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MINERAL NUTRIENT CONCENTRATION AND UPTAKE BY TOMATO IRRIGATED WITH RECIRCULATING AQUACULTURE WATER AS INFLUENCED BY QUANTITY OF FISH WASTE PRODUCTS SUPPLIED[1]

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ABSTRACT: Fish and tomato (*Lycopersicon esculentum* Mill.) production were linked in a recirculaing water system. Fish (tilapia) were fed a commercial diet with 32% protein. Tomato cultivars 'Laura' and 'Kewalo' were grown during summer 1988 and spring 1989, respectively, in a Raleigh, NC greenhouse. Plants were grown in biofilters at 4 plants/m^2 and surface irrigated 8 times daily with water pumped from an associated fish tank. Four tank-to-biofllter ratios were established by varying the filter size. Each system received identical nutrient inputs and an equal quantity of water was applied per plant. Biofilter drainage returned to the tanks. Biological filtration, aeration, and mineral assimilation by plants maintained water quality within limits for tilapia. All nutrients were assimilated above deficiency levels. Tissue concentrations of N, P, K and Mg were not limiting. Calcium was low and S high when their sole nutrient source was fish waste. Micronutrients were assimilated in excess of sufficiency, but toxicity was not seen. Irrespective of fruit yield, metabolic products of each kilogram increase in fish biomass provided sufficient nutrient for two tomato plants for a period of

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three months. Under reduced growth rates of mature fish, K became limiting. Alterations in fish feed mineral nutrient content are suggested which better meet plant requirements and still remain within the range of fish needs.

INTRODUCTION

Recirculating aquacultural water has considerable potential for hydroponic cultivation of higher plants (15,16,20,21,22). Dissolved and suspended organic materials accumulate rapidly in aquaculture systems and must be removed for efficient fish production (17). Nitrates and phosphates accumulate in filtered recirculatory fish culture systems (1,22). Hydroponic vegetable production has been demonstrated to control NO_3-concentrations in recirculatory aquaculture water (15,16,20,21,22). Reciprocating biofilters, which alternately flood and drain, provide uniform distribution of nutrient-laden water within the filtration medium and improved aeration of the substrate with each dewatering which benefits both nitrifying bacteria and plant roots (16,17,18,20,21).

Other integrated fish-vegetable systems removed suspended solids from the water by sedimentation in clarifiers prior to plant application (21). Removal of the solid wastes resulted in insufficient residual nutrients for good plant growth. Acceptable fruit yields have previously only been achieved with substantial supplementation of plant nutrients (15,16,21).

The objective of this study was to determine mineral nutrient concentration, balance and accumulation in tomato grown in sand biofilters and irrigated with aquaculture wastes.

MATERIALS AND METHODS

All-male (sex-reversed) hybrid tilapia [*Oreochromis mossambicus* (Peters) x *O. niloticus* (L.) Cichlidaceae] were cultivated in 500-L in-ground tanks with aeration provided by regenerative blowers at 0.7 L/s through two (3.8 x 3.8 x 15 cm) airstones per tank. Water temperatures were kept above 25°C by two Visitherm^{TM} 250W thermostatic aquaria heaters per tank. The rectangular tanks were formed with plywood, the bottom sloped to 45° and lined with 0.50 mm (two layers of 0.25 mm) black polyethylene (Figure 1). Each tank was coupled to a biofilter employing builder's grade sand as a substrate. Tank water level at capacity was 10 cm below the bottom of the biofilter. Biofilters were 1.2 m wide,

