Horticulture

Yield of Tomato Irrigated with Recirculating Aquacultural Water

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Aquacultural water, which rapidly accumulates organic materials that inhibit fish growth, has considerable potential for hydroponic cultivation of vegetable plants. By recirculating aquacultural water through sand biofilters, it is possible to integrate the two systems whereby both benefit: the vegetables are provided with nutrient-laden water and they control ammonia concentrations in the fish medium. Hybrid tilapia fish [*Oreochromis mossambicus* (Peters) × *O. niloticus* (L.)] and tomato (*Lycopersicon esculentum* Mill.) production were linked in a closed recirculating water system in a polyethylene greenhouse to determine the effect of tank-to-biofilter ratio on tomato yield. The fish were raised in tanks and fed a 32% protein feed. Tomatoes 'Laura' and 'Kewalo' were grown in sand biofilters during summer 1988 and spring 1989, respectively. Plant spacing was 4 plants/sq yd and each bed was irrigated eight times daily with water from the associated fish tank. Biofilter drainage returned to the tank by gravity. Four tank-to-biofilter (v/v) ratios (1:0.67, 1:1.00, 1:1.50, and 1:2.25) were studied with plant populations proportional to biofilter volume. Each system received equivalent nutrients (even though biofilter size and number of plants differed) and plants received equal water. Biological filtration, aeration, and mineral assimilation of plants maintained water quality for tilapia growth. Yield per plant decreased with increasing biofilter volume but total yield per biofilter increased with increasing biofilter volume. Fruit production per unit feed input and per unit fish biomass increase were highly correlated. From these studies, a balanced high per-plant yield and high total yield were observed with the 1:1.5 tank-to-biofilter ratio. The system operated efficiently so that both fish and fruit production were successful.

RECIRCULATORY aquacultural systems rapidly accumulate dissolved and suspended organic materials that inhibit fish growth (Nair et al., 1985). This 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). Previous integrated fish-vegetable systems have removed the solid waste fraction from the water by sedimentation in clarifiers prior to applying the material to plants (Rakocy, 1989b). Nitrates and phosphates have been shown to accumulate in clarified and filtered recirculatory aquaculture water (Balarin and Haller, 1982; Watten and Busch, 1984) and hydroponic vegetable production has aided in controlling nitrate concentrations in fish culture systems (Lewis et al., 1978; Naegal, 1977; Nair et al., 1985; Rakocy, 1989a; Watten and Busch, 1984). Reciprocating biofilters, which alternately flood and drain, provide 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). Both nitrifying bacteria and plant roots benefit in this cultural system (Lewis et al., 1978; Rakocy, 1989a, 1989b).

Tilapia (*Oreochromis* spp.; family Cichlidaceae) are grown worldwide for human consumption (Balarin and Haller, 1982; Pullen and Lowe ~ McConnell, 1982). They are easily cultured, grow rapidly, and have a potentially high market value in the USA. Hybrid tilapia were cultured in this system.

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

MATERIALS AND METHODS

All-male (sex-reversed) hybrid tilapia were cultivated in 132.5 gal in-ground tanks with aeration provided by regenerative blowers at 1.5 CFM through two (1.5- by 1.5- by 6-in) airstones per tank. Water temperatures were kept above 77 °F by two Visitherm 250W (Aquarium Systems, Mentor, OH) thermostatic aquarium heaters per tank. The rectangular tanks were formed with plywood, the bottom sloped and lined with 0.02 in. (2 layers of 0.01 in.) black polyethylene (Fig. 1).

Each tank was coupled to a biofilter containing builder's grade sand as a substrate. Tank water level at full capacity was 4 in. below the bottom of the biofilter. Biofilters were 4 ft wide, 1 ft deep, and of variable length (3.3, 4.0, 6.3, 9.3 ft) to achieve four ratios by volume to the fish tank (1:0.67; 1:1.00, 1:1.50, 1:2.25). Biofilters were lined with 0.02-in. (three layers of 0.006-in.) polyethylene plastic and the bottom sloped 1:200 along the length to direct drainage for return to the associated tank. Biofilter media were 99.25% quartz sand and 0.75% clay. The sand fractionation was as follows: very fine sand, 1.1%; fine sand, 5.2%; medium sand, 21.0%; coarse sand, 38.8%; and very coarse sand, 33.3%. The four

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Abbreviations: BFV, biofilter volume; FCR, feed conversion ratio.

tank-to-biofilter volume (BFV) ratios were used as treatments and each was replicated four times for each experiment.

