Research Reports

Soil Amendment with Different Peatmosses Affects Mycorrhizae of Onion

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Summary. **Formation of arbuscular mycorrhizae (AM) has been inhibited in soilless potting mixes that usually contain some proportion of peat moss. The cause of the inhibition has been thought to be high fertilizer P content in the media that suppresses spread of the fungal symbiont in the root tissue. However, there has also been some suggestion that the peats themselves may contribute to the inhibition. That possibility was explored in this study. A sandy-loam soil, in which mycorrhizae consistently enhance plant growth under P-limiting conditions, was amended with six different peats. Onions (*Allium cepa* 'White Lisbon'), as an indicator host, were grown in the mixes under P-limiting conditions, and were inoculated or not with the AM fungi *Glomus deserticola* or *Gigaspora rosea*. Plant growth response to inoculation with AM fungi (AMF) varied with the type of peat and AMF isolate. Inoculated plants generally had the highest root biomass when grown in soil amended with peat. Root colonization by the two fungal symbionts was also affected differently by different peat amendments. Root colonization by *Glomus deserticola* and *Gigaspora rosea* was inhibited by at least half of the peat types. However, the types of peat inhibitory to *Gigaspora rosea* colonization were not the same as those inhibitory to *Glomus deserticola* colonization. These results indicate that different peat amendments can suppress or enhance mycorrhiza formation on onion roots and resultant growth benefit under P-limiting conditions, depending on the mycorrhizal fungus used.**

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The ability of arbuscular-mycorrhizal fungi [also known as vesicular–arbuscular mycorrhizal (VAM) fungi] to colonize roots and enhance growth in diverse horticultural potting media has been well documented (Biermann and Linderman, 1983; Caron et al., 1985; Maronek et al., 1981; Matsubara et al., 1995; Menge et al., 1982; Plenchett et al., 1982; Snellgrove and Stribley, 1986). However, determining the optimal combinations of growth medium, host plant, and fungal isolate requires continual investigation. Nemec (1992) studied the effects of various potting media commonly used for citrus (*Citrus* spp.) seedling establishment on AMF, and Datnoff et al. (1991) evaluated the effects of many commercial vegetable potting mixes on *Glomus intraradices* activity and tomato (*Lycopersicon esculentum*) growth. In both studies, different mixes either favored or suppressed mycorrhiza formation due to differences in composition and/or fertilizer supplementation.

The wide range of potting mixes may contain primarily mineral soil amended with various types and amounts of organic substances, or more likely may be comprised totally of soilless materials, such as vermiculite, peat, compost, perlite, and bark. Many commercial mixes are further supplemented with fertilizers.

Generally, most research has supported the theory that higher levels of organic matter (Menge et al., 1982) and fertility (Biermann and Linderman, 1983) in potting mixes will decrease mycorrhizal colonization and function. The inhibitory impact of the mixes may be due to high soluble P, ammonium, fertilizer salt levels, and the acidity of peats. However, peat is often the dominant component of many mixes, and its specific characteristics may have a significant influence on AMF. Biermann and Linderman (1983) reported that the type of sphagnum peat was not a significant factor on root colonization by AMF unless the medium was 100% peat. Adding 25% soil or sand reduced the inhibitory effect. In contrast, 100% hypnum peat was less inhibitory than the sphagnum peats, apparently due to its different capacity to bind or chelate nutrients. Preliminary trials by us using four AMF isolates indicated that there could be specificity in the interactions of the fungal isolates, peat type, and level of peat amendment to the medium.

The objective of the present study was to determine if different peat mosses would have different, possibly inhibitory, effects on the establishment and performance of arbuscular mycorrhizae. We amended a sand-loam mixture with three rates of sphagnum or hypnum peats from six different sources, inoculated each mixture with each of two AMF species, and bioassayed mycorrhiza formation and growth response using onions. Based on our many experiments and the published literature, onions benefit significantly from mycorrhizae under the P-limiting test conditions, and thus

are good indicators with which to examine interactions between peat type, level of amendment, and AMF isolate.