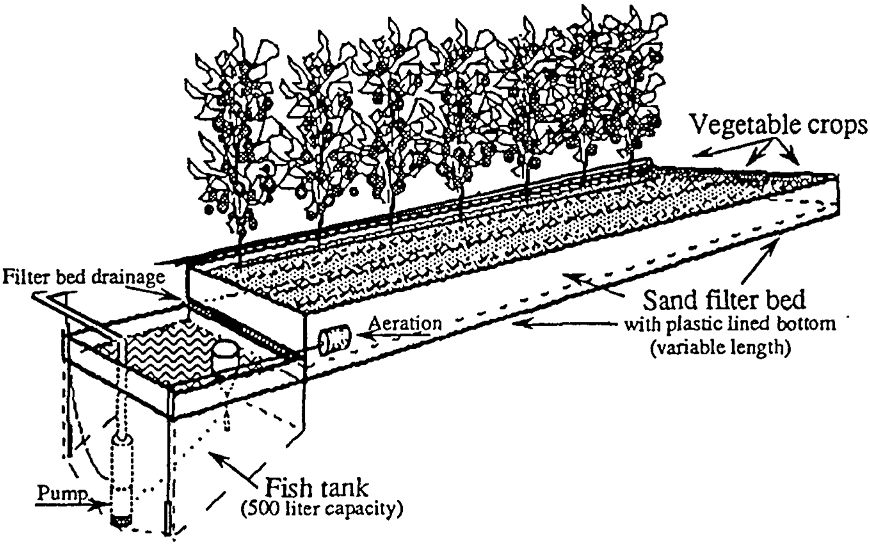

Fig. 1. Schematic diagram of the integrated aquaculture-olericulture system.

0.33 m deep, and lengths of 1.0, 1.25, 1.90, and 2.84 m to achieve four ratios by volume to the fish tank (Table 1). Biofilters were lined with 0.45-mm (three layers of 0.15-mm) polyethylene plastic, and the bottom sloped 1:200 along the length to direct drainage for return to the associated tank. Media composition was 99.25% quartz sand, 0.75% clay, and 0.0% silt. The sand fractionation was: very fine sand, 1.1%; fine sand, 5.2%; medium sand, 21.0%; coarse sand, 38.8%; and very coarse sand, 33.3%. Four tank-to-biofilter volume (BFV) ratios (1:0.66, 1:1, 1:1.50, and 1:2.25) were used as treatments.

The experiments were conducted in a double-layered polyethylene greenhouse in Raleigh, NC. Bacterial wilt [*Pseudomonas solanacearum* (Smith) Smith] was anticipated, and preplant fumigation of the sand with methyl bromide-chloropicrin (98-2 v/v) was made at 66 g/m^2. Each biofilter was inoculated with 1.0 L of Fritz-zyme #7 (suspension of *Nitrosomonas* Winogradsky spp. and *Nitrobacter* Winogradsky spp.), and irrigated with aquaculture effluent for 9 days prior to transplanting tomato seedlings in Experiment 1.

Table 1. Nutrient concentration of leaves, fruit and aerial whole plant of 'Laura' tomato as influenced by tank to biofilter ratio.