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 (trichloronitromethane) (98-2 v/v) was made at 2.5 oz/sq yd. Each biofilter was inoculated with 1 qt of Fritz-zyme no. 7 (Fritz Pet Products, Dallas, TX; suspension of *Nitrosomonas* Winogradsky spp. and *Nitrobacter* Winogradsky spp.), and irrigated with aquaculture effluent for 9 d prior to transplanting tomato seedlings in Exp. 1.

The fish were fed a diet of modified Purina Fish Chow 5140, with a minimum analysis of 32% crude protein, 3.5% crude fat, and not more than 7.0% crude fiber. The feed was not fortified with vitamins or trace elements. The rate of daily feed input was established as a variable percentage of standing fish biomass as influenced by age and mean individual weight (Pullen and Lowe ~ McConnell, 1982). The daily ration was divided equally into two feedings administered at 0800 and 1300 hours. The fish also grazed algae (*Oscillatoria* Vaucher spp., *Cyanophyta*, and *Ulothrix* Kützing spp., *Chlorophyta*), which grew in the water and on the tank sides.

Irrigation water was pumped from the bottom of each fish tank eight times daily between dawn and sunset and delivered to the biofilter surface at a rate of 132.5 gal/sq yr/d. The water flooded the biofilter surfaces, percolated through the medium, and drained back to the fish tank. The tanks were recharged to 4 in. below the bottom of the biofilter with city water to replace evapotranspiration losses when tank volumes were at 75% capacity (approximately weekly). Input water composition and pH were monitored.

Tomato (*Lycopersicon esculentum* Mill.) seedlings were transplanted into each biofilter at 4 plants/sq yd in each of two studies resulting in 4, 6, 9, or 14 plants/biofilter with increasing BFV (1:0.67, 1:1.00, 1:1.50, and 1:2.25, respectively). Fruit were harvested at the incipient color stage and weighed and graded according to U.S. grade standards from each plot. Fruit were graded as No. 1 if blemish free and greater than 0.25 lb, No. 2 with minor blemishes and greater than 0.10 lb, and otherwise as culls.

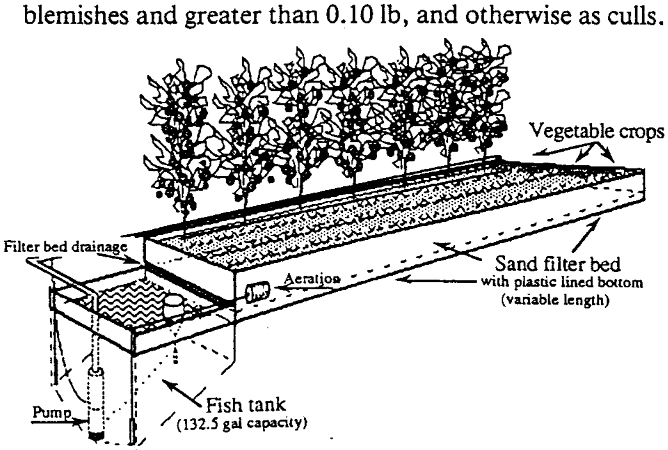

Fig. 1. Schematic diagram of the integrated aquaculture-olericulture system.

Table 1. Total inputs per biofilter and mean standing fish biomass during 'Laura' tomato crop interval.

Biofilter ratio	Water	Fish stocked†		Fish feed‡	Boric acid‡	$CaMg(CO_3)_2$‡	Bone meal‡	Feed conversion ratio, FCR§
v/v	gal	No.	lb	lb	oz	oz	oz	
1:0.67	280	36	1.2	21.6	0.4	4.4	1.6	1.3
1:1.00	330	37	1.4	22.4	0.5	4.4	2.4	1.2
1:1.50	380	36	1.2	22.3	0.8	4.4	3.6	1.3
1:2.25	535	39	1.2	22.3	1.2	4.4	5.4	1.2

† Number of fish and their biomass at stocking.
‡ All inputs reflect totals over the entire experiment.
§ FCR = fish feed per weight gained.

