Intensive production of *Oreochromis mossambicus* (Peters) with special reference to the relationship between water exchange rate and growth rate

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Abstract

An attempt is made to define the concepts "intensity and extensive production" as these terms are not clearly defined at present.

A significant positive correlation between water exchange and growth (production) was obtained with *Oreochromis mossambicus* at production levels below 2,5 kg.m^{-3}. The results of other researchers revealed similar relationships at higher production levels for other species of *Oreochromis*.

Introduction

Tilapia is the most important species of finfish cultured in Taiwan (Liao and Chen, 1983; Chen, 1976) and is one of the candidate groups for aquaculture in South Africa. Balarin and Haller (1983) state that "with the ever increasing demand for fish protein there is a general trend towards intensification, and intensive fish culture of tilapia is likely to play a key role in future development" (p 483).

The intensification of production is variously referred to as intensive production, intensive farming, intensive culture and intensive practice. Such measures result in yields of between 2 and 2 000 t.ha^{-1}.a^{-1}. At the lower end of the range the term "extensive" is used in different ways by different authors. Balarin and Haller (1983) define intensive fish farming as "farming which seeks to produce a maximum quantity of fish of high quality, in a minimum of water, by means of intensive, often exclusive feeding, requiring some form of aeration or water flow for oxygen supply and waste removal" (p 474). Extensive production, according to the same authors is "the production of fish without artificial feeding usually in ponds, and is dependent upon natural or enhanced natural productivity to provide nutritional requirements".

It is clear that intensive production is production in a water body where control is possible over the energy input into the system. The energy input refers to the artificial feed and the fish stocked. In extensive production, on the other hand, no control is exercised over the total energy input into the system as is the case in natural lakes, certain man-made dams, rice paddies, rivers and integrated farming systems where the manure of farm animals constitutes an uncontrolled energy input. A maximum production of about 2t.ha^{-1}.a^{-1} is possible from extensive production (Balarin and Haller, 1983) (Table 1).

The degree of intensification depends on:

- stocking density;
- extent of artificial feeding;
- successful removal of growth inhibiting substances, such as NH_3, NO_2, H_2S, and biogenic amines from the system;
- aeration;
- application of high technology and sound management; and
- capital investment and operational cost.

The growth rate of the fish in intensive production systems depends on the above factors while the size of the fish to be produced depends on consumer preference. The rate of water exchange per unit of ichthyomass determines the different levels of intensive production because this is the most effective way to eliminate growth-inhibiting substances from the system.

The incorporation of biological filtration (Watten and Busch, 1984) and the so-called "green water ponds" adjacent to the production pond (Liao and Chen, 1983) have the effect of reconstituting or maintaining water quality which would thus reduce water intake requirements as purification takes place at this level. The optimum relationship between water required and production should be determined experimentally for every production system. This information is important in countries where water is a scarce resource, such as South Africa.

The relationship between water exchange and production is one of the most neglected aspects in tilapia production research and very little information is available from the literature. According to Balarin and Haller (1983) "a flow rate of between 0,5 and 1,0 ℓ.min^{-1}.kg^{-1}, varying with the size range is generally adequate at Baobab farm" (p 480). This is at a stocking density of 200 to 500 fish m^{-3}. Granoth and Porath (1983) required 0,2 ℓ.min^{-1}.kg^{-1} at a stocking density of 110 fish m^{-3} and Zohar *et al.* (1985) used 0,08 and 0,09 ℓ.min^{-1}.kg^{-1} at stocking densities of 62,5 and 125 fish m^{-3} respectively.

One of the main objectives in this study was to determine the relationship between growth (production) and water used. These results were compared with relevant information in the literature where water flow had been recorded during production studies.

Materials and methods

The experiments were carried out over a period of three production seasons of 200 d each. Up to three circular vinyl portapools, 4,5 m diameter by 1 m deep with a capacity of 15 900 ℓ were used each season. The construction and management of the ponds as well as their effectiveness as production ponds were described by Visser *et al.* (1989) (Fig. 1).

Most of the waste food and faeces which accumulated at the central drain were flushed out by draining a known volume of water from the tank each day. Residual waste was removed by regular sweeping of the floor during drainage. When turbidity reached a Secchi disc reading of less than 30 cm (~ 25 NTU on the turbidimeter) half of the pond was drained and refilled with dechlorinated tap water.

