Observations on the effects of water exchange rate on the growth rate of *Oreochromis mossambicus* (Peters) Part 1: Production fish over a period of 200 days

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Abstract

An acceptable growth rate was obtained for *Oreochromis mossambicus* from a mean mass of 19.2 g at the time of stocking to 360.7 g at harvest over a period of 200 d in a pond where the water exchange rate of 0.71 $\ell\cdot min^{-1}\cdot kg^{-1}$ at stocking density of 90 $fish\cdot m^{-3}$ was sufficient to remove the growth limiting substances from the system.

A significant positive correlation level of $r=0.96$ ($p<0.001$) between water exchange rate and growth rate of *O. mossambicus* was obtained at all levels of intensive and super-intensive production.

A similar significant positive correlation ($r=0.93$) was recorded between stocking density and required water exchange rate. With an increase in stocking density progressively more water is required to produce 1 kg of fish over the same period of time. The demand for water per kg of fish produced increased drastically over the last quarter of the production period.

Introduction

Oreochromis mossambicus is indigenous to Zululand and can play an important role in the protein requirements of the fast-growing local communities. It is a palatable fish and it was therefore considered important to explore its culture potential.

Oreochromis mossambicus has been described as a slow-growing (Mires, 1983) and a poor culture fish (Torrans, undated; Hepher and Pruginin, 1981; Henderson-Arzapalo et al., 1980). Preliminary experimental production trials were undertaken to identify the requirements for an acceptable growth rate at different stocking densities.

During the 1986 to 1989 production trials Visser (1991) had found a positive correlation between water exchange rate and growth rate at production levels of up to 2.5 $kg\cdot m^{-3}$ of water. This paper reports on further studies to evaluate the water requirements at a wider range of stocking densities.

Little is known about the effect of the water exchange rate on the growth rate (production) of Tilapia. This information is of special importance in a country with limited water resources such as South Africa.

Material and methods

The present series of experiments were carried out over a period of 3 production seasons of 200 d each (Ponds V7 to V13, Table 1). The results of Visser (1991) (ponds V1 to V4, Table 1) are included for comparison.

The experimental programme was severely restricted by the lack of natural impounded water on the university campus. Chlorinated tap water had to be dechlorinated in 2 reservoirs with a total capacity of 244 m^3 and maturated before use in the fish ponds. Replication of the treatments was therefore not possible but significant tendencies were nevertheless observed which should further be investigated.

The construction and management of the 15.9 m^3 circular vinyl ponds (4.5 m dia. by 1 m deep), as well as their effectiveness as production ponds has been described by Visser et al. (1989) and Visser (1991). No provision for continuous water flow-through was, however, made in these earlier trials but water was exchanged daily for cleaning purposes and for maintaining turbidity levels of about 25 NTU (Ponds V1 to V4, Table 1).

In the 1990/91 trials Pond V7 was stocked with sex reversed (all male) fish at 29.2 $fish\cdot m^{-3}$. It was managed as in the previous trials but more water was used per $fish\cdot d^{-1}$ for cleaning purposes (Table 1).

In the 1991/92 trials one outdoor vinyl pond (V8) with a capacity of 15.9 m^3 was stocked with all male fish at 40 $fish\cdot m^{-3}$ but, in contrast to the previous trials, a continuous water exchange of 0.22 $\ell\cdot min^{-1}\cdot kg^{-1}$ was maintained (Table 1).

At the end of the 1991/92 season it became clear that density and water exchange play an important role in the growth rate of *O. mossambicus*. The 1992/93 experiments were therefore planned to accommodate this relationship. Smaller ponds were used in the present experiments because of the large volumes of water required at high stocking densities. Four circular fibreglass ponds (Ponds V10 to V13) with a 2 m dia., 0.5 m depth and with a 1.5 m^3 capacity, were installed inside a hothouse. In addition to these small ponds, one large 15.9 m^3 capacity outdoor vinyl pond (V9) was also used. The correct water depth was maintained in each pond by means of a vertical central overflow pipe. A screen prevented fish from escaping. Shade cloth (80%), placed over the ponds provided some shelter to the fish. The floors of the ponds were cleaned daily by means of a siphon. Details of the sex reversed (all male) fish stocked are summarised in Table 1 (Ponds V9 to V13). Outdoor pond V9 was stocked at the same $density\cdot m^{-3}$ as the small indoor pond V10.

