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Humic Substances Generally Ineffective in Improving Vegetable Crop Nutrient Uptake or Productivity

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***Abstract*. Soil application of humic acid (HA), generally derived from leonardite shale, is a common practice in California vegetable production. Five commercial HA formulations were evaluated for their effects on soil microbial activity, seedling emergence, crop productivity, and nutrient uptake when applied to representative agricultural soils. Two soils differing in organic matter content (8 and 25 g·kg^{-1}) were wetted to field capacity moisture content with solutions of water, nitrogen and phosphorus (P) fertilizer, HA, or fertilizer + HA and incubated aerobically at 25 °C. In the lower organic matter soil, a synergistic effect of fertilizer and HA was observed after 7 days of incubation on both microbial respiration and the amount of phospholipid fatty acids detected; these stimulatory effects were not observed in the higher organic matter soil. In a greenhouse pot study, the effects of HA on seedling emergence, dry mass accumulation, and P uptake of romaine lettuce (*Lactuca sativae* L.) were evaluated in four soils of low P availability; HA was applied to the soil at a rate simulating a field application of 2.2 kg·ha^{-1} a.i. HA had no significant effect on emergence rate or percentage, or P uptake, in any soil; plant dry mass was increased in one soil. Field trials were conducted in 2008 and 2009 evaluating the effects of pre-transplant soil application of HA at 1.1 or 3.4 kg·ha^{-1} a.i. on growth, nutrient uptake, and fruit yield of processing tomato (*Lycopersicon esculentum* Mill.). In neither year was macro- or micronutrient uptake increased with HA. Similarly, there was no significant HA effect on plant dry mass accumulation or fruit yield. We conclude that, at typical commercial application rates in representative field soils, HA is unlikely to significantly improve vegetable crop nutrient uptake or productivity.**

The use of humic substances (HS) to improve crop growth has been the subject of a substantial body of research over decades. HS refers to a complex, heterogeneous mixture of organic materials arising from the decay of plant and animal residues (MacCarthy et al., 1990). HS can be characterized as humic acid, fulvic acid, and humin on the basis of solubility in water as a function of pH (Varanini and Pinton, 1995). The reported effects of HS on soil physiochemical properties include stabilization of soil structure (Piccolo and Mbagwu, 1990) and increased cation exchange (Allison, 1973). Root growth enhancement has been attributed to improved soil structure, stimulation of soil microflora, and auxin-like effects (Chen and Aviad, 1990). Additionally, enhanced nutrient availability has been reported. This has been attributed to direct availability of nutrients from the HS (Stevenson and He, 1990; Tarafdar and Jungk, 1987), chelation of nutrients by the HS (Stevenson, 1991; Varanini and Pinton, 1995), or through more complex physiological interactions (Chen et al., 2004; Vaughan et al., 1985).

Many commercial products containing HS, most commonly humic acid (HA), are currently used in commercial vegetable production; these products are frequently soil-applied, often in combination with liquid fertilizer. The majority of these products are derived from leonardite or lignite (Chen et al., 2004). Although the potential bioactivity of products containing HA has been well documented, there are serious limitations in the existing scientific literature. The vast majority of positive reports have come from hydroponic or sand culture experiments (Chen et al., 2004). Few studies showing positive crop response to HS have been conducted under representative agricultural field conditions. Studies showing positive responses under field conditions have been conducted in low organic matter soils (Fagbenro and Agboola, 1993; Kunkel and Holstad, 1968; Lee and Bartlett, 1976). U.S. research suggests that, under representative field conditions, commercial HA formulations do not reliably provide agronomic benefits for vegetable production. Boyhan et al. (2001) found no HS effects on onion yield in 3 years of field trials but reported enhanced storage life in 1 year. Feibert et al. (2003) and Duval et al. (1998) reported no benefit from HS application in field production of onions and mustard greens, respectively.

This study was undertaken to determine the effects of five commercial HA formulations when applied to representative agricultural soils. Using laboratory, greenhouse, and field experiments, HA effects on soil microbial activity, seedling emergence, early growth, nutrient uptake, and crop yield were determined on lettuce and processing tomato.

