Yield of Tomato Irrigated with Recirculating Aquaculture Water as Influenced by Quantity of Fish Waste Products Supplied

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Abstract

Fish (*Oreochromis mossambicus* (Peters) x *O. niloticus* (L.)) and tomato (*Lycopersicon esculentum* Mill.) production were linked in a closed recirculating water system. Fish were fed a 32% protein feed. Tomato cultivars Laura and Kewalo were grown during summer 1988 and spring 1989, respectively, in a Raleigh, N.C. polyethylene greenhouse.

Plants were grown in sand biofilters at 4 plants m_{-2} and irrigated 8 times daily with water from the associated fish tank. Biofilter drainage returned to the tank by gravity. Four tank to biofilter (v/v) ratios were studied with plant populations proportional to biofilter volume. Each system received equivalent nutrient and plants received equal water.

Biological filtration, aeration and mineral assimilation by plants maintained water quality for good tilapia growth. Yield per plant of ‘Laura’ decreased with increasing biofilter volume. ‘Kewalo’ had a greater yield reduction with decreasing fish waste per plant. Fruit yields ranged 5 to 10 fold US fresh market field average and were superior to those of previous integrated aquaculture systems.

Introduction

Recirculating aquacultural water has considerable potential for hydroponic cultivation of higher plants (Lewis et al., 1978; Naegal, 1977; Nair, et al., 1985; Watten and Busch, 1984). Dissolved and suspended organic materials accumulate rapidly in recirculatory aquaculture systems and must be removed (Nair, et al., 1985).

Previous integrated fish-vegetable systems have removed the solid waste fraction from the water by sedimentation in clarifiers prior to plant application (Rakocy, 1989b). Nitrates and phosphates accumulated in clarified and filtered recirculatory aquaculture water (Balarin and Haller, 1982; Watten and Busch, 1984) and hydroponic vegetable production controlled NO_3^- concentrations (Lewis et al., 1978; McMurtry et al., 1990a; Naegal, 1977; Nair et al., 1985; Rakocy, 1989a; Watten and Busch, 1984).

Reciprocating biofilters, which alternately flood and drain, provide advantages of uniform distribution of nutrient-laden water within the filtration medium during the flood cycle and improved aeration from atmosphere exchange with each dewatering (Lewis et al., 1978; Nair et al., 1985; Rakocy, 1989a). These advantages benefit both nitrifying bacteria and plant roots (Lewis et al., 1978; Rakocy, 1989a, 1989b).

Tilapia (Oreochromis spp. and Sarotherodon spp.; Cichlidaceae) are grown worldwide for human consumption (Balarin and Haller, 1982; Pullen and Lowe-McConnell, 1982). Tilapia are easily cultured, grow rapidly, and have a high market value potential in the US. Hybrid tilapia (Oreochromis mossambicus (Peters) x O. niloticus (L.)) were cultured in this system (McMurtry et al., 1990a).

We were interested in fruit yield relative to quantities of available mineral nutrients resulting from fish metabolism. The purpose of this study was to determine how yield of tomato was influenced by biofilter volume and how biofilter volume influenced total yield per unit nutrient input.

Materials and Methods

Olericulture was integrated with recirculatory aquaculture (McMurtry et al., 1990a). All-male hybrid tilapia were cultivated in 500 liter in-ground aerated tanks. Each tank was physically associated with a biofilter employing a builder’s grade sand as substrate (Fig. 1). Four tank to biofilter volume (BFV) ratios were selected as treatments (Table 1).

The experiments were conducted in a double-layered polyethylene covered greenhouse in Raleigh, NC. Bacterial wilt (Pseudomonas solanacearum (Smith) Smith) was anticipated, and preplant fumigation of the sand with methyl bromide-chloropicrin (98-2) was made at 250 kg ha-1. Each biofilter was inoculated with 1.0 liter of Fritzzyme #7 (suspension of Nitrosomonas Winogradsky spp. and Nitrobacter Winogradsky spp.), and irrigated with aquaculture effluent for 9 days prior to transplanting tomato seedlings.

