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Effect of Light Intensity, Soil Type, and Lithium Addition on Spinach and Mustard Greens Leaf Constituents

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ABSTRACT

A greenhouse experiment was conducted near Weslaco, Texas (Lat. 26º 8' N, Long. 97º 57' W) between 14 Dec. 2005 and 17 Feb. 2006 to evaluate the effect of soil type and lithium addition on the leaf nutrients of spinach and mustard greens grown under two light environments. Cultivars Samish (*Spinacia oleracea*) and Florida Broadleaf (*Brassica juncea*) were sown in two soils, Hebbronville and Hidalgo (listed in order of increasing clay content), and grown in two light environments: ambient and ca. 50% of ambient. Greens type exhibited differences in most attributes tested. The Hidalgo soil generally improved greens agronomic attributes, leaf pigments, total leaf N, and the leaf mineral nutrients, Mg, S, Na, and Mn compared to plants grown in Hebbronville soil. Lithium additions, at a field equivalent rate of 10 lbs Li / Ac, improved greens fresh wt. (Hidalgo only), leaf dry wt. (Hidalgo only), and S and Li leaf concentrations. Leaf ascorbate was 2.5 x higher in 'Florida Broadleaf' than in 'Samish'. Greens grown under reduced light appeared to have had greater leaf area, more chlorophyll and carotenoid pigments (dry wt. basis), titratable acidity, total N, K, Mg, Na, S, Fe, and Li than plants grown in ambient light.

Keywords: *Brassica juncea*, *Spinacia oleracea*, ascorbic acid, shading.

Leafy greens are an excellent source of mineral nutrients and vitamins for the human diet (U. S. Dept. Agriculture, 1982). The growing environment and cultural practices can affect the accumulation of nutrients in (leafy) vegetables. Previous research has demonstrated that vegetable amaranth grown under reduced light accumulates higher levels of most mineral nutrients, NO_3, leaf protein, carotenoids, and soluble oxalates (Makus and Hettiarachchy, 2001). Mustard greens leaf nutrients and plant pigments are affected by soil type, light intensity and cultivar (Makus and Lester, 2002). Reduced light or simulated cloudy weather prior to mustard greens harvest has been reported to influence mustard greens pigments, chlorophyll a:b ratio, most mineral nutrients, and time of day affected fluxes in leaf NO_3 and Mg (Makus and Lester, 2004.). Decreasing light levels increased area per leaf, mineral nutrients, and pigments (dry wt. basis) of snap bean leaves (Makus, 2001). 'Carlo' snap beans, when grown under reduced light, had higher dry matter (%) and Mn levels but lower Fe levels in sieve size No. 3 pods (Makus, 2001). Lester and Crosby (2002) have reported that location or soil type, cultivar, year, and size influence honeydew melon fruit ascorbate, folate, and K levels.

Lithium salts applied to cucumbers can reduce the incidence of powdery mildew (Abood and Losel, 1991). Applied to potatoes, lithium inhibited the winged form of aphids (Harrewijn, 1983). Soil lithium content is quit variable, ranging from trace amounts to over 100 ppm (Kabata-Pendias and Pendias, 1984). In the Jordan Valley (Jordan) where soils ranged from 10 to 45 ppm Li, fruits from *Citrus limon*, *C. mitis*, and *C. paradisi* ranged from14 to 70 ug/g Li, whereas Solanaceous plants such as pepper were reported to range from 194 to 318 ug /g Li in leaves (Haddadin, et al., 2002). Watercress, grown hydroponically in 2mM Li, accumulated 1216 ppm Li although growth was depressed at this solution concentration (Magalhaes, et al.,1990). Plants have no Li requirement, but 1 mg / day has been proposed for humans weighing 70 kg. Vegetables, and in some cases drinking water, constitute 66 to 90% of the major Li dietary sources, a mineral which has been implicated in human wellness (hypertension, depressive state, hormonal balance, leukemia, diabetes, dental cavities, and immunological functions) (Schrauzer, 2002; Magalhaes, et al., 1990).