Materials and Methods

Five commercial formulations containing HA were used in this study (Table 1); these products were chosen as representative of the HA products in common use in California. Samples were oven-dried and analyzed for total carbon using a combustion gas analyzer (Carlo Erba 1500; Fisons Instruments, Beverly, MA) and nitrogen (N) by a nitrogen gas analyzer (Model FP-528; LECO Corp., St. Joseph, MI). Potassium (K) concentration was quantified by atomic absorption spectrometry (AAS) and phosphorus (P) concentration by inductively coupled plasma atomic emission spectrometry after microwave acid digestion (Sah and Miller, 1992).

In a greenhouse experiment, these products were evaluated for their effects on lettuce seedling emergence, growth, and P uptake. Four soils were collected from California fields in vegetable crop rotations, chosen for their limited P availability based on bicarbonate extraction (Olsen and Sommers, 1982); their physiochemical properties are given in Table 2. The soils were air-dried, screened through 5-mm mesh, and blended for uniformity. Pots of 1-L volume were filled with 750 g of dry soil. To simulate a preplant banded P fertilizer application, a band of liquid was applied to the soil surface. The liquid band contained water, HA alone, 10N–14.9P fertilizer alone, or a combination of HA and 10N–14.9P. Application rates were equivalent to a field rate of 2.2 kg·ha^{-1} a.i. for the HA and 16 and 24 kg·ha^{-1} N and P, respectively. After application, an additional 250 g of dry soil was added to each pot.

Ten clay-coated seeds of 'Green Towers' romaine lettuce were sown in each pot and covered with a thin layer of sand. The pots were placed in a greenhouse in a randomized complete block experimental design with five single pot replications of each soil × treatment combination. The pots were wetted on 2 Nov. 2007. The number of emerged seedlings in each pot was recorded daily from 8 to 16 Nov., after which the seedlings were thinned to one representative plant per pot. The greenhouse was maintained at 24/20 °C day/night temperature. Watering was done daily with a calcium nitrate solution containing 100 mg·L^{-1} NO_3-N throughout the experiment. Whole plants were harvested on 19 Dec. The plants were oven-dried, weighed, then ground to pass a 40-mesh screen. Tissue P concentration was determined as previously described.

A laboratory incubation experiment was conducted in 2008 to evaluate the effects of the HA on soil microbial respiration and microbial community structure. Soil was collected from two fields in vegetable rotations, differing in organic matter content; physiochemical characteristics are given in

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Table 2. The soils were air-dried, passed through a 5-mm screen, and blended for uniformity. One hundred grams of dry soil was placed in glass jars of 1-L volume. The soil was wetted to field capacity moisture content by adding water alone, fertilizer solution (10N–14.9P at 240 and 360 mg·L^{-1} N and P, respectively), HA solution (80 mg·L^{-1} a.i.), or a solution containing both HA and fertilizer. The concentrations of P and HA were calculated to simulate the concentration of these materials in the soil zone receiving a banded field application of 10 kg·ha^{-1} P and 2.2 kg·ha^{-1} a.i. HA. Four replicate jars of each soil × treatment combination were prepared, sealed, and incubated at a constant 25 °C. After 3 and 7 d, samples of the headspace air were removed from the jars and analyzed for CO_2 concentration using an infrared gas analyzer; from these data, the mass of carbon mineralized by microbial respiration was calculated.

At the end of 7 d, 50 g of moist soil was removed from each jar. These soil samples were subjected to phospholipid fatty acid (PLFA) analysis by gas chromatography, as described by Bossio and Scow (1998). The various PLFAs detected were classified according to the microbial group (fungi, bacteria, or actinomycetes) with which they are most closely associated; whereas not all PLFAs are exclusive to a particular group of microorganisms, this classification is widely recognized as providing a "fingerprint" of the active microbial communities in the soil (Drenovsky et al., 2004). This technique provided a method to determine which microbial communities were affected by HA.

