Study on Shrimp Waste Water and Vermicompost as a Nutrient Source for Bell Peppers

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Abstract. The aquaculture industry generates significant nutrient-rich wastewater that is released into streams and rivers causing environmental concern. The objective of this controlled environment study was to evaluate the effect of waste shrimp water (SW), vermicompost (VC), at rates of 10%, 20%, 40%, and 80% by volume alone or in combination with SW, controlled-release fertilizer (CRF), and water-soluble fertilizer (WSF) on bell peppers (*Capsicum annuum* L.) cv. X3R Red Knight. Application of VC at 80% or SW alone increased yields relative to unfertilized control. Combined applications of VC and SW increased yields compared with VC alone. Overall, total yields were greatest in the chemical fertilizer treatments (CRF and WSF) and least in the unfertilized control. SW and VC increased growth medium pH relative to the unfertilized control or to the chemical fertilizer treatments. In pepper fruits, the greatest nitrogen (N) content was found in the CRF treatment, although it was not different from VC at high rates or WSF treatments. Phosphorus concentration in peppers was greatest in the CRF treatment, less in all VC or SW treatments, but not different from unfertilized control or WSF treatment. Iron, magnesium (Mg), and zinc concentrations in peppers were greatest in CRF treatment but not different from control or WSF treatments. Overall, N accumulation in peppers was negatively correlated to growth medium pH and calcium (Ca); phosphorus (P) in peppers was negatively correlated to growth medium pH, Ca, and sodium (Na), whereas potassium (K) in peppers was negatively correlated to growth medium P, Mg, and Na. Results indicated: 1) SW may not be a viable pepper nutrient source; 2) SW can provide a similar nutrient supply as VC; and 3) chemical fertilizers can provide higher pepper yields compared with SW or VC alone or in combination.

Mississippi is the largest catfish producer and one of the largest fresh water farm-raised shrimp producers in the United States. These industries generate significant nutrient-rich

wastewater that may currently be released into streams and rivers.

In aquaculture systems, fish or shrimp feed costs are $\approx 50\%$ of total costs in modern high-volume fed monospecies aquaculture (Neori et al., 2004). However, some feed is not used and becomes waste. In addition, fish excreta is also a significant waste; this causes effluent discharge concerns. Rising fish or shrimp feed costs and environmental issues surrounding aquaculture systems are two important barriers for further increases in aquaculture production (Neori et al., 2004).

Research on finding new uses of the wastewater from shrimp aquaculture systems would be beneficial to the aquaculture industry and to the environment. In addition, it also may stimulate the development of shrimp-based aquaponics systems. Aquaponics is a system that combines recirculating fish aquaculture with

a plant hydroponic system. The possibilities for integrating the aquaculture and hydroponic systems have been investigated in the past (Hargreaves et al., 1991; Naegel, 1977; Pierce, 1980; Rakocy, 1992; Seawright et al., 1998; Watten and Busch, 1984). It is based on the idea that vegetable hydroponics could be used for removing excess nutrients from aquaculture effluents. In the process of using the aquaculture effluent, high-value vegetables or other crops could be produced. In general, researches were conducted to establish 1) the optimal ratio of fish to plants; 2) which nutrients should be supplemented to the plants; and 3) maintaining proper salt and pH conditions for the fish and for the plants. However, like with the aquaponics system, most of the research was focused on tilapia-based aquaculture, suitable only for warm climates or for controlled environmental conditions (Rafiee and Saad, 2005; Rakocy, 1992; Seawright et al., 1998; Watten and Busch, 1984), and there is no research dealing with shrimp-based effluents. There are no reports on shrimp-based aquaponics systems. Fish-based aquaponics systems have been developed by several universities in the United States, but these systems are mainly tilapia-based (Watten and Busch, 1984). One reason for tilapia's popularity is tilapia are resilient and fed at high rates with commercially manufactured complete diets, which results in higher mineral and organic nutrient concentrations in tilapia tanks.

The objective of this study was to evaluate SW as a nutrient source for bell peppers, applied either alone or in combination with VC, and compare these treatments with traditional chemical fertilizer application.

Materials and Methods

Experiment. Controlled environment condition experiment with bell peppers (*Capsicum annuum* L.) cv. X3R Red Knight was conducted using completely randomized design with four replications. Peppers were started from certified seed in 36-cell trays filled with growth medium (Metromix 300; Sun Gro Horticulture, Bellevue, WA). When plants reached 6 to 8 cm, they were transplanted in 3-gallon 1400 series pots. The experiment was conducted in a greenhouse at the North Mississippi Research and Extension Center in Verona (lat. 34°43'22" N, long. 88°43'22" W) with natural daylight and no supplemental lighting with 22 to 30 °C day temperatures and 18 to 22 °C night temperatures.