A randomized complete-block design with four replicates was used for each study. Analyses were performed for factorial experiments with Statview 512+ (Abacus Concepts, Berkeley, CA) on a PC.

1988 Experiment

Fish were stocked on 5 May 1988 and the number of fish, their biomass at stocking, the total feed input, and feed conversion ratios (FCR) are given in Table 1 (all inputs reflect totals over the entire experiment). Laura, an indeterminate greenhouse tomato, was transplanted into the biofilters on 13 May 1988 and trained to a single-stem. Total water replacement for evapotranspiration and leakage and the nutrient amendments made to the sand during the 89 d tomato crop interval are given in Table 1. Fish biomass increase data were based on this same interval. Excessive heat (> 100 °F) after 22 June resulted in fruit set only on trusses 1 to 4 and only these were included in yield.

1989 Experiment

Fish were stocked on 5 Jan. 1989. The number of fish, their biomass at stocking, the total feed input and FCR during the crop interval are given in Table 2. Kewalo, a semi-determinate, bacterial wilt-resistant tomato, was transplanted into the biofilters on 5 Jan. 1989 and was trained to a single-stem. Total water replacement for evapotranspiration and leakage and the sand biofilter amendments made during the 132 d tomato crop interval, are given in Table 2. Fish biomass increase data were based on this same interval.

RESULTS

1988 Experiment

Total fruit yield per biofilter increased linearly in proportion with BFV (r^2 = 0.89, P = 0.0001) while yield per plant decreased quadratically (r^2 = 0.77, P = 0.0001) with increasing BFV (Fig. 2). Fish biomass slighty increased with increasing BFV. Tomato yield per biofilter was positively correlated (CV = 3.099, r^2 = 0.19, P = 0.099) with the corresponding fish biomass increase.

Fruit yield per biofilter per unit feed input, fruit yield per unit fish biomass increase, and fruit yield per unit feed input less the associated fish biomass increase all increased with BFV indicating that an increasing percen-

Table 2. Total inputs per biofilter and mean standing fish biomass during 'Kewalo' tomato crop interval.

Biofilter ratio	Water	Fish stocked†		Fish feed‡	Ca oxide‡	Feed conversion ratio, FCR§
v/v	gal	No.	—— lb ——		oz	
1:0.67	445	10.0	9.7	15.6	8.9	0.8
1:1.00	485	10.5	9.7	15.6	10.6	0.8
1:1.50	598	10.0	9.6	15.6	7.2	0.8
1:2.25	823	10.0	9.4	15.6	1.8	0.8

† Number of fish and their biomass at stocking.
‡ All inputs reflect totals over the entire experiment.
§ FCR = Fish feed per weight gained.

tage of the nutrient input was assimilated by the plants with increasing BFV (Fig. 3). Fish food input minus the accompanying fish growth is a measure of residual nutrients available for plant use. Significant differences in yield per plant per residual feed input were not detected in any treatment contrast.

1989 Experiment

Total fruit yield per biofilter increased proportionally with the BFV ($r^2 = 0.53$, $P = 0.0013$), and yield per plant decreased ($r^2 = 0.77$, $P = 0.0001$) with increasing BFV (Fig. 4). Fruit yield per biofilter was positively correlated (CV = 0.598, $r^2 = 0.358$, $P = 0.0144$) with the accompanying fish biomass increase. Fruit yield per plant per unit mean standing fish biomass closely paralleled that of yield per plant per unit feed input. Fruit yield per biofilter per unit feed input, or fruit yield per unit fish biomass increase, and fruit yield per unit feed input less the associated fish biomass increase all increased with BFV (Fig. 5).

DISCUSSION

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.