Materials and methods

The soil medium used in the study was an uncultivated Willamette Valley alluvial loam mixed 1:1 by volume with river sand. This mix contained low available Bray I P [12 mg·kg^{-1} (ppm)] and 0.13 g·kg^{-1} (1.3%) organic matter, and had a pH of 6.3 (2:1 water supernatant). Soil was air-steam pasteurized at 70 °C (158.0 °F) for 1 h to eliminate any indigenous mycorrhizal or pathogenic fungi.

The peats used in the study were mainly sphagnum- or hypnum-based, and were obtained from different bog/swamp deposits. These included 1) a hypnum peat from Mt. Peco, Mont. (Peco); 2) a hypnum peat from Washington (Bonaparte; Bonaparte Peat, Tonasket, Wash.); 3) a sphagnum peat for potting mixes (Sunshine; SunGro Horticulture, Bellevue, Wash.); 4) a hypnum peat from Indiana (Indiana); 5) a sphagnum peat from Manitoba, Canada (Manitoba); and 6) a hypnum/sphagnum mixed peat from North Dakota (North Dakota).

All peats were air-dried and passed through a 2-mm (0.08-inch) sieve before mixing with the 1 loam : 1 sand mix. Each unsterilized peat was mixed into the base soil at rates of 10%, 20%, or 30% (by volume) in a twin-shell dry blender for 5 min. Inocula for the mycorrhiza treatments were also mixed in with the peat x soil treatments in the same process, with adjustments made to equalize inoculum potential by varying inoculum quantity.

Two mycorrhizal fungi and a nonmycorrhizal control comprised the mycorrhiza treatments. *Gigaspora rosea* inoculum was obtained from the International Culture Collection of Arbuscular and Mycorrhizal Fungi (INVAM), Morgantown, W.V. (culture ID# BR151). This AM fungus was selected because of its isolation from a highly organic tropical soil. *Glomus deserticola* inoculum was an in-house culture, originally isolated from a southern California field site. Both fungi were propagated on 'White Lisbon' bunching onions grown in 1 loam : 1 sand (by volume) under greenhouse conditions for 5 months. Inoculum for the study consisted of a mixture of the loam–sand, extraradical hyphae and spores, and colonized onion root segments. Nonmycorrhizal control inoculum was cultured similarly, without the presence of AMF. Propagule numbers were determined for each inoculum by the Most Probably Number method (Woomer, 1994), and inoculum quantities sufficient to provide 100 propagules per plant container were added to the peat:soil treatments.

Plastic tubular Super-Cell containers (Stuewe and Sons, Inc., Corvallis, Ore.) were filled to near capacity with 160 cm^3 (9.8 inch^3) of soil mix from each treatment and lightly misted with water. Three onion seeds were planted in each container, and covered with another 20 cm^3 (1.2 inch^3) of soil mix. A final misting with water wet the seed and soil profile.

Root washings from the pot cultures were applied to all containers, after being passed through a 38-µm (Tyler equivalent 400-mesh) sieve and Whatman #1 filter paper. Each container received 20 mL (0.68 fl oz) of filtrate from the combined sievings of all mycorrhizal and nonmycorrhizal pot cultures to standardize the rhizosphere microflora in all treatments.

After seed germination and seedling establishment, plants were watered according to need rather than on a preset schedule. Long Ashton Nutrient Solution (Hewitt, 1966) was applied weekly with P limited to half-strength (20 mg·kg^{-1}). Water or fertilizer was applied to each plant in equal amounts. Onions were thinned to one per container 2 weeks after emergence (about 3 weeks after seeding). Greenhouse controls were set to maintain 23/18 °C (73.4/64.4 °F) day/night temperatures, and supplemental lighting by high-pressure multivapor lamps supplied an average of 550 µmol·s^{-1}·m^{-2} (at container level) for 14-h daylengths.

Growth responses were assessed 10 weeks after seedling emergence. All roots were washed and cut from the bulb-shoots. The washed roots were blot-dried on paper towels, weighed and sub-sampled for microscopic evaluation of root colonization by AMF. The remaining root systems and bulbs/shoots were oven-dried at 70 °C for 48 h, and weights were obtained for all dried plant material.