Commercial trout pellets (35% protein) were fed at regular intervals during the day. The equation $y = 271 + 13.3x$ [where y is the food required ($mg\cdot d^{-1}$) and x is the wet mass of the fish (g)]

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TABLE 1
THE RELATIONSHIP BETWEEN PRODUCTION, WATER EXCHANGE AND STOCKING DENSITY PER m³ OF POND OVER A SEASON OF 200 d IN PONDS STOCKED WITH ALL MALE *O. MOSSAMBICUS*

Season	Pond No.	Pond capacity (ℓ)	Density (fish·m⁻³)	Mean mass at stocking (g)	Mean mass at harvest (g)	Mean mass increase (g)	Mean mass increase per day (g)	Production (kg·m⁻³)	Water flow (ℓ·min⁻¹·kg⁻¹)	Total water used (m³)	Water used to produce 1 kg of fish (m³)	Remarks
1986\87	V1	15 900	17	2.1	113	110.9	0.56	1.9	0.03	8.5	4.5	The flow rates are mean ℓ·min⁻¹.kg⁻¹ calculated from the water used daily (See **Methods**)
1987\88	V2	"	1.7	2.3	320	318.7	1.59	0.5	0.05	3.6	7.2	
"	V3	"	10.1	2.3	156	153.7	0.77	1.6	0.04	9.2	5.8	
"	V4	"	22.8	2.3	113	110.7	0.55	2.5	0.04	12.8	5.1	
1990\91	V7	"	29.2	17.4	152.9	135.5	0.68	3.6	0.1	67.6	18.6	
1991\92	V8	"	40	20.85	241.9	221.1	1.1	8.1	0.22	205.1	25.2	
1992\93	V9	"	10	16.68	336.6	319.9	1.6	3.0	0.11	52.2	17.4	
"	V10	1 500	10	17.70	193.5	175.8	0.9	1.8	0.11	38.0	21.1	
"	V11	"	30	19.00	268.6	249.6	1.3	6.6	0.25	328.4	49.8	
"	V12	"	60	22.40	299.2	276.8	1.4	13.8	0.48	1260.1	91.3	
"	V13	"	90	19.20	360.7	341.5	1.7	23.8	0.71	3106.6	130.5	

(Moriarty and Moriarty, 1973; Balarin and Hatton, 1979) was used as a guideline for calculating the daily food ration, but slightly more food was given to eliminate food shortage as a possible growth-limiting factor.

The water used in the flow-through system was not recirculated to prevent the accumulation of unknown quantities of growth-limiting substances in the water. The flow rate was derived from the regression equation $y = 0.0075x + 0.033$, where y is the flow rate ($\ell\cdot min^{-1}\cdot kg^{-1}$) and x the density ($fish\cdot m^{-3}$) (Plot A-A in Fig.3). The objective was to find a water exchange rate which would support a mean daily growth of about 1.5 g at different stocking densities. This would give a marketable size fish of about 300 g over a production period of 200 d. The above regression equation was derived by using data from one pond (V2, Table 1), the only pond where the mean daily growth of 1.59 g was acceptable, as well as data from the experiments of Siddique et al. (1991) where the growth rate was very similar to that of the fish in Pond V2. The latter authors used *O. niloticus* in ponds with a continuous water flow-through to waste of 0.5 $\ell\cdot min^{-1}\cdot kg^{-1}$ and at a density of 64 $fish\cdot m^{-3}$. It was assumed that the growth of *O. niloticus* is similar than that of *O. mossambicus* at the same stocking density and water exchange rate. It was further assumed that there is a straight line relationship between the increase in density and the increase in flow rate. The different densities and flow rates of ponds V9 to V13 (Table 1) were calculated from the equation to test the validity of the above assumptions.

