Changes in some water quality conditions in recycling water using three types of biofiltration systems during the production of the sharptooth catfish *Clarias gariepinus* (Burchell)

Part I: Relative efficiency in the breakdown of nitrogenous wastes by the different biofiltration units

JF Prinsloo*, W Roets, J Theron, LC Hoffman*** and HJ Schoonbee**
Aquaculture Research Unit, University of the North, Private Bag X1106, Sovenga 0727, South Africa

Abstract

A comparison is made of the relative efficiencies in the breakdown of nitrogenous wastes of three types of water recirculation biofiltration units used during the production of the sharptooth catfish *Clarias gariepinus* (Burchell). Two types of trickling filters were employed. One contained PVC shavings with a calculated surface contact area of 1 220 m^2. The second is a more sophisticated biofilter unit made up with Siporax porous sintered glass cylinders with a total surface water contact area of 32 000 m^2. The third filter consisted of a rotating biological contactor unit with a water contact surface area of 271.2 m^2. Investigations showed that the PVC shavings filter unit was clearly the most efficient of the three by transforming more than 96% of the NH_3-N into NO_3-N. This was followed by the rotating biological contactor with a 93% efficiency and lastly by the Siporax filter with an almost 93% efficiency. The outcome of the section on the production of *Clarias gariepinus* follows in **Part 2** of this series.

Introduction

Traditionally aquaculture is usually synonymous with pond fish culture. Originally, this implied the extensive propagation of fish in outdoor ponds where ample clean unpolluted water is available with little or no problem with water quality conditions (Bardach et al., 1972). Valuable information was subsequently gained in a number of countries on the use of fish polyculture in ponds utilising the various niches in a pond ecosystem. Use was also made of the addition of agricultural wastes to increase fish pond productivity further, thereby increasing fish yields (Prinsloo and Schoonbee, 1984a, b, c); Prinsloo and Schoonbee, 1986).

To further improve the productivity of fish pond systems, some integrated aquaculture-agriculture systems were investigated under local conditions such as duck-fish and vegetable production using the same water (Prinsloo and Schoonbee, 1987). To economise on the use of water in aquaculture in the present series of investigations, the indoor recirculation of water was coupled with the intensive monoculture of fish. This approach has already been followed for several decades in different countries in the world with variable degrees of success (Dryden, 1986). Problems are, however, encountered with the release and accumulation of metabolic wastes in pond water which may lead to potentially toxic conditions as well as to significant fluctuations in some water quality parameters such as pH, alkalinity, turbidity, ammonia and, in the prevailing dissolved oxygen levels of the recirculation water. In order to remedy this situation, steps were implemented to minimise and, in some cases, also to reduce the initial levels of some of the potentially toxic metabolic wastes discharged into the recirculation water (Miller and Libey, 1983; Manthe and Malone, 1987; Stickney, 1986). Various types of mechanical and biological filters were developed to aerate the water and to facilitate the breakdown processes of nitrogenous wastes (Tucker, 1985; Provenzana and Winfield, 1987; Knösche, 1994; Timmons and Losordo, 1994). In the present investigation, the relative efficiencies of three types of biofiltration units, participating in the breakdown of nitrogenous wastes, were investigated in the semi-intensive production of the sharptooth catfish *Clarias gariepinus* (Burchell) in indoor water recirculation fish production systems. Results on the actual production of the sharptooth catfish over a 78 d period is considered in **Part 2** of this series.

Materials and methods

Fish production units

Three of five water recirculating units, housed in a 625 m^2 fibreglass tunnel (System 1 to 3, Fig. 1), were used in the production of *C. gariepinus*. The three units were basically identical and differed only in their respective types of biological filter units employed. The temperature inside the tunnel was regulated by four thermostatically activated electric extraction fans located at the one end of the tunnel, extracting cold air through a 40 m^2 wet wall. Matured, clean tap water was used to fill all the water-recirculating systems in the tunnel. Each of the

* To whom all correspondence should be addressed.
☎ (015) 268-2294; fax(015)268-2294;
e-mail koosp@unin.unorth.ac.za
** Presently at Department of Animal Science, University of Stellenbosch, P/Bag X1, Matieland, 7602, South Africa
*** Presently at Cape Nature Conservation, P/Bag X5014, Stellenbosch, 7599, South Africa

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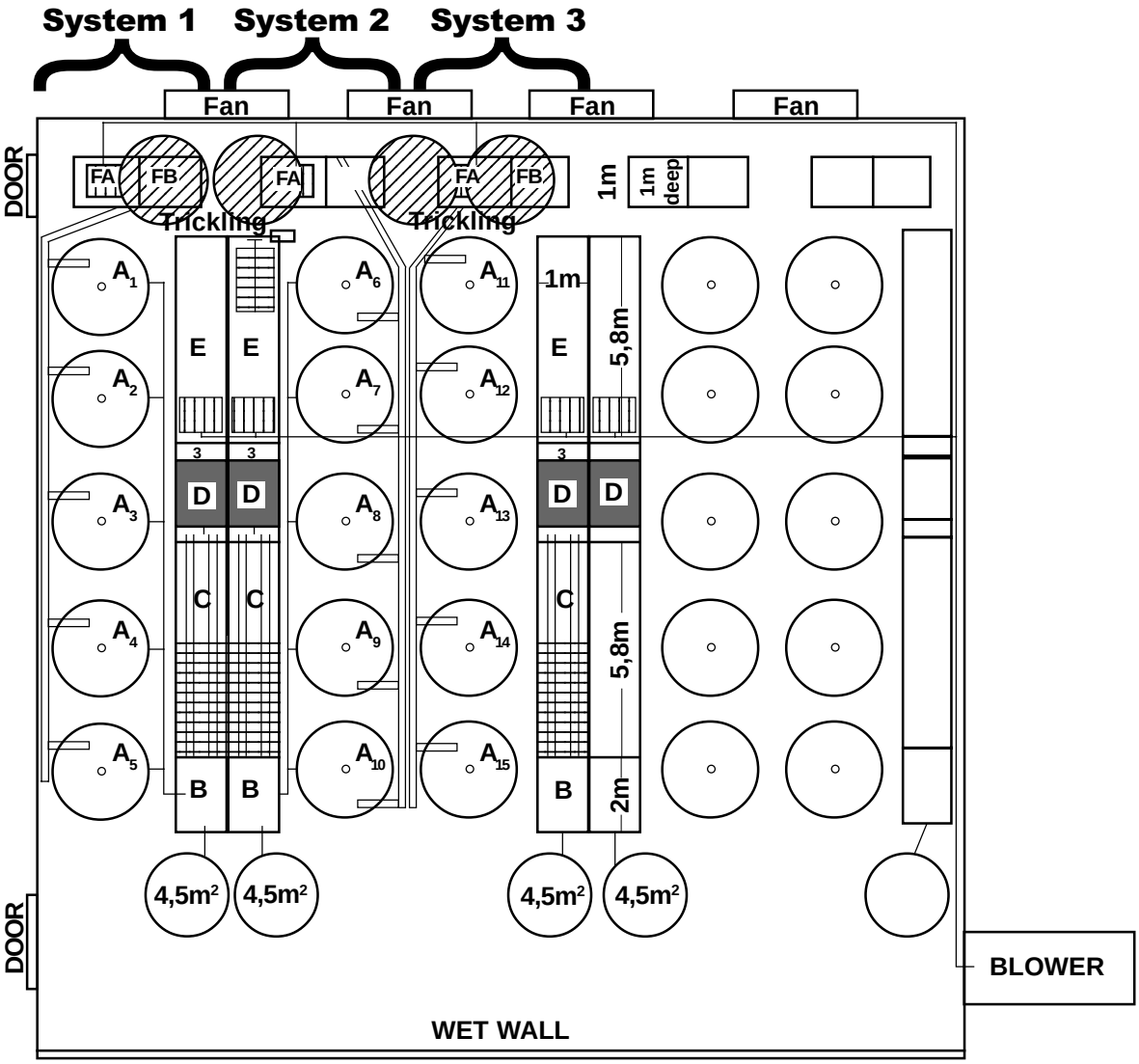