Biofilter Ratio (v/v)	Plants per plot		N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B
			----------Dry Wt. (%)					----------Dry Wt. ($\mu g \cdot g^{-1}$)					
a) Leaf tissue													
1: 0.67	4	mean	4.30	0.74	3.65	0.69	0.39	4908	223	143	99	31	53
1: 1.00	6	mean	4.32	0.72	3.70	0.76	0.38	4732	220	211	152	32	74
1: 1.50	9	mean	4.59	0.78	3.88	0.81	0.40	5366	235	170	118	33	76
1: 2.25	14	mean	4.62	0.76	3.80	0.90	0.43	5765	235	177	125	35	90
Contrasts	LSD (P= 0.05)		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	20
4 vs 6 plants	mean difference		$-.02^{NS}$	$+.02^{NS}$	$-.05^{NS}$	$-.07^{NS}$	$+.02^{NS}$	$+176^{NS}$	$+3^{NS}$	-68^{NS}	-53^{NS}	-1^{NS}	-21^{*}
4 vs 9 plants	mean difference		$-.29^{NS}$	$-.04^{NS}$	$-.23^{NS}$	$-.12^{NS}$	$-.01^{NS}$	-458^{NS}	-13^{NS}	-28^{NS}	-19^{NS}	-2^{NS}	-24^{*}
4 vs 14 plants	mean difference		$-.32^{NS}$	$-.02^{NS}$	$-.15^{NS}$	$-.22^{NS}$	$-.04^{NS}$	-858^{NS}	-13^{NS}	-34^{NS}	-26^{NS}	-4^{NS}	-37^{***}
b) Fruit tissue													
1: 0.67	4	mean	4.54	0.73	3.85	0.28	0.21	2151	86	44	80	20	29
1: 1.00	6	mean	4.91	0.65	3.80	0.21	0.23	2314	84	45	91	23	39
1: 1.50	9	mean	5.01	0.57	3.56	0.16	0.19	1787	75	37	67	19	33
1: 2.25	14	mean	4.82	0.66	3.66	0.31	0.27	2200	103	38	106	20	35
Contrasts	LSD (P= 0.05)		0.26	0.04	0.23	0.02	0.17	143	6	3	6	1	2
4 vs 6 plants	mean difference		$-.37^{**}$	$+.08^{***}$	$+.05^{NS}$	$+.07^{***}$	$-.02^{*}$	-163^{*}	$+2^{NS}$	-1^{NS}	-11^{***}	-3^{***}	-10^{***}
4 vs 9 plants	mean difference		$-.47^{***}$	$+.16^{***}$	$+.29^{*}$	$+.12^{***}$	$+.02^{*}$	$+364^{***}$	$+11^{***}$	$+7^{***}$	$+13^{***}$	$+1^{NS}$	-4^{***}
4 vs 14 plants	mean difference		$-.28^{*}$	$+.07^{***}$	$+.19^{NS}$	$-.03^{***}$	$-.06^{***}$	-48.5^{NS}	-17^{***}	$+6^{***}$	-26^{***}	0^{NS}	-6^{***}
c) Aerial whole plant tissue													
1: 0.67	4	mean	3.62	0.91	3.73	2.24	0.79	10814	171	457	907	43	104
1: 1.00	6	mean	3.92	0.71	4.03	2.37	0.78	10999	134	479	848	44	124
1: 1.50	9	mean	3.52	0.58	3.80	2.56	0.84	10606	139	420	1202	41	145
1: 2.25	14	mean	3.49	0.46	3.29	2.45	0.97	8267	131	390	1445	38	166
Contrasts	LSD (P= 0.05)		0.27	0.13	0.43	NS	0.14	2048	NS	NS	390	NS	21
4 vs 6 plants	mean difference		$-.30^{*}$	$+.20^{***}$	$-.30^{NS}$	$-.13^{NS}$	$+.01^{NS}$	-182^{NS}	$+37^{NS}$	-22^{NS}	$+59^{NS}$	-1^{NS}	-20^{NS}
4 vs 9 plants	mean difference		$+.11^{NS}$	$+.33^{***}$	$-.07^{NS}$	$-.32^{NS}$	$-.06^{NS}$	$+208^{NS}$	$+32^{NS}$	$+37^{NS}$	-30^{NS}	$+2^{NS}$	-41^{***}
4 vs 14 plants	mean difference		$+.13^{NS}$	$+.45^{***}$	$+.45^{*}$	$-.21^{NS}$	$-.18^{*}$	$+2546^{*}$	$+40^{*}$	$+67^{NS}$	-54^{*}	$+4^{NS}$	-62^{***}

$^{NS, *, **, ***}$ Nonsignificant or significant at the P = 0.05, 0.01, or 0.005 levels, respectively.

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 percentage of standing fish biomass as influenced by age and mean individual weight (19). 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* Kiltzing spp., Chiorophyta) which grew in the water and on the tank sides.

Irrigation water and sediment were drawn from the bottom of the fish tanks eight times daily between dawn and sunset and pumped to the biofilter surface at a rate of 500 L/m^2 of biofilter surface area per day. Water pH and elemental composition was continually monitored.