The effect of soil application of HA on processing tomatoes was evaluated in field trials conducted at the University of California–Davis in 2008 and 2009. A Yolo silt loam soil (mixed, nonacid, thermic Typic Xerorthents) with 12 mg·kg^{-1} bicarbonate-extractable P was tilled into 1.5-m-wide raised beds. On 18 Apr. 2008, a pre-transplanting banded application of HA and fertilizer was applied 10 cm deep in the center of each soil bed. The treatments included each of the HA products at both a 1.1 and 3.4 kg·ha^{-1} a.i. rate applied with 10N–14.9P fertilizer at 34 kg·ha^{-1} P, 10N–14.9P fertilizer at that rate without HA (P alone), and a treatment receiving only an equivalent amount of N (no HA or P). The HA products were thoroughly blended with the 10N–14.9P before application to simulate commercial HA/fertilizer solutions.

The field was transplanted with 'Heinz 9780' processing tomato plants on 24 Apr. at ≈16,000 plants/ha; plant spacing was 41 cm in row and 1.5 m between rows. The experimental design was randomized complete block with five replications; individual plots were one bed wide × 30 m long. On 10 June, the above-ground portion of four whole plants per plot were harvested, oven-dried, and ground. Total N, P, and K were determined as previously described; zinc, manganese, iron, and copper concentration was determined by AAS after microwave acid digestion. The field was sprinkler-irrigated to

Table 1. Description of the humic acid (HA) products tested.

				g·kg^{-1} dry mass			
Trade name	Manufacturer[z]	Form	% HA	Carbon	Nitrogen	Phosphorus	Potassium
Actagro humic acid	Actagro LLC	Liquid	10	320	7	0.1	177
Actagro liquid humus	Actagro LLC	Liquid	11	290	4	0.1	102
Organo liquid hume	Black Earth Humates Ltd.	Liquid	6	410	12	0.2	92
Quantum-H	Horizon Ag Products	Liquid	6	360	12	31.0	127
ESP-50	Earthgreen Products	Powder	50	240	21	77.0	163

[z] Actagro LLC, Biola, CA; Black Earth Humates Ltd., Edmonton, Alberta, Canada; Horizon Ag Products, Modesto, CA; Earthgreen Products, Dallas, TX.

Table 2. Characteristics of the soils used in the greenhouse and incubation experiments.

Expt.	Soil	texture	pH	Organic matter (g·kg^{-1})[z]	Bicarbonate phosphorus (mg·kg^{-1})[y]
Greenhouse	1	Sandy clay loam	7.7	8	3
	2	Clay loam	7.8	9	5
	3	Loam	7.4	9	12
	4	Loam	7.3	11	10
Incubation	1	Sandy clay loam	7.8	8	7
	2	Loam	7.9	25	59

[z] By the method of Nelson and Sommers (1982).

[y] By the method of Olsen and Sommers (1982).

Table 3. Effect of humic acid (HA) and phosphorus (P) fertilizer on lettuce dry mass, greenhouse experiment.