Figure 1

Diagram showing the different components of each of the three biofiltration systems inside the temperature-controlled fibreglass tunnel. Al-15: fish holding tanks. B-E: different sections of the canals holding the lamellar and scrubbing filters as well as the RBC (System 2). The water lettuce, P. stratiotes, *was housed in section E. Aeration was applied in sections E and FA. Water was pumped from section FB (to the trickling filters in Systems 1 and 3) or directly to the fish tanks (System 2).*

three fish production units consisted of three separate components, namely a specific biofiltration unit, five aquatan fish holding tanks (A) of 5 m^3 each and a mechanical filtration device, consisting of lamellar plates (C) and a scrubbing filter (D) located in a 1 m wide sedimentation canal, used for the removal of suspended solids from the recirculating water. This was followed by a 1 x 6 m section (E), originally holding the floating water lettuce *Pistia stratiotes* for possible removal of nutrients from the system. (Initial measurements, however, showed this plant to be insignificant in the effective removal of nitrogen and phosphorus from the system and it was subsequently removed).

Water from the various trickling filters which was pumped from compartments FB (Fig. 1) in Systems 1 and 3 were either gravitated through the filters to the aquadams or, in the case of the rotating biodrum (System 2), pumped directly from the biodrum compartments to the fish holding tanks. In all cases, water was discharged at an angle into the tapered aquadams. This enabled the rotation of the water to force all the suspended waste material towards the central outlet pipe from where it was discharged into the sedimentation canals.

Trickling filters

PVC shavings were used in trickling filter 1, System 1 (Fig. 1), which consisted of thin cuttings from PVC pipe using a lathe. The shavings were tidily packed on evenly spaced stacks, each covered with shadecloth inside two 4.5 m^3 fibreglass tanks, providing a calculated total surface area of 1 220 m^2. The two trickling filter tanks were mounted on a 2 m high stand which facilitated the gravitational flow of water from the filters to the five fish tanks. Siporax material produced by Schott Glaswerke, Germany, was used in trickling filter 2, System 3 (Fig. 1), packed into six plastic crates, stacked on top of each other inside each of the two 4.5 m^3 fibreglass tanks. It is known that Siporax filters

are capable of both aerobic nitrification and anaerobic denitrification of water (Greulich, 1986). The calculated total surface area of these two Siporax filters amounted to 32 000 m^2.

The rotating biological contactor (RBC), used in System 3 (Fig. 1), consisted of 113 circular fibreglass discs of 1 m in diameter each, fitted against each other on a rotating stainless steel axle. Rotation of the unit in the water column using an electric motor with a gearbox, was 6.5 r/min. Only 45% of the disc-water contact area was submerged during rotation through the water column. The total surface area of the RBC discs amounted to 271.2 m^2.

All the biological filters were protected from direct sunlight, using 70% shade cloth covers.

Mechanical filters used in the removal of suspended solids

With the exception of the 6 m section used to house the water lettuce plants (Section D, Fig. 1), the sedimentation canals were mainly employed for the settling of solids from the fish holding tanks suspended in the water column.

Water entered the canal through an open 2 m long section (Section B). The water is then forced through a slit into the bottom of the lamellar separator (Section C) containing 50 corrugated fibreglass sheets mounted at a 45° angle so that the water flows upwards and backwards through the slits between the fibreglass sheets into a horizontally arranged collecting gutter which then takes the water to Section D. The water so discharged, is then forced upwards through a slit at the bottom of the canal through a scrubbing filter which further traps remaining suspended material still present in the water column.

From Section D, the water overflows into Section E, originally intended to house the water lettuce *P. stratiotes*. In both trickling filter systems (Systems 1 and 3), water flows from section E into the pump compartment (F) from where it was elevated to trickle downwards through the trickling filter units into a collecting tank. Water was then gravity-fed from here to their respective fish holding tanks. In the case of the RBC, water flowed directly through the rotating biodrum before being discharged into the pump compartment from where it was returned to the fish holding tanks. In each case, a 0.75 kW Femco pump with a pumping capacity of 552 m^3/d at a 4 m head was employed to return the water to the trickling filters (Systems 1 and 3), or directly to the fish holding tanks (RBC, System 2).

It was calculated that the entire volume of water recirculated five times per day through each system. The lamellar filter sections in each system were drained once per day with the exception of Sundays, and completely and thoroughly cleaned from solids which settled and accumulated there. The scrubbing filter unit was regularly cleaned from suspended material three days per week. This implies that an average of 12% of the total volume of water of each recirculating system was replaced daily with clean maturated water.

Aeration of water

A mechanical blower was used to aerate the water at two points in each system. Aeration took place at the inflow of compartment E and again in the pump compartment (FA, Fig. 1) before the water is either discharged into the trickling filters of Systems 1 and 3 or returned to the aquatanks in System 2.

Water quality analysis

Water samples were collected at two different sites in each system. One sample was taken from the water leaving each of the biological filtration units before discharge into the aquadams. A second sample was collected from the water which leaves the aquadams, before entering the sedimentation canal of each system. Daily measurements at these points included dissolved oxygen (DO) (% saturation), pH and temperature. Minimum and maximum daily water and air temperatures (°C) were recorded using Thies thermographs. Nitrite (as NO_2-N mg/ℓ), nitrate (as NO_3-N mg/ℓ), ammonia (as NH_3-N mg/ℓ) and orthophosphate (as PO_4 mg/ℓ) were measured on Mondays, Wednesdays and Fridays. Conductivity (µS/cm), magnesium (as $CaCO_3$ mg/ℓ), calcium (as $CaCO_3$ mg/ℓ) and total hardness (as $CaCO_3$ mg/ℓ) as well as turbidity (NTU) were determined on Mondays. All analyses of the various parameters were done according to International Standards (*Standard Methods*, 1992).

Application of lime

As a result of declining pH values in the systems, the application of lime to all three systems commenced from Day 17. Daily quantities of lime applied never exceeded 1 kg/system and fluctuated between 300 and 900 g/system·d, depending on the prevailing pH of the water.

Densities of *C. gariepinus* used

Fish used in the present investigation were obtained from a commercial catfish producer (Blyde River Aquaculture). All 15 aquadams were each stocked with 520 young fish with a mean individual mass at stocking of 83 g. Prior to introduction, all fish were prophylactically treated for possible ectoparasites. The treatment consisted of a 3 h exposure of the fish to water containing 0.04 mg/ℓ malachite green and 50 mg/ℓ formalin.