The fish were fed a diet of modified Purina Fish Chow 5140 (McMurtry et al, 1990a). The rate of daily feed input was established as a variable percentage of standing fish biomass as influenced by age and mean individual weight (McMurtry et al., 1990a; Pullen and Lowe-McConnell, 1982). The fish also grazed algae which grew in the water and on the tank walls. Fish standing biomass was adjusted to uniform levels across treatments monthly and feed rate was adjusted based upon previous feed conversion ratio (FCR) (McMurtry et al., 1990a).

Irrigation water was pumped from the bottom of the fish tanks 8 times daily between dawn and sunset and delivered to the biofilter surface at a rate of 500 l m-2 per day (McMurtry et al., 1990d). The water flooded the biofilter surfaces, percolated through the medium, and drained back to the fish tank. The tanks were recharged with city water equal to evapotranspiration when tank volumes were 75% capacity (approximately weekly). Input water composition and pH were reported by McMurtry et al.(1990d).

Tomato (Lycopersicon esculentum Mill.) seedlings were transplanted into each biofilter at 4 plants m-2 in each of 2 studies resulting in 4, 6, 9, and 14 plants per biofilter with increasing BFV. Fruit were harvested at the incipient color stage. Fruit were graded as No. 1 if blemish free and greater than 100 g, No. 2 with minor blemishes and greater than 50 g, and otherwise were culls.

A randomized complete-block design with 4 replicates was used. Analyses were performed for factorial experiments with Statview™ 512+ on a PC; including Scheffe F-test, and one factor multi-comparison ANOVA. When F-test values were significant, LSDs were calculated.

Experiment 1

Fish tanks were stocked on 5 May 1988 and the number of fish, their biomass at stocking, the total feed input, mean standing fish biomass, and the fish biomass increase during the crop interval are given in Table 1. ‘Laura’ was transplanted into the biofilters on 13 May 1988. This indeterminate greenhouse variety was grown as a single-stem.

Total water make-up for evapotranspiration and leakage and the nutrient amendments to the sand made during the 89 day tomato crop interval are given in Table 1. Excessive heat (> 40°C) after 22 June resulted in fruit set only on trusses 1-4 and only these were included in yield. Plants infected with bacterial wilt were excluded from harvest data.

Cucumber were grown during the fall of 1988, but data are not reported.

Experiment 2

Fish tanks were stocked on 5 January 1989. The number of fish, their biomass at stocking, the total feed input, mean standing fish biomass, and the fish biomass increase during the crop interval are given in Table 2. ‘

Kewalo’ was transplanted into the biofilters on 5 January, 1989. This semi-determinate, bacterial wilt-resistant cultivar was grown as a single-stem. Total water make-up for evapotranspiration and leakage and the biofilter amendments made during the 132 day tomato crop interval are given in Table 2.

Results

Experiment 1

Yield per biofilter increased with increasing BFV and yield per plant declined with increasing BFV (Table 3). Yield per biofilter differed in each treatment contrast except for the 1: 0.67 vs 1: 1.00 and 1: 1.00 vs 1: 2.25 v/v treatment contrasts. Yield per plant differed for all treatment comparisons except for the 1: 1.00 vs 1: 1.50 and the 1: 1.50 vs 1: 2.25 v/v treatment contrasts. There was no difference in fruit quality distribution across treatments. Mean fruit weight across treatments was 184 g (SD= 98) (data not shown).

Fish food input was the nutrient source driving the system and tomato yield per plant per unit feed input declined with increasing BFV (Table 4). Yield per plant for each unit feed input differed among treatment comparisons except for the 1: 1.00 vs 1: 1.50 and the 1: 1.50 vs 1: 2.25 v/v treatment contrasts.