	Plant dry mass (g)				Plant P uptake (mg)			
Treatment	Soil 1	Soil 2	Soil 3	Soil 4	Soil 1	Soil 2	Soil 3	Soil 4
Actagro humic acid	0.19 b[z]	0.43 b	0.86 d	1.37 b	0.36 b	0.82 c	1.91 c	4.28 c
Actagro liquid humus	0.19 b	0.44 b	0.96 d	1.24 b	0.42 b	0.93 c	2.06 c	3.81 c
Organo liquid hume	0.28 b	0.52 b	0.92 d	1.03 b	0.51 b	1.11 c	1.90 c	3.10 c
Quantum-H	0.26 b	0.61 b	0.81 d	1.10 b	0.55 b	1.18 c	1.83 c	3.20 c
ESP-50	0.36 b	0.65 b	0.91 d	1.29 b	0.80 b	1.43 c	2.05 c	3.55 c
Actagro humic acid + P	1.64 a	1.72 a	3.44 a	2.96 a	6.72 a	6.40 ab	19.85 a	14.60 b
Actagro liquid humus + P	1.73 a	1.87 a	3.28 ab	2.78 a	6.52 a	6.74 ab	19.72 a	16.95 ab
Organo liquid hume + P	1.91 a	1.52 a	3.44 a	2.99 a	7.35 a	6.08 ab	17.68 a	16.63 ab
Quantum-H + P	1.67 a	1.91 a	3.02 abc	2.49 a	6.59 a	7.04 a	18.80 a	14.96 b
ESP-50 + P	1.91 a	1.48 a	2.63 c	3.20 a	7.38 a	5.48 b	12.76 b	20.57 a
P alone	2.08 a	1.89 a	2.69 bc	2.74 a	7.52 a	6.56 ab	15.66 ab	15.39 b
No HA acid or P	0.21 b	0.50 b	0.79 d	1.06 b	0.48 b	1.03 c	1.68 c	2.80 c
Contrasts								
HA alone versus HA + P	**	**	**	**	**	**	**	**
HA + P versus P alone	NS	NS	*	NS	NS	NS	NS	NS
HA alone versus no HA or P	NS	NS	NS	NS	NS	NS	NS	NS

[z] Mean separation within columns by Duncan's multiple range test, $P < 0.05$.

NS, *, **Nonsignificant at $P < 0.05$ or significant at $P < 0.05$ or 0.01, respectively.

Table 4. Effects of humic acid (HA) and fertilization on soil microbial respiration (mg carbon/kg dry soil), incubation experiment.

	Soil 1		Soil 2	
Treatment	3 d	7 d	3 d	7 d
Actagro humic acid	22.2 b[z]	42.7 c	62.7 e	88.6 e
Actagro liquid humus	23.4 b	40.6 c	65.0 de	93.6 d
Organo liquid hume	22.3 b	39.0 c	65.8 d	92.7 de
Quantum-H	22.4 b	39.3 c	62.5 e	88.4 e
ESP-50	22.9 b	41.9 c	62.9 de	89.1 de
Actagro humic acid + fertilizer	28.4 a	56.9 b	73.5 c	107.7 bc
Actagro liquid humus + fertilizer	25.8 a	58.4 b	75.2 bc	110.6 ab
Organo liquid hume + fertilizer	28.5 a	58.3 b	79.0 a	112.6 a
Quantum-H + fertilizer	30.4 a	63.0 a	72.6 c	105.6 c
ESP-50 + fertilizer	30.4 a	58.9 ab	78.4 a	112.4 a
Fertilizer alone	28.6 a	54.5 b	77.1 ab	112.2 a
No HA or fertilizer	23.2 b	39.9 c	64.0 de	91.2 de
Contrasts				
HA alone versus no HA or fertilizer	NS	NS	NS	NS
HA alone versus HA + fertilizer	**	**	**	**
HA + fertilizer versus fertilizer alone	NS	**	NS	NS

[z] Mean separation within columns by Duncan's multiple range test, $P < 0.05$.

NS, *, **Nonsignificant at $P < 0.05$ or significant at $P < 0.05$ or 0.01, respectively.

establish the transplants and then drip-irrigated for the remainder of the season. Irrigation volume was based on reference evapotranspiration (modified Penman) and crop canopy width (percent of ground coverage). Eight weekly N fertigations began at early bloom and delivered a total of 180 kg·ha^{-1} N. The plots were mechanically harvested at commercial maturity on 28 Aug., and total and marketable yields were determined. Fruit soluble solids concentration was measured by refractometer on blended samples of ≈3 kg of fruit per plot.

The processing tomato field experiment was repeated at the University of California–Davis in 2009 in a field of Reiff loam (mixed, nonacid, thermic Typic Xerorthents) with 13 mg·kg^{-1} bicarbonate-extractable P. The trial structure was similar to the 2008 trial with minor modifications. All HA treatments were combined with 19 kg·ha^{-1} P from 10N–14.9P. Also, the 3.4-kg·ha^{-1} a.i. rate of ESP-50 was eliminated at the manufacturer's request because they considered the product to be economically impractical at that rate. Transplanting occurred on 29 Apr. On 22 May, four whole plants per plot were harvested for dry weight determination, and whole leaf samples were collected and oven-dried for macro- and micronutrient analysis. Irrigation and N fertigation were done as described for the 2008 trial. The plots were mechanically harvested on 2 Sept.; total and marketable yield were determined and fruit soluble solids concentration measured.