Soils used in vegetable production in south Texas vary in chemical and physical properties. These differences influence fertilizer and soil moisture dynamics and ultimately the nutritional quality of the vegetable crops grown on them. Furthermore, spring and fall-grown crops are often exposed to different light environments. The objective of this greenhouse study was to evaluate the effects of light intensity, soil type, and added lithium on two greens crops and to measure the subsequent plant response and several leaf constituents.

MATERIAL AND METHODS

The experiment consisted of growing two leafy greens in two soil types, with and without added lithium under two light environments with all factorial treatments occurring once in each of four replicates in an RCB design. There were 64 pots in the experiment, each containing one plant. Two kg of air-dried, unsterilized Hebbronville (Course-loamy, mixed, hyperthermic Aridic Haplustalfs) and Hidalgo (Fine-loamy, mixed, hyperthermic Typic Calciustolls) soils were added to 15 cm dia. x 15 cm h white plastic pots and placed in a plastic-covered greenhouse receiving either ambient (available) light or ca. 50% of ambient light (by use of shade fabric). Minimum night temperatures were set at 12 ± 2 ^{0}C and day temperatures were set to cool at 27 ± 2 ^{0}C. Air temperature and photosynthetically active radiation (PAR) were measured by shielded thermocouples and LI-190SA quantum sensors, respectively, under both light environments every 60s and outputted hourly to a CR-10 data logger (Campbell Sci, Logan, UT). Average hourly PAR values were summed by hourly interval over the respective growing periods. Five seeds per pot of 'Samish' and 'Florida Broadleaf' (Willhite Seed, Poolville, TX) were sown on 7 Dec. 2005. 'Florida Broadleaf' was reseeded 10 days later because of poor stand. Plants were thinned to 1 per pot 14 days after planting (DAP). Water soluble 20N-20P-20K fertilizer at 250 mg per pot was added to pot saucers at -2 and 53 DAP, and 132 mg calcium nitrate per pot added at 46 and 54 DAP. Soluble trace elements (Peter's S.T.E.M.) were added at 50 mg per pot in at 39 DAP. Lithium (as Li_2SO_4) was added at 40 mg per pot at 0, 32, 49, and 52 DAP for a total soil applied equivalent of 10 lbs. Li/Ac. All fertilizations and supplemental watering was applied to the pot saucers using deionized water. Frequency of watering was based on incipient visual soil drying. The 50% light regime was started 31 DAP. Minolta Chlorophyll Meter (Model SPAD-502) readings were taken 53 DAP.

Porometry measurements were made 54 DAP with a LI-1600 Steady State Porometer (LI-COR, Lincoln, NE). Ambient light-grown and shaded 'Samish' and 'Florida Broadleaf' greens were harvested 56 and 63 DAP, respectively. On each respective harvest date, plant fresh weight, leaf number, and leaf area (LI-1800 leaf area meter) were determined. After harvest, pots were stored at 10° C until roots could be washed from the soil and then forced-air dried at 60° C for 3 days before weighing. Approx. 50 g of leaves were frozen, lyophilized, and ground by a Wiley Mill to pass through a 40 mesh screen. From the latter sub-samples, pigments were analyzed spectrometrically (Wellburn and Lichtenthaler, 1984); and leaf and soil (Li, only) nutrients were determined by ICP spectroscopy (Plank, 1992). Total leaf N was determined by dry combustion (Elementar Vario Max, Mt. Laurel, NJ). Approx. 0.5 g of freeze-dried leaf material was used for ascorbate analyses based on the procedure of Lester and Crosby (2002) and total titratable acidity by autotitration and computed as percent soluble oxalate (dry wt. basis).

Greens type, lithium addition, and soil type were analyzed as a 2 x 2 x 2 factorial experiment for each light level. All factorial treatments occurred randomly in each of the four replications under each of two light levels. Differences between response means were tested using the PDIFF option of the LSMEANS statement of PROC GLM of SAS Version 8.2 (SAS Institute, Cary, NC). The data were re-analysed using PROC MIXED of SAS Version 9.0.