Fish feed input minus the accompanying fish growth is a measure of residual nutrient available for plant utilization. Significant differences in yield per plant per residual feed input were not detected in any treatment contrast. Yield per plant per unit standing fish biomass declined with increasing BFV. Significant differences in yield per plant for each unit fish biomass increase were found only in contrasts which included the 1: 0.67 v/v treatment. Yield per plant per unit mean standing fish biomass differed in each treatment contrast including the 1: 0.67 v/v treatment.

Results of fruit yield per biofilter and yield per plant, together with the corresponding fish biomass increase, are given in Fig. 2. Total fruit yield increased in direct proportion to BFV (r2=.887, P= .0001) while yield per plant declined quadratically (r2=.765, P= .0001) with increasing BFV. Tomato yield per biofilter was positively correlated (CR= 0.427, CV= 3.099, r2= 0.182, P= .099) with the corresponding fish biomass increase.

Fruit yield per biofilter per unit feed input, per unit fish biomass increase, and per unit feed input less the associated fish biomass increase all increased with BFV (Fig. 3) indicating that an increasing percentage of the nutrient input was assimilated by the plants with increasing BFV (McMunry et al., 1990c).

Experiment 2

Fruit set was good through the eighth truss. Yield per biofilter increased with BFV and the yields per plant declined with increasing BFV (Table 5). Differences in yield per biofilter were found only in the 1: 0.67 vs 1: 2.25 v/v and 1: 1.00 vs 1: 2.25 v/v treatments.

Differences in yield per plant were found between each treatment combination except between 1: 0.67 vs 1: 1.00 v/v and 1: 1.50 vs 1: 2.25 v/v treatment contrasts. There was no treatment difference in fruit quality distribution across treatments except in the 1: 1.00 vs 1: 2.25 v/v ratio contrast. Mean fruit weight across treatments was 121 g (SD= 70) (data not shown).

Tomato yields per unit feed input declined with increasing BFV (Table 6). Yield per plant per unit feed input differed between each treatment combination except 1: 1.00 vs 1: 1.50 v/v and 1: 1.50 vs 1: 2.25 v/v treatment contrasts. Fruit yield per plant per unit mean standing fish biomass closely paralleled that of yield per plant per unit feed input.

Fish feed input less the accompanying fish growth is a measure of residual nutrient available for plant utilization. Differences in yield per plant per residual feed input were detected in each treatment combination except for between 1: 0.67 vs 1: 1.00 v/v and 1: 1.50 vs 1: 2.25 v/v treatment contrasts. Yield per plant per unit fish growth declined with increasing BFV. Yields per plant per unit fish biomass increase were also different in each treatment combination except for 1: 1.00 vs 1: 1.50 v/v and 1: 1.50 vs 1: 2.25 v/v ratio contrasts.

Fruit yield per biofilter and yield per plant, together with the corresponding fish biomass increase, are shown in Fig. 4. Total fruit yield increased proportionally to the BFV ($r2=$ 0.533, $P= .0013$) while yield per plant declined in an approximately quadratic ($r2= 0.771$, $P= .0001$) relationship with increasing BFV. Fruit yield per biofilter was positively correlated ($CR= 0.922$, $CV= 0.598$, $r2= 0.358$, $P= .0144$) with the accompanying fish biomass increase.

Fruit yield per biofilter per unit feed input, or per unit fish biomass increase, or per unit feed input less the associated fish biomass increase all increased with BFV (Fig. 5)

Discussion

All water quality variables were maintained within acceptable levels for tilapia by circulation through the biofilters (McMurtry et al., 1990a). Nitrogenous compounds, which frequently limit fish production in other recirculatory water systems (Lewis et al., 1978), did not reach toxic levels (McMurtry et al., 1990a) and were extracted by the plants (Naegal, 1977; McMurtry et al., 1990a, 1990c).

