Mineral Content and Yield of Bush Bean, Cucumber, and Tomato Cultivated in Sand and Irrigated with Recirculating Aquaculture Water.

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Additional index words. *Cucumis sativus* L. cv. Burpee Hybrid II, *Lycopersicon esculentum* Mill. cv. Champion, *Oreochromis aureus* L., *Phaseolus vulgaris* L. cv. Blue Lake 274, biofiltration, hydroponics, integrated agriculture, sand culture.

Abstract. Fish production and biofiltration provided by sand-cultured vegetable crops were linked in a closed system of recirculating water. Performance was evaluated in terms of water quality, vegetative and fruit production, fish growth, and mineral accumulation in the sand filter. Blue tilapia (*Oreochromis aureus* L.) were stocked at 813 mixed-sex fingerlings totaling 37.8 kg in a tank with a mean volume of 22500 l., an initial density of 36 fish m^{-3} . The fish were fed a commercial chow with an analysis of not less than 32% crude protein. The cultivated vegetable species were: bush bean (*Phaseolus vulgaris* L. cv. Blue Lake 274), cucumber (*Cucumis sativus* L. cv. Burpee Hybrid II), and tomato (*Lycopersicon esculentum* Mill. cv. Champion). All crops were grown in a glass greenhouse without shading or screening in Raleigh, NC during summer 1986. The aqua-integrated crops were irrigated with water drawn from the bottom of the tilapia cultivation tank and pumped to the sand/vegetable beds for 30 minutes every three hours between dawn and sunset. Drainage from the 0.5 m deep sand beds was returned to the fish tank. The fish tank volume to aqua-integrated crop area ratio was 225 l. m^{-2}. The initial fish biomass to plant growing area ratio was 0.38 kg m^{-2} ; the final ratio of fish biomass (+86 days) to plant growing area was 1.44 kg m^{-2} . Each crop was cultivated in a medium of sandy loam soil amended with composted horse manure as a "control". The aqua-integrated crops developed rapidly and exhibited significant fruit production despite heat and pathological stress. Fish food totaling 139 kg produced an increase of 106.38 kg fish (plus progeny) and 231.23 kg (edible portion) of fresh vegetables. Fish metabolites, uneaten feed, and dead algae served as nutrient sources for vegetable production. Biological filtration, aeration, mineral assimilation by the vegetable crops, and the addition of make-up water served to maintain the water quality within limits for cultivation of tilapia. Integrated cultivation of fish, biological filtration, and hydroponically grown vegetables increases the economic potential of the food crops. This co-production concept appears particularly suited to regions with sandy soils, low or poorly distributed rainfall, and/or inadequate per capita nutrition levels.

Received for publication; HortScience, 22: ; North Carolina Agricultural Research Service, Number 11019. The authors gratefully acknowledge the assistance of R. L. Noble, B. Noon, R. P. Patterson, S. Pulver, J. Riddle, and R. Tucker for their help on the project. Mention of a trademark, proprietary product, or vendor does not imply its approval to the exclusion of other products or vendors that may also be suitable. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

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A successful integration of fish culture, biological filtration, and hydroponic vegetable cultivation could greatly increase the economic production of these foods. Benefits of integrating aquaculture and olericulture in a controlled environment are; 1) conservation of soils, water resources, and plant nutrients in areas where these are limiting, 2) availability of high-quality food products in close proximity to centers of need or population, and 3) intensive, symbiotic co-production permits reduced operating costs relative to either cropping system in isolation. Operation of such a symbiotic system would be applicable in arid, semi-arid, and tropical regions where fish and fresh vegetables are in high demand (11, 23, 29, 31, 32). Near urban areas, and particularly during winter in temperate regions, fresh 'organically' grown vegetables can expect premium prices. Markets for fresh fish abound in landlocked regions and overfished coastal areas through the world (6, 9, 23, 29).