Portions of roots sampled for mycorrhiza evaluation were cut into 1-cm (0.39-inch) segments, then cleared and stained by a modified Phillips and Hayman (1970) procedure in which lacto-phenol was replaced with lacto-glycerin. Fungal colonization in roots was determined by observing the stained root segments using the grid-line intersect method (Giovannetti and Mosse, 1980). Percentage of roots colonized by AMF was determined based on the presence or absence of vesicles and/or arbuscules in 100 root intersections per root sample.

Soils amended with the different peats were analyzed at the start of the

Table 1. Extractable nutrient levels for a sand–loam soil mixture amended with six different peats at a 20% (by volume) amendment rate.

Peat[z]	pH	P[y]	K	Ca	Mg	Na	CEC
		(mg·kg^{-1})[x]		(cmol·kg^{-1})[x]			
None	6.3	12	74	7.8	3.6	0.2	12.0
Peco	6.4	11	74	9.7	3.7	0.2	15.3
Sunshine	6.4	9	74	8.0	3.5	0.2	13.6
Bonaparte	6.2	10	74	10.2	3.7	0.3	15.6
North Dakota	6.3	11	70	9.8	4.1	0.3	14.7
Manitoba	5.9	11	74	8.2	3.7	0.2	15.0
Indiana	6.2	10	74	11.5	4.0	0.3	17.4

[z]None = unamended 1 sand : 1 loam mix; Peco = hypnum peat from Mt. Peco, Mont.; Sunshine = Sunshine sphagnum peat for potting mixes (SunGro Horticulture, Bellevue, Wash.); Bonaparte = Bonaparte 50 hypnum : 50 sphagnum peat (Bonaparte Peat, Tonasket, Wash.); North Dakota = hypnum/sphagnum mixed peat from North Dakota; Manitoba = sphagnum peat from Manitoba, Canada; Indiana = hypnum peat from Indiana.
[y]P = plant-available P (Bray I), CEC = calculated cation-exchange capacity, TN = total N.
[x]1.0 mg·kg^{-1} = 1.0 ppm, 1.0 cmol·kg^{-1} = 1.0 meq/100 g, 1.0 g·kg^{-1} = 0.1%.

study for nutrient content by the Soil Testing Laboratory at Oregon State University. Extractable P was analyzed by the Bray dilute acid-fluoride method. Extractable K, Ca, Mg, and Na, and calculated cation exchange capacity (CEC) were determined with atomic absorption spectrophotometry following extraction with ammonium acetate. Other extractable nutrient levels were determined by routine methods of the laboratory (Berg and Gardner 1978). The nutrient levels for the base soil medium amended with the various peats at the 20% (by volume) amendment rate are listed in Table 1.

All treatments were replicated 8 times in a randomized complete block design. Treatments were arranged as a factorial with mycorrhizal treatment (M), peat amendment (PA), and rate of amendment as factors. Dry weights of shoots and roots were square-root transformed, and the percentage of roots colonized by AMF were arcsin transformed to correct for unequal variance and best model fit. Data were subjected to analysis of variance (Systat 8.0; SPSS, Inc., Evanston, Ill.), whereby the rate effect was determined to be insignificant at $P < 0.05$, and removed as a factor in the model. Comparisons between groups of treatments are based on orthogonal contrast probabilities, and data are expressed as averages (transformed back to original units) over replications by rates.

Results

Root colonization by the mycorrhizal fungi was significantly influenced by the presence of peat, being inhibited in the majority of peats examined, compared with the nonamended soil base (Table 2). Differences in root colonization occurred between *Glomus deserticola* and *Glomus rosea* for different peats, contributing to a highly significant interaction ($P \leq 0.001$). All noninoculated onion roots were free of any signs of AMF colonization.

Peat amendment to sandy loam significantly influenced onion biomass both as a factor alone (PA) and interactively with M (Table 2). Shoot biomass of nonmycorrhizal onions was not significantly increased when peats were added, while root biomass was significantly reduced. Mycorrhizal onions responded differently to peat amendments, depending upon the fungal isolate. *Glomus deserticola*-inoculated plants grown in soil amended with peat had significantly reduced shoot weights but increased root weights, compared to nonamended soil. However, *Glomus rosea*-inoculated plants did not follow this pattern, and were less affected by the addition of peat (Table 2).