Full-shade air temperature exceeded 40°C daily following anthesis on the third truss in summer 1988. Heat stress resulted in morphological deformation of floral organs which reduced fruit set (Levy et al., 1978). Therefore, total yield potential was greatly reduced and the crop was terminated. ‘Laura’ tomatoes are typically grown through the eighth truss and yield potential without heat stress was thought to be approximately twice that realized in this experiment.

In both experiments, fruit yield per biofilter increased with BFV which suggested a greater efficiency in nutrient extraction from aquaculture effluents with increasing plant number per unit fish biomass or per unit feed input. Plants assimilated an increasing percentage of the nutrient input with increasing BFV (McMurtry et al., 1990c). This was corroborated by lower nutrient concentrations in the water with increasing BFV (McMurtry et al., 1990a, 1990d). Increasing fish growth rate with increasing BFV (McMurtry et al., 1990a) was attributed to the reduced nutrient concentrations in the water.

Yields per plant increased with decreasing BFV, reflecting greater per plant nutrient availability which was corroborated by greater per plant uptake of most nutrients (McMurtry et al., 1990c). Nutrient loading in the biofilters from residues of previous experiments may have influenced yield following Experiment 1 (McMurtry et al., 1990a, 1990c). The difference in fruit quality distribution between experiments was attributed mainly to the smaller fruit size of variety ‘Kewalo’.

Experiment 1 fruit production per unit feed input and per unit fish biomass increase were essentially parallel and slightly different in magnitude, reflecting the high FCR of the immature fish. Fruit yield per unit feed input less the associated fish biomass increase increased with BFV and the rate of this increase with BFV was greater than that of per unit feed input or per unit fish biomass increase.

This reflected an increasing efficiency in nutrient extraction from the aquaculture water with increasing BFV (McMurtry et al., 1990c). This further suggests that biofilter nutrient loading rates increased with decreasing BFV. Fish growth and fruit yield rates were both satisfactory and were highly correlated with each other. This was attributed to a lack of previous nutrient accumulation in the biofilters.

Experiment 2 fruit production per unit feed input and of fruit yield per unit fish biomass increase were different in magnitude. This reflected the reduced FCR of the mature fish cultured during this interval (McMurtry et al., 1990a). Fruit yield per unit feed input less the associated fish biomass increase increased with BFV at a rate essentially parallel to per unit feed input and per unit fish biomass increase.

The differential between fruit yield per unit feed input and yield per unit input less the associated fish biomass increase increased with BFV. This suggested somewhat greater efficiency in nutrient removal by plants from the water with increasing BFV.

Experiment 2 correlation values for fruit yield per each unit input category were not as high as those for Experiment 1. This was attributed to disparate nutrient availability resulting from unequal assimilation per unit input in preceding studies. We agree with Rakocy (1989b) that optimum ratios among feed input rate, standing fish biomass, system water volume, and biofilter volume need to be established for various combinations of fish and vegetable species.

Fruit production rates were high, with ‘Laura’ yield ranging 102 to 153 g m^{-2} d^{-1} and ‘Kewalo’ yield ranging 78 to 157 g m^{2} d^{-1} with decreasing BFV. Regardless of tank to biofilter (v/v) ratio, fruit yields were superior to those of previously reported integrated aquaculture systems (Naegal, 1977; Watten and Busch, 1984; Rakocy, 1989a).

Productivity in the Naegal (1977) system equated to 48 g m^{-2} d^{-1} and ranged 21 to 90 g m^{-2} d^{-1} in the Watten and Busch (1984) system. The mean yield rate for several tomato varieties reported by Rakocy (1989a) equated to 11 g m^{-2} d^{-1}. Even when Lewis et al. (1978), Burgoon and Baum (1984) and Rakocy (1989b) made substantial nutrient supplements including Fe, K and P, our yields were comparable to or exceeded those in their studies. Nutrient comprising the solid fraction of fish wastes was apparently available for plant assimilation (McMurtry et al., 1990c).

