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Nutritional Stresses in Tomato Genotypes Grown under High-pressure Sodium Vapor Lamps

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Abstract. **Three genotypes ('Heinz 1350', neglecta-1, yellow-green-5) of tomato (*Lycopersicon esculentum* Mill.) were grown during winter under natural light or with natural light supplemented with light from high-pressure sodium vapor (HPS) lamps (200–400 $\mu mol \cdot s^{-1} \cdot m^{-2}$). The plants were grown in sand culture with NO_3^- or NH_4^+ nutrition. Symptoms resembling Ca, Mg, K, and P deficiencies developed on the foliage of plants exposed to radiation from HPS lamps. Clustering of short branches in the lateral and terminal growing regions (*yg*-5) and epinasty ('Heinz 1350' and *neg*-1) developed on the shoots receiving HPS irradiation. Ethylene evolution by the three genotypes was enhanced by the supplemental lighting and NH_4^+ nutrition. Concentrations of Ca, Mg, K, and P in the shoots were lower in plants receiving HPS irradiation than in plants grown under natural light. Dry weights of shoots were increased by supplemental lighting relative to the weights of the plants receiving only natural light. Total accumulation of Ca, Mg, K, and P was not suppressed by HPS lighting, indicating that the phytotoxic effects of the lamps was not due to their effects on total nutrient accumulation.**

The intensity and duration of sunlight are inadequate for greenhouse production of many horticultural crops during the winter months in northern climates. Electric lamps extend the day length and increase the photosynthetic photon flux density (Boivin et al., 1987; Cathey and Campbell, 1977, 1979, 1980; Koontz and Prince, 1986; Koontz et al., 1987; Tibbitts et al., 1983).

Coinciding with our use of HPS lamps to start seedlings and to maintain vigorous growth in relatively large plants of 'Heinz 1350' tomato, developmental aberrations resembling nutrient deficiencies were observed. Lower leaves of these plants became purple then yellowed, withered, and abscised in a manner characteristic of P deficiency. Upper leaves rolled or cupped giving symptoms commonly observed in Ca-deficient plants. Other symptoms resembled Mg deficiency (mottling, interveinal chlorosis) and K deficiency (marginal and interveinal necrosis). None of these symptoms could be corrected by fertilization with the elements considered to be lacking. Plants removed from HPS lighting gradually recovered from the injury in several weeks.

Under the HPS lamps, a yellow-green mutant of tomato (*yg*-5) (Clayberg et al., 1966) developed abnormally in the terminal and lateral growing regions of the shoots where a clustering of growing points with diminished stem elongation occurred. Necrosis in the clusters were symptomatic of Ca deficiency. These plants recovered if moved to a location away from the HPS radiation.

Our objective was to determine whether the growth aberrations were a phytotoxic response to the irradiation or if they developed from nutrient deficiencies induced by the HPS lamps.

We selected three tomato genotypes, 'Heinz 1350', *yg*-5, and neglecta-1 (*neg*-1) (Stubbe, 1957), because of their variations in tolerance to NH_4^+ and capacities to accumulate K^+ (Barker and Lachman, 1986; Maynard et al., 1966) and the observed responses to HPS lighting. In a glasshouse, seedlings were started under natural light with one transplanting in 1 peat : 1 vermiculite (v/v). These seedlings were transplanted, one per pot, to 1.5 kg of unbuffered quartz sand in 15-cm-diameter (0.9 liter) plastic pots. At the 10-leaf stage, the potted plants were continued under natural light or were transferred to natural light supplemented with HPS lamps. Under both light regimes, plants were grown in sand culture with N supplied as 0.015 M NO_3^- or NH_4^+ in modified Hoagland's solutions (Barker et al., 1966). Nutrients were applied daily by surface irrigation to percolate through the medium. The experimental design was a split-plot with four randomized complete blocks. Lighting regime was the whole-plot factor, and N source and genotype were subplot factors.