Individual peats increased or decreased onion biomass in conjunction with a particular AM treatment. Mycorrhizal onions grown in soil amended with Manitoba peat had lower shoot and root biomass relative to other peats, regardless of the AMF species, whereas the corresponding nonmycorrhizal plants had some of the highest growth compared to amendment with other peats.

In general, root weights of onions inoculated with either AMF isolate were substantially greater when grown in Peco, Bonaparte, and Indiana peats (52% to 80%). compared to nonamended soil.

Analyses of nutrient levels of peat:soil mixes (Table 1) generally did not show any pronounced differences between types of peat amended to the sandy loam base. Ammonium and nitrate-forms of nitrogen fluctuated with various peats, while iron and manganese levels were slightly elevated when peats were present. Iron was distinctly elevated in some peat mixes (33% to 362% increase). However, the variability in the levels of nutrients did not indicate trends that related to data.

Discussion

The organic matter content in nursery container potting mixes is thought to suppress AM establishment and function. The exact components of the mixes that contributed to this inhibition, however, had not been clarified. Menge et al. (1982) determined that the organic matter content in the medium or soil above a certain level influenced mycorrhiza establishment and effectiveness on citrus, especially in nursery potting mixes. They were not able to implicate any component of the mixes as the inhibiting agent, however. Biermann and Linderman (1983) suggested that the poor nutrient-holding capacity of potting mixes with high peat content necessitates the use of high rates of plant fertilization that results in high concentrations of P in the soil solution that inhibited AMF. Adding soil or river sand (including silt) or other nutrient-binding materials to the mixes largely negated the effect. This effect was also related more to sphagnum than hypnum peats (with high humic content) where P-retaining properties of the latter are more soil-like.

The study of different potting mixes by Datnoff et al. (1991) suggested that inhibition of *Glomus intraradices* in some mixes was the result of the fertilizer charge incorporated in the mix. The possibility that some peats in those mixes might have some inherent inhibitory capacity on mycorrhiza establishment

TN	NH_4-N	NO_3-N	Fe	Mn	Cu	Zn
$(g \cdot kg^{-1})^x$			$(mg \cdot kg^{-1})^x$			
3.0	9.4	5.7	80	4.8	1.6	0.7
1.0	2.8	13.4	106	7.1	1.6	1.0
0.5	10.2	2.6	110	7.8	2.0	0.8
1.2	3.1	13.5	152	7.9	1.9	0.9
0.9	8.1	12.2	82	4.0	1.5	0.8
0.6	14.9	2.5	136	13.0	1.9	0.9
1.3	3.5	11.2	370	7.4	1.8	1.1

was not considered. We considered that possibility in this study, and demonstrated that different peats do indeed have some deleterious effect on mycorrhiza formation and on the potential for mycorrhiza-induced plant growth enhancement under P-limiting conditions. The nature of the inhibitory factor, however, remains unknown.

A further finding in this study is that different peats interact differently with different mycorrhizal fungi. A reduction in AMF colonization level usually resulted in reduced plant growth, but not always. A reduction in intraradical colonization by an AMF may not reduce its effectiveness in P uptake if the fungus compensates by producing more extraradical hyphae in the soil. We did not measure extraradical hyphae in this study, but there is reason to suspect that soil or medium factors could have restricted their development (Graham et al., 1982).

Many factors could reduce either intraradical or extraradical hyphal development, including nutrient levels or nutrient-holding properties of the medium, other chemical factors in the soil mixes, or biological factors in the soil mixes. We measured the extractable nutrient levels in the various soil–peat mixtures in this study and found no striking variation in pH (except it was lower in Manitoba peat than any of the other peats) or nutrient elements from the base soil without peat amendment, except possibly the high Mn level in Manitoba peat and the varied levels of ammonium-N and nitrate-N as well as Fe content among the various soil-peat mixtures. We did not evaluate differences in microbial content of the various peats, although some could have contained mycorrhiza-suppressive microbes.