During the initial stages of the investigation, a few mortalities occurred. These were then replaced by similar sized fish. The number of fish per individual aquadam was then corrected at the time when biomass determinations were made on fish of that specific dam.

Feeding programme

A commercial catfish diet (6.6% moisture, 34.6% protein, 3.9% fat, 2.1% ash) supplied by Brenco Feed, Louis Trichardt, was used. Fish were fed 6 d/w at 4 h intervals during the day (08:00, 12:00, 16:00). The total amount of feed was adjusted weekly following mass determinations of the fish. The pellets were provided using demand feeders. The investigation lasted for 78 d.

Calculations of biological filter efficiency

The filter performance of each system was determined by calculating the NH_3-N transformation rates for the period Monday to Thursday. These calculations were made according to methods developed by Bovendeur et al. (1987) and are based on the following:

- Amount of NH_3-N added to each system
  (feed kg x 55.4* = *x* g NH_3-N/kg)
  (55.4: This is an adapted factor differing from the factor*

given in Bovendeur et al. (1987) because the feed used in this experiment had a different protein content)

- Amount NH_3-N utilised by fish (growth 72.7%)
- Expected amount of NH_3-N in water column (faecal loss 33.2%, non-faecal loss to be 34.1%)
- Dilution by water exchange (% water exchange)
- Measured amount of NH_3-N (water quality data)
- amount into system minus amount utilised plus dilution = expected amount
- This expected amount of NH_3-N minus the measured amount of NH_3-N = amount of NH_3-N transformed by the biological filters into NO_3-N
- Amount NH_3-N removed divided by expected amount times 100 = % efficiency

The NH_3-N "removal efficiency" of the biological filters was calculated from Day 6 to 73. Calculations were made on a weekly basis on Monday and Friday mornings before the first feeding programme commenced.

Results

Physical and chemical conditions

Air and water temperature

Mean air and water temperatures in the tunnel are indicated in Table 1. Minimum water temperature never declined below 24°C, reaching a maximum of 32°C on Day 13 with a mean water temperature for the entire period of 78 d of 28.4°C. The mean air temperature for this period was 27.5°C, fluctuating between a low of 14°C (Day 48) and a maximum of 42°C (Day 3). Results showed that the fluctuations around the mean water temperature for the entire experimental period were remarkably small, fluctuating between 27°C and 30°C.

Oxygen saturation

Mean, minimum and maximum oxygen saturation values measured over the 78 d period of investigation, summarised for successive 10 d intervals for the in- and outflow of the fish holding tanks, are presented in Table 2. A comparison of the oxygen saturation values of the three filter systems clearly shows the PVC trickling filter to be superior to both the RBC and Siporax filtering units. In the case of the PVC system, mean values for successive 10 d intervals measured a 90% or higher saturation at the inlets to the fish tanks (90% - 95%) throughout the period of investigation. Oxygen saturation of the water leaving the fish tanks showed a little decline, with mean values fluctuating between 82% and 92%. The inlet waters of both the RBC and Siporax filter units were similar, but in all cases significantly lower than the values obtained for the PVC system. This also applies to the outlet values of both systems.

Although the outlet oxygen saturation levels of the RBC and Siporax filter units were initially comparable during the first 30 d, the oxygen saturation values for the Siporax system began to decline much more during the following 48 d. In none of these two cases, however, was there a dramatic decline in oxygen saturation values, with lowest mean values recorded for these two systems at the points of outlets being 72% (RBC) and 67% (Siporax), respectively.

Conductivity

The 10 d mean, minimum and maximum values for electrical conductivity in the three systems over a period of 78 d are summarised in Table 3. All three systems showed a gradual increase in conductivity over the first four to five 10 d periods from 114 µS/cm (Siporax) to 271 µS/cm (PVC). Fluctuations in conductivity which occurred in all three systems during the last 30 to 40 d can be ascribed to a combination of factors, namely water replacement, addition of lime to compensate for lower pH values and the increase in food. There was, however, no dramatic increase in conductivity in any of the three systems during the period of investigation.

TABLE 1
MEAN, MINIMUM AND MAXIMUM WATER AND AIR TEMPERATURES OF THE THREE WATER RECIRCULATING BIOFILTRATION SYSTEMS OVER THE 78 d PRODUCTION PERIOD OF *C. GARIEPINUS*

Days	Water temperature °C		Air temperature °C	
	Mean	Range	Mean	Range
3	28.5	26 - 31	29.8	18 - 42
7	28.8	27 - 31	24.5	17 - 32
13	28.0	24 - 32	26.8	18 - 36
20	29.5	28 - 31	25.0	18 - 32
27	29.5	28 - 31	29.3	19 - 40
34	28.8	27 - 31	29.0	18 - 40
41	30.0	29 - 31	30.3	21 - 40
48	28.0	26 - 30	25.8	14 - 38
55	28.5	27 - 30	27.0	18 - 36
63	27.0	24 - 30	28.8	18 - 40
69	27.3	26 - 29	26.5	15 - 38
76	27.8	26 - 30	26.8	17 - 37
78	27.3	26 - 28	28.5	17 - 40
Total mean	28.4	26.3 - 30.4	27.5	17.3 - 37.7

TABLE 2
SUCCESSIVE 10 d MEAN, MINIMUM AND MAXIMUM VALUES FOR OXYGEN SATURATION (%) MEASURED AT THE INLETS AND OUTLETS OF THE FISH HOLDING TANKS OF ALL THREE BIOLOGICAL FILTER SYSTEMS

Periods in days	N	Oxygen saturation values in %					
		System 1		System 2		System 3	
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
		Mean and range	Mean and range	Mean and range	Mean and range	Mean and range	Mean and range
1 - 10	9	91 69 - 96	90 76 - 95	81 78 - 85	83 80 - 86	87 83 - 93	87 82 - 98
11 - 20	9	95 92 - 96	92 83 - 95	82 74 - 91	83 76 - 90	85 78 - 93	84 76 - 90
21 - 30	9	93 90 - 95	89 87 - 93	77 60 - 83	79 59 - 92	78 68 - 83	78 64 - 89
31 - 40	8	90 87 - 92	86 81 - 92	72 55 - 81	72 56 - 85	75 60 - 84	71 56 - 83
41 - 50	7	91 90 - 94	86 82 - 88	76 72 - 82	73 69 - 79	79 72 - 84	70 62 - 75
51 - 60	6	92 89 - 94	86 82 - 90	76 67 - 80	72 65 - 80	77 69 - 84	67 61 - 75
61 - 70	7	92 90 - 95	85 83 - 91	79 72 - 86	74 67 - 80	77 70 - 83	69 62 - 76
71 - 78	6	93 92 - 95	82 79 - 86	83 79 - 85	74 66 - 79	82 76 - 85	69 62 - 75

TABLE 3
SUCCESSIVE 10 d MEAN, MINIMUM AND MAXIMUM VALUES FOR ELECTRICAL CONDUCTIVITY (µS/cm) MEASURED AT THE INLETS AND OUTLETS OF THE FISH HOLDING TANKS OF ALL THREE BIOLOGICAL FILTER SYSTEMS