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TABLE 1
SUMMARY OF THE CHARACTERISTICS OF EXTENSIVE AND INTENSIVE TILAPIA PRODUCTION

	Type of production unit	**Feeding**	**Aeration**	**Water requirement**	**Sex of fish**	**optimum stocking density m^{-2}**	**Production in one season of + 200 d ($kg.m^{-2}$)**
A. Extensive production							
(No control over energy input)	Rivers Dams Lakes Rice paddies	No pelleted feeds	No additional aeration	No artificial water exchange, except flow in rivers and rice paddies	Mixed	0,5-5 (population density)	0,02-0,2
B. Intensive production (Control over energy input)							
i)Semi-intensive	Ponds	Fertilisers, manure, waste, pelleted feeds	No additional aeration or limited aeration	No water exchange or biological filters but top-up for evaporation and seepage	All males or mixed	1-3	0,2-0,5
ii) Intensive	Specially designed fish ponds or tanks (Taiwanese type), cages	Pelleted feeds and sometimes supplemented with manure	Paddle wheels, air in ponds	Water exchange and/or biological filters (Maximum water requirement is less than 0,03 $\ell.min^{-1}.kg^{-1}$)	All male	3-10	0,5-3
iii) Super-intensive	Specially designed fish tanks, (complex technology and management) race ways, cages	Pelleted feeds	Paddle wheels, air	Water requirement more than 0,03 $\ell.min^{-1}.kg^{-1}$	All male	10-plus (depending on size at stocking)	3 plus

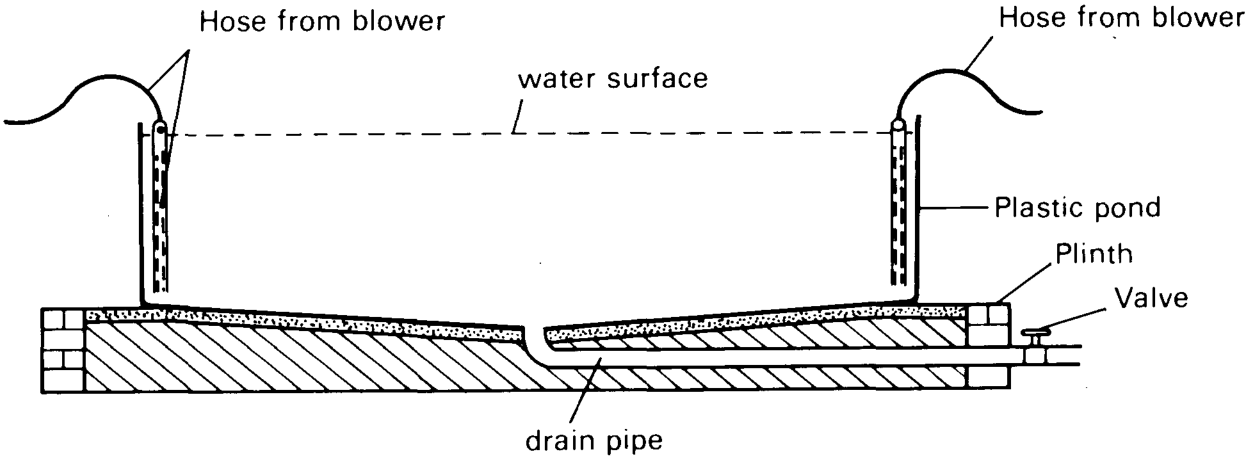

Figure 1
Transverse section of pond

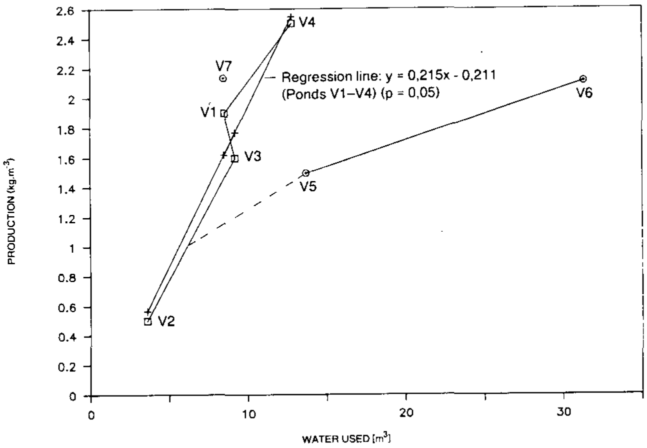

Figure 2
The relationship between water used and production per cubic metre of pond over a season of 200 d in ponds tocked with O. mossambicus *(Table 2)*

