

Fish Culture and Hydroponics at Low Salinities

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ABSTRACT: Since 2003, integrated tilapia culture has been introduced at a number of sites in the Sultanate of Oman. Nile tilapia (*Oreochromis niloticus*) and red hybrid tilapia (*Oreochromis* sp.) have been grown successfully across a range of salinities (0-20ppt) confirming previous studies on optimal salinities for growth conducted elsewhere. In order to study the mineral cycle, the mineral content of commercial fish feed and effluent from experimental fish production tanks was determined. The tanks were supplied with brackish groundwater at 3 and 6 ppt, and stocked with red hybrid tilapia (initial stocking density 100 kg/m³). When tilapia were cultured intensively in tank systems, with low daily water exchange, some dissolved nutrients including magnesium, calcium, sulphur and boron accumulated to approach or exceed levels suitable for fertilising vegetable crops. Some key nutrients, including nitrogen, potassium and phosphorus were deficient. In a preliminary trial, low-salinity, tilapia effluent was shown to support the early growth of tomato plants in a hydroponic culture system.

Introduction

Integrated tilapia farming in Oman was initiated through a program of farm-based research led by specialists in aquaculture and crop production from Sultan Qaboos University (Goddard *et al.*, 2004; Opara *et al.*, 2007). Tilapia culture was integrated into traditional farming through the use of irrigation water to supply fish culture tanks. Initially four farm sites were selected to offer different rearing environments. One was located at an inland oasis, whilst the others were in villages on the Al-Batinah coastal plain. Salinities at the various sites ranged from fresh to strongly brackish (0-20ppt salinity). Three of the farms were used for studies on the integration of fish production with various field crops, including cabbages, alfalfa and date palms. The fish-growing systems at each farm comprised rectangular concrete channels 20m long x 3m wide x 1m deep. Water exchange was generally restricted to the normal, early morning and evening periods of crop irrigation (Goddard, 2005).

No significant differences were found in growth rate or feeding efficiency across the range of salinities on the various farms. In mixed-sex fish, salinity did however have marked effects on reproduction. Observations from breeding tanks indicated that as salinity increased reproduction decreased. Using fry production as a measure of reproductive success; fish reproduced normally at salinities between 0-5ppt, fry survival was reduced at 10ppt and at 20ppt no fry were produced. These observations confirm previous reports. Failure to produce fry at 20ppt may reflect the inhibitory effects of salinity on breeding behaviour, gametogenesis, gametes on release into the water, fry survival or a combination of these factors (Suresh and Lin, 1992).

Tilapia do not occur naturally in the Gulf region but have been widely introduced in recent years as biological agents

for mosquito control. Wild populations are now common but are generally of unknown genetic composition (McLean *et al.*, 2002). Nile tilapia originating from Egypt were imported from the United Arab Emirates for the first culture trials in Oman. More recently fish have been imported from Thailand in order to benefit from the fast growing, high yielding strains which have been developed through long term breeding programs in SE Asia. Since June 2004, fry of Chitralada, G.I.F.T. and red hybrid tilapia strains have been purchased from Nam Sai Farms Co. Ltd. of Prachinburi, Thailand. The first trials, completed with Chitralada strain, gave the most encouraging results, with high survival and growth from fry to 3-400 g in four-five months and to weights in excess of 1 kg in 9-12 months (Goddard, 2005).

Effluent from the integrated farms in Oman has been used to irrigate a variety of field crops. Postharvest quality and safety attributes of cabbages irrigated with tilapia tank effluent was examined at one farm. Results obtained showed that application of tilapia effluent depressed head-size, firmness and chlorophyll content and also increased the incidence of head splitting. The cause of these evident, but non-significant effects could not be established from the study. Fresh cabbage safety was not significantly affected by tilapia effluent, as determined by water activity, number of lactic acid bacteria and total plate count (Opara *et al.*, 2007).

No previous reports were found of integrated fish culture and hydroponics at low salinities. This activity, termed by some *aquaponics* (Rakocey, 1997) has been most commonly applied using freshwater for the combined production of warm-water fish with plants, such as lettuce and herbs, which have short production cycles. Tomatoes were chosen for the present study since favourable results had been obtained elsewhere in this study (Al-Yahyai, Al-Ismaïly and

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Plate 1. Collecting water samples from the fish tanks at Rumais Agricultural Station.