Periods in days	N	Conductivity values in µS/cm					
		System 1		System 2		System 3	
		Mean	Range	Mean	Range	Mean	Range
1 - 10	7	125	73 - 163	131	80 - 177	114	68 - 141
11 - 20	9	168	129 - 195	158	130 - 190	170	148 - 198
21 - 30	7	225	195 - 244	201	163 - 238	207	167 - 238
31 - 40	4	254	228 - 282	252	232 - 271	208	174 - 276
41 - 50	5	271	255 - 307	262	220 - 309	186	166 - 194
51 - 60	4	266	246 - 273	230	212 - 244	195	185 - 209
61 - 70	4	255	235 - 286	216	210 - 223	182	147 - 210
71 - 78	4	228	164 - 276	283	209 - 347	200	146 - 244

TABLE 4
SUCCESSIVE 10 d MEAN, MINIMUM AND MAXIMUM VALUES FOR pH RECORDED AT THE INLETS AND OUTLETS OF THE FISH HOLDING TANKS OF ALL THREE BIOLOGICAL FILTER SYSTEMS

Periods in days	N	pH values					
		System 1		System 2		System 3	
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
		Range	Range	Range	Range	Range	Range
1 - 10	7	6.60 - 7.65	6.65 - 7.39	6.63 - 7.21	6.45 - 7.17	6.47 - 7.21	6.48 - 7.24
11 - 20	9	6.64 - 7.62	6.29 - 7.41	5.97 - 7.27	6.10 - 7.19	6.24 - 7.23	6.13 - 7.21
21 - 30	9	6.91 - 7.45	6.62 - 7.10	6.33 - 6.73	6.32 - 6.70	6.54 - 6.92	6.35 - 6.99
31 - 40	8	6.77 - 7.11	6.52 - 6.98	6.44 - 7.02	6.30 - 7.03	6.36 - 6.77	6.34 - 6.76
41 - 50	7	6.34 - 7.27	6.13 - 6.77	6.02 - 6.85	6.00 - 6.56	6.09 - 6.76	5.97 - 6.46
51 - 60	5	6.45 - 7.00	6.04 - 6.60	5.95 - 6.69	5.91 - 6.46	6.02 - 6.62	5.90 - 6.38
61 - 70	7	5.51 - 7.32	5.29 - 7.19	4.92 - 7.15	5.14 - 7.08	5.11 - 7.13	5.20 - 7.08
71 - 78	6	5.20 - 7.61	4.74 - 7.38	5.33 - 7.17	4.65 - 7.15	4.81 - 7.13	4.61 - 7.21

pH

The 10 d minimum and maximum values for pH of the in- and outflow waters of the fish holding tanks for all three systems are summarised in Table 4. Minimum values of pH of the water in all three systems were characterised by values which were predominantly less than 7. Although pH was corrected for by using quick lime as from Day 17, there was an increasing tendency in the further decline in pH, with minimum values falling below 6 in one or more of the systems as from Day 45. In this respect the pH values of both the in- and outlet waters in the PVC system only declined below 6 as from Day 70, which coincided with a power failure due to a plane accident which interrupted the electricity supply to the Research Unit. In the RBC system, pH declined below 6 as from Day 56 whilst in the Siporax system, a pH value of 5.97 was recorded on Day 45. All three systems yielded minimum pH values of less than 5 during the last 8 d of the investigation, which can partially be ascribed to the power failure which occurred during Days 70 to 76.

Turbidity

Measurements of turbidity in all three systems remained generally constant and reasonably low, fluctuating between 3 and 4 NTU with a lowest value of 2 recorded in System 3 (Siporax).

Calcium, magnesium and total hardness

Initial values of calcium hardness (150 to 180 mg/ℓ), magnesium hardness (60 to 80 mg/ℓ) and total hardness (210 to 260 mg/ℓ) showed a constant increase with time in all three systems, particularly so as from Day 27 when the total hardness exceeded 900 mg/ℓ in all three systems and with calcium hardness concentrations fluctuating between 810 to 840 mg/ℓ, magnesium hardness varied from 110 to 150 mg/ℓ. It was in Systems 1 and 2 where the highest concentration for all three parameters was recorded between Days 34 to 48. Hardness values in System 3 (Siporax) were, with a few exceptions, consistently lower than in the other two systems.

Alkalinity

Values obtained for alkalinity in all three systems clearly reflected the overall low values of pH throughout the period of investigation. A slight increase from an initial 22 to 27 mg/ℓ during Day 1, to 52 to 71 mg/ℓ during Day 13 was followed by a general variation, with values fluctuating between 16 to 44 mg/ℓ during the rest of the project.

Orthophosphates (soluble reactive phosphorus - SRP)

A summary of the 10 d mean, minimum and maximum values for orthophosphates of the inflowing water into the three biofiltration systems is given in Table 5. Two tendencies were observed in the values recorded during the successive 10 d periods of investigation. The PVC and RBC systems followed an almost identical pattern in increasing concentrations with individual, and in most cases, mean values exceeding 2 mg/ℓ as from Day 34. In the case of the Siporax biofiltration system, phosphate levels remained generally much lower than in the other two systems, with mean concentrations fluctuating between 1.28 and 1.86 mg/ℓ.

Ammonia

The 10 d mean, minimum and maximum values of ammonia for the in- and outflow water of the fish holding tanks of all three biofiltration systems, are summarised in Table 6 and Fig. 2. The ammonia concentrations in all three biofiltration systems remained high and built up to maximum values during the tenth day, exceeding 13 mg/ℓ in all in- and outlet measurements, of the fish holding tanks. After a slight decline between Days 11 and 15, ammonia levels began to drop significantly as from Day 17, with a marked decline in all three systems between Days 18 and 20. The overall mean values for ammonia calculated for the second 10 d period for both the in- and outlet measurements remained relatively high in all three systems, exceeding 4 mg/ℓ with one exception (3.47 mg/ℓ - outlet PVC).

A dramatic decline in ammonia concentrations which was already observed from Day 17 (Fig. 2) then continued to be maintained for the rest of the investigation with values for ammonia in both the in- and outlet systems predominantly remaining below 1 mg/ℓ. Comparing the actual mean concentrations at the inlets and outlets of the three systems, the PVC system generally performed the best in terms of reducing the ammonia concentrations in the system. Second best was the Siporax system followed by the RBC, being only slightly inferior in performance to the Siporax system.

TABLE 5
SUCCESSIVE 10 d MEAN, MINIMUM AND MAXIMUM VALUES FOR ORTHOPHOSPHATE (mg/ℓ) MEASURED AT THE INLETS AND OUTLETS OF THE FISH HOLDING TANKS OF ALL THREE BIOLOGICAL FILTER SYSTEMS

Periods in days	N	Orthophosphate values in mg/ℓ					
		System 1		System 2		System 3	
		Mean	Range	Mean	Range	Mean	Range
1 - 10	7	0.81	0.09 - 1.39	0.71	0.08 - 1.28	0.67	0.07 - 1.14
11 - 20	9	1.70	1.21 - 1.99	1.43	1.14 - 1.79	1.47	1.06 - 1.68
21 - 30	7	1.42	1.31 - 1.54	1.11	0.83 - 1.37	1.33	1.05 - 1.59
31 - 40	4	2.01	1.88 - 2.26	1.98	1.85 - 2.25	1.41	1.15 - 1.65
41 - 50	5	2.24	1.93 - 2.62	2.57	2.24 - 3.36	1.48	1.38 - 1.87
51 - 60	4	2.64	2.15 - 3.07	2.70	2.55 - 2.99	1.86	1.60 - 2.13
61 - 70	4	2.83	2.59 - 3.10	2.58	2.35 - 2.88	1.80	1.45 - 2.23
71 - 78	4	1.72	1.19 - 2.04	2.24	1.91 - 2.59	1.28	1.05 - 1.60