Table 5. Effects of humic acid (HA) and fertilization on phospholipid fatty acid (PLFA) detection in soil, incubation experiment.

		PLFA detected (nmol·g^{-1} dry soil)			
Soil	Treatment	Total	Fungi	Bacteria	Actinomycetes
1	Actagro humic acid	26.1 ab[z]	5.7 ab	13.5 ab	1.44 ab
	Actagro liquid humus	27.4 ab	6.0 ab	14.2 ab	1.48 ab
	Organo liquid hume	25.4 ab	5.6 ab	13.2 ab	1.44 ab
	Quantum-H	29.8 a	6.3 a	15.2 a	1.59 ab
	ESP-50	26.2 ab	5.7 ab	13.9 ab	1.48 ab
	Actagro humic acid + fertilizer	30.2 a	6.6 a	16.0 a	1.61 ab
	Actagro liquid humus + fertilizer	28.8 a	6.2 a	15.0 a	1.53 ab
	Organo liquid hume + fertilizer	28.5 a	6.1 a	15.0 a	1.53 ab
	Quantum-H + fertilizer	25.3 ab	5.4 ab	13.4 ab	1.40 ab
	ESP-50 + fertilizer	29.9 a	6.4 a	15.6 a	1.63 a
	Fertilizer alone	22.0 b	4.4 b	11.6 b	1.28 bc
	No HA or fertilizer	14.9 c	2.6 c	8.0 c	1.09 c
Contrasts					
HA alone versus no HA or fertilizer		**	**	**	**
HA alone versus HA + fertilizer		*	NS	*	NS
HA + fertilizer versus fertilizer alone		**	*	**	*
2	Actagro humic acid	52.3 abc	11.9 abc	29.2 abc	3.02 abc
	Actagro liquid humus	58.5 a	13.4 a	32.8 a	3.34 a
	Organo liquid hume	49.4 abc	11.6 abc	27.7 abc	2.71 bcd
	Quantum-H	57.7 a	13.4 a	32.3 a	3.24 ab
	ESP-50	59.4 a	13.7 a	33.0 a	3.37 a
	Actagro humic acid + fertilizer	43.0 c	10.1 c	24.1 c	2.45 d
	Actagro liquid humus + fertilizer	55.5 ab	12.9 ab	31.0 ab	3.11 abc
	Organo liquid hume + fertilizer	46.3 abc	10.7 bc	25.8 bc	2.60 cd
	Quantum-H + fertilizer	56.7 ab	13.1 ab	31.8 a	3.06 abc
	ESP-50 + fertilizer	51.5 abc	12.0 abc	29.7 abc	2.83 abcd
	Fertilizer alone	59.3 a	13.6 a	33.0 a	3.32 a
	No HA or fertilizer	54.3 ab	12.4 abc	30.3 ab	3.10 abc
Contrasts					
HA alone versus no HA or fertilizer		NS	NS	NS	NS
HA alone versus HA + fertilizer		NS	NS	NS	NS
HA + fertilizer versus fertilizer alone		**	**	**	**

[z] Mean separation by Duncan's multiple range test at $P < 0.05$.

NS, *, **Nonsignificant at $P < 0.05$ or significant at $P < 0.05$ or 0.01, respectively.

Data were analyzed using the SAS General Linear Model procedure (Version 9.1; SAS Institute, Cary, NC). Differences among treatments were further evaluated using both Duncan's multiple range test and orthogonal contrasts.