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Biofilter ratio (v/v)	**Water (liters)**	**Fish stocked No.**	**Fish feed (kg)**	**Boric acid (g)**	**$CaMg(CO_3)_2$ (g)**	**Bone meal (g)**	**Mean standing Fish Biomass (kg)**

1:0.67	1060	36	0.56	9.82	10.0	125	4.00
1:1.00	1249	37	0.63	10.16	15.0	125	4.56
1:1.50	1438	36	0.56	10.12	22.5	125	4.23
1:2.25	2025	39	0.55	10.13	33.4	125	4.49

Biofilter ratio (v/v)	**Water (liters)**	**Fish stocked No.**	**Fish feed (kg)**	**Ca Oxide (g)**	**Mean standing Fish Biomass (kg)**	
1: 0.67	1686	10.0	4.40	7.10	253	6.39
1: 1.00	1836	10.5	4.42	7.10	300	6.50
1: 1.50	2262	10.0	4.36	7.10	203	6.46
1: 2.25	3115	10.0	4.27	7.10	51	6.54

Biofilter ratio (y/v)	**Plants (plot-1)**	**Total Yield (kg· plot-1)**	**Total Yield (kg· plant-1)**	**Fruit Quality No. 1 (%)**	**Fruit Quality No. 2 (%)**
1: 0.67	4	13.66	3.41	64.3	32.1
1: 1.00	6	16.99	2.83	61.7	36.5
1: 1.50	9	20.98	2.44	63.9	30.3
1: 2.25	14	31.65	2.26	67.5	27.9
Contrasts	LSD (P= 0.05)	4.22	0.43	NS	NS
4 vs 6 plants mean difference		-3.3	+0.6*	+ 10.7	-4.3
4 vs 9 plants mean difference		-8.3**	+ 1.0***	+ 4.6	+ 1.9

4 vs 14 plants mean difference	-18.0***	+ 1.2***	-0.7	+ 1.6

NS,*,**,*** Nonsignificant or significant at the P 0.05, 0.01, or 0.005 levels, respectively

Biofilter ratio (v/v)	**Plants (Plt) per Plot**	**Fruit Plt^{-1} per Fish Feed Input ($\text{kg}\cdot\text{kg}^{-1}$)**	**Fruit Plt^{-1} per Feed Input Less Fish Increase ($\text{kg}\cdot\text{kg}^{-1}$)**	**Fruit Plt^{-1} per Standing Fish Biomass ($\text{kg}\cdot\text{kg}^{-1}$)**
1: 0.67	4	0.31	0.81	0.86
1: 1.00	6	0.25	0.86	0.62
1: 1.50	9	0.22	0.64	0.58
1: 2.25	14	0.20	0.74	0.50

Contrasts | LSD (P= 0.05) 0.04 NS | 4 vs 6 plants mean difference +0.05* -0.06 | 4 vs 9 plants mean difference +0.10*** +0.16 | 4 vs 14 plants mean difference +0.10*** +0.06 | NS,*,**,*** Nonsignificant or significant at the P 0.05, 0.01, or 0.005 levels, respectively

Biofilter ratio (v/v)	Plants (plot-1)	Total Yield (kg· plot-1)	Total Yield (kg· plant-1)	Fruit Quality No. 1 (%)	Fruit Quality No. 2 (%)
1: 0.67	4	19.88	4.98	46.3	53.7
1: 1.00	6	22.06	3.68	49.1	50.9
1: 1.50	9	27.34	3.04	43.7	55.9
1: 2.25	14	33.11	2.48	37.0	61.9
Contrasts | LSD (P= 0.05) 8.43 0.90 NS NS					
4 vs 6 plants mean difference -2.2 + 1.3** -2.9 +3.0					
4 vs 9 plants mean difference -7.5 + 1.9*** +2.5 -2.2					

4 vs 14 plants mean difference -13.2** +2.5*** +9.3 -8.2
NS,*,**,*** Nonsignificant or significant at the P 0.05, 0.01, or 0.005 levels, respectively