The 12 treatments (Table 1) consisted of untreated control (irrigated with tap water); SW (irrigated only with SW); VC at 10%, 20%, 40%, and 80% by volume, either alone or in combination with SW; CRF (Osmocote Plus N:P:K at 15:9:12; Scotts-Sierra Horticultural Products Co., Marysville, OH), and WSF (greenhouse-grade general purpose fertilizer N:P:K at 20:20:20; Scotts-Sierra Horticultural Products Co.). The WSF treatment was fertilized with 100 mg·kg⁻¹ of N with 1100 mL of WSF when other treatments received either tap water or SW. The untreated control had 2800 g of growth substrate in each pot. Vermicompost was added to the growth medium once by

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volume and mixed thoroughly before transplanting peppers.

The SW was provided by Lauren Farms, Leland, MS. Nutrient concentration of SW was as follows in mg·kg⁻¹: NO₃-N (28–30), P (3.6), K (8.3), Ca (56), Na (65), Mg (17), iron (0.06), zinc (0.02), boron (0.32), and copper was under detection limit of inductively coupled argon plasma spectrometer (ICAP). The VC was obtained from Church Hill Worm Farm (Church Hill, MS). Nutrient concentration of VC was as follows: N 1.48%, P 3.85%, and K 0.41%.

Approximately 55 d were needed from transplanting for peppers to become green and 77 d to become red. Harvesting was done on a continual basis by picking marketable red peppers, taking fresh weight, and drying them in a drying oven at 68 °C for 72 h for dry weight and nutrient analysis. Subsamples of dried peppers were taken, ground, and analyzed for nutrient content at the Mississippi State Soil Testing laboratory. Immediately after the last harvest, growth medium from each pot was sampled; samples were dried at room temperature and sent for analysis of residual phyto-available nutrients using the Lancaster soil test method (Cox, 2001). Tissue and soil extracts were measured on ICAP (Perkin Elmer, Norwalk, CT).

Statistical analysis. The effect of 12 treatments on several nutrient concentrations in soil and tissue was determined by conducting a one-way analysis of variance using the GLM procedure of SAS (SAS Institute Inc., 2008). The effect of treatments was significant ($P < 0.05$) on all but two responses and further multiple

means comparison was done using the least significant difference method at the 1% level. A 1% level was used to protect Type I experimentwise (family) error rate from overinflation resulting from the relatively large number of treatments. For all responses, normal distribution and constant variance assumptions on the error terms were verified by constructing a normal probability plot of the residuals and a plot of residuals vs. fitted values, respectively (Montgomery, 2009); and appropriate transformation was applied when violated. Correlation analyses of nutrients in soil and tissue were also conducted to determine if nutrient concentrations in peppers can be predicted from those in the growth medium.

Results

Effects on yields. Overall, total pepper yields, number of fruits per plant, and average fruit weight were highest in the chemical fertilizer treatments (CRF and WSF) and lowest in unfertilized controls (Table 1). Application of SW increased yields relative to the control. The combination of SW and VC at 10% further increased yields relative to their application alone. Yields at the SW applied alone were greater than that from VC alone at 10% to 80%. Overall, the combination of SW and VC increased yields, but yields and average fruit weight were still below those at chemical fertilizer treatments (SLF or WSF). It is evident that nutrient availability from SW or VC applied alone or in combination could not match CRF or WSF nutrient availability for bell peppers.

Effects on pH and residual nutrients. Treatments had significant effect on growth medium pH and residual nutrients measured at harvest (Table 2). Generally, all SW and VC treatments had higher pH, untreated control and WSF had lower pH, and the CRF treatment had the lowest pH. Results demonstrated SW or VC applied alone or in combination may raise growth medium pH, whereas CRF can lower it. Interestingly, concentrations of soil P, Ca, Mg, and zinc at harvest were greater in VC at 80% or SW plus VC at 80% than in chemical fertilizer treatments. Concentrations of K were highest in the CRF, less in VC 80%, and relatively low in WSF treatments. Higher yields in chemical fertilizer treatments could be from two factors: (1) better match between nutrient availability and pepper plant requirements; and/or (2) insufficient N availability from SW or VC applications. The results suggest that SW and VC application to bell peppers must be supplemented with another N source.