Tomato (*Lycopersicon esculentum* Mill.) seedlings were transplanted into each biofllter at 4 plants/m^2 in each of two studies resulting in 4, 6, 9, or 14 plants per biofilter with increasing BFV. Foliar tissue samples were taken at harvest of the first mature fruit. Plants infected with bacterial wilt were excluded from foliar tissue analysis. The fourth whole compound leaf from the growing tip was collected from each plant and collectively analyzed for each biofilter. Fruit samples were taken from trusses three and four and combined for analysis. All aerial plant tissue from two plants was collected for analysis at the termination of the crop. Plant tissue and fish food analysis were conducted using the following procedures: atomic absorption spectrophotometry for K, Ca, Mg, Fe, Mn, Zn, and Cu; vanadomolybdophosphoric yellow procedure (12) for P; a Kjeldahl procedure (2) using a salicylic acid modification was used for N; a curcumin method (9) for B; and a turbidametric procedure (11) for S. All analyses are reported on a dry weight (DW) basis.

Total above-ground DW in each plant portion was calculated from the respective fresh weight:DW ratio of representative tissue samples. Total plant mineral uptake was calculated from aerial whole plant and fruit DW, multiplied by the respective elemental concentrations in the assayed tissues. The percentage of elemental inputs assimilated by the plants was calculated from the above plant uptake (x100) divided by the summation of the respective elemental concentrations of each input, except those present in the water, multiplied by the respective input mass.

A randomized complete-block design with four replicates was used. Analyses were performed for factorial experiments with Statview^{TM} 512+.

1988 Experiment: Fish were stocked on 5 May 1988 and harvested on 23 August 1988. Tomato ('Laura') was transplanted 13 May 1988. This indeterminate greenhouse variety was trained to a single-stem and harvested through the fourth truss. A cucumber crop was grown prior to Experiment 2, but results are not reported here.

1989 Experiment: Fish were restocked 5 January and harvested on 27 May 1989. 'Kewalo' was planted 5 January, 1989. This semideterminate, bacterial wilt-resistant variety was trained to a single-stem and harvested through the eighth truss.

RESULTS

1988 Experiment: All leaf nutrient concentrations ('Laura') were above normal sufficiency levels except Ca. No differences in leaf nutrient concentrations occurred between treatments except for B (Table 1a). Boron concentrations were different at P = 0.01 and were positively correlated to level of boric acid amendment of the medium. There were no visual deficiency or toxicity symptoms, although concentrations of Fe, Mn, Zn, and Cu were each approximately five times normal recommendations. Concentrations of all mineral elements assayed in the 'Laura' fruit tissue differed between treatments, but we could not identify a pattern related to treatment (Table 1b). Aerial whole plant concentrations of P and K decreased with increasing BFV (Table 1c). Generally, K, S, and Fe concentrations decreased with increasing BFV while N, Mg and Zn concentrations generally increased with BFV. Boron concentration increased with BFV and was directly correlated to treatment amendment level.

Minerals assimilated by all plants collectively in each biofilter increased with BFV (Table 2a). The percentage of total inputs assimilated by the plants also increased with BFV (Table 2b).

1989 Experiment: The P, K, S, Cu, and B concentrations in 'Kewalo' tomato leaves generally decreased with increasing BFV (Table 3a). In general, Mg concentration in leaves increased with BFV. Levels of each element except N and K were found to be above sufficient levels. Nitrogen concentration was low in all treatments, but showed no significant treatment effect. Potassium concentration was above sufficiency levels in the 1:0.67 and 1:1.00 v/v ratios and below sufficiency, but above deficiency levels in the 1:1.5 and 1:2.25 v/v ratios. No visible nutrient deficiency symptoms were seen. There was no visual evidence of toxicity symptoms, although concentrations of Fe, Cu, and B were each

Table 2. Nutrient assimilation and percent of nutrient input assimilated per plot by 'Laura' tomato as influenced by tank to biofilter ratio.