TABLE 6
SUCCESSIVE 10 d MEAN, MINIMUM AND MAXIMUM VALUES FOR AMMONIA (mg/ℓ) MEASURED AT THE INLETS AND OUTLETS OF THE FISH HOLDING TANKS OF ALL THREE BIOLOGICAL FILTER SYSTEMS

Periods in days	N	Ammonia values in mg/ℓ					
		System 1		System 2		System 3	
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
		Mean and range	Mean and range	Mean and range	Mean and range	Mean and range	Mean and range
1 - 10	9	5.61 0.07 - 14.03	5.75 0.04 - 14.09	5.89 0.07 - 13.42	6.08 0.04 - 13.97	5.71 0.07 - 13.42	5.95 0.04 - 13.79
11 - 20	9	4.93 0.12 - 11.90	3.47 tr - 7.99	5.13 0.12 - 11.77	4.20 0.24 - 8.42	5.57 0.18 - 11.65	4.49 tr - 9.52
21 - 30	7	0.09 tr - 0.17	0.25 tr - 0.56	0.31 0.07 - 0.49	0.50 tr - 0.94	0.22 0.07 - 0.43	0.35 tr - 0.67
31 - 40	4	0.53 0.22 - 1.22	1.55 0.53 - 4.27	1.00 0.60 - 2.07	2.01 0.71 - 5.06	0.99 0.56 - 2.26	1.76 0.60 - 4.64
41 - 50	5	0.21 0.09 - 0.26	0.51 0.31 - 0.76	0.60 0.32 - 0.76	0.86 0.55 - 1.26	0.49 0.24 - 0.57	0.62 0.38 - 0.96
51 - 60	4	0.31 0.09 - 0.39	1.22 0.22 - 2.27	0.83 0.43 - 1.04	1.71 0.50 - 2.90	0.74 0.29 - 0.96	1.45 0.32 - 2.64
61 - 70	4	0.36 0.16 - 0.71	0.57 0.31 - 1.89	0.80 0.37 - 1.35	1.36 0.55 - 2.42	0.74 0.31 - 1.35	1.15 0.39 - 2.09
71 - 78	4	0.24 0.10 - 0.48	1.41 0.38 - 3.82	0.55 0.35 - 0.98	1.77 0.63 - 4.23	0.46 0.28 - 0.89	1.63 0.45 - 4.26

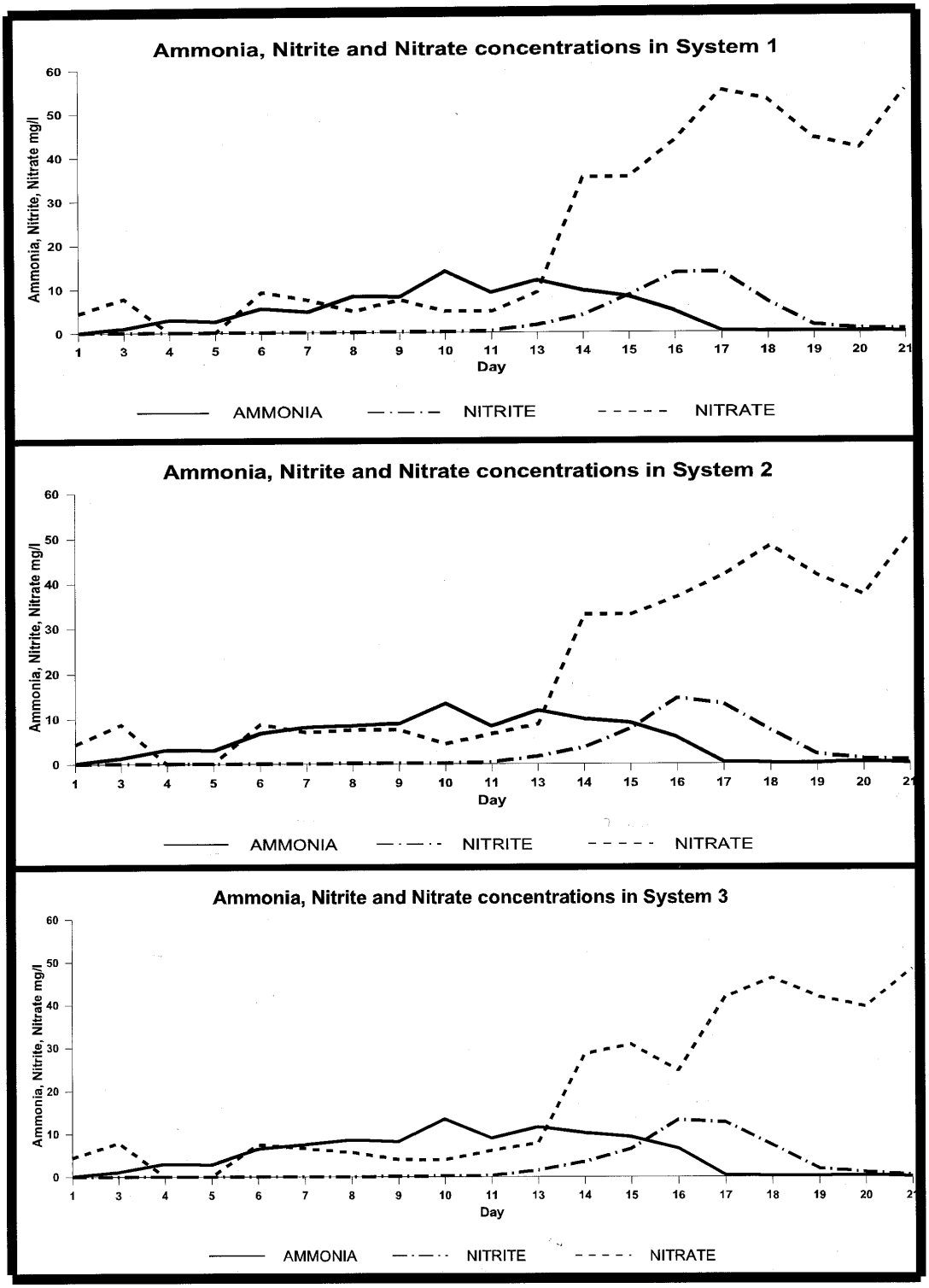

Figure 2

Ammonia (NH_3-N), nitrite (NO_2-N) and nitrate (NO_3-N) concentrations (mg/ℓ) at the inlets of the recirculation water to the fish holding tanks in Systems 1, 2 and 3 during the first 21 d of the investigation

Nitrite

The 10 d mean, minimum and maximum values for nitrite for all three biofiltration systems are given in Table 7 and Fig. 2. All three systems showed a rapid increase in nitrite values during the second 10 d period when peak values were reached in both the in- and outlet circulation water of the fish holding tanks. All three systems showed a dramatic decline in the nitrite values for both the in- and outlet waters as from the third 10 d period (Fig. 2).