In addition to the above, water from one of the portapools was recycled through a biological filter in the 1988/89 experiment (pond V7 in Table 2). The filter consisted of a 5,7 m^3 circular concrete pond fitted with 80 mm stones over which a 20 mm surface layer of finely crushed stone was spread. Water was continuously recycled from the filter to the production pond, at a rate of 18 $\ell.min^{-1}$ by a submersible pump located in a sump at the centre bottom of the filter. This gave a water turnover in the production pond of 1,6 times per day. The tank was artificially aerated when the dissolved oxygen (DO) level dropped to below 2 $mg.\ell^{-1}$.

Details of the fish used are summarised in Table 2. The juveniles that bred in ponds V5 to V7 were not included in the production figures. Commercial trout pellets (35% protein) were fed. The daily ration was derived from the equation $y=271+13,3\ x$, where y is the food required ($mg.d^{-1}$) and x is the wet mass of the fish (g) (Moriarty and Moriarty, 1973; Balarin and Hatton, 1979). Fish were weighted at monthly intervals.

Regular recordings were made of minimum and maximum temperatures, pH (Orion meter model 221), turbidity (Hellige turbidimeter and Secchi disc), DO (YSI oxygen analyser), rainfall and ammonia (Orion microprocessor ionalyser).

Results and discussion

The results presented are preliminary since replication of the different treatments was not possible, but significant tendencies were observed. It was assumed that the rate of removal of growth inhibiting substances from the production system was the only significant variable in this experiment, because the chemical and physical environment was kept within narrow limits (Tables 3 and 4).

A significant positive correlation existed between production and water used ($r=0,946$, $p=0,05$) in the four ponds (V1 to V4) stocked with monosex *O. mossambicus.* From the regression equation $y=0,215x - 0,211$ it follows that about 5 m^3 water was required to produce 1 kg fish at production levels of up to 2,5 $kg.m^{-3}$ (Fig. 2) (y = production; x = water used).

The comparatively high water requirements in the production of mixed sexes is evident in Table 3 and Fig. 2 (Ponds V5 and V6). The biological filter incorporated in pond V7 reduced the water requirements for mixed sex production dramatically (Fig. 2). Pond V7 required only 27% of the water that was required in pond V6 with approximately the same production. In monosex production a

TABLE 2

THE RELATIONSHIP BETWEEN PRODUCTION AND WATER USED PER CUBIC METRE OF POND OVER A SEASON OF 200 d IN PONDS STOCKED WITH *O. MOSSAMBICUS*

Season	Pond No.	Sex	Density at harvest (m^{-3})	Mean mass at stocking (g)	Mean mass increase (g)	Mean mass increase per day (g)	Production (kg)	Production period (days)	Water used (m^3)	Mean water used per fish per day (ℓ)	Water used to produce 1 kg of fish (m^3)	Mean water used at harvest (ℓ.min^{-1}.kg^{-3} biomas^3)	Remarks
1986/87	V1	Monosex	17	2,1	110,9	0,56	1,9	200	8,5	2,5	4,5	0,02	-
1987/88	V2	Monosex	1,7	2,3	318,7	1,59	0,5	"	3,6	10,6	7,2	0,03	-
	V3	Monosex	10,1	2,3	153,7	0,77	1,6	"	9,2	4,6	5,8	0,02	-
	V4	Monosex	22,8	2,3	110,7	0,55	2,5	"	12,8	2,8	5,1	0,02	-
Mean			12,9			0,87	1,6		8,5	5,1	5,7	0,02	-
1988/89	V5	Mixed	15,7	4,1	92,9	0,47	1,5	"	13,9	4,4	9,2	0,04	-
	V6	Mixed	14,4	3,9	144,1	0,72	2,1	"	31,2	10,8	14,9	0,06	-
	V7	Mixed	15,2	4,3	137,7	0,69	2,2	"	8,7	2,9	4,0	0,01	Biological filter incorporated

filter may accordingly be expected to reduce the water-production ratio to well below the mean of 5:1 described above. The turning point in water requirement of mixed sex production was at a mean fish mass of about 50 g, i.e. when they became sexually mature and breeding commenced. A similar growth-water relationship existed when mean mass increase per day (g) was plotted against water used per fish per day (l) (Fig. 5 ponds V1 to V7).