Recirculating aquacultural water has demonstrated considerable potential for hydroponic cultivation of higher plants (2, 6, 9, 16, 22, 23, 31). A literature search has not revealed a prior combined use of sand and higher plants as a filtration medium. Dissolved and suspended organic materials accumulate rapidly in aquaculture systems and must be removed for efficient fish production (23). Through water purification and reuse, recirculating systems consume less than 10% of the water utilized in pond culture of fish to produce equivalent yields (28, 29). Even in filtered, recirculatory fish culture systems, nitrates and phosphates accumulate (3, 31). Hydroponic vegetable production has been demonstrated as a means of controlling nitrate concentrations in recirculating fish culture systems (2, 16, 22, 23, 29, 31); thereby, eliminating the need for a microbial denitrification unit. Nutrient-loaded aquacultural water eliminates the expense of inorganic fertilizers by recycling fish metabolites and dead algae into plant food production.

The purpose of this research was to assess the relationships and yield potential of integrating recirculatory aquaculture and sand-based hydroponic vegetable horticulture as a food production system. Our goal was to assess the effectiveness of a sand medium to provide mechanical water filtration and support microbial nitrification to maintain water quality conditions suitable for intensive fish culture while simultaneously maintaining substrate conditions beneficial to root growth and mineral assimilation. We specifically examined the botanical availability and proportional balance of nutrients in fish feces and urine, nutrient loading in the media and water quality variables important to fish health.

Blue tilapia (*Oreochromis aureus* L.; family *Cichlidae*), a river fish originally from West Africa, are grown worldwide for human consumption, and there has accrued substantial international experimentation with the species (3, 11, 19, 27).. Tilapia are easily cultured, grow rapidly, and have a high market value potential in the US (30). The hardiness of this species all but assures the success of novice fish culturalists (3, 31).

Blue tilapia were cultivated in a tank with a mean volume of 22500 liters (Fig. 1). The stocking of 813 mixed-sex fingerlings totaling 37.8 kg provided a density of 36 fish per cubic meter. The fish were fed Purina Fish Chow 7140, which had an analysis of not less than 32% crude protein, not less than 3.5% crude fat, and not more than 7.0% crude fiber. Table 1 presents the mineral content of the feed input. The daily ration was divided equally into two feedings administered at 0800 and 1700 hours. An initial feeding rate of 3% of total fish biomass per day was reduced when feed remained uneaten for longer than 15 minutes (25). Fish food input was gradually reduced to about 1% of fish biomass per day by the end of the 86-day feeding regime. Total feed input to the system was 139.0 kg. The fish also grazed on algae.

The cultivated vegetable crops included bush bean (*Phaseolus vulgaris* L. cv. Blue Lake 274), cucumber (*Cucumis sativus* L. cv. Burpee Hybrid II), and tomato (*Lycopersicon esculentum* Mill. cv. Champion). These crops were grown in a glass greenhouse without shading or insect screening (due to lack of funding) in Raleigh, NC during summer 1986. The total aqua-integrated cultivation area was 100 m^2, and the medium volume was 200 m^3 (the crop species discussed occupied 38 m^2, volume 64 m^3, and other crop species occupied the remaining space).

Figure 1 provides a schematic view of the aquaculture-olericulture integration. The medium in the aqua-integrated plots was a builder's grade sand with a composition of 98.3% quartz sand and 1.7% silt. No additional nutrient amendments were added to the aqua-integrated plots. The sand beds were 1.5 m wide x 7.5

m long x 0.5 m deep, sloped 1:200 along their length, and lined with 0.15 mm (6 mil.) polyethylene plastic to capture drainage for return to the fish tank. Each sand bed was cultivated as five 2.25 m^2 plots.

Control treatment media consisted of a sandy loam soil amended with composted horse manure at a ratio of 5 parts soil : 1 part manure (v/v). The control-plots were mulched with straw and watered as needed. Bush bean and cucumber were grown in 5 aqua-integrated plots and one control plot of 2.25 m^2. The tomato (an indeterminate variety) was cultivated double-stem in 10 aqua-integrated plots and 2 control plots. Tomatos and beans were grown at 3 densities to assist determination of spatial variables in yield optimization. Bush beans were grown at 12.5, 16.7, and 20.0 plants m^{-2}. The tomatos were grown at 1.8, 2.6, and 4.0 plants m^{-2}. Cucumbers were cultivated at a density of 6.7 plants m^{-2}.