In the 1988 experiment, fruit production per unit feed input and per unit fish biomass increase were essentially parallel and slightly different in magnitude, reflecting the high FCR (pounds of feed input:pounds of fish biomass increase) of immature fish (Table 1, Fig. 3).

Fruit yield per unit feed input less the associated fish biomass increase did increase with BFV, and the rate of that increase with BFV was greater than the rates for fruit production per unit feed input or fruit production per unit fish biomass increase. Because there was the same amount of feed input and the same amount of fish in each of the varying-sized tanks, this reflected an increasing efficiency in nutrient extraction by the plants from the aquaculture water with increasing BFV.

Fish growth and fruit yield rates were both satisfactory and were highly correlated with each other (Fig. 2) and can be attributed to a lack of previous nutrient accumulation in the biofilters. Full-shade air temperature exceeded 100°F daily following anthesis of flowers 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 from trusses 1 to 4.

In the 1989 experiment, fruit production per unit feed input and fruit yield per unit fish biomass increase were different in magnitude (Fig. 5). The difference reflected the reduced FCR of the mature fish cultured during this interval (i.e., in this experiment the fish were more ma-

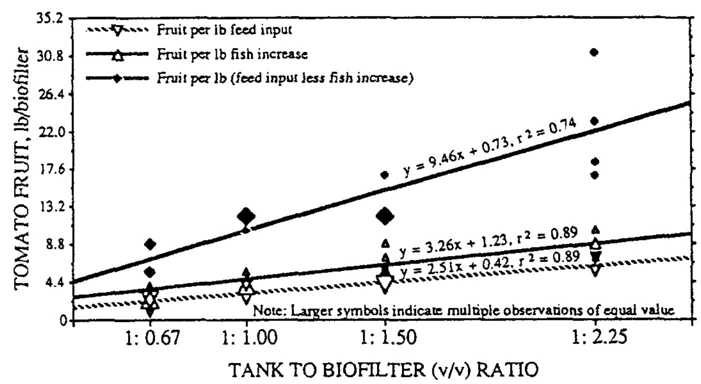

Fig. 3. Fruit yield per biofilter of 'Laura' tomato for each pound of feed input, each pound of fish biomass increase, and each pound of feed input less the associated fish biomass increase, as influenced by tank to biofilter ratio.

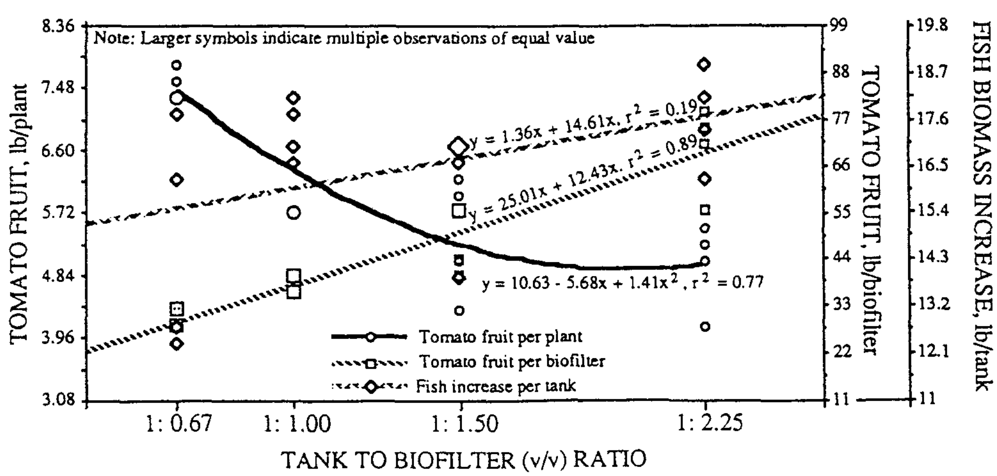

Fig. 2. Fruit yield per plant and per biofilter of 'Laura' tomato, with the corresponding fish biomass increase, as influenced by tank to biofilter ratio.

ture and FCR should be naturally lower) (Table 2). The FCR below 1.0 indicated that the fish were indeed grazing algae.