A mean of 5,1 ℓ.fish^{-1}.d^{-1} was used in ponds V1 to V4 stocked with monosex fish, 7,6 ℓ.fish^{-1}.d^{-1} in ponds V5 to V6 stocked with mixed sexes and only 2,9 ℓ.fish^{-1}.d^{-1} in pond V7 which was stocked with mixed sexes but which incorporated the biological filter (Table 2).

Although the figures for ponds V1 to V4 showed a significant correlation between water used and production (growth), it must be borne in mind that satisfactory growth throughout the 200 day-period only occurred in pond V2. In this pond 7,2 m^3 of water was used to produce 1 kg of fish which was slightly higher than the mean of 5,1 for ponds V1 to V4 (Table 2).

When the amount of water used immediately before harvest time (maximum water requirement per day) was analysed, it showed that pond V2, where the best growth occurred, needed a mean of 0,03 ℓ.min^{-1}.kg^{-1} which is 33% higher than that of ponds V1, V3 and V4 where slower growth and even stunting occurred. The mixed sexes needed more water and the pond with the biological filter less water (Fig. 2 and Table 2).

The question arises whether this significant correlation between water and production (growth) exists at all densities and at all levels of intensive production. The present series of experiments only deal with production levels of up to 2,5 kg.m^{-3} and densities up to 22,8 fish m^{-3} and further experimentation is needed.

An analysis of the literature revealed further interesting tendencies (Figs. 4 and 5 and Table 3). Although the different species and production systems indicated cautious interpretation, the evidence suggested that this line of investigation should be pursued. Only four publications were encountered giving both production figures and water flow rate (Granoth and Porath, 1983; Zohar *et al.*, 1985; Watten and Busch, 1984 and Henderson-Arzapalo and Stickney, 1983). Analysis of this data is summarised in Table 3. A significant correlation ($p=0,02$) was found between water usage and fish production in the experiment of Zohar *et al.* (1985) (ponds Z1 and Z2

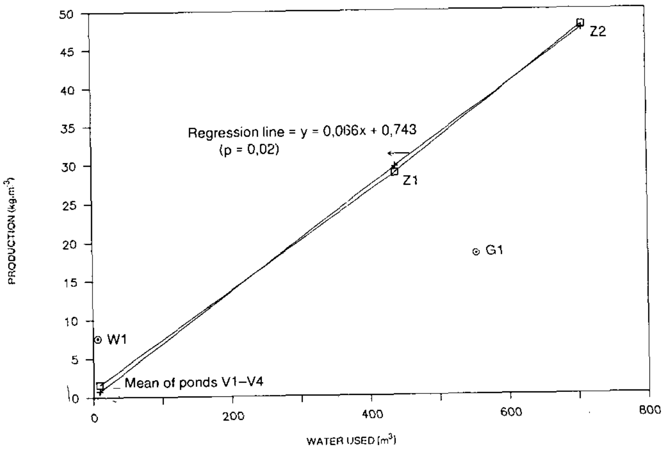

Figure 3

The relationship between water used and production per cubic metre of pond. A comparison of different management systems (Table 3)

TABLE 3
A COMPARISON OF WATER TO PRODUCTION RELATIONSHIPS PER CUBIC METRE OF POND IN DIFFERENT MANAGEMENT SYSTEMS (INFORMATION EXTRACTED FROM PUBLICATIONS)