The lamps were 1000-W HPS in concave, reflective fixtures (Sylvania Lumalux S52 lamps in MG-1000 HPS fixture, GTE Products Corp., Fall River, Mass.). The irradiance from the lamps was 200 $\mu mol \cdot s^{-1} \cdot m^{-2}$ at the bench top and 400 $\mu mol \cdot s^{-1} \cdot m^{-2}$ at 60 cm above the bench (quantum sensor on Model LI 185 meter, LICOR). The supplemental lighting was provided from 0600 to 2200 HR. The natural daylength from sunrise to sunset at Amherst, Mass., (lat 42°N) averaged 9.3 hr during the experiment (23 Dec. 1986 to 23 Jan. 1987). Air temperatures were maintained at 20C with no variation due to time, location, and regime of lighting in the greenhouse.

After 4 weeks of plant growth under the treatments, ethylene evolution from the plants was determined by sealing the plants in bell jars and sampling the internal atmosphere after about 24 hr for analysis by gas chromatography (Corey et al., 1987). After this determination, the shoots were harvested, dried, weighed, and ground to pass a 30-mesh screen. Extracts of the ground samples were made with 1M HCl for K, Ca, and Mg analyses by atomic absorption spectrophotometry (Barker and Corey, 1988). Phosphorus was determined colorimetrically on samples that were ashed in a muffle furnace (Barker and Corey, 1988). All data were processed by analysis of variance, and means were compared by Student's *t* test, by Fisher's LSD, or by Duncan's multiple range test.

Within 3 to 4 days after placement under the HPS lamps, leaves of 'Heinz 1350' became discolored with bronzing and purpling. These symptoms progressed through stages of yellowing, withering, and abscission. The plants also became epinastic with a decline of the petioles from 30° to 45° from horizontal within this period (Fig. 1A). Leaves of *neg*-1 developed interveinal chlorosis, cupping, and epinasty (Fig. 1B). Leaves of *yg*-5 became bronze-colored within a few days after the plants were placed in the supplemental radiation. In about 2 weeks, their lower leaves became mottled with bleaching. Clusters of growing points developed in about 2 weeks (Fig. 1C). Developmental aberrations attributed to lighting were not affected by source of N. Symptoms of moderate NH_4^+ toxicity (foliar necrosis, epinasty) were apparent on the plants grown under natural sunlight, but these symptoms were masked by the injury due to the HPS lamps.

Ethylene evolution for all genotypes was increased by the combined stresses of HPS lighting and NH_4^+ nutrition relative to that of plants grown under natural lighting or on NO_3^- nutrition (Fig. 2).

The predominant effect of HPS lighting was depression of K, Ca, Mg, N, and P concentrations in tomato shoots relative to their concentrations in the shoots of plants grown with only natural irradiation (Tables 1 and 2). Interactions of type of lighting with form of N and genotype, however, were significant. With NH_4^+ nutrition, the concentration of each of these elements was lower in shoots of 'Heinz 1350' and *neg*-1 grown with supplemental lighting than in these plants grown with only natural irradiation. With NO_3^- nutrition, 'Heinz 1350' and *neg*-1 shoots grown under the HPS lamps had lower concentrations of Ca, Mg, and N than those grown under natural sunlight, but the depressions in concentrations of K were not statistically