Effect on nutrient content of peppers and nutrient removal with fruits. Pepper nutrient content was also affected by the treatments (Table 3). Peppers in CRF and SW alone treatments had higher N content compared with peppers in untreated control. Peppers in CRF also had higher P content relative to most other treatments, although not different from untreated control or from WSF. Potassium content in peppers in the VC 10% treatment was higher than in chemical fertilizers but not different from the untreated control. Peppers in untreated control had higher Mg concentration than peppers in chemical fertilizer treatments.

The concentration of iron in pepper fruits in the SW and in all VC plus SW treatments was lower than in the control and lower than in the chemical fertilizer treatments (Table 3). The concentration of manganese (Mn) in pepper fruits in the SW, in the VC plus SW treatments, in the VC at 20% and VC at 80% was lower than in the control and lower than in the CRF treatments. The concentration of zinc in peppers in the SW and in the VC at 10% plus SW was lower than in the control and lower than in the CRF treatment (Table 3).

Generally, removal of nutrients [N, P, K, Ca, Mg, sulfur (S), iron (Fe), Mn, zinc (Zn), copper (Cu), and boron (B)] with pepper fruits (a function of nutrient content and pepper yields)

Table 1. Mean total fruit weight, number of fruits, and pepper fruit weight from the 12 treatments.^z

Treatment	Total wt (g)	No. of fruits	Pepper fruit wt (g)
Untreated control	114 d	2 e	65 f
Shrimp water	962 b	9 cd	890 bc
VermiComp 10%	122 d	2 e	107 f
VermiComp 10 + SW	1025 b	12 c	977 b
VermiComp 20%	166 d	2 e	161 ef
VermiComp 20 + SW	985 b	11 c	1022 b
VermiComp 40%	261 cd	3 e	309 de
VermiComp 40 + SW	1081 b	13 bc	1013 b
VermiComp 80%	528 c	7 d	571 cd
VermiComp 80 + SW	1232 b	18 ab	1190 b
Osmocote CRF	1624 a	19 a	1690 a
20–20–20 WSF	1924 a	22 a	1922 a

^zMeans sharing the same letter are not significantly different.

SW = shrimp water; CRF = controlled-release fertilizer; WSF = water-soluble fertilizer.

Table 2. Mean nutrient concentrations in the growth medium from the 12 treatments.^z

Treatment	pH	OM (%)	Phosphorus (mg·kg ⁻¹)	Potassium (mg·kg ⁻¹)	Calcium (mg·kg ⁻¹)	Magnesium (mg·kg ⁻¹)	Zinc (mg·kg ⁻¹)	Sulfur (mg·kg ⁻¹)	Sodium (mg·kg ⁻¹)
Untreated control	7.03 c	6.7 ab	15 e	98 e	1735 d	606 c	1.2 d	480 ab	63 b
Shrimp water (SW)	7.80 b	5.5 b	27 e	100 e	1953 d	713 abc	1.3 d	395 b	548 a
VermiComp 10	8.03 ab	5.7 b	95 d	148 de	2935 abc	648 c	2.4 c	410 b	65 b
VermiComp 10 + SW	8.30 a	6.6 ab	103 cd	169 cde	2630 bc	837 ab	2.6 c	478 ab	699 a
VermiComp 20	8.23 ab	6.9 ab	134 c	147 de	3158 a	598 c	3.1 c	495 ab	56 b
VermiComp 20 + SW	8.37 a	7.2 ab	139 c	140 de	2520 c	666 bc	3.2 c	518 ab	522 a
VermiComp 40	8.07 ab	8.5 a	263 b	178 cd	3067 ab	687 abc	6.0 b	611 a	60 b
VermiComp 40 + SW	8.33 a	6.4 ab	259 b	148 de	2930 abc	739 abc	6.1 b	462 ab	514 a
VermiComp 80	8.23 ab	7.5 ab	433 a	355 b	3217 a	837 ab	8.0 a	539 ab	78 b
VermiComp 80 + SW	8.27 ab	8.0 a	416 a	233 c	2968 abc	840 a	7.7 a	577 a	579 a
CRF	5.10 d	6.6 ab	215 b	464 a	1807 d	650 c	3.1 c	473 ab	71 b
20–20–20 WSF	7.20 c	7.1 ab	88 d	149 de	1876 d	647 c	1.0 d	511 ab	70 b

^zMeans sharing the same letter are not significantly different.