Researcher	Pond No	Species and sex	Stocking density (m^{-3})	Mean mass at harvest (g)	Mean mass increase (g)	Mean mass increase per day (g)	Production (kg)	Production period (days)	Total water used (m^3))	Mean water used per fish per day (ℓ)	Water used to produce 1 kg of fish (m^3)	Pond size (capacity)	Water used at harvest (ℓ.min^{-1}. kg^{-1}, biomass)	Growth at harvest	Remarks
Granoth *et al.* (1983)	G1	*O.niloticus* x *O.aureus* Monosex	110	300	150	2,1	16,5	72	557,5	70,4	33,8	450 ℓ	0,2	Growth fair	—
Zohar *et al.* (1985)	Z1	Same as pond G1	62,5	600	460	2,8	28,8	164	437,4	42,7	15,2	40 m^3	0,08	Growth started to slow down	—
	Z2		125	523	383	2,3	47,9	164	708,5	34,6	14,8	40 m^3	0,09		
Visser		*O.mossambicus*													
	V1	Monosex	17	113	110,9	0,56	1,9	200	8,5	2,5	4,5	15,9 m^3	0,02	Stunted	
	V2	Monosex	1,7	320	318,7	1,59	0,5	,,	3,6	10,6	7,2	,,	0,03	Growth fair	
(Present study)	V3	Monosex	10,1	156	153,7	0,77	1,6	,,	9,2	4,6	5,8	,,	0,02	Growth slowed down	
	V4	Monosex	22,8	113	110,7	0,55	2,5	,,	12,8	2,8	5,1	,,	0,02	Stunted	
	V5	Mixed	15,7	97	92,9	0,47	1,5	,,	13,9	4,4	9,2	,,	0,04	Stunted	
	V6	Mixed	14,4	148	144,1	0,72	2,1	,,	31,2	10,8	14,9	,,	0,06	Growth slowed down	
	V7	Mixed	15,2	142	137,7	0,69	2,2	,,	8,7	2,9	4,0	,,	0,01	,,	Biological filter
Watten *et al.* (1984)	W	*O.aureus* Monosex	17,0	521	459,0	2,5	7,6	181	7,5	2,4	1,0	7,3 m^3			1. Biological filter 2. Settling tanks 3. Hydroponic bed (produced 291 kg tomatoes)
Henderson-Arzapalo *et al.* (1983)	H7	*O.mossambicus* Monosex	1 000	35	33	0,6	33	55	2 558,7	45,7	77,5	60 ℓ	0,9	Growth fair	Juvenile fish

TABLE 4
RELATIONSHIP BETWEEN WATER REPLACEMENT, GROWTH AND WATER QUALITY (MEANS OVER 200 d)

Season	Pond No.	Water used per fish per day (ℓ)	Mean daily mass increase (g)	Secchi disc reading (cm)	O_2 (mg.ℓ$^{-1}$)	Mean maximum daily temp. (°C)	Mean minimum daily temp. (°C)	pH	Total NH_3 Centre bottom of pond (m mole ℓ$^{-1}$)	Total NH_3 Side of pond and 50 cm depth (m mole ℓ$^{-1}$)
a)	**Monosex**									
86/87	V1	2,5	0,56	-	-	-	-	-	-	-
87/88	V2	10,6	1,59	42,6 Max. Clear Min. 22,5	7,5 Max. 12,4 Min. 4,9	27,2 Range:	24,2 19-31	7,2 Max. 9,2 Min. 5,3	0,013 Max. 0,138 Min. <0,001	0,011 Max. 0,126 Min. <0,001
	V3	4,6	0,77	29,7 Max. Clear Min. 15,0	5,8 Max. 13,4 Min. 1,3	27,8 Range:	24,6 19-32	7,2 Max. 10,0 Min. 5,5	0,040 Max. 0,592 Min. <0,001	0,036 Max. 0,479 min. <0,001
	V4	2,8	0,55	29,5 Max. Clear Min. 16,9	5,5 Max. 11,6 Min. 1,3	27,8 Range:	24,9 19-33	6,8 Max. 9,6 Min. 5,4	0,090 Max. 0,451 Min. <0,001	0,061 Max. 0,502 Min. <0,001
b)	**Mixed sexes**									
	V6	10,8	0,72	60,3 Max. Clear Min. 30,0	6,5 Max. 10,2 Min. 2,3	27,3 Range:	24,0 18-32	7,3 Max. 10,4 Min. 5,3	0,034 Max. 0,169 Min. <0,001	0,028 Max. 0,158 Min. <0,001
	V5	4,4	0,47	49,1 Max. Clear Min. 20,0	5,3 Max. 10,2 Min. 1,0	26,4 Range:	23,6 18-32	7,0 Max. 9,3 Min. 5,5	0,108 Max. 0,412 Min. <0,001	0,099 Max. 0,396 Min. <0,001
c)	**Mixed sexes and biological filter incorporated**									
	V7	2,9	0,69	84,4 Max. Clear Min. 25	5,1 Max. 9,2 Min. 1,3	27,1 Range:	24,2 18-32	6,6 Max. 8,9 Min. 5,5	0,005 Max. 0,652 Min. <0,001	0,079 Max. 0,502 Min. <0,001