Representative fish samples were weighed at 21 to 30 d intervals in order to make adjustments to the predicted growth rate on which the calculation for the daily food rations and water exchange was based.

The ponds were artificially aerated by means of a blower to ensure an oxygen concentration of higher than 5 $mg\cdot\ell^{-1}$.

Daily recordings were made of minimum and maximum temperatures, and weekly recordings of pH (Orion meter, model 221) DO (YSI Oxygen analyser) and total ammonia (Orion microprocessor ionanalyser). The latter figures were converted to obtain the values of the toxic NH_3 component, taking pH and temperature into consideration (Table 3). Regression lines were drawn with Statgraphics Version 6.

Results and discussion

Excellent growth was obtained at intensive stocking densities of *O. mossambicus* in the small production ponds in spite of the doubts expressed by some authors as to the potential of *O. mossambicus* as a production fish in intensive culture. (Henderson-Arzapalo et al., 1980; Hepher and Pruginin, 1981; Torrans, undated). Fingerlings stocked at 90 $fish\cdot m^{-3}$ with a mean mass of 19.2 g reached a mean mass of 360.7 g in the relatively short production period of 200 d (Table 1, Pond V13). This appears to be the best known growth rate recorded for this species stocked at such a high density.

A significant positive correlation between growth rate (production) and water exchange rate at production levels of up to 2.5 $kg\cdot m^{-3}$ was described for *O. mossambicus* (Visser, 1991). This correlation ($r = 0.96$ and $p < 0.001$) also existed at higher production levels but it does not follow a straight-line relationship because relatively more water was required as density and production levels increased (Fig. 1). The equation $y = 0.4663\ x^{0.485}$ describes this relationship for *O. mossambicus* [y = production ($kg\cdot m^{-3}$) and x = water used (m^3)]. This correlation existed in the outdoor as well as the small indoor ponds and even in those ponds where different methods of water exchange were employed.

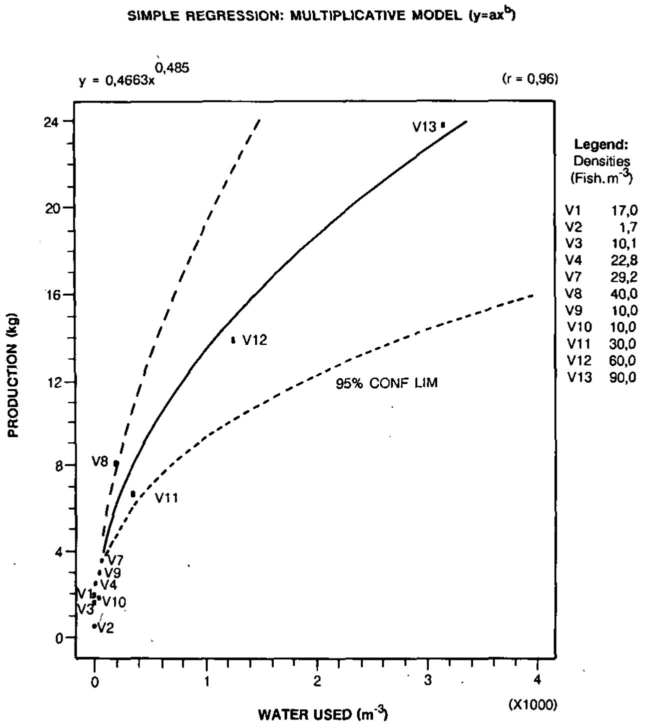

Figure 1
The relationship between water used and production per m^3 of pond (Table 1)