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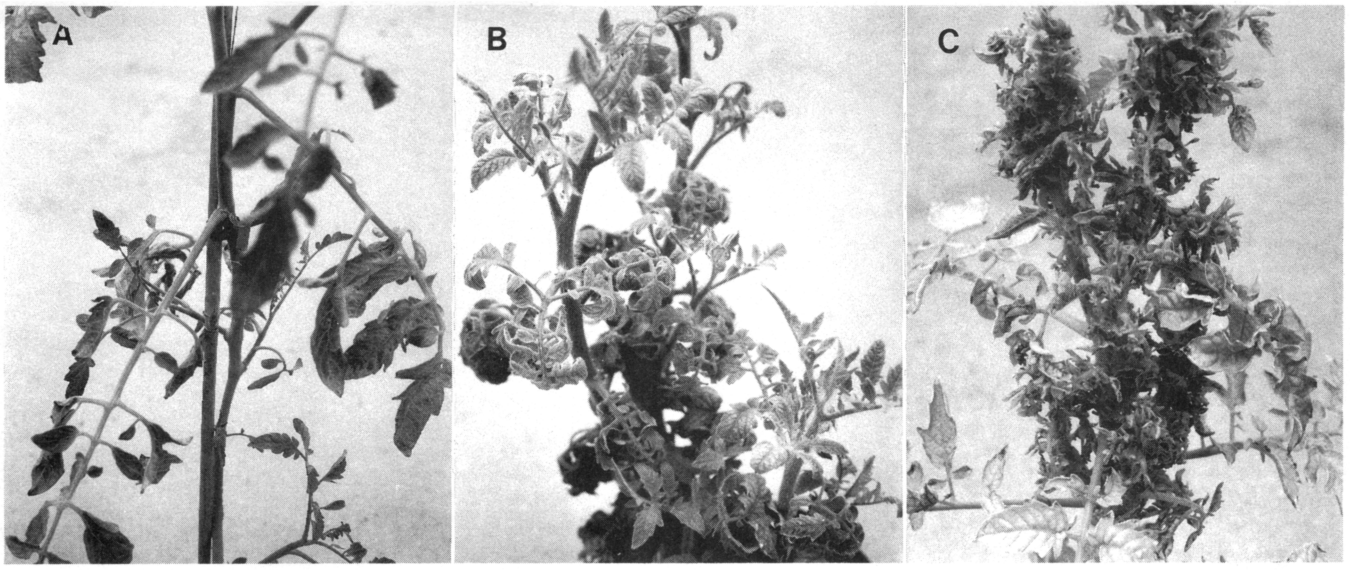

Fig. 1. Appearance of 'Heinz 1350' (**A**), *neg*-1 (**B**), and *yg*-5 (**C**) after 30 days of supplemental irradiation by HPS lamps.

Table 1. Analysis of variance of main effects and interactions of kind of light, genotype of tomato, and source of N on tomato shoot composition, ethylene evolution, and dry weight.

Source of variation	Dependent variable and significance by F test											
	Elemental composition											
	Concentration[z]					Content[y]						
	K	Ca	Mg	N	P	K	Ca	Mg	N	P	Ethylene[z]	Dry wt[z]
Light (L)	***	***	***	***	**	NS	NS	NS	**	**	***	***
Genotype (G)	**	***	***	***	***	***	***	***	***	***	NS	***
N Source (N)	**	***	***	***	NS	***	***	***	*	***	***	*
G × L	***	***	***	**	NS	NS	***	***	***	***	NS	NS
N × G	NS	***	***	***	NS	NS	***	***	NS	NS	*	NS
N × L	**	NS	*	NS	***	**	**	**	NS	***	*	NS
N × G × L	NS	***	**	NS	**	NS	**	NS	NS	NS	NS	NS

[z]Data in Table 2.
[y]Data in Table 3.

Table 2. Elemental composition of tomato shoots as affected by genotype, N form, and light source.

significant. Also, with NO_3^- nutrition, P concentrations of 'Heinz 1350' and *neg*-1 were not affected significantly by type of lighting. The *yg*-5 plants were higher in Ca, Mg, and P but lower in K concentrations with NO_3^- nutrition under the HPS lamps than under natural light. With NH_4^+ nutrition, all of the elements except N were lower in the *yg*-5 plants grown under HPS lighting than under natural light.

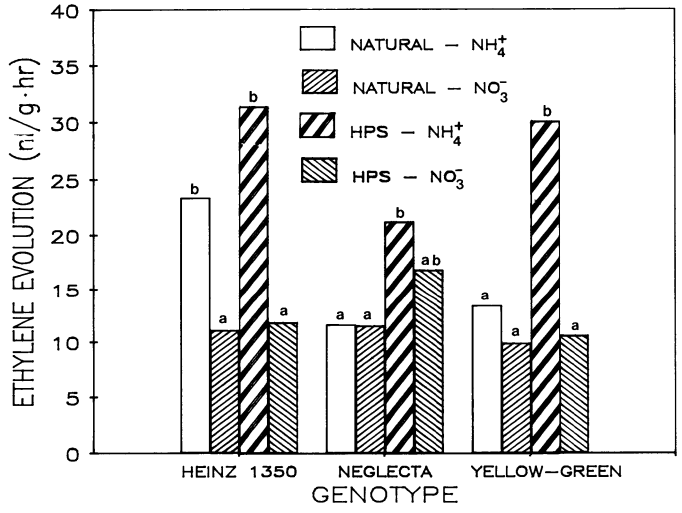

Fig. 2. Ethylene evolution by tomato genotypes grown under natural or supplemental HPS lighting and receiving NO_3^- or NH_4^+ nutrition. Means of columns headed by different letters within genotype are significantly different by Duncan's multiple range test ($P \leq 0.05$).