Results and Discussion

The HA products varied considerably in their chemical composition (Table 1), undoubtedly reflecting differences in leonardite deposits from which they originated, extraction techniques, and perhaps nutrient elements added (information not disclosed by the manufacturers). Although there were large differences in macronutrient content, particularly P, the implications for crop fertility were limited. At normal field application rates (typically less than 5 kg·ha^{-1} HA), nutrient availability from these products would be insignificant.

HA had no significant effect on lettuce emergence percentage or the speed of emergence in the greenhouse experiment; across treatments, emergence percentage averaged 79% with 9.7 mean days to emergence. Soils varied significantly in final emergence

Table 6. Effect of humic acid (HA) and phosphorus (P) fertilization on tomato early growth and whole plant nutrient concentration, 2008.

Treatment[z]	HA rate (kg a.i./ha)	Plant dry wt (g)	Nitrogen (g·kg^{-1})	Phosphorus (g·kg^{-1})	Potassium (g·kg^{-1})	Zinc (mg·kg^{-1})	Manganese (mg·kg^{-1})	Iron (mg·kg^{-1})	Copper (mg·kg^{-1})
Actagro humic acid	1.1	84.0 ab[y]	47.4	4.6 a	34.8	22 bc	143 a	730	15 b
Actagro liquid humus		92.8 a	45.9	4.0 b	33.7	22 c	148 a	728	15 b
Organo liquid hume		82.0 ab	45.8	3.9 b	34.9	22 bc	122 a	752	16 b
Quantum-H		92.4 a	46.4	4.4 ab	33.8	23 bc	144 a	703	15 b
ESP-50		91.2 a	46.8	4.0 b	33.7	24 bc	145 a	730	16 b
Actagro humic acid	3.4	83.6 ab	46.7	4.3 ab	34.5	23 bc	136 a	702	16 b
Actagro liquid humus		85.6 ab	47.7	4.4 ab	35.9	23 bc	144 a	742	15 b
Organo liquid hume		94.4 a	45.7	4.0 b	34.3	22 bc	134 a	749	15 b
Quantum-H		83.2 ab	47.4	4.5 a	35.7	23 bc	150 a	777	16 b
ESP-50		86.4 ab	46.1	4.0 b	35.0	23 bc	142 a	751	16 b
P alone		86.8 ab	46.3	3.9 b	34.3	25 ab	140 a	652	16 b
No HA or P		69.6 b	46.0	3.4 c	34.7	27 a	96 b	773	18 a
Contrasts									
All HA treatments versus P alone		NS	NS	NS	NS	*	NS	*	NS
All P treatments[x] versus no HA or P		**	NS	**	NS	**	**	NS	**

[z] All HA treatments include P fertilization.

[y] Mean separation within columns by Duncan's multiple range test, $P < 0.05$.

[x] Includes all HA treatments and the P alone treatment.

NS, *, **Contrasts nonsignificant at $P < 0.05$ or significant at $P < 0.05$ or 0.01, respectively.

percentage (from 72% in soil 4% to 86% in Soil 1) but not in speed of emergence.

There was a significant treatment × soil interaction in lettuce growth and P uptake, so treatment effects were evaluated separately for each soil. P fertilization strongly influenced lettuce growth in all soils (Table 3). However, only in Soil 3 did the addition of HA increase lettuce dry mass above that of P fertilization alone. In the absence on P fertilization, no HA product increased lettuce growth in any soil. Similarly, P uptake was strongly stimulated by P fertilization, but only in Soil 4 did the addition of one HA product increase P uptake over P fertilization alone; even in Soil 4, the HA products as a group did not have a stimulatory effect on P uptake.

Fertilization increased soil microbial respiration in both soils in the incubation experiment (Table 4). In the absence of fertilization, HA had no effect on microbial respiration; with fertilization, HA significantly increased microbial respiration after 7 d in the low organic matter soil (Soil 1). Microbial respiration was not enhanced by HA application in the higher organic matter soil (Soil 2).