Al-Rawahy, 2009) for the growth of tomatoes under low-saline field conditions. The present study was undertaken in order to quantify mineral levels in tilapia tank effluent used in a combined fish culture and hydroponic system and to compare the growth rates of red hybrid tilapia at two salinities. The experiment ran for eight weeks. The effluent water was used for the hydroponic production of tomatoes. Measurements were taken of fish growth, feed conversion efficiency, mineral production, and tomato plant growth.

Materials and Methods

Experimental System

The fish were held in two rectangular concrete tanks, 2m long x 1m wide x 1m deep (Plate 1). They were supplied with water from two mixing tanks, one saline and one freshwater, to give fish culture tank water salinities of approximately 3 ppt (Tank 1) and 6 ppt (Tank 2). Water in the tanks was aerated using round (15 cm diameter) diffuser units, supplied with air from a 1- HP blower. A small, partial exchange of water (10%) was made in each tank every 3 days. The experimental system was constructed at the Rumais Agricultural Station. The entire system, including the fish culture tanks, water mixing tanks and the hydroponics system was housed within a framed plastic mesh cover, in order to reduce the incidence of sunlight.

Table 1. Mineral supplement in the commercial tilapia food¹

Minerals	mg kg ⁻¹ of dry diet
Cobalt sulphate	1.0
Copper sulphate	5.0
Manganese oxide	75.0
Zinc sulphate	150.0

Supplied as components of a vitamin and mineral supplement.

¹Goddard and McLean (2001).

Fish

Red hybrid tilapia (*Oreochromis sp.*), originating from stocks purchased from Nam Sai Farms, Thailand, were obtained from the Agricultural Experiment Station, Sultan Qaboos University. 32 fish were stocked in each tank to give an initial stocking density of approximately 100 kg/m³. The fish were fed to near satiation at 08.00 each morning and a record kept of the total food used for each tank. The food used was a commercially-produced, floating tilapia diet (ARASCO, Saudi Arabia) containing 32% crude protein and a vitamin mineral supplement. The mineral content of the food is shown in Table 1. The fish were weighed individually to the nearest 0.1g at the start and end of the experiment and total lengths measured to the nearest 1.0 mm.

Tomatoes

The hydroponic system consisted of irrigation lines (drippers) fixed in a rectangular table (2x4 m) and connected with a water storage tank. Each fish culture tank was connected with a pump to circulate the water and feed the irrigation lines. Mixing tanks were supplied with fresh, saline or fish tank effluent which were then mixed to provide the various irrigation water treatments.

Tomato plants, *Lycopersicon esculentum* (Var. GENAN) were grown in small pots filled with perlite and drip-fed irrigation solution (Plate 2). Plants were irrigated twice a day for 15 minutes. The leached water was collected beneath the pots and directed to the same irrigation tank. Five irrigation water treatments were used; fish culture effluent from the low saline fish tank (E3), fish culture effluent from the high saline fish tank (E6), freshwater (FW), low saline (S3) and high saline (S6). Tomato plant growth was measured as plant height, total fresh weight, total leaf area and root weight.

Water Analyses

Water samples for pH, ammonia, salinity and mineral content were collected at one-week intervals for eight weeks. pH was measured using pH metre (Model 3020, Jenway, UK) and salinity measured using a conductivity metre (Model 4020, Jenway, UK). Nitrogen content was determined using the phenol-hypochlorite, Solarzano method for determination of the ammonia content of seawater (Solarzano, 1969). The elemental mineral content of



Plate 2. tomato plants at the start of the hydroponics trial.

the various irrigation solution treatments were determined using ICP instrument (Optima 3300 DV, Perkin-Elmer, Germany). Samples were pre-filtered using Whatman 0.45 filter paper.

Statistics

Tests for levels of significance in the tomato plant growth experiments were carried out using one-way ANOVA and differences in means by Duncan's multiple range test, using a probability of 0.05.

Results and Discussion

The fish showed favourable and almost identical growth at both salinities over an 8-week period (Table 2). Fish in the low salinity system (2-3 ppt) showed weight gains of 63.4 % and fish in the higher salinity tanks (4-7 ppt) 63.5 % (Table 2). Food conversion rates were similar at both treatments. Tilapia growth and food conversion values were similar at both salinities and exceeded reported values for red hybrid tilapia in commercial production systems (Jaucey, 1998). These results may reflect an enhanced level of feeding and husbandry and optimal temperature and dissolved oxygen levels during the experiment. Both salinities used in this experiment fell below the optimal

range for red hybrid tilapia, which is grown commercially in brackish water systems, within an optimal range of 10-18 ppt salinity (Suresh and Lin, 1992).