Despite the effects of the HPS lamps on the appearance, ethylene evolution, and elemental concentrations, the dry weights of the shoots were increased by supplemental lighting from the HPS lamps (7.8 g/plant) relative to weights of the plants receiving only natural sunlight (5.2 g/plant). Plants exposed to HPS lighting were taller and had thicker stems than those under the natural lighting alone. These growth increases offset the losses in weight due to leaf drop on 'Heinz 1350'. The increased growth of plants under the supplemental lighting was unexpected, for these plants appeared to be unproductive and short-lived. This effect may be seasonal, varying with irradiation from the sun.

Because of the larger shoot weights of plants exposed to HPS radiation, with only two exceptions, total accumulation of Ca, Mg, K, N, or P was not affected significantly or was increased by HPS lighting relative to the accumulation of these elements in plants irradiated only by sunlight (Tables 1 and 3). Calcium accumulation in 'Heinz 1350' shoots was suppressed by HPS lighting, and NH_4-N suppressed total Ca accumulation when HPS lighting was used. Overall, plants grown on NH_4^+ nutrition were lower in total Ca, Mg, K, and P and were

Table 2. Elemental composition of tomato shoots as affected by genotype, N form, and light source.

Genotype	Nitrogen form	Light source[z]	Elemental concn (% dry wt)				
			K	Ca	Mg	N	P
Heinz 1350	NO_3^-	NAT	4.63	2.90	0.75	3.38	0.46
		HPS	3.87^{NS}	1.53***	0.51**	2.42**	0.43^{NS}
	NH_4^+	NAT	5.25	1.22	0.37	3.92	0.54
		HPS	3.36**	0.39***	0.24**	3.10**	0.33**
neg-1	NO_3^-	NAT	5.16	3.07	0.74	3.82	0.62
		HPS	4.50^{NS}	2.48***	0.61**	3.32*	0.57^{NS}
	NH_4^+	NAT	4.92	1.78	0.41	4.72	0.66
		HPS	3.46*	0.88***	0.29*	4.00**	0.44**
yg-5	NO_3^-	NAT	7.08	3.36	0.70	4.25	0.58
		HPS	4.56**	3.47^{NS}	0.86**	4.08^{NS}	0.86**
	NH_4^+	NAT	6.92	1.24	0.35	5.58	0.82
		HPS	3.01***	0.58***	0.25^{NS}	5.75^{NS}	0.52**
LSD[y]			1.04	0.32	0.07	0.62	0.15

[z]NAT, irradiation from the sun; HPS, irradiation from the sun and HPS lamps.
[y]Fisher's LSD ($P \leq 0.05$) for comparing means for N form within genotype or means for genotype within N form.
Table 3. Total element accumulation in tomato shoots as affected by lighting and by the interactions of lighting and genotype and genotype and N form.

Table 3. Total element accumulation in tomato shoots as affected by lighting and by the interactions of lighting and genotype and lighting and N source.

Genotype or N source	Element (mg/plant) and lighting[z]									
	Potassium		Calcium		Magnesium		Nitrogen		Phosphorus	
	NAT	HPS	NAT	HPS	NAT	HPS	NAT	HPS	NAT	HPS
					Main effect of light					
Mean	275	293^{NS}	120	113^{NS}	30	35^{NS}	213	267*	30	38*
					Light × genotype interaction					
Heinz 1350	396	379^{NS}	176	107**	47	41^{NS}	296	283^{NS}	41	41^{NS}
neg-1	271	313^{NS}	127	129^{NS}	30	35^{NS}	237	281^{NS}	35	38^{NS}
yg-5	158	187^{NS}	57	102**	13	28**	106	237**	14	34**
					Light × N source interaction					
NO_3^-	283	352*	167	183^{NS}	40	51**	201	252*	29	47**
NH_4^+	267	234^{NS}	73	43*	20	19^{NS}	225	281*	31	29^{NS}