Fruit yield per unit feed input less the associated fish biomass increase did increase with BFV at a rate essentially parallel to fruit production per unit feed input and fruit production per unit fish biomass increase (Fig. 5). The differential between fruit yield per unit feed input and fruit yield per pound increased with BFV. As in the 1988 experiment, this increase 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 Exp. 1 (Fig. 2, 4). This difference was attributed to disparate nutrient availability resulting from unequal assimilation per unit input in preceding studies (Tables 1, 2). We agree with Rakocy (1989b) that optimum ratios among feed input rate, system water volume, and biofilter volume must be established for various combinations of fish and vegetable species.

Fruit production rates were high, with Laura yield ranging from 0.25 to 0.35 lb/sq yd/d and Kewalo yield ranging from 0.20 to 0.35 lb/sq yd/d with decreasing BFV. Regardless of tank to biofilter 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 0.1 lb/sq yd/d and were 0.05 to 0.20 lb/sq yd/d in the Watten and Busch (1984) system. The mean yield for several tomato varieties reported by Rakocy (1989a) equated to 0.02 lb/sq yd/d. Our yields were similar to, or exceeded, those reported in studies by Lewis et al. (1978), Burgoon and Baum (1984) and Rakocy (1989b), all of whom made substantial nutrient supplements including Fe, K, and P.

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

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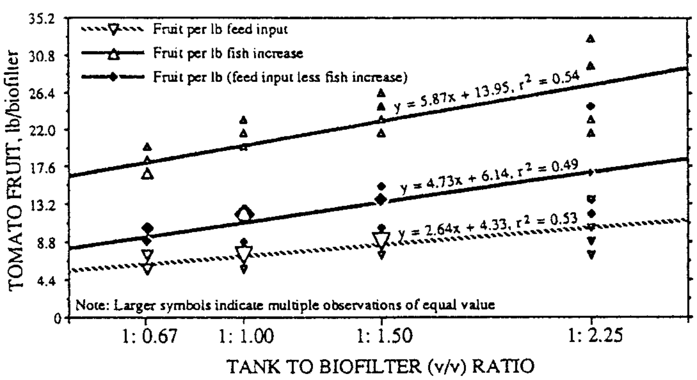

Fig. 5. Fruit yield per biofilter of 'Kewalo' tomato for each pound of feed input, each pound of fish biomass increase, and each pound of feed input less the associated fish biomass increase, as influenced by tank to biofilter ratio.

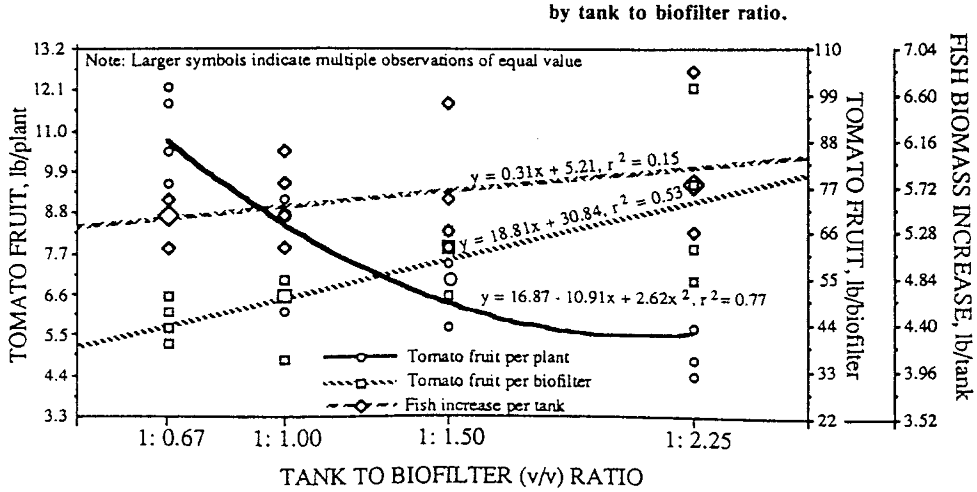

Fig. 4. Fruit yield per plant and per biofilter of 'Kewalo' tomato, with the corresponding fish biomass increase, as influenced by tank to biofilter ratio.

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