PLFA analysis of the soil from the incubation experiment also revealed a treatment × soil interaction, so treatment effects were analyzed separately for each soil (Table 5). In the low organic matter soil (Soil 1), fertilization significantly increased total PLFA as well as those associated with fungi and bacteria. HA, either alone or in combination with fertilization, increased total PLFA and those associated with all microbial groups. However, in the higher organic matter soil (Soil 2), neither fertilization nor HA significantly increased PLFA detection. Compared with fertilization alone, the combination of HA and fertilization resulted in a small but significant decrease in PLFA.

Preplant P fertilization alone significantly increased early plant growth in the 2008 tomato field trial compared with the no P treatment, but no HA + P treatment increased growth compared with P fertilization alone (Table 6). All treatments receiving P fertilization had increased plant P concentration, but as a group, HA treatments did not increase P concentration above P fertilization alone. Compared with P fertilization alone, HA had inconsistent effects on plant micronutrient concentration, increasing iron but decreasing zinc. The concentration of all micronutrients in all treatments was sufficient for maximum growth based on the standards given by Jones et al. (1991). Although no individual treatment was significantly higher-yielding than the no HA or P treatment, as a group, the P-fertilized treatments significantly increased both total and marketable fruit yield (Table 7). HA treatments did not increase fruit yield above P fertilization alone. Neither P fertilization nor HA affected fruit soluble solids concentration.

P fertilization, whether alone or with HA, significantly increased early plant growth and leaf P and N concentration compared with the no HA or P treatment (Table 8). However, the addition of HA to the P fertilizer had no significant effect on early growth or the concentration of any nutrient. Although early growth was P-limited, by the end of the season, there were no significant P fertilization or HA effects on tomato yield or fruit soluble solids concentration, which averaged 102 Mg·ha^{-1} and 5.5 °Brix, respectively, across treatments.

This study found soil application of commercial HA products to be generally ineffective in improving plant growth with positive response in lettuce observed in only one of four soils and no measurable effect on tomato seen in either year. This lack of beneficial effects of soil application of HA agreed with the results of Feibert et al. (2003) and Duval et al. (1998). These results were also consistent with the conclusions drawn by Chen et al. (2004) in their recent review of the use of HS in agriculture. They concluded that although HS can affect plant productivity through a variety of mechanisms, soil application of commercial humic products at typical use rates is unlikely to elicit a significant agronomic response. They based this conclusion on the observation that across numerous nutrient solution studies, the concentration of HS required to stimulate plant growth was typically in the range of 75 mg·L^{-1}. Applying that analogy to field soils,

Table 7. Effect of humic acid (HA) and P fertilization on tomato fruit yield and quality, 2008.

Treatment[z]	HA rate (kg a.i./ha)	Total fruit yield (Mg·ha^{-1})	Mkt. fruit yield (Mg·ha^{-1})	Fruit soluble solids (°Brix)
Actagro humic acid	1.1	122	117	5.58
Actagro liquid humus		119	113	5.54
Organo liquid hume		121	119	5.42
Quantum-H		118	111	5.58
ESP-50		117	113	5.50
Actagro humic acid	3.4	113	109	5.46
Actagro liquid humus		124	117	5.44
Organo liquid hume		124	121	5.52
Quantum-H		120	116	5.54
ESP-50		125	120	5.54
P alone		124	119	5.62
No HA or P		112	107	5.42
		NS	NS	NS
Contrasts				
All HA treatments versus P alone		NS	NS	NS
All P treatments[y] versus no HA or P		*	*	NS

[z] All HA treatments include P fertilization.

[y] Includes all HA treatments and the P alone treatment.

NS, *Nonsignificant at $P < 0.05$ or significant at $P < 0.05$.

P = phosphorus.

Table 8. Effect of humic acid (HA) and phosphorus (P) fertilization on tomato early growth and leaf nutrient concentration, 2009.