The myriad of AMF isolates now documented and catalogued in repositories throughout the world is testimony to the fact that AM fungi retrieved from diverse soil environments may have evolved specificity for characteristics of the site of origin. An isolate may perform efficiently when inoculated into a medium with chemical characteristics similar to its indigenous environment, be it of low or high fertility, but it may become inactive or suppressed when subjected to inherently adverse characteristics (Abbott and Robson, 1978; Davis et al., 1985). Because it is not always possible to ascertain a pot-cultured isolate's indigenous soil environment, the isolates tested in many documented studies realistically may not be suited to the growth medium used. Thus, there is continued need to examine the interactions of growth media, plant hosts, and AMF isolates. While we only examined two AMF isolates in this study, we demonstrated variation in their behavior in a mycorrhiza-conducive soil medium amended with different peatmosses, but no differences in their ability to colonize and enhance growth of onions. The results underscore the potential for different fungi in different media to behave differently.

Table 2. Plant biomass and root colonization (C) of 'White Lisbon' onion grown in a sandy loam base as affected by arbuscular mycorrhizal fungal inoculation and peat amendment (PA).

Mycorrhiza treatment (M)[z]	PA[y]	Shoot dry wt[x] (g/plant)	Root dry wt[x] (g/plant)	C (%)
–AM	None (NPA)	0.041	0.024	---
	Peco	0.058	0.023	---
	Sunshine	0.043	0.020	---
	Bonaparte	0.078	0.031	---
	North Dakota	0.052	0.018	---
	Manitoba	0.084	0.023	---
	Indiana	0.067	0.020	---
Glomus deserticola (Gd)	None (NPA)	0.534	0.046	57.1
	Peco	0.507	0.070	59.0
	Sunshine	0.404	0.058	34.4
	Bonaparte	0.479	0.071	52.5
	North Dakota	0.492	0.067	29.7
	Manitoba	0.341	0.058	52.3
	Indiana	0.494	0.083	27.8
Gigaspora rosea (Gr)	None (NPA)	0.503	0.045	51.1
	Peco	0.602	0.065	45.1
	Sunshine	0.443	0.061	49.4
	Bonaparte	0.547	0.064	64.0
	North Dakota	0.365	0.054	29.3
	Manitoba	0.347	0.044	39.5
	Indiana	0.505	0.065	50.1
Analysis of variance (P)				
M		<0.001	<0.001	0.509
PA		<0.001	<0.001	<0.001
M × PA		<0.001	0.008	<0.001
MSE		0.014	0.002	0.005
Contrasts (P)				
–AM:NPA vs. all PA		0.386	0.001	<0.001
Gd:NPA vs. all PA		0.002	0.002	<0.001
Gr:NPA vs. all PA		0.184	0.049	<0.001
+PA:-AM vs. (Gd+Gr)		<0.001	<0.001	---
+PA:Gd vs. Gr		0.527	0.165	<0.001
NPA:-AM vs. (Gd+Gr)		<0.001	<0.001	---
NPA:Gd vs. Gr		0.367	0.877	<0.001

[z]Mycorrhiza treatment = M; treatment without inoculation = –AM, or inoculation with two fungal isolates = Gd or Gr.
[y]NPA = 1 sand : 1 loam mix without peat amendment; Peco = hypnum peat from Mt. Peco, Mont.; Sunshine = Sunshine sphagnum peat for potting mixes (SunGro Horticulture, Bellevue, Wash.); Bonaparte = Bonaparte 50 hypnum : 50 sphagnum peat (Bonaparte Peat, Tonasket, Wash.); North Dakota = hypnum–sphagnum mixed peat from North Dakota; Manitoba = sphagnum peat from Manitoba, Canada; Indiana = hypnum peat from Indiana.
[x]Each mean calculated from 24 observations (8 replications × 3 rates). MSE = mean square error term derived from analysis of variance. Em dashes indicate data or analysis not applicable (1.000 g = 0.0353 oz).

In summary, many factors can come into play when artificial media, especially soilless media, are prepared with the expectation that inoculation with mycorrhizal fungi would be successful in benefiting plant growth and health. This study demonstrated that all peats are not equal in physical, chemical, and biological ways, so one could not predict the outcome of mycorrhizal inoculations into media with peat variation. From our study, some appear to have deleterious effects on mycorrhizae establishment and function, independent of fertilizer supplementation as is seen in

many commercial mixes. Development of management strategies to compensate for those possible deleterious effects from the use of peats will require further research.