Comparing the water quality in terms of nitrite after flowing through the three filter systems, i.e. before discharge into the fish

TABLE 7
SUCCESSIVE 10 d MEAN, MINIMUM AND MAXIMUM VALUES FOR NITRITE (mg/ℓ) MEASURED AT THE INLETS AND OUTLETS OF THE FISH HOLDING TANKS OF ALL THREE BIOLOGICAL FILTER SYSTEMS

Periods in days	N	Nitrite values in mg/ℓ					
		System 1		System 2		System 3	
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
		Mean and range	Mean and range	Mean and range	Mean and range	Mean and range	Mean and range
1 - 10	7	0.06 0.02 - 0.14	0.07 0.02 - 0.17	0.05 0.02 - 0.13	0.08 0.02 - 0.11	0.05 0.02 - 0.16	0.07 0.02 - 0.18
11 - 20	9	5.69 0.32 - 13.70	9.25 0.41 - 19.06	5.73 0.29 - 14.52	9.16 0.42 - 16.99	5.37 0.29 - 13.28	9.16 0.39 - 17.57
21 - 30	7	0.38 0.17 - 0.74	2.33 0.83 - 4.13	0.45 0.17 - 0.83	2.39 0.99 - 4.29	0.43 0.17 - 0.91	1.88 0.99 - 4.21
31 - 40	4	1.53 0.17 - 4.13	3.05 0.33 - 8.66	1.59 0.17 - 4.13	2.89 0.41 - 7.67	1.69 0.25 - 4.04	3.06 0.41 - 8.17
41 - 50	5	0.53 0.25 - 0.91	1.55 0.74 - 2.39	0.64 0.25 - 1.16	1.67 0.83 - 2.56	0.73 0.25 - 1.32	1.80 0.90 - 2.64
51 - 60	4	1.03 0.25 - 1.49	2.29 0.66 - 3.38	1.12 0.25 - 1.57	2.31 0.74 - 3.47	1.26 0.25 - 1.82	2.50 0.83 - 3.55
61 - 70	4	0.70 0.08 - 1.82	2.67 0.58 - 4.46	0.78 0.08 - 2.06	2.70 0.58 - 4.62	0.90 0.08 - 2.23	2.79 0.58 - 4.70
71 - 78	4	0.36 0.17 - 0.91	2.89 1.40 - 5.45	0.46 0.17 - 1.16	2.89 0.57 - 5.20	0.52 0.25 - 1.24	3.06 1.57 - 5.45

tanks, the PVC filter clearly outperformed the other two systems as from the third 10 d period with one exception. The RBC also yielded lower nitrite values than the Siporax filter system (Table 7).

Nitrate

A summary of the 10 d mean, maximum and minimum values for nitrates in the three biofiltration systems is given in Table 8 and Fig. 2. Mean values of nitrate for the first 10 d for both in- and outlet recirculation water of the fish holding tanks of all the systems differ slightly from each other, fluctuating between 5 and 7 mg/ℓ. A very significant increase in nitrate then occurred in all three systems as from the second 10 d period.

A further increase in nitrate concentrations occurred during the third 10 d period, with inflow values exceeding 40 mg/ℓ in all three systems. Water leaving the fish tanks had slightly lower nitrate values, fluctuating between 37.21 mg/ℓ (PVC) and 36.59 mℓ/g (RBC and Siporax). As from the fourth 10 d period, the nitrate values of the inflow water in the PVC system stabilised around 49 mg/ℓ until the last period, when a significant decline in the nitrate values occurred (36.96 mg/ℓ). A similar tendency was observed for the inflowing water of the RBC and Siporax systems where the mean nitrate values in both these cases were similar but sightly lower than those recorded for the PVC system. Here, there was also a marked decline in nitrate concentration during the last 10 d of the investigation. In all three systems, however, the nitrate concentrations in the outflow water were much higher, varying between 43.17 mg/ℓ (PVC) and 41.91 mg/ℓ (RBC).

The calculated nitrogen efficiency of the three biological filters

According to results in Tables 9, 10 and 11, the trickling biological filter in System 1 had the best NH_3-N "removal efficiency" namely 96.7%. The RBC in System 2 was the second most efficient with a NH_3-N "removal efficiency" of 93.5%. Where Siporax was used as filter medium, the NH_3-N "removal efficiency", although the least, was still good at 93.0%.

Discussion

The potential of water-recirculating systems in aquaculture has been adequately reviewed by a number of research workers (Miller and Libey, 1983; Dryden, 1986; Bovendeur et al., 1987; Lucchetti and Gray, 1988; Wortman and Wheaton, 1991; Van Rijn, 1996). The maintenance of an acceptable water quality is, however, extremely important for the optimal production of fish in these systems. One of the most important components of such systems is the filtration unit employed in the "removal" (transformation) of potentially toxic waste products, in particular metabolic wastes such as ammonia and nitrite into non-toxic components such as nitrates (Miller and Libey, 1983; Tucker, 1985;

TABLE 8
SUCCESSIVE 10 d MEAN, MINIMUM AND MAXIMUM VALUES FOR NITRATE (mg/ℓ) MEASURED AT THE INLETS AND OUTLETS OF THE FISH HOLDING TANKS OF ALL THREE BIOLOGICAL FILTER SYSTEMS

Periods in days	N	Nitrate values in mg/ℓ					
		System 1		System 2		System 3	
		Inlet	Outlet	Inlet	Outlet	Inlet	Outlet
		Mean and range	Mean and range	Mean and range	Mean and range	Mean and range	Mean and range
1 - 10	7	6.59 4.4 - 9.2	5.29 3.5 - 7.5	6.18 4.4 - 8.8	5.84 4.0 - 6.6	5.72 4.0 - 7.9	5.22 4.0 - 6.6
11 - 20	9	35.74 4.8 - 55.0	33.39 5.3 - 50.6	31.98 6.6 - 48.4	29.37 4.3 - 48.4	29.72 6.2 - 46.2	27.95 4.3 - 48.4
21 - 30	7	44.51 38.7 - 55.0	37.21 27.7 - 46.6	42.25 33.9 - 50.6	36.59 27.7 - 46.6	40.86 32.6 - 48.4	36.59 30.0 - 44.4
31 - 40	4	49.50 38.3 - 63.8	37.52 32.6 - 43.6	47.30 36.5 - 59.4	37.18 33.0 - 44.0	47.08 38.3 - 59.4	37.40 32.6 - 44.9
41 - 50	5	48.22 40.9 - 57.2	48.92 37.8 - 58.1	49.71 40.9 - 66.9	45.57 36.9 - 56.3	47.08 38.7 - 56.8	43.38 33.0 - 56.3
51 - 60	4	48.29 44.0 - 53.2	40.59 37.0 - 44.4	46.86 44.9 - 51.9	39.50 34.8 - 46.6	43.78 37.8 - 48.0	41.14 35.2 - 48.0
61 - 70	4	50.12 44.4 - 56.3	35.95 32.6 - 40.0	48.62 40.9 - 56.3	45.64 42.2 - 29.5	47.61 38.7 - 56.8	37.29 32.6 - 42.2
71 - 78	4	36.96 28.2 - 45.8	43.12 35.6 - 54.1	38.61 27.7 - 45.3	41.91 34.8 - 52.4	38.06 27.3 - 44.4	42.90 36.5 - 52.4

Stickney, 1986). The fish production systems as used in the present investigation can also qualify as intensive water recirculation fish production units where the biological purification of the water used consists of biofiltration in combination with solid-based nutrient removal (Van Rijn, 1996).