Biofilter Ratio (v/v)	**Plants (Plt) per Plot**	**Fruit Plt^{-1} per Fish Feed Input ($kg·kg^{-1}$)**	**Fruit Plt^{-1} per Feed Input Less Fish Increase ($kg·kg^{-1}$)**	**Fruit Plt^{-1} per Standing Fish Biomass ($kg·kg^{-1}$)**
1:0.67	4	0.70	1.07	0.78
1:1.00	6	0.52	0.81	0.57
1:1.50	9	0.43	0.67	0.47
1:2.25	14	0.35	0.57	0.38
Contrasts LSD (P=0.05)		0.12	0.21	0.13

4 vs 6 plants mean difference	+0.18**	+0.26*	+0.21***
4 vs 9 plants mean difference	+0.27***	+0.39***	+0.31***
4 vs 14 plants mean difference	+0.35***	+0.50***	+0.40***

NS,*,**,*** Nonsignificant or significant at the P 0.05, 0.01, or 0.005 levels, respectively.

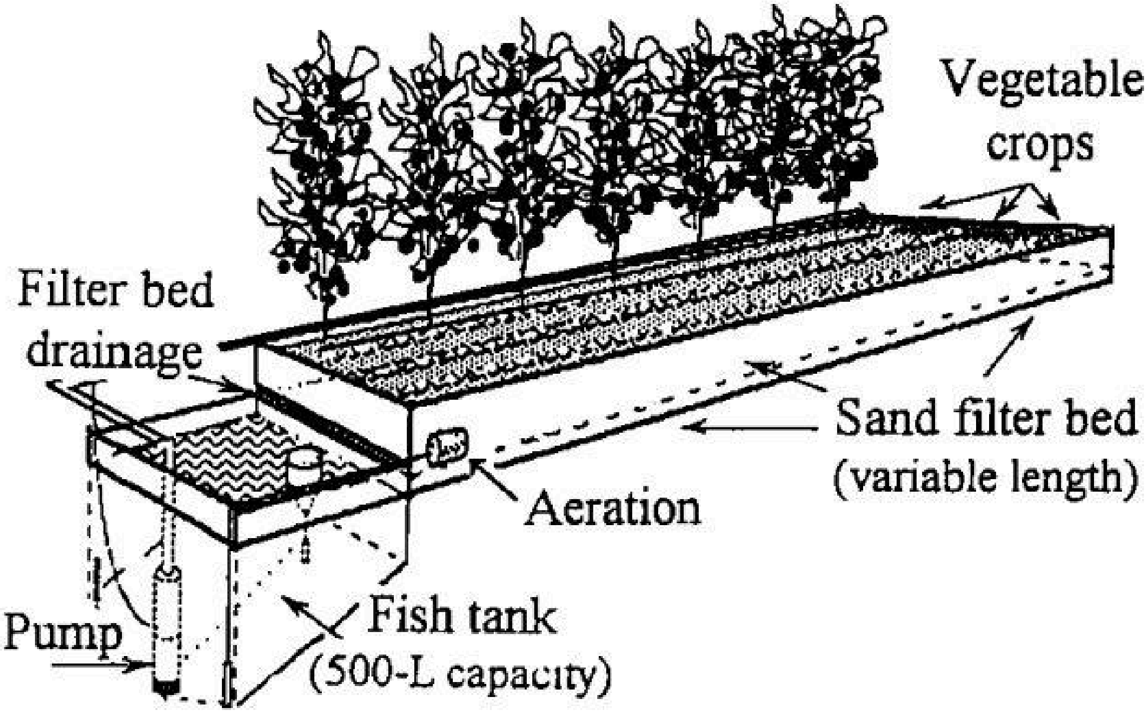

FIGURE 1. *Schematic diagram of the integrated fish/vegetable co-culture system.*