Irrigation water was drawn from the bottom of the tilapia cultivation tank every 3 hours between dawn and sunset and pumped to the sand/vegetable beds. Saturation of the sand-bed was achieved in about 5 minutes, and pumping continued at a rate to maintain saturation for 30 minutes. Drainage from the 0.5 m deep sand beds was returned to the fish tank. The return discharged at 0.5 m above the tank water level, providing cascade aeration. Bed drainage continued to return to the aquaculture tank on a declining volume basis for about 15 minutes after the termination of each pump cycle.

The fish tank volume to growing area ratio was 225 l m^{-2}, and the initial fish biomass to plant growing area ratio was 0.38 kg m^{-2}. The final ratio of fish biomass (+86 days) to plant growing area was 1.44 kg m^{-2}.

Dissolved oxygen was determined by a YSI Model 54 oxygen meter. Levels of nitrogenous compounds in the fish tank were monitored daily with a Hach kit. Methyl orange alkalinity was determined by titration.

Samples of the medium were taken at harvest of first mature fruit. A total of 27 samples were taken per 2.25 m^2 plot, equally representing the 0-160 mm,160-320 mm, and 320-480 mm profiles (Fig. 2). Nine sets of profile samples were taken per plot; 3 sets each taken at 50 mm, 175, and 300 mm from the irrigation furrow axis.

All water and medium samples were analyzed by the Agronomic Division of the North Carolina Department of Agriculture using a modified Kjeldahl procedure (5) for N concentration in the water, an ammonium molybdate-ascorbic acid colorimetric analysis for P, and a buffered ammonium chloride colorimetric analysis for S. Determination of Ca, Mg, Fe, Mn, Zn, and Cu was made by atomic absorption spectrophotometry and K by flame emission. For analysis of medium samples; P, K, Ca, Mg, Mn, Zn, and Cu was determined using the Mehlich 3 extractant and procedure (20, 21), and buffered ammonium chloride colorimetric method was used for S.

Foliar samples were taken at harvest of the first mature fruit. The petiole and lamina of the 4th leaf from the growing tip were collected from each plant and collectively analyzed for each respective plot. Plant tissue and fish food analysis was conducted using atomic absorption spectrophotometry for K, Ca, Mg, Fe, Mn, Zn, and Cu, vanadomolybdophosphoric yellow procedure (14) for P, Kjeldahl procedure (4) using a salicylic acid modification was used for N, a curcumin method (7) for B, and a turbidanetric procedure (12) for S.

Survival of the initial fish stocking was 99.3%, with losses limited to fish jumping out of the rearing tank. The fish biomass increased from 37.08 kg at stocking to 106.38 kg by the end of the 86-day feeding regime; an annualized weight gain of 792%. The feed conversion ratio was 1 : 1.31 (76.3% of feed converted into fish biomass). The final mean individual weight (not including progeny) was 180 g. The annualized increase in fish biomass was 20.1 kg m^{-3} (mixed sex and age). All-male cultivation could increase the yield rate 3-4 fold. Females use substantial energy resources to produce offspring, which limits their weight gain. At more intensive stocking densities (7-10 kg m^{-3} or 4-6 fold those used in this study), production could increase well above 120 kg m^{-3} yr^{-1} (3, 10). In addition to the weight gain of the stocked individuals, reproduction occurred. Collected progeny were about 60 individuals in the 5 to 62 gram range (total 350 g) and over 1000 below 1 gram each.

All water quality variables were maintained within acceptable levels by circulation through the sand beds except the dissolved oxygen levels, which were low relative to excellent fish growth requirements. The range and means of the most important aquatic environmental factors are given in Table 2. An analysis of the well water (for the initial charge and make-up of evapotranspiration) and the irrigation water (irrigation water analysis does not include suspended materials) is given in Table 3. Nitrogenous compounds, which frequently limit the production of fish in systems which recirculate water (16), never reached toxic levels and were apparently extracted by the plants (22).

Table 4 presents yield of edible portion and yield rates for bush bean, cucumber, and tomato from both aqua-integrated and control treatments. All crops developed rapidly and yielded substantially despite heat stress. Some of the heat stress could have been reduced through the use of shade fabric and/or an evaporative cooling system. The development of bacterial wilt (*Pseudomonas solanacearum*) in the aqua-integrated tomato plants also restricted growth.