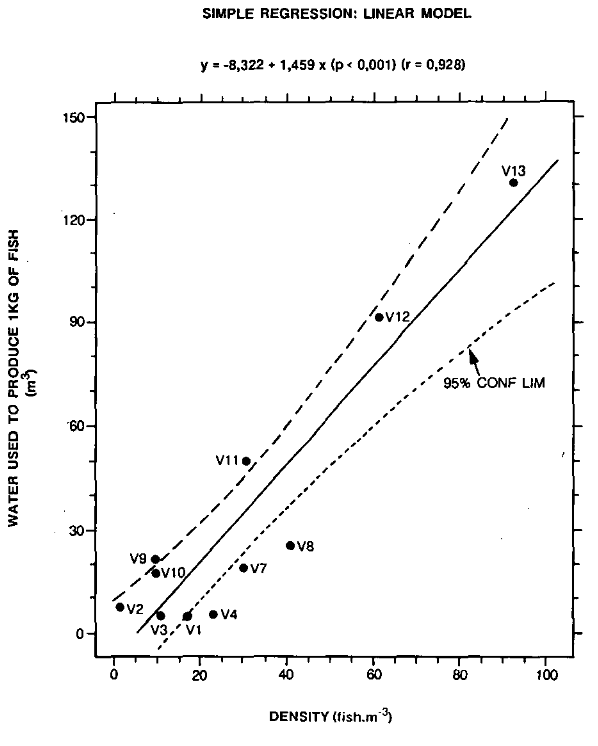

Figure 2
The relationship between density and water used to produce 1 kg of fish per m^3 of pond

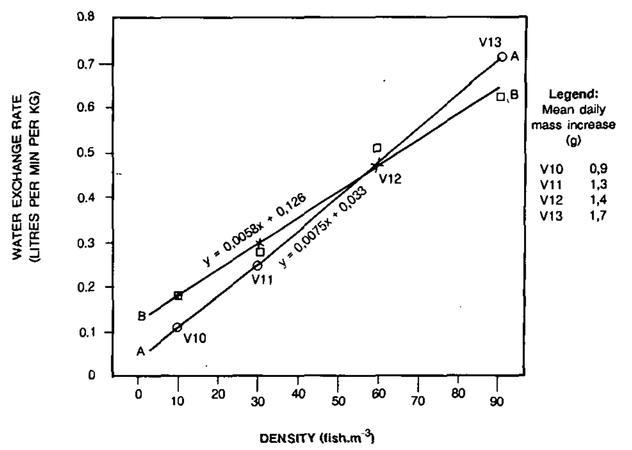

Figure 3
Water exchange rate used for fish stocked at 4 different densities (line A-A). The equation of line B-B is recommended for further experimentation to ensure a mean growth of 1.5 $g \cdot d^{-1}$

Increased stocking densities increased the demand for water needed to sustain acceptable growth. Figure 2 shows the relationship between fish density and the water needed to produce 1 kg of fish. This straight-line relationship is expressed by the equation $y = 1.459x - 8.322$ [y = water used to produce 1 kg of fish (m^3) and x = density ($fish \cdot m^{-3}$)]. Pond V13 with a stocking density of 90 $fish \cdot m^{-3}$ needed 130.5 m^3 of water to produce 1 kg of fish whereas Pond V2 with a stocking density of 1.7 $fish \cdot m^{-3}$ needed only 7.2 m^3 (Table 1).

Henderson-Arzapalo et al. (1980) observed a hypersensitive reaction or auto-immune response in *O. mossambicus* which is a biomass-related response to a secretion or excretion through the mucous membrane of the skin of the fish into the water. This response retards growth and may prevent overcrowding in nature.

Density stress probably induces a faster secretion or excretion of the substance responsible for the auto-immune response in *O. mossambicus* described by Henderson-Arzapalo et al. (1980). From the available information in the literature on the quantity of water used in tilapia production trials, it appears that some of the other species of *Oreochromis* are not as severely stressed by stocking density. Henderson-Arzapalo et al. (1980) did not observe a hypersensitive reaction in *O. aureus*. Zohar et al. (1985) used only 15.2 m^3 and 14.8 m^3 water to produce 1 kg of fish at densities of 50 and 100 $fish \cdot m^{-3}$ respectively. They used the hybrid *O. aureus* x *O. niloticus* in their trials. The relatively small volumes of water required for this hybrid fish to produce 1 kg of fish, compared with *O. mossambicus* (Table 1), indicate that they may not have such a severe auto-immune response present in the hybrid, rendering it much more suitable for intensive fish culture purposes.