Biofilter Ratio (v/v)	Plants per plot		N (g)	P (g)	K (g)	Ca (g)	Mg (g)	S (g)	Fe (g)	Mn (g)	Zn (g)	Cu (g)	B (g)
a) Nutrient assimilation													
1: 0.67	4	mean	23.6	3.8	20.0	1.3	1.1	8.1	0.15	0.32	0.62	0.04	0.08
1: 1.00	6	mean	43.3	5.8	33.6	2.1	2.1	13.1	0.21	0.53	0.94	0.06	0.20
1: 1.50	9	mean	54.4	6.2	38.8	2.0	2.1	13.1	0.23	0.48	1.33	0.06	0.19
1: 2.25	14	mean	71.4	10.1	55.8	5.0	4.2	15.1	0.34	0.62	2.00	0.09	0.29
Contrasts	LSD (P= 0.05)		10.8	1.5	8.3	0.6	0.5	3.7	0.07	0.20	0.34	0.02	0.06
4 vs 6 plants	mean difference		-19.7***	-1.9*	-13.6***	-0.7*	-1.0***	-5.0*	-0.1^{NS}	-0.2*	-0.3^{NS}	-0.03*	-0.1***
4 vs 9 plants	mean difference		-30.9***	-2.4***	-18.8***	-0.7*	-1.0***	-5.0*	-0.1*	-0.2^{NS}	-0.7***	-0.03*	-0.1***
4 vs 14 plants	mean difference		-47.9***	-6.3***	-35.8***	-3.7***	-3.1***	-6.9**	-0.2***	-0.3**	-1.4***	0.05***	-0.2***
b) Percent nutrient input assimilated			(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
1: 0.67	4	mean	2.9	4.9	11.2	1.1	2.1	38.8	2.3	13.5	30.1	8.9	3.8
1: 1.00	6	mean	5.2	6.9	18.2	1.6	3.8	54.0	3.0	21.6	44.6	15.2	6.8
1: 1.50	9	mean	6.5	7.1	21.1	1.6	3.9	54.0	3.3	19.5	63.6	15.0	4.4
1: 2.25	14	mean	8.5	10.5	30.3	4.0	7.6	62.1	4.9	25.5	95.4	20.2	4.7
Contrasts	LSD (P= 0.05)		1.3	1.7	4.5	0.5	1.0	15.2	1.0	8.1	16.3	4.1	1.5
4 vs 6 plants	mean difference		-2.3***	-2.0*	-6.9**	-0.6*	-1.7***	-15.1^{NS}	-0.7^{NS}	-8.1^{NS}	-13.9^{NS}	-6.3**	-3.0***
4 vs 9 plants	mean difference		-3.6***	-2.1*	-9.9***	-0.5*	-1.8***	-15.1^{NS}	-1.0^{NS}	-6.0^{NS}	-32.8***	-6.1**	-0.6^{NS}
4 vs 14 plants	mean difference		-5.6***	-5.6***	-19.1***	-2.9***	-5.6***	-23.3**	-2.6***	-12.0**	-64.6***	-11.2***	-0.9^{NS}

$^{NS, *, **, ***}$ Nonsignificant or significant at the P= 0.05, 0.01, or 0.005 levels, respectively.

approximately four times, Mn two to three times, and Zn seven to ten times recommended sufficiency levels.

'Kewalo' fruit K and S concentrations generally decreased with increasing BFV (Table 3b). Fruit Zn concentration increased with BFV, while B concentration was highest in the intermediate treatment ratios.

Aerial whole plant Mg and Zn concentrations generally increased with BFV, while P, K and B concentrations decreased with increasing BFV (Table 3c). Generally, Cu concentrations decreased with increasing BFV.

Uptake by the plants of all nutrients except K and Fe increased with BFV (Table 4a). The percentage of total inputs assimilated by the plants also increased with BFV (Table 4b).

DISCUSSION

Plant growth was adequately maintained on minimal N, P, and K nutrient levels. This was probably due to the constant replenishment by recirculated aquacultural water (16,23). The proportional balance of N, P, and K in the aquaculture waste was adequate for tomato nutrition. A slight increase in fish biomass and/or feed input rate in the 1989 experiment may have raised all leaf tissue N concentrations. Tomatoes may have also assimilated N in organic amino acid forms. Ghosh and Burns (8) found that tomatoes utilized alanine, glutamic acid, histidine, and leucine as effectively as inorganic N sources.