The physical and chemical characteristics of the tilapia effluent are given in Tables 3 and 4. pH levels in both fish tanks were neutral to alkaline across a range of 7.1-9.0. Measurement of electrical conductivity revealed some fluctuations with average conductivity in Tank 1, over the eight week trial, 3.3 mS/cm and in Tank 2, 5.75 mS/cm. The major ions present were chlorine, sodium, magnesium and calcium. Low levels of nitrogen and potassium and were measured and only trace amounts of soluble phosphorus detected. Overall the TDS level was very high (range 1670-4877 ppm) with evidence of accumulation.

Maximum plant growth in hydroponic systems requires nutrition consisting of 16 essential elements. Three macronutrients, carbon, oxygen and hydrogen are supplied by water and carbon dioxide. The other essential macronutrients include nitrogen, potassium, calcium, magnesium, phosphorus and sulphur. The seven micronutrients include chlorine, iron, manganese, boron, zinc, copper and molybdenum. A balance between these nutrients is required for optimal plant growth, since high levels of one nutrient can influence the bioavailability of others (Rakocey, 1997).

Whilst TDS levels in the present study were very high, the individual mineral levels measured over this 8-week trial revealed some major deficiencies in terms of the mineral requirements of tomatoes. The sodium and chloride content of the brackish water, combined with any residual salt in the fish meal content of the fish diet, resulted in elevated TDS levels. These levels of TDS, in excess of 2000 ppm, are potentially toxic (Rafiee et al., 2005) Levels of nitrogen, phosphorus and potassium were extremely low, N range 1.69-5.29ppm, P range <0.05-1.02ppm and K range 2.02-19.3ppm. Recommendations for hydroponic tomatoes, grown in perlite, are for levels of 70 ppm N, 50 ppm P and 120 ppm K, during the period

Table 2. Feeding and growth data for red hybrid tilapia grown at two salinities for eight weeks.

	Tank 1 (3 ppt salinity)	Tank 2 (6 ppt salinity)
Initial weight (g)	193 ± 39.1	202 ± 38.0
Final weight (g)	304 ± 62.7	318 ± 55.3
Weight gain (%)	63.4	63.5
Specific growth rate (SGR) ¹	0.81	0.82
Food conversion ratio (FCR) ²	0.95	0.91

¹Specific growth rate, SGR = (ln initial weight – ln final weight)/100/t.

²Food conversion ratio, FCR = g dry food fed/g wet weight gain.

Table 3. pH, conductivity (E.C.), total dissolved solids (TDS) and nutrient accumulation of major cations from tilapia tanks operating at low (E3) and high salinity (E6) and of the freshwater (FW), low saline (S3) and high saline (S6) controls.

	Treatment	pH	E.C.	TDS	Cl ⁻	Na	Mg	Ca	K
Week 1	3E	7.7	2.6	1670	454	284	90.3	66.4	17.8
	6E	7.7	4.2	2707	696	435	162	103	15.5
Week 2	3E	7.5	2.8	1805	501	479	97.7	67.7	19.3
	6E	8.1	4.8	3040	766	109	177	107	16.7
Week 3	3E	8.1	3.3	2093	552	345	111	96.7	2.4
	6E	8.2	5.1	3245	-	537	195	141	2.1
Week 4	3E	7.2	2.9	1837	544	340	106	86.7	2.3
	6E	7.4	4.5	2854	798	499	180	125	2.0
Week 5	3E	8.4	3.5	2240	645	403	130	109	3.2
	6E	8.5	6.1	3885	1083	647	242	163	3.1
Week 6	3E	8.9	3.9	2464	648	405	132	112	3.1
	6E	9.0	6.7	4262	1083	677	251	170	3.0
Week 7	3E	7.2	3.9	2483	710	444	147	126	3.9
	6E	7.1	7.0	4480	1219	762	286	194	3.9
Week 8	3E	7.8	4.1	2656	715	447	146	125	3.9
	6E	7.1	7.6	4877	1201	438	144	124	3.8
Week 1	FW	6.9	0.6	378	157	98	5	9	3.5
	S3	7.8	3.5	2221	595	372	139	62	0.4
	S6	7.4	7.1	4550	1117	698	298	132	1.0

TDS, Cl, Na, Mg, Ca, K, values in mg/l
E.C. values in mS/cm

Table 4. Nitrogen, phosphorus, potassium, sulphur and micro-nutrient content (boron, manganese, copper and iron) of effluent from tilapia tanks operating at low (E3) and high salinity (E6) and of the freshwater (FW), low saline (S3) and high saline (S6) controls.