The water exchange rate of 0.5 $\ell \cdot min^{-1} \cdot kg^{-1}$. at a stocking density of 64 $fish \cdot m^{-3}$ described for *O. niloticus* by Siddique et al. (1991) is similar to that of *O. mossambicus* in pond V12 with comparable growth rates. The auto-immune response of *O. niloticus* therefore appears to correspond with that of *O. mossambicus*.

It is clear from the present study that the removal of the above-mentioned growth-inhibiting secretions or excretions is the most important factor to be taken into consideration in the production of *O. mossambicus*. It is also more likely that the hypersensitivity reaction sets in when the water exchange rate ($\ell \cdot min^{-1} \cdot kg^{-1}$) drops below a certain level, which is different for different stocking densities and not only at a biomass of 20 $g \cdot \ell^{-1}$ (20 $kg \cdot m^{-3}$) as

TABLE 2
THE RELATIONSHIP BETWEEN WATER EXCHANGE AND PRODUCTION FOR DAYS 0-100, 101-200 AND 151-200

Pond	Pond capacity (m^3)	Density (fish·m^{-3})	Water used to produce 1 kg of fish (m^3)			Percentage of total water used		Percentage of total production	
			0-100	Days 101-200	151-200	Days 151-200	101-200	Days 151-200	101-200
V7	15.9	29.2	10.0	26.6	31.7	46.9	67.2	26.4	47.5
V8	15.9	40	14.4	33.1	37.2	40.1	69.2	27.3	53.0
V9	15.9	10	6.8	25.1	53.5	41.0	80.4	13.3	55.7
V10	1.5	10	8.2	39.7	73.5	38.7	72.1	11.1	38.3
V11	1.5	30	21.2	78.1	121.3	44.3	73.9	18.2	47.1
V12	1.5	60	39.7	135.5	170.0	44.5	74.2	23.9	50.0
V13	1.5	90	67.8	180.6	225.3	46.0	75.6	26.6	54.6
Mean			24.0	74.1	101.7	43.1	73.2	21.0	49.5

suggested by Henderson-Arzapalo and Stickney (1983). The bacteria in biological filters may well remove the growth-inhibiting substances from the pond water. This aspect, however, needs further investigation.

The equation $y = 0.0075\,x + 0.033$ (Plot A-A in Fig. 3) used for calculating the water exchange rate of the indoor Ponds V10 to V13 did not support the targeted mean growth rate of 1.5 $g{\cdot}d^{-1}$ at all densities as has been anticipated when the experiment was planned. The fish in the high density Pond (V13) grew slightly faster whereas those at lower densities (Ponds V10 & V11) grew slightly slower. These different growth rates were obtained in spite of the fact that the un-ionised ammonia (NH_3) levels in all the ponds remained negligible (<0.001 m moles·ℓ^{-1}) and other factors such as O_2, pH and temperature were very similar throughout the production period (Table 3). The slower growth at the lower density levels (Ponds V10 and V11) can only be ascribed to the insufficient removal of the so-called growth-inhibiting substance described by Henderson-Arzapalo et al. (1980). The regression equation $y = 0.0058x + 0.126$ is now recommended for further experimentation in an attempt to achieve a mean growth rate of 1.5 $g{\cdot}d^{-1}$ at all density levels. The water exchange data points used for calculating this equation [Plot B-B (Fig. 3)] were derived from the following equation:

$$\frac{\text{Envisaged mean growth } (1.5\ g{\cdot}d^{-1}) \quad \times \quad \text{Existing water exchange rate } (\ell{\cdot}min^{-1}{\cdot}kg^{-1})}{\text{Existing mean growth } (g{\cdot}d^{-1})}$$

$$= \text{Recommended water exchange rate } (\ell{\cdot}min^{-1}.kg^{-1})$$

e.g. Pond V10

$$\frac{1.5 \times 0.11}{0.9} = 0.18\ \ell{\cdot}min^{-1}{\cdot}kg^{-1}$$

This calculation is possible because of the straight-line relationship between density and water used to produce 1 kg of fish (Fig. 2).