The growth of plants, their cation-anion balance, proton balance and composition of metabolic products are greatly influenced by the form of N absorbed (5). Much of the ammoniacal-N in the aquaculture water was not oxidized prior to irrigation of the biofilter, as in other integrated systems, and was available for tomato assimilation. Acceptable fruit yields were partially attributed to plant availability of both NH_4^+ and NO_3^- ions, a condition which produces the greatest growth and protein production in most plants (6,10). Highest N uptake rates were observed by Blondel and Blanc (4) when both N forms, NH_4^+-N and NO_3^--N, were present in the nutrient solution. Plant availability of NH_4^+-N at low concentrations, as in this system, may have stimulated NO_3^- reduction, and thereby benefited plant growth and yield (13).

Because the reduction of NO_3^- to NH_3 in the plant requires energy, it may be supposed that with uptake of NH_4^+ energy is conserved and diverted to other metabolic processes including ion uptake and growth. High plant tissue concentrations of cations was attributed to the dominant NO_3^--N nutrition which

Table 3. Nutrient concentration of leaves, fruit and aerial whole plant of 'Kewalo' tomato as influenced by tank to biofilter ratio.

Biofilter Ratio (v/v)	Plants per plot		N	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B
			Dry Wt. (%)					Dry Wt. ($\mu g \cdot g^{-1}$)					
a) Leaf tissue													
1: 0.67	4	mean	3.23	0.59	3.80	3.99	0.88	9887	265	55	197	26	79
1: 1.00	6	mean	3.24	0.44	3.27	3.99	0.83	10375	165	67	209	27	76
1: 1.50	9	mean	3.42	0.33	2.00	3.47	1.08	8470	206	46	141	18	61
1: 2.25	14	mean	3.41	0.36	1.44	3.42	1.39	6076	221	41	183	19	57
Contrasts	LSD (P= 0.05)		NS	0.07	1.00	NS	0.37	2940	67	NS	NS	9	12
4 vs 6 plants	mean difference		-.02^{NS}	+.15***	+0.5^{NS}	+.00^{NS}	+.06^{NS}	-488^{NS}	+100**	-13^{NS}	-12^{NS}	-1^{NS}	+3^{NS}
4 vs 9 plants	mean difference		-.20^{NS}	+.26***	+1.8***	+.52^{NS}	-.20^{NS}	+1418^{NS}	+59^{NS}	+10^{NS}	+56^{NS}	+8^{NS}	+18**
4 vs 14 plants	mean difference		-.18^{NS}	+.23***	+2.4***	+.57^{NS}	-.51*	+3811*	+44^{NS}	+15^{NS}	+14^{NS}	+7^{NS}	+22***
b) Fruit tissue													
1: 0.67	4	mean	2.77	0.64	4.65	0.31	0.19	2189	268	14	54	9	65
1: 1.00	6	mean	3.19	0.68	4.80	0.30	0.20	2238	1147	21	51	12	88
1: 1.50	9	mean	2.94	0.66	4.70	0.31	0.23	2082	613	17	64	12	85
1: 2.25	14	mean	2.84	0.51	3.47	0.29	0.22	1635	384	14	66	12	68
Contrasts	LSD (P= 0.05)		NS	NS	0.66	NS	NS	317	NS	NS	20	NS	19
4 vs 6 plants	mean difference		-.42^{NS}	-.05^{NS}	-.15^{NS}	+.01^{NS}	-.01^{NS}	-20^{NS}	-978^{NS}	-8^{NS}	+3^{NS}	-3^{NS}	-24*
4 vs 9 plants	mean difference		-.17^{NS}	-.02^{NS}	-.04^{NS}	-.00^{NS}	-.04^{NS}	+107^{NS}	-344^{NS}	-4^{NS}	-11^{NS}	-4^{NS}	-19^{NS}
4 vs 14 plants	mean difference		-.07^{NS}	+.13^{NS}	+1.2***	+.02^{NS}	-.03^{NS}	+554***	-116^{NS}	-1^{NS}	-12^{NS}	-0^{NS}	-3^{NS}
c) Aerial whole plant tissue													
1: 0.67	4	mean	2.87	0.86	4.24	4.17	0.98	10908	462	69	451	32	86
1: 1.00	6	mean	3.12	0.82	4.51	4.50	0.95	12564	398	92	419	38	89
1: 1.50	9	mean	3.07	0.68	3.99	3.83	1.24	9570	308	67	502	27	60
1: 2.25	14	mean	2.91	0.61	2.59	3.62	1.66	9139	282	44	645	25	64
Contrasts	LSD (P= 0.05)		NS	0.22	1.38	NS	0.26	NS	NS	23	140	10	20
4 vs 6 plants	mean difference		-.26^{NS}	+.04^{NS}	-.27^{NS}	-.33^{NS}	+.03^{NS}	-1656^{NS}	+64^{NS}	-22^{NS}	+32^{NS}	- 6^{NS}	- 4^{NS}
4 vs 9 plants	mean difference		-.20^{NS}	+.18^{NS}	+.25^{NS}	+.34^{NS}	-.26^{NS}	+1339^{NS}	+154^{NS}	+3^{NS}	- 51^{NS}	+6^{NS}	+26*
4 vs 14 plants	mean difference		-.05^{NS}	+.25*	+1.7*	+.54^{NS}	-.69***	+1770^{NS}	+181^{NS}	+25*	-194*	+7^{NS}	+22*

