Weight Gain (IWG)	**Experiment**	**Final Weight (F_w) (g)**	**Initial Weight (W_0) (g)**	**(F_w – W_0)/180 days**
	O. niloticus (greenhouse)	50.00	1.7	0.27g/day
	O. niloticus (open ponds)	28.40	1.7	0.15g/d
	O. macrochir (greenhouse)	26.73	2.4	0.13g/d
	O. macrochir (open ponds)	21.20	2.5	0.10g/d
Food Conversion Ratio (FCR)	**Experiment**	**Total feed (F) (g)**	**Total Weight Gain (W) (g)**	**(F/W) (g/g)**
	O. niloticus (greenhouse)	564.0	48.3	11.68
	O. niloticus (open ponds)	462.6	26.6	17.39
	O. macrochir (greenhouse)	442.1	24.2	18.27
	O. macrochir (open ponds)	368.9	18.7	19.73
Specific Growth Rate (SGR %)	**Experiment**	**W_t**	**W_0**	**100 × (ln–ln W0)/t (IWG)**
	O. niloticus (greenhouse)	50.0	1.7	7.2%
	O. niloticus (open ponds)	28.4	1.7	2.2 %
	O. macrochir (greenhouse)	26.73	2.4	1.75 %
	O. macrochir (open ponds)	21.2	2.5	1.0 %

During the period from December to January there was an increase in water temperatures in the open ponds (average of 25°C), but this was 3.82°C lower than in the greenhouse ponds. This is in agreement with studies that also found that water temperatures 25-30°C were more suitable for culture of tilapia to obtain optimum growth performance and survival rate (El-sherif et al., 2009; Mirea et al., 2013). Josiah et al. (2014) also observed that the optimum range for growth and food conversion was 21- 28°C. Mean values of temperature and pH were significantly higher in the greenhouse ponds compared to the open ponds. In contrast, conductivity and total dissolved solids were higher in the open ponds while there was no significant difference in dissolve oxygen during the experiment. Mean values for nitrate, nitrogen and reactive phosphorus were significantly higher in greenhouse ponds compared to the open ponds and ammonium was low during the experiment. Other measured water quality parameters were within the range for growth of tilapia fish species.

The specific growth rate (SGR) values of *O. niloticus* and *O. macrochir* in all treatments had a general increase throughout the experimental period. SGR was influenced by temperature, turbidity, sulphates, pH and also differed according to the species. The results showed that the SGR values of *O. niloticus* and *O. macrochir* at the end of the experimental period increased by 7.2% and 1.8% in the greenhouse, respectively; and by only 2.2% and 1% in open ponds respectively. The improvement in SGR for the faster growing *O. niloticus* was notable in the greenhouse ponds, while that of *O. macrochir* almost doubled from 1% to 1.8% in greenhouse ponds. Some other studies show that *Oreochromis macrochir* had high growth rates and feed conversion ratio at temperatures above 25°C (Santos et al. 2013; Nsonga, 2014). Nevertheless, *Oreochromis niloticus* remained the superior fish in terms of growth performance under both culture conditions, and it outperformed *O. macrochir* by a large margin when cultivated under greenhouse conditions. Therefore, growth performance indicators also clearly showed that *O. niloticus* is superior to *O. macrochir*, with *O. macrochir* in greenhouse culture only being comparable to *O. niloticus* in open ponds. The relationship between water temperatures and the corresponding FCR was also evident as fish cultured in greenhouses had a much better FCR compared to those in open ponds. This superior FCR then results in a greater weight gain and better utilization of feed resources for the fish farmer.

The environmental conditions were ideal for the optimum growth. Fish growth rate was highest in the greenhouse. The regression analysis revealed that, there were positive relationships between weight gain and length of fish with temperature and dissolved oxygen in greenhouse ponds for *O. niloticus*. The analysis also revealed that there were significant relationships between fish size (weight and length) with alkalinity, turbidity, conductivity, chlorophyll *a* and total dissolved solids in open ponds for *Oreochromis macrochir*. It is unlikely that these water quality parameters alone have a direct effect on the fish growth in open ponds, but instead, where rather a reflection of the differences between water quality of greenhouse and open ponds.

Oreochromis niloticus and *O. macrochir* had higher survival rates in the greenhouse ponds than in open ponds. Poor survival in open ponds might have been partly due to predation as the aquaculture site is frequented by fish eating birds and monitor lizards. No mortalities due to other issues such as disease or injury were recorded. It can be concluded that optimizing the environmental and water temperature as well as keeping all other water variable and sufficient nutritional needs in the greenhouse will increase the survival, growth rate and reproductive performances of *O. niloticus* and *O. macrochir* at Henderson and in natural regions I, II and III where temperatures are generally low.

Conclusion

In conclusion, the results of this study clearly demonstrated that the greenhouse environment was able to maintain the temperature within the optimum range throughout the study period. This then should enable enhanced production throughout the year as well as improve on growth rates and feed conversion efficiency of the fish. The greenhouse is an essential, efficient, economical and important tool for the optimization of survival, growth and reproduction of *O. niloticus* and *O. macrochir* in the cooler sub-tropical regions of Africa. Indigenous fish species like *O. macrochir* will be difficult to promote for aquaculture given their inferior growth performances to *O. niloticus*.

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