Although the bush bean harvest was made before full maturity because of time constraints, the control plot yield for this planting was 75% of the US field average for a full crop (18). The mean aqua-integrated yield was 243% the US field average. The median density bush bean plots produced the highest yields per unit area.

Cucumber yield was 0.85 kg m^{-2} wk^{-1} in the control plot and averaged 2.04 kg m^{-2} wk^{-1} in the aqua-integrated plots during the 3.6 week period of fruit harvest. Commercial greenhouse operations in the tropics may cultivate 4 crops per year, harvesting each for 6.5 weeks (26) or 26 harvest-weeks per year. Based on this regime, the aqua-integrated cucumber yield would be 291% (control =121%), a typical commercial yield.

Tomato control plot yield averaged 1.84 kg m^{-2} wk^{-1} for the 3.3 week period of fruit harvest. Aqua-integrated plots averaged 1.38 kg m^{-2} wk^{-1} despite the bacterial wilt. The high-density tomato plots averaged 2.09 kg m^{-2} wk^{-1}, and the best plot yield was 10.51 kg m^{-2} wk^{-1}. Pruned indeterminate tomato varieties tend to yield at a linear rate over 14-16 weeks (13). Operators of commercial greenhouses in tropical regions may cultivate 2 crops per year, harvesting each for 16 weeks or 32 harvest-weeks per year. Assuming a linear yield rate, the mean aqua-integrated tomato yield was 206% of the average commercial grower in North Carolina (26). Based on 30% of a 16-week harvest realized in the first 3.3 weeks (time period before the disease onset), the mean aqua-integrated yield rate equates to 30.5 kg m^{-2} wk^{-1} or 143% of commercial growers.

The control medium was found to have a significantly higher initial mineral content than did the sand. Analysis of the control medium before amendment and of the sand before irrigation is given in Table 5. The mean mineral composition of all samples taken in either medium was not found to have changed substantially over the course of the cropping period. However, nutrient levels in the 0-160 mm profile within 50 mm of the irrigation furrow did show a substantial increase. Fig. 2 presents the mean values of P, K, Mn, and CEC by sampling region. P, K, and Mn concentrations were greatest nearest the furrow and at the surface. CEC changes tended to be greatest near furrows because of accumulation of organic matter on the surface. Mean nutrient levels and standard deviations of all aqua-integrated samples at date of tissue sampling and the mean of samples adjacent to the furrows are given in Table 6. In general the concentrations of P, K, Ca, Mg, Mn, Zn, and Cu were less in the aqua-integrated plots than in the control soil. Also, P, K, Mn, Zn, and Cu concentrations in the aqua-integrated medium were greater close to the irrigation furrow than the medium as a whole.

Plant growth was adequately maintained on minimal nutrient levels (Table 3) due to the constant replenishment characteristic of a system based on recirculated water (16). Mineral composition of foliar tissue is presented in Table 7, and includes sufficiency and deficiency level standards (North Carolina Department of Agriculture), control plot levels, and aqua-integrated mean levels and standard deviations. The "deficiency" levels represent a composition at which visually detectable symptoms are known to exist. The "sufficiency" level cited is the lower limit of the known sufficiency range. Minimum critical levels (MCL) have not been determined for these cultivars. Of the mineral elements essential for proper nutrition of higher plants, all levels except those discussed below, were found to be assimilated above sufficiency recommendations. The following nutrient levels were below sufficiency standards but above deficiency levels; 1) N in all the crop species, 2) S in the bush bean foliage, 3) K in the cucumber foliar tissue, 4) and P, K, Ca, and Mg in the tomato crop. Additionally, in the tomato crop, B and S levels were below and at deficiency level respectively.

None of the crops had tissue mineral contents below the MCL because there were no visual symptoms and the yields were very good. A moderate increase in the fish biomass to growing area ratio might raise the mineral levels such that all are within the recommended "sufficiency" range. The lower levels might also be mitigated by planting in previously charged beds (nutrient and microbes) rather than "virgin" sand or by amendment of the medium and/or by foliar application of the isolated (crop-specific) element(s).