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Ferric Ethylenediaminetetraacetic Acid Photodegradation in a Commercially Produced Soluble Fertilizer Affects Iron Uptake in Tomato

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Additional index words. plant nutrition, iron chelate, FeDTPA, photochemistry

Summary. Irradiating a ferric ethylenediaminetetraacetic acid (FeEDTA)-containing commercially available soluble fertilizer with ultraviolet (UV) and blue radiation from high intensity discharge (HID) lamps caused the photooxidation of the FeEDTA complex, resulting in the loss of 98% of soluble iron. The loss of soluble iron coincided with the development of a precipitate that was mostly composed of iron. The effects of using an irradiated FeEDTA-containing fertilizer solution on plant growth and nutrition under commercial conditions were studied. Application of the irradiated fertilizer solutions to greenhouse grown tomato plants (Lycopersicon esculentum) resulted in lower levels of iron (6%) and zinc (9%), and higher levels of manganese (8%) and copper (25%) in leaf tissue compared to control plants that received a nonirradiated fertilizer solution. Leaf macronutrient levels (phosphorous, potassium, calcium, and magnesium), leaf dry weight, leaf number, and plant height was not affected by application of the irradiated fertilizer solution.

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The application of soluble fertilizers in greenhouse plant production is necessary to maintain plant growth under optimal environmental conditions. To supply Fe, Mn, Cu, and Zn in a soluble form, these metals are often chelated in the fertilizer solution with EDTA [also DTPA (diethylenetriamine-pentaacidic acid), EDDHA (ethylenediaminedi-o-hydroxyphenylacetic acid), and/or HEDTA (hydroxyethylenediaminetriacetic acid) for Fe]. Iron chelates are chromophores (i.e., chemical compounds that absorbs light/colored chemical compounds) that absorb strongly in the UV and blue regions of the spectrum. Absorption of this energy causes the photodegradation (photooxidation) of the Fe-chelate complex (Hamaker, 1956). The chelating agent EDTA when complexed with Fe and exposed to UV and blue radiation, photooxidizes into gloxylic acid, carbon dioxide (CO_2), formaldehyde, and amine residue(s) (Frissel et al., 1959; Hamaker, 1956). In previous studies, photodegradation of FeEDTA- or FeDTPA-containing nutrient solutions resulted in the loss of soluble Fe and the formation of a precipitate that was mostly composed of Fe (Albano and Miller 2001a, 2001b). Marigolds (*Tagetes erecta*) grown hydroponically in an irradiated FeDTPA-containing nutrient solution had lower levels of Fe and higher levels of Mn in leaf tissue, and greater root-associated ferric-chelate reductase activity than in plants grown in a nonirradiated nutrient solution (Albano and Miller, 2001c). An enhanced ability of roots of dicots and nongraminaceous monocots to reduce ferric chelates when Fe is unavailable in the rhizosphere is a physiological trait associated with strategy I Fe efficiency (Bienfait, 1988). The effects, however, of using a commercially available Fe-chelate-containing fertilizer solution that has been irradiated on greenhouse plant production under commercial-type conditions is unknown. Therefore, the objective of this study was to determine under commercial-type conditions the effects of an irradiated FeEDTA fertilizer solution on leaf nutrient levels and plant growth.