Treatment[z]	HA rate (kg a.i./ha)	Plant dry wt (g)	Nitrogen (g·kg^{-1})	Phosphorus (g·kg^{-1})	Potassium (g·kg^{-1})	Zinc (mg·kg^{-1})	Manganese (mg·kg^{-1})	Iron (mg·kg^{-1})	Copper (mg·kg^{-1})
Actagro humic acid	1.1	19.3 a[y]	56.4	6.2 b	23.9	28	102	772	18
Actagro liquid humus		22.1 a	55.8	6.1 b	23.8	27	100	687	18
Organo liquid hume		20.5 a	56.2	6.4 b	24.2	27	105	724	18
Quantum-H		19.8 a	56.8	6.3 b	23.9	27	107	758	18
ESP-50		22.2 a	56.5	6.2 b	23.8	27	95	787	19
Actagro humic acid	3.4	20.5 a	56.0	6.3 b	24	28	105	881	19
Actagro liquid humus		22.7 a	56.5	6.7 b	24.5	27	106	769	18
Organo liquid hume		22.5 a	56.6	6.2 b	23.9	28	98	737	21
Quantum-H		21.7 a	56.2	6.4 b	24.2	27	108	740	18
P alone		21.8 a	57.2	6.8 ab	23.9	26	106	753	18
No HA or P		15.5 b	54.5	4.3 c	23.7	27	102	757	19
Contrasts									
All HA treatments versus P alone		NS	NS	NS	NS	NS	NS	NS	NS
All P treatments[x] versus no HA or P		**	**	**	NS	NS	NS	NS	NS

[z] All HA treatments included P fertilization.

[y] Mean separation within columns by Duncan's multiple range test, $P < 0.05$.

[x] Includes all HA treatments and the P alone treatment.

NS, *, **Contrasts nonsignificant at $P < 0.05$ or significant at $P < 0.05$ or 0.01, respectively.

it would take in excess of 50 kg·ha^{-1} a.i. of HS to reach that concentration in the root zone soil solution. Typical soil application rates for commercial HA products are less than 5 kg·ha^{-1} a.i. and commonly only 2 to 3 kg·ha^{-1}. A prime constraint of HA application rate is cost; Feibert et al. (2003) listed the cost of liquid HA products at $8 to $15/kg a.i.

Even at such low use rates, banded application of HA creates zones of higher concentration. In the incubation study, we mimicked a banded application of 2.2 kg·ha^{-1} a.i. with a resultant soil solution concentration of 80 mg·L^{-1} HA. In the low organic matter soil, that HA concentration was sufficient to enhance microbial activity, at least in the short term (the study ended after 7 d). The HA applications in the greenhouse and field studies were also banded, but there was an important difference. A considerable period of time elapsed between soil application and the establishment of a substantial root system, time in which irrigation would have diluted the HA concentration.

Beyond the issue of HA application rate, other important factors may limit agronomic benefit from HA application to agricultural soils. In nutrient solution studies, plant growth response to HS tended to peak at less than 100 mg·L^{-1} (Chen and Aviad, 1990). Native soil dissolved organic matter (DOM), which can perform some of the same functions as applied HA (Chen et al., 2004), may be present at sufficient concentration to minimize or negate any benefit of applied HA. Although DOM may be less than 30 mg·L^{-1} in very low organic matter soils (Chen and Katan, 1980), in higher organic matter soils, DOM may reach 400 mg·L^{-1} (Chen and Schnitzer, 1978). This may explain the lack of positive benefits of HA in the higher organic matter soil in the incubation study and why reports of beneficial effects of HA in field trials have been limited to low organic matter soils (Fagbenro and Agboola, 1993; Kunkel and Holstad, 1968; Lee and Bartlett, 1976).

Finally, some potential benefits of HA are of practical significance only in a minority of fields. Consider enhanced micronutrient uptake, a commonly reported benefit of HA in nutrient solution studies (Chen and Aviad, 1990; Varanini and Pinton, 1995). Growth-limiting micronutrient deficiencies are rare in California vegetable fields; for example, in a survey of 78 lettuce fields (Hartz et al., 2007), only one field had tissue zinc concentration below the established sufficiency level, and no fields had deficient tissue levels of manganese or iron.

In summary, commercial HA formulations can be biological active when applied to representative field soils. However, at typical application rates, significant improvements in vegetable crop nutrient uptake or productivity are unlikely.

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