The bacterial pathogen *P. solanacearum* was unintentionally introduced to the crop. The medium was not sterilized before planting because this innoculant was not encountered in preliminary work. We think that tomato yields were substantially reduced as a result of this infection. However, the 67% later (least) affected aqua-integrated tomato plants yielded 94.7% that of the unaffected "control" plants.

This study afforded an opportunity to assess the effects of heat stress on the crop yield. Problems were encountered only when a 40-year record, two-week heatwave (1) enveloped the Raleigh, NC are and full-shade air temperature exceeded 40°C daily. With high insolation levels and air temperature, leaf temperatures were certainly well above optimum. Visually apparent stress symptoms were limited mainly to the tomato crop. Morphological deformities of the floral parts in the tomato crop (17) coincided with the hottest period (about 2 weeks after initial fruit set) with a resultant decline in fruit set within both treatment groups. Prior to the heatwave, the aqua-integrated plants set 3 to 4 times more fruit than the control.

Because the tomato plants in the control plots were not exposed to the bacterial wilt, they were able to rebound as temperature moderated. The aqua-integrated plants, weakened by both extreme temperature and disease, generally continued to decline in growth rate and in vigor relative to the non-wilt affected control plants although they generally continued to develop fruit that had set before the heatwave. The most severely wilted plants ceased to develop new growth while a third responded to moderating temperatures with renewed flowering and fruit set, although this also was with reduced vigor.

Makeup water requirements (due to evaporation, transpiration and leakage) were fulfilled with well water and averaged about 7.0% of the system volume per day. The pH remained below 7.0 such that virtually all of the ammonia remained in ionized form (non-toxic to fish), and plant assimilation of nitrogenous compounds maintained nitrite concentrations below tolerance limits ($D_{50} = 2.1$ mg l^{-1}) for tilapia (3, 31).

In other fish rearing systems, periodic additions of a base are necessary to stabilize pH because the nitrification process is acidifying; the oxidation of 1 mg NH_3-N counteracts 7.14 mg of alkalinity (8, 15, 23, 29, 30). Alkaline amendment was not necessary in this system because of two factors: a) nitrification took place in the sand beds where organic matter accumulated to provide buffering capacity, and b) N was provided in both ammonical and nitrate form.

Ammonical-N and nitrite in the fish excrement is rapidly converted to nitrate by microbes and the nitrate ions are absorbed by the root cells and exchanged for hydroxide ions (or bicarbonate ions produced during respiration). Availability of both ammonium and nitrate ions reduces the tendency of the nutrient solution to undergo a change in pH during plant growth. Ammonium ions react with hydroxide ions released during anion adsorption to form ammonium hydroxide, which provides a large buffer due to weak ionization (24).

Reciprocating biofilters offer the advantages of uniform distribution of nutrient-laden water within the filtration medium during the flood cycle and improved aeration through complete atmosphere exchange with every dewatering (16, 23, 25, 29). These advantages benefit both nitrifying bacteria and plant roots. (16, 25, 29). Uniform crop development and generally satisfactory performance of this system can be attributed in part to the reciprocating water movement, which ensured even distribution of nutrients and O_2 to all plants by drawing atmospheric O_2 through the medium during every drainage period. Consistent and balanced nutrient availability and exchange of medium atmosphere during every irrigation cycle may account for greater aqua-integrated yield over control plot yield and over typical US yield. This combination of food-production systems offers an opportunity to produce exceptional yields of both vegetables and fish with a reduction of direct production costs relative to present stand-alone systems.

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(Page 2)

Table 1. Mineral analysis of Purina Fish Chow #7140.

Fish Food Composition	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	S	B
	%	ppm	%	%	%	ppm	ppm	ppm	ppm	ppm	ppm
Purina 7140	5.08	6542	1.51	1.03	0.26	449	147	136	27	1866	35

(Page 6)

Table 2. Summary of aquacultural water quality.

PARAMETER	UNITS	MEAN	RANGE
Temperature	°C	26.9	23.0 - 31.0
[Hydrogen-ion]	pH	6.5	6.3 - 6.9
Nitrite (NO2-N)	mg l-1	0.1	0.01 - 0.5
NH3+NH4+-N	mg l-1	0.9	0.5 - 1.5
Dissolved Oxygen	ppm	2.7	0.9 - 7.5
Total alkalinity	mg l-1	20.0	10.0 - 40.0

(Page 6)

Table 3. Mineral analysis of well water (recharge) and fish tank (irrigation water).