Materials and methods

TREATMENTS. Plantex Florida Special [20–10–20 (20N–4.3P–16.6K); Plantex Corp., Brampton, Ontario, Canada] water-soluble fertilizer was prepared as a 100× stock solution based on a 1× concentration of 200 mg·L^{-1} (ppm) N by dissolving one 11.3-kg (25 lb) bag of dry fertilizer into 114.4 L (30.22 gal) of distilled-deionized (DDI) water. After thoroughly mixing, 5 L (1.3 gal) of the 100× fertilizer solution was poured into a 50-L (13.2-gal) Nalgene low-density polyethylene (LDPE) carboy (Nalgene Co., Rochester, N.Y.), brought to volume with DDI water (yielding a 10× fertilizer solution), mixed, and then divided into two 25-L (6.6-gal) LDPE Nalgene carboys. Fertilizer solutions (25 L) were irradiated or nonirradiated for 15 d with 1400 μmol·m^{-2}·s^{-1} (400 to 700 nm), 24 μmol·m^{-2}·s^{-1} (250 to 400 nm) measured at the external container surface with a radiometer–quantum sensor (LI-250; LI-COR, Lincoln, Nebr.) and UV meter (Apogee Instruments Inc., Logan, Utah), respectively. Carboys were placed on their sides for irradiation and nonirradiated containers were covered with aluminum foil. Irradiance intensity was varied by adjusting lamp-bank distance from solution containers. The radiation source was a combination of 400-W HID metal halide (Sylvania M400/U; OSRAM Sylvania LTD, Danvers, Mass.) and high-pressure sodium lamps (Sylvania LU400) (one lamp of each type above each container). The study was conducted in a controlled environment growth chamber and solution temperature was maintained at 20 °C (68.0 °F) by adjusting air temperature. Treatments derived from the irradiated and nonirradiated fertilizer solutions consisted of two unaltered solutions: 1) nonirradiated (NI) and 2) irradiated with precipitate (that formed when solution was irradiated) remaining in solution (I+P); and one altered solution: irradiated with precipitate removed (I–P) by centrifugation as previously described (Albano and Miller, 2001a). Elemental concentration [(P, K, Fe, Mn, Cu, and Zn) determined by ICP (inductively coupled argon plasma-atomic emission spectrometry)], and pH of the 1× NI and I–P treatment solutions are presented in Table 1. FeEDTA was qualitatively measured in the NI and I–P fertilizer solutions (10× concentration) spectrophotometrically at 258 nm (the wavelength that FeEDTA maximally absorbs) (Hill-Cottingham, 1957).

GROWING CONDITIONS. 'Florida 91' tomato seeds were sown in Fafard 4P soilless medium (Fafard Inc., Anderson, S.C.) in six-celled grow packs [40 cm^3 (2.4 inch^3) per cell, three seeds per cell, 30 Apr. 2001)] in a greenhouse at the U.S. Horticultural Research Laboratory, Fort Pierce, Fla. with a heating/venting temperature of 16/27 °C (60.8/80.8 °F), respectively. A pack of six plants constituted a single replication and six replications of each treatment (NI, I+P, and I–P) were made. Plants were thinned to one plant per cell at the emergence of cotyledons, and treatments were initiated 19 d after sowing when the first leaf was expanding. Treatment solutions were prepared from the 10× fertilizer stock solutions previously described with DDI water, and were applied [325 mL (11.0 fl oz)] per six-cell grow pack every other day, avoiding any application to foliage. Carboys containing treatment solutions were agitated prior to drawing 325 mL of solution for application to grow packs. A total of seven treatment applications were made to plants in grow packs with treatment applications 1 to 4 and 5 to 7 formulated as 0.5× (100 mg·L^{-1} N) and 1× (200 mg·L^{-1} N) solutions, respectively. Leaching fraction averaged 25% over the course of the study. Thirteen days after initiating treatments (32 d after sowing), five of the six plants per grow pack were randomly selected for harvest. At harvest, leaf number and stem length (measured from cotyledon node to apical meristem) were recorded. Leaves were harvested, washed, dried, dry weight recorded, and prepared for elemental analysis by ICP as described previously (Albano et al., 1996). The study was repeated with the following modifications: 1) treatments were initiated 15 days after sowing (seeds were sown on 9 July 2001), and 2) DDI water (325 mL) was applied to grow packs on days 9 and 11 after initiating treatments to prevent wilting. The average greenhouse min/max temperatures over the course of the initial and repeat experiments were 22/30 °C (71.6/86.0 °F) and 23/30 °C (73.4/86.0 °F), respectively.

MEDIUM ANALYSIS. Soluble minerals in Fafard 4P medium were determined by ICP on the extract obtained using a modified 1:2 dilution method as described by Lang (1996). Medium [200 cm^3 (12.2 inch^3)] from a newly opened bag of medium was diluted with 400 mL (13.5 fl oz) of DDI