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

Table 4. Nutrient assimilation and percent of nutrient input assimilated per plot by 'Kewalo' tomato as influenced by tank to biofilter ratio.

Biofilter Ratio (v/v)	Plants per plot		N (g)	P (g)	K (g)	Ca (g)	Mg (g)	S (g)	Fe (g)	Mn (g)	Zn (g)	Cu (g)	B (g)
a) Nutrient assimilation													
1: 0.67	4	mean	72.5	19.5	111.7	64.9	16.4	18.5	0.99	0.11	0.72	0.06	0.20
1: 1.00	6	mean	99.5	23.5	146.3	88.8	21.0	26.2	2.01	0.20	0.89	0.09	0.28
1: 1.50	9	mean	122.4	27.3	170.2	105.2	36.0	28.1	1.66	0.20	1.41	0.09	0.27
1: 2.25	14	mean	151.7	29.7	145.5	138.1	64.3	35.5	1.69	0.18	2.54	0.11	0.34
Contrasts	LSD (P= 0.05)		32.9	5.3	NS	36.0	12.6	8.8	NS	0.06	0.91	0.03	0.08
4 vs 6 plants	mean difference		-27.0^{NS}	-4.0	-34.6^{NS}	-23.9^{NS}	-4.6	-7.7^{NS}	-1.02^{NS}	-0.09**	-0.17^{NS}	-0.03*	-0.08*
4 vs 9 plants	mean difference		-50.0**	-7.8**	-58.5*	-40.3*	-19.6**	-9.6*	-0.67^{NS}	-0.08*	-0.69^{NS}	-0.03*	-0.08^{NS}
4 vs 14 plants	mean difference		-79.3***	-10.2***	-33.8^{NS}	-73.2***	-47.8***	-17.0***	-0.70^{NS}	-0.07*	-1.82***	-0.05***	-0.14***
b) Percent nutrient input assimilated			(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
1: 0.67	4	mean	22.0	31.2	131.1	23.0	82.7	162.8	69.5	30.7	155.5	66.4	126.5
1: 1.00	6	mean	30.1	37.6	171.7	27.4	105.7	230.7	141.0	54.9	192.1	102.4	178.6
1: 1.50	9	mean	37.1	43.7	200.0	41.9	181.2	246.9	116.0	53.2	305.7	102.0	175.5
1: 2.25	14	mean	46.0	47.5	170.8	106.5	323.2	312.2	118.4	49.0	550.6	125.4	215.7
Contrasts	LSD (P= 0.05)		10.0	8.4	NS	22.3	63.5	77.2	NS	16.5	197.0	34.3	50.8
4 vs 6 plants	mean difference		-8.2^{NS}	-6.4^{NS}	-40.6^{NS}	-4.4^{NS}	-23.0^{NS}	-67.9^{NS}	-71.6^{NS}	-24.2**	-36.6^{NS}	-36.0*	-52.1*
4 vs 9 plants	mean difference		-15.1**	-12.5**	-68.6*	-18.9^{NS}	-98.5**	-84.2*	-46.6^{NS}	-22.4*	-150.3^{NS}	-35.6*	-49.0^{NS}
4 vs 14 plants	mean difference		-24.0***	-16.3***	-39.7^{NS}	-83.6***	-240.5***	-149.5***	-49.0^{NS}	-18.3*	-395.1***	-59.0***	-89.2***