OM = organic matter; CRF = controlled-release fertilizer; WSF = water-soluble fertilizer.

was greatest in chemical fertilizer treatments and least in untreated control (Table 4). However, removal of K, Ca, and Mg with peppers in some other fertility treatments was not different from chemical fertilizer treatment.

Correlations between nutrient concentrations in peppers and residual nutrients in the growth medium. Nitrogen in peppers and N removal were negatively correlated with growth medium pH and Ca but positively correlated with growth medium K (Table 5). Phosphorus content in peppers was negatively correlated with growth medium pH, Ca, and Na, whereas P removal was negatively correlated with growth medium pH and Ca and positively with K. Potassium in peppers was negatively correlated with growth medium P and Na, whereas K removal was negatively correlated with growth medium Ca and positively correlated with growth medium K. Calcium in peppers was negatively correlated with growth medium K; Ca removal was negatively correlated with growth medium Na. Magnesium in peppers was negatively correlated with growth medium P, K, and Zn, whereas Mg removal was negatively correlated with growth medium Ca and positively correlated with Na. Sulfur in peppers was negatively correlated with growth medium pH and Na; S removal was negatively correlated with growth medium pH and Ca and positively correlated with K.

Iron in peppers was negatively correlated with growth medium pH, Ca, Mg, and Na, and

Fe removal was negatively correlated with growth medium pH and Ca and positively correlated with K. Manganese in peppers was negatively correlated with growth medium pH, P, Ca, Mg, Zn, and Na, whereas Mn removal was negatively correlated with growth medium pH, K, and Ca. Zinc in peppers was negatively correlated with growth medium pH and Na and positively correlated with K, whereas Zn removal was negatively correlated with growth medium pH, K, and Ca. Copper in peppers was negatively correlated with growth medium pH, Ca, and Na and positively correlated with K, whereas Cu removal was negatively correlated with growth medium pH, and Ca was positively correlated with K. Boron in peppers was positively correlated with growth medium P and Zn, and B removal was negatively correlated with growth medium pH, and Ca was positively correlated with K (Table 5).

Discussion and Concluding Remarks

To our knowledge, this is the first study using SW as a nutrient source for bell peppers. We found only one report on using SW as nutrient source for vegetables. Castellani et al. (2009) evaluated SW producing hydroponic lettuce and watercress. The authors found SW was not sufficient to support lettuce growth but did meet the nutrient demand of watercress (Castellani et al., 2009). Their study and results from our study seem to suggest SW alone may

not be sufficient to meet nutrient requirements of fast-growing vegetables.

Aquaponics research has intensified in recent years throughout the world. There have been reports from countries with various climates such as the United Kingdom (Price, 2009), Canada (Savidov et al., 2007), and Saudi Arabia (Al-Hafedh et al., 2008). In the United States, significant research has been conducted at the University of Virgin Islands (UVI) by Dr. James Rakocy, who has developed a commercial-scale aquaponic system (Rakocy, 1997) based on earlier research by Watten and Busch (1984). The system developed at the UVI has been modified and used by commercial entities in the United States (Rakocy et al., 2004). Apparently, further research is needed on using waste SW to develop a shrimp-based aquaponics system. Our results indicate bell peppers may not be suitable for a SW aquaculture system; however, other vegetables or herbs that have less nutrient requirements might be suitable.

Dufault and Korkmaz (2000) used biosolids from shrimp aquaculture as fertilizer for bell peppers grown on loamy sand soil and compared it with SRF (Osmocote). The authors found increased bell pepper yields with an increase in shrimp aquaculture biosolid; however, the greatest yields were achieved in SRF treatment. Similar to results from this study, the authors found an increase in soil nutrients, Na,