[z]NAT, irradiation from the sun; HPS, irradiation from the sun and HPS lamps.
accumulation were significant (see text for summary).
interaction of light × genotype × N form had no effect on element accumulation. The effects of N form and genotype on element accumulation were significant (see text for summary).

higher in total N than plants grown on NO_3^- nutrition. These results were due apparently to effects that NH_4^+ has on nutrient accumulation and on plant growth (Barker et al., 1966). The *yg*-5 plants accumulated lesser amounts of these nutrients than plants of the other genotypes. These effects appeared to be related to the genetic differences in the sizes of the plants.

Epinasty, foliar symptoms, and leaf abscission of each genotype indicated injury from HPS lighting. Ethylene evolution by plants grown with NH_4^+ nutrition and HPS lighting indicated that the plants were stressed (Yang, 1980). In a previous study, tomatoes stressed by Ca, Mg, or K deficiency had higher rates of ethylene production than unstressed plants (Barker and Corey, 1988). Here, foliar symptoms resembled those of deficiencies of P, Ca, Mg, and K, and, with few exceptions, shoot analyses demonstrated that the concentrations of these elements were lower in plants under the HPS lights than in plants grown only under natural radiation. Tremblay et al. (1988) noted that Ca concentrations in young tomato shoots were lower for plants grown under HPS lamps than for plants grown under two kinds of fluorescent lamps. In studies with poinsettia (*Euphorbia pulcherrima* Willd. ex Klotzsch), foliar symptoms resembling those of Mo deficiency were noted (A.V.B. unpublished data). All of these observations and the results in Table 2 suggest that nutrient deficiencies may have been the stresses that were induced in plants receiving radiation from HPS lamps. On the other hand, the total accumulation of elements in the shoots showed that the plants absorbed about the same total amount of nutrients under both lighting regimes. Also, the symptoms of bronzing, purpling, and yellowing of the lower leaves developed earlier than symptoms of nutrient deficiency might appear. Nutrient concentrations in the *yg*-5 plants grown on NO_3^- nutrition were not suppressed by HPS irradiation, despite abnormal growth. Possibly, nutrient assimilation was inhibited by the lamps, but impaired nutrient absorption does not seem to be the cause of the abnormal growth occurring under HPS irradiation. None of the elemental concentrations detected in the shoots appeared to be within the deficient range for tomato (Chapman, 1965).

Plant growth or yield has been increased with supplemental lighting relative to growth or yield obtained with only natural lighting (Boivin et al., 1987; Cathey and Campbell, 1979). Enhanced growth resulted from taller plants, thicker stems, and thicker leaves. Indications of physiological stress also have been noted with plants grown under artificial lighting. In some studies, for example, chlorophyll concentrations in leaves were lower for plants grown under HPS lighting than under other lighting regimes (Koontz et al., 1987; Tibbitts et al., 1983). In other studies, increased branching was a response to supplemental irradiation with HPS lamps (Cathey and Campbell, 1979, 1980). Irradiation in previous studies was in the range of 100 to 700 $\mu mol \cdot s^{-1} \cdot m^{-2}$, but generally near the lower part of this range. Cathey and Campbell (1980), for example, grew tomatoes and other species at about half the light intensity that we used and detected no damage to the crops with 16 hr of HPS irradiation. Intensities equivalent to those used by us were effective for plant growth in their growth chambers, (Cathey and Campbell, 1977). Mortensen and Stromme (1987) noted that different light qualities with the same levels of photosynthetically active radiation affected plant growth and morphology differ-

ently. Phytotoxicity of high-intensity light provided continuously by fluorescent lamps has been attributed to mercury emission lines (365 and 546 nm) appearing as spikes in the spectrum (Klein et al., 1965). The spectrum of the HPS lamps does not exhibit these particular spikes prominently (Cathey and Campbell, 1980), but other bands of possibly phytotoxic radiation may have caused the growth abnormalities. Because all of the plants received irradiation from the sun, spectral deprivation of any irradiation necessary for plant growth and development was unlikely.