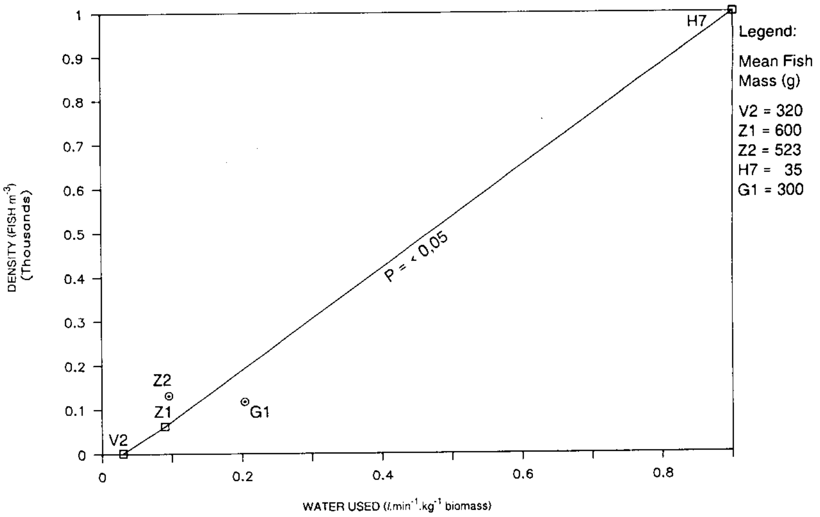

Figure 4
The relationship between density and the volume of water required to support acceptable fish growth. A comparison of different management systems (Table 3)

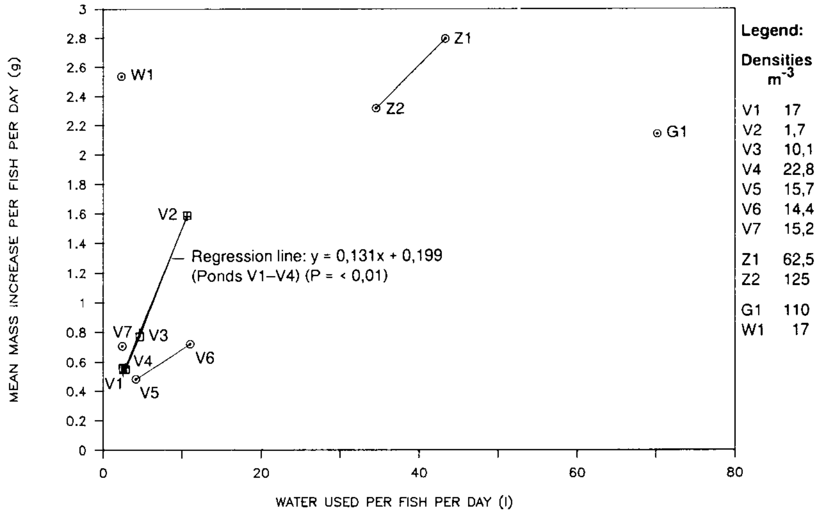

Figure 5
The relationship between water used per fish per day and the mean mass increase per fish per day. A comparison of different management systems (Table 3)

in Table 3 and Fig. 3) and the mean of ponds V1 to V4 of this study. The resultant regression ($y = 0{,}66x + 0{,}743$) implied a dramatic increase in the water use: production ratio of 15:1 in the 2,5 to 47,9 kg.m^{-3} production range. Their water use: production ratio was 3 times higher than what was found for production values below 2,5 kg.m^{-3}.

The management system of Watten and Busch (1984) which had a biological filter, settling tanks and a hydroponic bed incorporated, needed very little water to produce 1 kg of fish (1:1). Granoth and Porath (1983) required much more water (33,8:1) but this could be ascribed to the small 450 ℓ capacity tanks they were using as well as the short production period of 72 d. Similar relationships are evident when mean mass increase per fish per day is plotted against water used per fish per day (Fig. 5).

When the results from three different researchers working at fish densities of 1,7 to 1 000 m^{-3} were collated and using only those results where the fish still maintained a fair growth, a linear relationship emerged between fish density m^{-3} and water requirement immediately before harvest (ℓ.min^{-1}.kg^{-1} biomass) (Fig. 4). This also suggests that the water use: production ratio increases with increase in fish density. Further research on high density production is, however, needed to provide conclusive evidence.

Conclusion

The results obtained from the present study as well as those analysed from the literature clearly show a strong relationship between retention time and fish growth. A certain minimum volume of water appears to be needed to remove growth-inhibiting metabolites and other wastes from the production system. This relationship will be dependent on size, different sexes and densities used. It is therefore necessary to determine the relationship experimentally for each system before commercial application, especially in regions where water is a scarce resource.