	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	S	pH
	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	
Wellwater for tank recharge	7.7	0.1	1.0	3.0	1.3	0.03	0.00	0.03	0.01	0.30	6.10
Fish Tank water for irrigation	8.4	0.8	3.0	4.5	0.9	0.33	0.10	0.65	0.01	1.75	6.35

Table 4. Yield of edible portion and comparative yield rates for bush bean, cucumber, and tomato.

CONTROL	YIELD ($kg\ m^{-2}$)	RATE ($kg\ m^{-2} wk^{-1}$)	RATE ($kg\ m^{-2} yr^{-1}$)	NC GRNHS ($kg\ m^{-2} yr^{-1}$)	US FIELD AVGS[s] ($kg\ m^{-2} yr^{-1}$)
Bush Bean, Blue Lake[†]	0.40	0.05 [z]	2.57 [x]	N/A	0.53 [s]
Cucumber, Burpee F II	4.55	0.85 [y]	22.08 [w]	31.69 [u]	2.59 [s]
Tomato, Champion	6.06	1.84 [y]	58.99 [v]	21.32 [t]	1.91 [s]
AQUA-INTEGRATED	YIELD ($kg\ m^{-2}$)	RATE ($kg\ m^{-2} wk^{-1}$)	RATE ($kg\ m^{-2} yr^{-1}$)	NC GRNHS ($kg\ m^{-2} yr^{-1}$)	US FIELD AVGS[s] ($kg\ m^{-2} yr^{-1}$)
Bush Bean, Blue Lake[†]	1.29	0.16 [z]	8.35 [x]	N/A	0.53 [s]
Cucumber, Burpee F II	7.28	2.04 [y]	52.97 [w]	31.69 [u]	2.59 [s]
Tomato, Champion (avg.)[†]	4.57	1.38 [y]	44.02 [v]	21.32 [t]	1.91 [s]
Tomato, high-density plots	6.87	2.09 [y]	66.90 [v]	21.32 [t]	1.91 [s]

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[z] Bush bean yield prorated over 8 weeks which crop occupied greenhouse space.

[y] Average yield per week during period of fruit harvesting.

[x] Bush bean yield per week for 52 weeks per year (six crops).

[w] Based on four crops per year, each harvested 6.5 weeks (26 harvest weeks per year).

[v] Based on two crops per year, each harvested 16 weeks (32 harvest weeks per year).

[u] Average two-year yield rate of greenhouse trials conducted at North Carolina State Univ., M. Peet, et al.

[t] Average per week yield of greenhouse tomato growers in North Carolina harvesting for 32 weeks per year.

[s] Derived from Knott's Handbook for Vegetable Growers (1977 data).

[†] Bush bean harvested prior to full maturity due to time constraints.

[††] Aqua-integrated tomato crop contracted bacterial wilt.

(Page 7)

Table 5. Analysis of control medium prior to amendment with manure and sand medium prior to irrigation^z.

Medium Treatment	CEC	P	K	Ca	Mg	H^+	Mn	Zn	Cu	BS	CEC BUF
	meq	mg/cdm	meq	meq	meq	pH	mg/cdm	mg/cdm	mg/cdm	%	meq
Soil, before manure	8.7	199+	0.72	6.8	0.75	6.30	36.0	19.0	6.60	89.0	no data
Sand, before irrigation	0.5	6	3.90	0.1	0.07	5.30	2.1	1.2	0.30	100	no data

z Milliequivalents (meq) per 100 cubic centimeters.

(Page 8)

Table 6. Medium analysis, at date of first mature fruit as influenced by aqua-integrated system^z.