The South African Water Quality Guideline (Department of Water Affairs and Forestry, 1996) proposed the target water temperature for growth of warm-water fish species to be 28 to 30°C. The ideal temperature range for *C. gariepinus* was indicated to be 20 to 30°C, with an optimum of 27°C for juveniles, and 25°C for adults (Viveen et al., 1985). The mean water temperature of 28.4°C recorded during the present investigation therefore lies well within the ideal limits indicated for the optimal growth of *C. gariepinus*.

According to Stickney (1986) the DO concentration of water should be above 5 mg/ℓ (90 mm Hg pO_2) at which concentration it is not yet a limiting factor to fish growth. Boyd and Lichtkoppler (1979) stated that DO is probably the most critical water quality variable in fish culture. Britz (1988) agreed that DO concentration is one of the two major parameters which may limit intensive fish culture. It is generally agreed in the relevant literature, that DO concentration is an extremely important and critical factor in recirculation fish culture systems where biological filters are employed in the oxidation of potentially harmful nitrogenous wastes as it affects the efficiency of biological filtration during the nitrifying processes of particular bacteria (Manthe et al., 1984; 1988).

It was observed during the experimental period of the present study that the oxygen saturation values were usually highest in System 1. What is surprising though, is the comparative lower oxygen saturation levels in System 3, as both systems mentioned contained trickling filters which are known as efficient aerators of water (Krüner and Rosenthal, 1983). A possible reason for the lower oxygen concentration in System 3 can possibly be the relatively small space occupied by the Siporax filter medium compared to the PVC shavings of System 1 and more importantly, the fact that the Siporax filter gradually clogged up due to the development of a biofilm growth on it, resulting in a lowered aeration of this particular filter system. This then may possibly explain the reduced oxygen saturation levels recorded for System 3 as from Day 25 (Table 2) which is reflected in the mean saturation values for the rest of the duration of the investigation. In System 2 (containing the RBC biological filter) the oxygen concentration was also lower than that of the PVC trickling filter as no trickling of water took place to aerate the water except for the mixing at the surface of the water in the sedimentation tank. A combination of suspended solids as well as the mechanism of the RBC are both oxygen consumptive processes (Miller and Libey, 1986) which may explain the reduced oxygen levels recorded for System 2 as from Day 25. This may also account for

TABLE 9
THE QUANTITIES OF NITROGEN INTRODUCED INTO SYSTEM 1 (PVC FILTER) BASED ON MEASUREMENTS MADE ON MONDAY AND FRIDAY MORNINGS AT 08:00 PRIOR TO FEEDING TIME OF FISH

Period of measurement	Calculated quantity of nitrogen per kg feed (in g) applied to system	N (in g) released into water	Expected quantity of NH_3-N (mg/ℓ) following water exchange	Actual quantity of NH_3-N in water measured in mg/ℓ	Quantity NH_3-N removed from system by biological filter (mg/ℓ)	Efficiency expressed as %
20-23/1	1 013.8	681.3	11.2	14.03	-2.83	-25.3
27-30/1	711.6	478.2	5.0	0.31	4.72	93.8
03-06/2	1 122.4	754.3	12.0	0.11	11.86	99.1
10-13/2	1 960.0	1317.1	19.4	1.22	18.18	93.4
17-20/2	1 401.7	942.0	11.2	0.24	10.96	97.9
24-27/2	1 615.8	1085.8	12.9	0.24	12.66	98.1
02-05/3	1 779.6	1195.9	14.2	0.37	13.83	97.4
09-12/3	1 955.7	1314.2	15.6	0.39	15.21	97.5
16-19/3	2 089.3	1404.0	16.7	0.71	15.99	95.6
23-26/3	2 070.2	1391.2	16.6	0.48	16.12	97.1
Total						**869.9**
Mean						**96.65**

TABLE 10
THE QUANTITIES OF NITROGEN INTRODUCED INTO SYSTEM 2 (RBC FILTER) BASED ON MEASUREMENTS MADE ON MONDAY AND FRIDAY MORNINGS AT 08:00 PRIOR TO FEEDING TIME OF FISH

Period of measurement	Calculated quantity of nitrogen per kg feed (in g) applied to system	N (in g) released into water	Expected quantity of NH_3-N (mg/ℓ) following water exchange	Actual quantity of NH_3-N in water measured in mg/ℓ	Quantity NH_3-N removed from system by biological filter (mg/ℓ)	Efficiency expressed as %
20-23/1	1 013.8	681.3	11.2	13.42	-2.22	-19.8
27-30/1	719.9	483.3	5.1	0.37	4.73	92.7
03-06/2	839.3	564.0	10.3	0.38	9.87	96.3
10-13/2	2 260.6	1519.1	22.3	2.07	20.27	90.1
17-20/2	1 606.0	1079.2	12.9	0.73	12.12	94.3
24-27/2	1 796.6	1207.3	14.4	0.76	13.61	94.7
02-05/3	1 928.6	1296.0	15.4	1.04	14.39	93.3
09-12/3	2 187.5	1470.0	17.5	0.98	16.52	94.4
16-19/3	1 891.3	1271.0	15.1	1.35	13.78	91.1
23-26/3	2 108.1	1416.7	16.9	0.98	15.92	94.2
Total						841.1
Mean						93.46

TABLE 11
THE QUANTITIES OF NITROGEN INTRODUCED INTO SYSTEM 3 (SIPORAX FILTER) BASED ON MEASUREMENTS MADE ON MONDAY AND FRIDAY MORNINGS AT 08:00 PRIOR TO FEEDING TIME OF FISH

Period of measurement	Calculated quantity of nitrogen per kg feed (in g) applied to system	N (in g) released into water	Expected quantity of NH_3-N (mg/ℓ) following water exchange	Actual quantity of NH_3-N in water measured in mg/ℓ	Quantity NH_3-N removed from system by biological filter (mg/ℓ)	Efficiency expressed as %
20-23/1	1 013.8	681.3	11.2	13.42	-2.22	-19.8
27-30/1	808.0	543.0	8.4	0.43	7.97	94.9
03-06/2	950.7	638.8	9.8	0.31	9.49	96.8
10-13/2	1 850.5	1243.5	18.3	2.26	16.04	87.7
17-20/2	1 093.4	734.8	8.8	0.59	8.16	93.3
24-27/2	1 508.6	1013.8	12.1	0.71	11.39	94.1
02-05/3	1 644.2	1104.9	13.2	0.96	12.24	92.7
09-12/3	1 815.2	1219.8	14.5	0.90	13.62	93.8
16-19/3	1 592.6	1070.3	12.7	1.35	11.39	89.4
23-26/3	1 872.7	1258.5	15.0	0.89	14.09	94.1
Total						**836.8**
Mean						**92.98**

the less efficient oxidation of ammonia and, to a certain extent nitrite, in the recirculation water.