	Tank	N ¹	P	S	B	Mn	Cu	Fe
Week 1	3E	5.29	<0.05	15.9	<0.02	<0.01	0.01	<0.02
	6E	2.58	<0.05	29.0	<0.02	<0.01	<0.01	<0.02
Week 2	3E	1.77	<0.05	21.5	<0.02	<0.01	0.01	<0.02
	6E	2.23	0.08	37.5	0.27	0.012	<0.01	<0.02
Week 3	3E	4.36	<0.05	19.4	0.35	<0.01	0.021	<0.02
	6E	4.29	<0.05	22.0	0.27	<0.01	0.068	<0.02
Week 4	3E	2.37	0.42	25.3	0.25	0.023	0.017	<0.02
	6E	1.97	<0.05	40.2	0.33	0.53	0.01	<0.02
Week 5	3E	3.27	0.07	30.2	0.39	<0.01	0.013	<0.02
	6E	3.32	<0.05	57.1	0.34	<0.01	0.016	<0.02
Week 6	3E	3.00	<0.05	24.3	0.39	<0.01	0.024	<0.02
	6E	4.80	<0.05	44.0	0.30	<0.01	0.025	<0.02
Week 7	3E	2.38	1.02	<0.05	0.35	<0.01	0.027	<0.02
	6E	3.74	0.19	<0.05	0.41	0.046	0.028	<0.02
Week 8	3E	1.69	0.89	<0.05	0.35	<0.01	0.032	<0.02
	6E	2.45	0.87	<0.05	0.34	<0.01	0.028	<0.02
Week 1	FW	-	<0.05	1.38	<0.02	<0.01	<0.01	<0.01
	S3	-	<0.05	22.0	0.21	<0.01	<0.01	<0.02
	S6	-	7.41	48.8	0.25	<0.01	<0.01	<0.02

¹Total ammonia nitrogen

Values in mg/l

Cadmium, nickel, cobalt, zinc and vanadium were below the detection limit of the ICP at 0.01mg/l.

from transplant to the first fruit clusters (Hochmuth and Hochmuth, 2001). Sulphur and the levels of most essential micronutrients were also low in the fish tank effluent. Iron, manganese, zinc, copper and molybdenum fell below the recommended levels. Whilst trace elements are added to the fish diet as part of a vitamin and mineral supplement (Table 2) these were likely assimilated by the fish or excreted as components of insoluble compounds.

The results of the tomato plant growth experiments showed significantly higher growth where low saline fish effluent was used, when compared with the high saline fish effluent and the saline and freshwater controls (Table 5). In this preliminary study the minerals associated with the solids (uneaten food, fish faeces, dead algal cells and associated bacteria) which accumulated in the fish tanks were not measured. It is likely that these minerals, some

Table 5. Tomato plant growth (height, fresh weight, leaf area and root weight) at different irrigation water treatments, low saline fish effluent (3E), higher saline fish effluent (6E), low saline (S3), high saline (S6) and freshwater (FW).

Treatment	Height (cm)	Fresh weight (g)	Leaf area (cm ²)	Root weight (g)
3E	39.80 ^a	25.40 ^a	9.33 ^a	11.20 ^a
6E	30.83 ^b	7.33 ^b	4.37 ^{bc}	6.67 ^b
S3	23.50 ^d	4.00 ^c	4.40 ^{bd}	3.75 ^d

Mean values in each column followed by the same superscript are not significantly different ($P > 0.05$).

in association with organic compounds, contributed to the nutrient needs of the tomatoes

Conclusions

Growth and feed conversion efficiency of the red hybrid tilapia exceeded normal commercial values and provide further strong evidence of the potential to culture tilapia in saline water in Oman. The hydroponic growth of tomatoes was restricted to the early stages of plant growth. This was due to late planting and high summer temperatures which inhibited fruiting. However, the limited data available showed that the use of low salinity fish effluent promoted the growth of leaves and roots of early-stage tomato plants. It is recommended that the experiments be repeated in the appropriate season and should include the use of control groups receiving an optimal mineral supplement. The mineral content of solids and organic compounds generated in the fish tanks should also be examined in order to better understand the mineral cycle.

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