Crop, Treatment	CEC	P	K	Ca	Mg	H^+	Mn	Zn	Cu	BS	CEC
	meq	mg/cdm	meq	meq	meq	pH	mg/cdm	mg/cdm	mg/cdm	%	meq
Bush Bean, Control, mean	5.71	255	0.77	4.0	0.79	6.40	42.0	13.5	7.7	88.1	6.19
Control, St.Dev.	3.00	130	0.49	2.0	0.54	0.83	16.8	4.7	4.3	13.8	2.48
Bush Bean, Aqua, mean	0.24	4.4	0.01	0.2	0.07	5.65	1.06	1.1	0.6	100	0.19
Next to furrow^y	0.12	5.6	0.02	0.2	0.09	5.94	2.16	2.5	0.9	100	0.19
Aqua, St.Dev.	0.08	0.8	0.01	0.0	0.02	0.20	0.81	0.9	0.3	0	0.06
Cucumber, Control, mean	7.37	313	0.87	5.6	0.94	5.78	42.0	20.0	6.9	92.9	7.88
Control, St.Dev.	2.51	92.0	0.49	1.8	0.40	0.33	9.6	11.0	3.7	3.2	2.55
Cucumber, Aqua, mean	0.30	3.6	0.01	0.2	0.10	5.85	1.9	1.8	0.7	72.6	0.40
Next to furrow^y	0.43	10.0	0.02	0.3	0.10	6.29	5.1	4.9	1.3	84.8	0.52
Aqua, StDev.	0.08	4.3	0.01	0.1	0.10	0.26	1.7	1.5	0.3	13.1	0.11
Tomato, Control, mean	6.43	270	0.60	0.5	0.93	6.47	42.4	10.2	3.4	89.0	7.01
Control, St.Dev.	2.33	90.0	0.26	1.6	0.54	0.54	10.9	3.7	0.8	6.8	2.27
Tomato, Aqua, mean	0.40	9.4	0.02	0.3	0.11	6.03	2.6	1.5	4.7	93.8	0.35
Next to furrow^y	0.36	8.5	0.03	0.3	0.09	6.27	5.6	3.6	1.1	100	0.36
Aqua, St.Dev.	0.25	17.0	0.02	0.2	0.22	0.41	3.3	1.3	2.2	11.2	0.26

z Milliequivalents (meq) per 100 cubic centimeters.

y "Next to furrow data" is the mean sample values from the top 160 mm profile at 50 mm from the furrow axis.

Table 7. Foliar tissue analysis of bush bean, cucumber, and tomato at date of first mature fruit.

Crop	Treatment	N %	P ppm	K %	Ca %	Mg %	Fe ppm	Mn ppm	Zn ppm	Cu ppm	S ppm	B ppm
Bean												
	Sufficiency[z]	5.00	3000	2.25	1.50	0.30	50	20	20	5	2000	20
	Control	3.89	4630	7.15	1.32	0.41	119	30	40	12	632	24
	Aqua-mean	4.22	3862	3.32	2.70	0.64	146	104	139	15	1692	15
	Aqua-St. Dev.	0.12	488	0.31	0.54	0.09	67	24	51	2	154	4
	Deficiency[y]	<3.50	<2000	<1.25	<0.30	<0.15	<30	<15	<15	<3	<1500	<15
Cucumber												
	Sufficiency[x]	6.00	3000	4.00	1.50	0.25	45	30	20	5	2000	25
	Control	5.39	6409	5.24	2.64	0.63	111	33	63	14	3521	26
	Aqua-mean	4.64	4673	3.07	2.15	0.71	98	103	186	14	2204	20
	Aqua-St. Dev.	0.52	1175	1.46	0.35	0.07	9	47	82	1	884	4
	Deficiency[y]	<4.00	<2000	<2.00	<0.75	<0.15	<30	<20	<15	<3	<1500	<15
Tomato												
	Sufficiency[x]	3.50	3500	3.50	1.00	0.30	45	30	20	5	3000	30
	Control, mean	3.61	5606	4.03	0.98	0.32	94	30	25	14	3035	28
	Aqua-mean	3.16	3497	3.11	0.94	0.28	67	58	49	17	936	15
	Aqua-St. Dev.	0.34	918	0.26	0.25	0.03	9	13	16	26	197	1
	Deficiency[y]	<2.50	<1800	<2.00	<0.50	<0.20	<25	<20	<15	<3	<1500	<15

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[z] Sufficiency guidelines for field grown bush bean by the North Carolina Department of Agriculture.

[y] Deficiency guidelines for the respective crop by the North Carolina Department of Agriculture.

[x] Sufficiency guidelines for greenhouse cultivated crop by the North Carolina Department of Agriculture.