The results on pH showed that the levels of this parameter remained above 6.2 in all three systems for much of the investigation. The significant decline in pH experienced during Days 70 to 76 was, as mentioned earlier, largely caused by a power failure. This power failure resulted in the ammonia and nitrite concentrations to increase due to the lack in water circulation and aeration. This also resulted in a drastic lowering of the pH of the water in all three systems. The decline in pH for this reason can be explained by the acidic character of the nitrification process as it consumes alkalinity when ammonia is converted to nitrate (Miller and Libey, 1986) with the formation of carbonic acid which in turn may lead to a drastic decline in the alkalinity and pH of the water (Miller et al., 1981; Lucchetti and Gray, 1988).

In experiments utilising trickling biological filters, Krüner and Rosenthal, (1983) found that low pH of the water may severely restrict the efficiency of nitrifying bacteria by reducing their ammonia removal capacity to almost zero at pH levels of the water below 5.6. Lucchetti and Gray (1988), likewise found that the nitrification process is retarded at pH 6.0 and completely ceases at pH 5.5.

In the present investigation, an increase in the alkalinity and pH was effected in all three systems by the periodic addition of $CaCO_3$. The application of lime was further increased during the sudden pH decline which occurred during Days 70 to 71. The regular exchange of water also facilitated higher alkalinity values of the recirculating water.

The results on the conductivity of the recirculation water in the three systems showed that the conductivity levels were initially fairly low but increased with time as the investigation progressed. Fluctuations in conductivity which occurred can largely be attributed to regular water replacement as well as the addition of $CaCO_3$. The mean conductivity values of 212, 204 and 179 µS/cm for the three systems corresponded well with values of 218 and 189 µS/cm recorded for fish production studies by Prinsloo and Schoonbee (1986) during the polyculture of fish.

Both hardness and salinity of water are directly linked to the conductivity of the water. Water hardness also influences fish growth. In hard water (250 mg/ℓ alkalinity) fish will spend less metabolic energy for osmoregulation than fish kept in soft water (<100 mg/ℓ) thus providing more metabolic energy for growth. Against this background it can be stated that the average conductivity in all three systems throughout the experiment never really influenced the growth of the fish negatively, except perhaps for the first two weeks. The interaction during the initial stages of the investigation between the different levels of ammonia, nitrite and nitrate in all three systems, is graphically illustrated in Fig. 2. It is clear that the ammonia concentrations in all three systems peaked between Days 10 and 13 where, after the ammonia concentrations began to decline. This agrees with findings in the literature namely that the first stage of NH_3-N nitrification in biological filters commences after approximately 12 d, followed by a second phase namely nitrite oxidation, which in the present investigation peaked between Days 16 to 17, compared to 35 d (Krüner and Rosenthal, 1983). The comparatively high water temperature ($\bar{x}$ = 28.4°C) which prevailed in the tunnel, most likely played an important role in the efficiency of the filters. Individual peaks experienced in ammonia coincided with periodic increases in feed ration. Other factors which may have affected ammonia concentrations in the water, are fluctuations in pH, coupled with periodic water exchange. According to Boyd and Lichtkoppler (1979) toxic levels for un-ionised ammonia for short-term exposure usually lie between 0.6 and 2.0 mg/ℓ for pond fish with sublethal effects occurring at 0.1 to 0.3 mg/ℓ. Lethal concentrations of total ammonia were found to be 4 mg NH_4-N/

ℓ for tilapia at pH values between 7.3 and 7.5 and temperatures above 20°C (Krüner and Rosenthal, 1983).

The initial build-up of nitrite between Days 13 and 19 in all three systems is clearly a reflection of nitrite as an intermediate product in the nitrification process. Here again the comparatively high water temperatures play an important role in the appreciable nitrite oxidation which took place over such a short period of time. According to Krüner and Rosenthal (1983) and Muir (1982) nitrite oxidation may take as long as 35 to 40 d. Individual nitrite peaks in concentrations experienced after 19 d in the three systems, coincided with periodic increases in feed application. According to DWAF (1996) the target nitrite concentration is 0 to 0.05 mg NO_2-N/ℓ for fish. A range of 0.06 to 0.25 is also considered safe for a number of warm-water fish. It is also stated that nitrite concentrations of 10 to 15 mg NO_2-N/ℓ can safely be tolerated by *C. gariepinus*, a fact which was substantiated by the present investigation. According to Fig. 2 the nitrification process as reflected by nitrate concentrations in all three systems was well established by Day 14. Fluctuations in nitrate levels during the present investigation were largely associated with pH fluctuations. Nitrate is reported to be relatively harmless, unless it is present in abnormally high concentrations (Thurston et al., 1984; Michaels, 1988). Viveen et al. (1985) reported that *C. gariepinus* can tolerate nitrate concentrations of 250 to 300 mg/ℓ. According to Balderston and Sieburth (1976), nitrate may become toxic to fish at levels exceeding 181 mg NO_3-N/ℓ. Nitrate in the water is therefore seen as essentially non-toxic to fish (Krüner and Rosenthal, 1983). DWAF (1996) gives the target water quality range for nitrate as >300 mg/ℓ at which concentration it does not have any known adverse effects on fish. Nitrate levels in the present investigation never exceeded 70 mg NO_3-N mg/ℓ in any of the three systems with no apparent negative effects on the growth and health of the catfish in all three systems.

Filter efficiency, water quality and the subsequent fish production, should indicate which configuration of the three systems presented the best intensive production potential for *C. gariepinus*. The fish production data obtained indicated that System 1 had the highest fish yield with Systems 2 and 3 second and third, respectively. The overall water quality of the three systems which is indicative of filter efficiency, indicated the same trend. Calculations derived from the amount of nitrogen input into the water, the amount utilised by the fish, dilution through water exchange and the amount of ammonia "removed" from the water by the biological filter in each system, also verified this tendency. In System 1, the trickling biological filter had a mean NH_3-N "removal" efficiency of 96.65%. The RBC system had a mean NH_3-N "removal" efficiency of 93.46% with System 3 with Siporax as medium, had a mean NH_3-N "removal" efficiency of 92.98%.

Apart from the actual findings of the present investigation into the use of biofilters in fish production under local conditions, and the experience gained with the setup and functional operation of the three different types of biofiltration under the same water temperature, water volume and recirculation conditions, certain problems were identified which must receive attention in any future fish production operation of this kind. Some of these are the following:

- Filters should first be activated for the nitrification processes to commence before the fish are introduced. In this way the initial large fluctuations and high values in ammonia and nitrite, with resultant fish mortalities, can be avoided.
- The periodic low pH values experienced, which necessitated the application of lime, also need urgent attention. Lime applications should timeously be adjusted upwards to cater for serious declines in pH in the biofiltration systems with higher fish densities.
- A solution will have to be found to combat the peaks in ammonia and nitrite levels following the upward adjustment in feed application. The temporary phasing-in during the feeding periods of auxiliary biofilters might alleviate this problem.
- The present setup of the lamellar and scrubbing filters as used in the sedimentation canal during the present investigation showed an overloading in settled solids, resulting in increased levels of ammonia and nitrite in the systems. The introduction of drum filters for the continuous automatic removal of suspended solids may solve this problem and will at the same time eliminate the time-consuming efforts in the manual removal of this material.
- The present investigation showed that the efficiency of biofilters need not be associated with employment of expensive commercial biofiltration devices. System 1, in which PVC shavings from off-cuts of PVC pipes were used as filter medium, clearly outperformed the other two systems, including the more expensive commercially available Siporax.

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