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Iron Availability in Rockwool may Affect Rose Nutrition

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Abstract. **Rockwool is an inert medium for use in greenhouses. It is reported to contribute negligible nutrients to plants. However, *Rosa multiflora* 'Burr' rootstocks grown in Grodan rockwool exhibited no visible Fe chlorosis with an Fe-free nutrient solution. Leaf chlorophyll content was 2.65 mg·g^{-1} with Fe and 2.85 mg·g^{-1} without Fe. Available Fe concentrations of three commercial materials (Hortiwool, Grodan block, and Grodan loose), estimated by using diethylenetriaminepentaacetic acid (DTPA) extraction (2 DPTA : 1 rockwool, v/w), were 43.0, 0.33, and 3.95 mg Fe/liter, respectively. With long-term DTPA extractions (20:1), Fe extracted from Hortiwool and loose Grodan increased for ≈3 days before leveling off, while Fe extracted from Grodan block increased for 6 days. Measurable levels of Mn, Cu (348 mg·liter^{-1}), and Zn were found in DTPA extracts of Hortiwool; measurable levels of Mn and Cu were extracted from loose Grodan and measurable levels only of Mn from Grodan block.**

The use of rockwool as a growing medium in greenhouse production has increased to 4000 to 5000 ha world-wide. Rockwool has traditionally been described as totally inert medium, with no available nutrients. During rockwool production, Ca is added as a fluxing agent to aid in melting and producing fiber from rock or slag materials. Since Ca increases the water solubility of the medium, Fe oxides are also added to provide strength and decrease solubility. These Fe oxides may subsequently serve as a source of Fe to plants growing in rockwool. Sonneveld and Voogt (8), who examined iron nutrition of vegetables in rockwool, found that plants grown in rockwool required less Fe than those grown in nutrient film. Slight chlorosis occurred only if no Fe was added in solution, and usually when the pH of the root environment increased temporarily. Other studies (7) found that Zn, Cu, and B deficiencies can be induced with cucumbers growing in rockwool. Deficiency symptoms were not obtainable with Mn, even when none was added to the nutrient solution. Elucidation of micronutrient availability from rockwool may clarify whether these materials provide some of the required minor elements.

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Cuttings of 'Burr' rose were rooted in perlite under intermittent mist and then held in a cooler at 2° to 4°C for 4 weeks. Ten rooted cuttings were selected for the experiment based on uniformity and pre-existing interveinal chlorosis. No specific iron deficiency-inducing treatments had been applied. Roots were rinsed with deionized water, sheared to a length of ≈5 cm, and planted in 280 g of loose Grodan rockwool in 2-liter plastic containers. Roses were irrigated twice daily with deionized water for 2 days after planting. On day 3, 1 liter of nutrient solution containing (in mM) 2 $Ca(NO_3)_2 \cdot 4H_2O$, 4 KNO_3, 1 NH_4NO_3, 0.1 KH_2PO_4, 0.5 $MgSO_4 \cdot 7H_2O$, 0.03 H_3BO_3, 0.0015 $ZnSO_4 \cdot 7H_2O$, 0.0005 $CuSO_4 \cdot 5H_2O$, 0.006 $MnCl_2 \cdot 4H_20$, 0.0003 Na_2MoO_4, and, in controls, 0.049 $Fe(NO_3)_3 \cdot 9H_2O$ with 0.047 *N*-hydroxyethylethylenediaminetriacetic acid (HEDTA), which was flushed through the medium in each container. Thereafter, the nutrient solution was recirculated to irrigate the plants. Individual reservoirs of nutrient solution were used to irrigate each plant by bringing them up to weight (1500 g) daily with deionized water and recirculating. The initial solution was renewed after 2 weeks, with subsequent renewals at weekly intervals.

After 24 days in rockwool, leaf samples from each plant were assayed to determine the extent of Fe chlorosis. Where possible, the three youngest leaves whose leaflets had expanded to at least a 90° angle of the blades on each side of the midrib were sampled. The terminal one-third of each leaflet was removed and leaf pieces were randomly selected for assaying. A total of 100 mg of tissue was used from each plant. Chlorophyll was extracted from the leaf tissue with dimethyl sulfoxide (3), and the concentration