The above-average growth in the bigger outdoor Pond V9, compared with the below-average growth in the small indoor Pond V10, both of which were stocked at similar densities and had similar water exchange rates, suggests that *O. mossambicus* may respond differently in different size ponds at the same stocking density. This needs further investigation.

The volume of water used to produce 1 kg of fish increased rapidly with the increase in biomass during the production season of 200 d. A mean of 24.0 m^3 of water was used to produce 1 kg of fish over the first 100 d. This increased to 74.1 m^3 over the second 100 d and 101.7 m^3 over the last 50 d (Table 2). On average, 73.2% of the total water was used during the last 100 days while this period yielded only 49% of the total production. This relationship became even worse in the last 50 days when a mean of 43.1% of the total water was used to produce only 21% of the total fish mass gain.

From the discussion it is clear that relatively much less water is required over the first 100 days of production to produce 1 kg of fish. Consumer fish size preference and availability of water will thus have to be considered when determining the production period.

The abnormally high feed conversion rate in Ponds V9 to 13 (Table 3) may be artificial because slightly more food than necessary was given to the fish to eliminate food shortage as a possible growth-limiting factor.

TABLE 3
MEANS OF DISSOLVED OXYGEN, WATER TEMPERATURE, pH AND UN-IONIZED AMMONIA (NH_3) LEVELS AS WELL AS THE FOOD CONVERSION RATIOS AND MEAN DAILY GROWTH OF *O. MOSSAMBICUS*

Pond No.	Daily minimum temperature (°C)	Daily maximum temperature (°C)	O_2 (mg·ℓ$^{-1}$)	NH_3 (m mole·ℓ$^{-1}$)	pH	Food conversion	Mean daily growth (g)
V2	24.2 Range : 19-31	27.2	7.5 4.9-12.4	<0.001 Max:<0.001	7.2 5.3-9.2	1:1.9	1.59
V3	24.6 Range : 19-32	27.8	5.8 1.3-13.4	<0.001 Max: 0.003	7.2 5.5-10.0	1:2.5	0.77
V4	24.9 Range : 19-33	27.8	5.5 1.3-11.6	0.002 Max: 0.014	6.8 5.4-9.6	1:2.3	0.55
V7	21.7 Range : 16-34	28.7	7.5 2.0-12.1	0.001 Max: 0.010	7.1 6.0-9.0	1:3.4	0.68
V8	23.2 Range : 18-32	28.0	5.7 1.5-10.5	0.001 Max: 0.005	6.6 5.9-7.5	1:1.9	1.1
V9	25.6 Range : 20-34	27.5	7.2 4.5-8.1	0.001 Max: 0.002	6.7 6.1-7.1	1:2.2	1.6
V10	25.6 Range : 20-34	27.5	6.7 5.6-8.5	<0.001 Max: 0.001	6.5 6.2-7.0	1:3.1	0.9
V11	25.6 Range : 20-34	27.5	6.9 5.1-7.9	<0.001 Max:<0.001	6.6 6.3-7.0	1:3.1	1.3
V12	25.6 Range : 20-34	27.5	6.4 3.8-7.5	<0.001 Max:<0.001	6.5 6.1-7.2	1:3.0	1.4
V13	25.2 Range : 20-30	27.5	6.2 4.2-7.7	<0.001 Max:<0.001	6.6 6.1-7.3	1:3.0	1.7

Conclusions and recommendations

Additional replicated experimentation is needed to verify the above results but it is clear that a definite relationship exists between growth of *O. mossambicus* and water exchange. The results also showed that *O. mossambicus* can be used in super-intensive culture systems but only when ample water is available, such as in irrigation schemes or possibly also in water-cooling systems of power stations. It is also extremely important to investigate the physical and chemical nature of the substances responsible for the anticipated auto-immune response of this fish species under intensive production systems.

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