The lack of information on minimum water requirements is probably the reason why *O. mossambicus* has been described as a slow-growing fish (Mires, 1983) or poor culture fish (Torrans, (undated); Hepher and Pruginin, 1981; Henderson-Arzapalo *et al.*, 1980).

It is also clear that only monosex *O. mossambicus* should be used in intensive and super-intensive farming, because mixed sexes put heavy demands on water resources. Further investigation into biological filters is recommended.

The auto-immune response referred to by Henderson-Arzapalo *et al.* (1980) is also a phenomenon that needs further investigation.

According to these authors, the initiation of the hypersensitivity reaction in *O. mossambicus* is at about 20 g.ℓ^{-1} (20 kg.m^{-3}, biomass). It must be borne in mind that about 1 800 m^3 of water was used to produce the 20 kg at a density of 1 000 fish m^{-3}. It is clear that this hypersensitivity is a combination of a biomass and density related response and progressively more water is required at this level to maintain an acceptable growth. (*O. aureus* did not show such a severe hypersensitivity reaction).

With our present knowledge, it is risky to define "the three levels of intensive production" in tilapia, based on water requirements as suggested in Table 1. It, however, appears that other factors, in addition to the water requirements, start to play a growth-inhibiting role at about 3 kg.m^{-3} (biomass), requiring progressively more water to support growth (Figs. 2 and 3). More than 0,03 ℓ.min^{-1}.kg^{-1} will be needed to maintain a fair growth in *O. mossambicus*. This level is therefore tentatively suggested as the lower range of super-intensive production (Table 1).

References

BALARIN, JD and HALLER, RD (1983) Commercial tank culture of tilapia. *Proceedings of the International Symposium on Tilapia in Aquaculture* (Israel). 473-583.

BALARIN, JD and HATTON, JP (1979) Tilapia: A Guide to their Biology and Culture in Africa. University of Stirling. 174 pp.

CHEN, TP (1976) *Aquaculture Practices in Taiwan.* Page Bros. (Norwich) Ltd. 162 pp.

GRANOTH, G and PORATH, D (1983) An attempt to optimize feed utilization by tilapia in a flow-through aquaculture. *Proceedings of the International Symposium on Tilapia in Aquaculture* (Israel). 550-559.

HENDERSON-ARZAPALO, A and STICKNEY, RR (1983) Effects of stocking density on two tilapia species raised in an intensive culture system. *Proc. Ann. Conf. S.E. Assoc. Fish and Wildl. Agencies* **34** 379-387.

HENDERSON-ARZAPALO, A, STICKNEY, RR and LEWIS, DH (1980) Immune hypersensitivity in intensively cultured tilapia species. *Transactions of the American Fisheries Society* **109** 244-247.

HEPHER, B and PRUGININ, Y (1981) *Commercial Fish Farming with Special reference to Fish Culture in Israel.* John Wiley and Sons Inc. 261 pp.

LIAO, IC and CHEN, TP (1983) Status and prospects of tilapia culture in Taiwan. *Proceedings of the International Symposium on Tilapia in Aquaculture* (Israel). 588-596.

MIRES, D (1983) A technical evaluation of tilapia cultures. *Proceedings of the International Symposium on Tilapia in Aquaculture* (Israel). 600-610.

MORIARTY, CD and MORIARTY, DJW (1973) Quantitative estimation of the daily ingestion of phytoplankton by *Tilapia nilotica* and *Haplochromis nigriipinnis* in Lake George, Uganda. *J. Zool. Lond.* **17**(1) 15-23.

TORRANS, L (Undated) Blue Tilapia Culture in Arkansas. University of Arkansas EC 560. 1-19.

VISSER, JGJ, BARHAM, WT and SCHOONBEE, HJ (1989) Intensive production of monosex *Oreochromis mossambicus* in small plastic ponds: A preliminary investigation. *Proceedings of the Aquaculture 88 Symposium of the Foundation for Research and Development.* **37** 144-149.

WATTEN, BJ and BUSCH, RL (1984) Tropical production of tilapia (*Sarotherodon aurea)* and tomatoes (*Lycopersicon esculentum)* in a small scale recirculatory water system. *Aquaculture* **41** 271-283.

ZOHAR, G; RAPPAPORT, U and SARIG, S (1985) Intensive culture of tilapia in concrete tanks. *Bamidgeh* **37**(4) 103-111.