Table 3. Mean nutrient content of pepper fruits from the 12 treatments.^z

Treatment	Nitrogen (%)	Phosphorus (%)	Potassium (%)	Magnesium (%)	Sulfur (%)	Iron (mg·kg ⁻¹)	Manganese (mg·kg ⁻¹)	Zinc (mg·kg ⁻¹)
Untreated control	2.3 cd	0.33 ab	3.1 ab	0.20 a	0.18 abc	49 abc	7.8 a	24 abcd
Shrimp water (SW)	2.9 ab	0.24 b	2.4 bcde	0.15 abc	0.14 cd	19 e	1.5 bc	17 e
VermiComp 10	2.1 d	0.30 b	3.2 a	0.17 abc	0.15 bcd	38 bcde	5.5 ab	21 cde
VermiComp 10 + SW	2.7 abc	0.25 b	2.5 abcde	0.18 ab	0.14 cd	20 e	1.7 bc	16 e
VermiComp 20	2.1 d	0.28 b	3.0 abc	0.14 abc	0.21 a	41 bcd	2.1 bc	20 cde
VermiComp 20 + SW	2.3 cd	0.26 b	2.6 abcde	0.18 ab	0.15 bcd	26 de	1.6 bc	19 de
VermiComp 40	2.1 d	0.30 b	2.8 abcd	0.15 abc	0.15 bcd	42 bcd	2.7 abc	26 abc
VermiComp 40 + SW	2.8 abc	0.26 b	2.3 cde	0.15 abc	0.13 d	18 e	1.3 bc	20 cde
VermiComp 80	2.4 bcd	0.25 b	2.2 de	0.11 c	0.16 abcd	32 cde	1.0 c	24 abcd
VermiComp 80 + SW	2.5 abcd	0.27 b	2.3 de	0.14 abc	0.15 bcd	22 de	1.0 c	23 bcd
Osmocote CRF	3.2 a	0.43 a	2.4 bcde	0.13 bc	0.19 ab	68 a	9.1 a	30 a
20–20–20 WSF	2.7 abcd	0.35 ab	2.1 e	0.12 bc	0.16 abcd	54 ab	2.9 abc	28 ab

^zMeans sharing the same letter are not significantly different. The effect of treatment on percent calcium was not significant and its overall mean was 0.152. The effect of treatment on boron and calcium was not significant and its overall mean was 18.42. However, the assumptions needed for analysis of variance for copper, ppm (average 1.83), could not be met.

CRF = controlled-release fertilizer; WSF = water-soluble fertilizer.

Table 4. Mean nutrient uptake by pepper from the 12 treatments.^z

Treatment	Nitrogen (g)	Phosphorus (g)	Potassium (g)	Calcium (g)	Magnesium (g)	Sulfur (g)	Iron (mg)	Manganese (mg)	Zinc (mg)	Copper (mg)	Boron (mg)
Untreated control	1.4 f	0.2 f	1.9 f	0.09 c	0.0 e	0.12 e	3.0 e	0.5 c	1.5 e	0.1 d	1.3 e
Shrimp water (SW)	25.7 b	2.1 bc	21.4 bc	1.33 a	0.01 cd	1.21 bc	17 bcd	1.3 c	14.8 c	0.9 c	16.5 bc
VermiComp 10	2.3 ef	0.3 ef	3.4 ef	0.16 c	0.00 e	0.16 e	4.1 de	0.6 c	2.2 e	0.1 d	1.8 e
VermiComp 10 + SW	26.7 b	2.4 bc	24.0 b	1.74 a	0.02 bc	1.33 bc	19 bc	1.8 c	15.6 c	0.9 c	16.1 bc
VermiComp 20	3.4 ef	0.4 ef	4.9 ef	0.23 bc	0.0 e	0.33 de	6.5 cde	0.3 c	3.2 e	0.2 d	3.1 e
VermiComp 20 + SW	23.4 bc	2.7 b	26.5 ab	2.2 a	0.05 abc	1.56 b	26 b	1.7 c	19.5 bc	1.0 c	18.7 b
VermiComp 40	6.6 de	0.9 de	8.7 de	0.51 b	0.0 e	0.46 d	13 bcde	0.9 c	8.0 d	0.3 d	6.2 de
VermiComp 40 + SW	28.3 b	2.7 b	23.7 b	1.49 a	0.02 bc	1.32 bc	13 bc	1.3 c	20.2 bc	1.0 c	18.5 b
VermiComp 80	13.7 cd	1.5 cd	12.5 cd	0.59 b	0.001 de	0.92 c	19 bc	0.6 c	13.9 c	1.0 c	11.5 cd
VermiComp 80 + SW	30.0 b	3.2 b	27.0 ab	1.9 a	0.03 abc	1.78 b	26 b	1.2 c	27.3 b	1.2 c	22.8 b
Osmocote CRF	53.6 a	6.4 a	40.5 a	1.97 a	0.09 ab	3.12 a	73 a	13.5 a	48.9 a	13.5 a	32.0 a
20–20–20 WSF	51.3 a	6.7 a	40.2 a	2.01 a	0.11 a	3.1 a	103 a	5.6 b	54.5 a	9.6 b	32.4 a

^zMeans sharing the same letter are not significantly different.

CRF = controlled-release fertilizer; WSF = water-soluble fertilizer.

Table 5. Correlation coefficients between nutrients in the soil (columns) and nutrient content in pepper and nutrient uptake by pepper (rows).