$^{NS, *, **, ***}$ Nonsignificant or significant at the P= 0.05, 0.01, or 0.005 levels, respectively.

stimulated uptake and translocation of cations as counter-ions (3). Following the reduction of NO_3^- in the plant, organic anions accumulate to balance the cation charge originally accompanying the NO_3^- ions (7).

Under high fish growth (feed) rates, N, P, K, and Mg availability were not limiting in any treatment. Irrespective of fruit yield, metabolic by-products from each kilogram increase in fish biomass provided adequate nutrition for two tomato plants for a period of three months. Under reduced feed rates applied to mature fish, we found that if we grew more than one plant per kilogram of standing fish biomass, or the increase in fish biomass was less than 0.43 kg per plant then K became limiting. We concur with Rakocy (21) that optimum ratios between feed input rate, standing fish biomass, system water volume, and biofilter volume needs to be established for various combinations of fish and vegetable species.

The fish feed formulation employed in these studies appears to be relatively low in Ca if residual quantities are required to support plant growth. Amendment of the biofilter medium with $CaMg(CO_3)_2$ was ineffective in supplying Ca to the immediate crop. Subsequent application, as in Experiment 2, of CaO was made primarily to maintain the water above pH 5.5, and tissue Ca concentrations reflected this input. Available Mg levels in the fish wastes were adequately proportioned with respect to N, P, and K. Available S levels in fish wastes were high relative to N, P, and K. This suggests that the fish feed S concentration might be reduced from 1600 ppm to less than 800 ppm without detrimental effect on either fish or tomato production.

Concentrations of Fe, Mn, Zn, and Cu were high in all plant tissues but no toxicity symptoms were seen. A contributing factor to excess uptake of these elements, in addition to high availability levels, might be attributed to NO_3^- nutrition which stimulates organic anion synthesis and hence cation accumulation (5,7). Kirkby and Knight (14) showed that when the cation level of a nutrient solution is maintained, plant tissue concentrations of cations and organic anions increase dramatically in response to NO_3^- nutrition. Concentrations of Fe, Mn, Zn, and Cu in the whole plant tissues were significantly higher than in the associated leaf or fruit tissues. This suggests that these metals were primarily incorporated into stem tissue. Tissue levels of Fe and Cu per kilogram feed input were not found to be substantially different between Experiment 1 and 2. This suggests that plant assimilation rates paralleled feed input rates less fish assimilation. Leaf tissue and whole plant Zn concentrations were very high in

Experiment 1, and even greater in Experiment 2. This suggests that Zn was disproportionately high in the fish feed, and that the plants were not capable of extracting Zn at a rate approaching the residual from the feed input less fish assimilation regardless of BFV. Fish feed Zn concentration may be reduced from 65 ppm to approximately 10 ppm without detriment to the fish or plants.

Mineral uptake by the plants in Experiment 2 in excess of input quantities were found for K, Ca, Mg, S, Fe, Zn, Cu, and B (Table 4b). This was attributed to the availability of residual nutrient from previous experiments when nutrient residues remained in the soil. They included fish feed, dolomitic lime, and the root masses of prior crops. Based on tomato nutrient assimilation rates, it would seem appropriate to modify fish feed composition as follows without adversely affecting plant growth: N increased by 5 to 10%; P reduced by 50%; K reduced by 30 to 50%; Ca increased by 200 to 300%; Mg, and B unchanged; S reduced by 50%; Fe, Mn, and Cu reduced to 25%; and Zn reduced to 15% of feed concentrations used in this study.

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