Nutrient	Nutrient in the soil								
	pH	Organic matter	Phosphorus	Potassium	Calcium	Magnesium	Zinc	Sulfur	Sodium
Nutrient content in pepper fruits									
Nitrogen	-0.387*	-0.191	-0.014	0.350*	-0.482**	0.173	-0.084	-0.191	0.221
Phosphorus	-0.582**	-0.067	-0.142	0.295	-0.461**	-0.353*	-0.213	-0.066	-0.532**
Potassium	0.019	-0.184	-0.365*	-0.293	0.089	-0.368*	-0.256	-0.184	-0.356*
Calcium	0.201	0.140	-0.178	-0.339*	0.059	-0.116	-0.103	0.140	0.271
Magnesium	0.038	-0.179	-0.453**	-0.413*	-0.224	-0.135	-0.334*	-0.179	0.164
Sulfur	-0.416*	-0.132	-0.096	0.256	-0.193	-0.341*	-0.135	-0.132	-0.463**
Iron	-0.738**	-0.034	-0.191	0.306	-0.396*	-0.483**	-0.265	-0.033	-0.710**
Manganese	-0.697**	-0.261	-0.339*	0.152	-0.458**	-0.404*	-0.342*	-0.260	-0.400*
Zinc	-0.545**	0.204	0.257	0.512**	-0.245	-0.177	0.143	0.204	-0.583**
Copper	-0.824**	-0.196	0.004	0.660**	-0.478**	-0.198	-0.125	-0.196	-0.327*
Boron	-0.032	0.145	0.343*	0.310	0.103	0.062	0.374*	0.145	-0.201
Fruit wt	-0.318	0.051	0.123	0.351*	-0.401*	0.163	-0.069	0.051	0.260
Nutrient uptake by pepper									
Nitrogen	-0.409*	-0.001	0.086	0.405*	-0.461**	0.128	-0.105	-0.001	0.202
Phosphorus	-0.345*	-0.020	0.040	0.326*	-0.438**	0.042	-0.115	-0.019	0.085
Potassium	-0.309	0.020	0.107	0.356*	-0.395*	0.165	-0.069	0.020	0.280
Calcium	-0.149	0.108	0.119	0.203	-0.261	0.183	-0.015	0.108	0.460**
Magnesium	-0.232	0.010	0.086	0.277	-0.391*	0.180	-0.068	0.010	0.365*
Sulfur	-0.450**	-0.009	0.121	0.456**	-0.443**	0.099	-0.078	-0.009	0.147
Iron	-0.525**	-0.044	-0.029	0.357*	-0.482**	-0.120	-0.198	-0.044	-0.163
Manganese	-0.776**	-0.239	-0.066	0.558**	-0.468**	-0.160	-0.164	-0.239	-0.148
Zinc	-0.466**	0.063	0.134	0.443**	-0.439**	0.044	-0.076	0.063	0.022
Copper	-0.576**	-0.135	-0.038	0.428**	-0.448**	-0.161	-0.176	-0.135	-0.203
Boron	-0.338*	0.043	0.184	0.423*	-0.387*	0.191	-0.007	0.043	0.260

*Significantly different from 0 at the 5% level; **significantly different from 0 at the 1% level.

and salinity with increased rates of SW bio-solids (Dufault and Korkmaz, 2000).

This is also the first study to evaluate combined application of SW and VC to peppers. Previous research demonstrated addition of VC can significantly increase pepper yields (Arancon et al., 2004; Huerta et al., 2010), which is logical because VC adds nutrients to soil or growth medium and improves soil physical and biological characteristics. However, other authors did not find increase in pepper yields as a result of VC application at 20% by volume to the growth medium (Bachman and Metzger, 2008). The latter finding is similar to that in our study; addition of 10%, 20%, or 40% of VC did not increase yields relative to untreated control.

Results from this study demonstrated that concentration of the nutrients in the growth medium measured at harvest cannot be a good predictor for the concentration of the nutrients in peppers, because there were no significant correlations between these two measurements. Of all the measured nutrients, only the nutrient removal of K was mostly correlated with the concentration of K in the growth medium at harvest.

Results indicated: 1) SW may not be a viable nutrient source for peppers; 2) SW can provide a similar nutrient supply as VC; 3) chemical fertilizers can provide greater pepper yields compared with SW or VC alone or in combination; and 4) except for K, nutrient concentration in the growth medium measured at harvest may not be a good predictor of nutrient accumulation in bell peppers.

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