Due to the physical proximity of the fixed blocks (light treatments), it is unlikely that the variation between units in the different blocks exceeded the variation between units in the same block (prior to application of treatments). Consequently, replicates nested within blocks were used to test block effects. These light level comparisons are discussed, but no data will be shown.

RESULTS

Analysis by both PROC GLM and PRO MIXED gave virtually similar results. The LSMEANS from PROC MIXED were used in the tables. Interactions will be discussed, but interaction means will not be shown.

Soils and environment. The characteristics of the two soils have been reported elsewhere (Makus and Lester, 2002). Basically, the lighter textured Hebbronville soil contains the least amount of clay (11 vs 23%) and % carbon (0.30 vs 1.01), has lower pH (7.6 vs 8.0) and electrolytes (0.08 vs 0.68 dS/M) and higher bulk density (1.51 vs 1.22), compared to the heavier textured Hidalgo soil. The Hidalgo soil was typically 2 to 18 times higher in extractable Ca, K, Mg, Mn, P, S, Na, Zn, Cu, and B than the Hebbronville soil. Lithium soil test values were 1.7 and 4.3 ppm for the Hebbronville and Hidalgo soils, respectively.

Mean temperatures and cumulative light (as PAR) before shade application (31 DAP) was 21.4° C and 133 mMol./s/m^2, respectively. Mean temperatures and cumulative average hourly photon flux (as PAR) between light treatment initiation and spinach harvest (23 days later) were 22.6° (ambient) and 22.4° C (shaded), respectively; and 104 (ambient) and 58 mMol./s/m^2 (shaded), respectively. Mean temperatures and cumulative light (as PAR) between light treatment initiation and mustard greens harvest (30 days later) were 22.8° (ambient) and 22.6° C (shaded), respectively; and 144 (ambient) and 78 mMol./s/m^2 (shaded), respectively.

Light and temperature averages (5 hr interval) the morning of the spinach harvest were as follows: 22.9° / 22.9° C for ambient / shaded temperatures and 364 / 221 µMol./s/m^2 for ambient / reduced light. Light and temperature averages (5 hr interval) the morning of the mustard greens harvest were as follows: 21.7° / 22.0° C for ambient / shaded temperatures and 295 / 116 µMol./s/m^2 for ambient / reduced light.

Greens Grown Under Ambient light.

Agronomic. 'Florida Broadleaf' plants had greater total wt., area per leaf, and root dry wt., but fewer leaves at harvest than 'Samish' (Table 1). Plant leaf dry wts. were similar. Greens grown in Hidalgo soil were higher in plant fresh wt., leaf number ('Samish', only), area per leaf, and leaf and root dry wts. Lithium addition had no affect on plant fresh wt., area per leaf, root dry wt., but increased leaf dry wt. (Hidalgo soil, only).

Leaf greenness and pigments. 'Samish' leaves had higher SPAD values, chlorophyll a:b ratio, but lower chlorophyll:carotenoid (C:C) ratios than leaves of 'Florida Broadleaf' (Table 2.). Leaves of plants grown in Hidalgo soil had similar SPAD values, lower chlorophyll a:b ratios and higher C:C ratios than leaves from greens grown in Hebbronville soil. Added Li did not affect leaf pigments. Total leaf chlorophyll and carotenoid levels were higher in Hidalgo-grown 'Samish' leaves compared to Hebbronville-grown leaves. Soil type did not affect these pigment levels in leaves of 'Florida Broadleaf'.

Leaf ascorbic acid. 'Florida Broadleaf' leaves contained more than twice the level of total ascorbate as did 'Samish' leaves, but neither soil type nor lithium addition had an affect on leaf ascorbate levels (Table 2).

Leaf total organic acids (as oxalates). 'Samish' leaves were lower than 'Florida Broadleaf' leaves in total organic acids. Total organic acid levels were higher in Hebbronville-grown 'Florida Broadleaf' leaves, than from leaves of plants grown in Hidalgo soil. Levels in 'Samish' leaves were not influenced by soil type. Lithium addition had no affect on leaf total organic acid concentration (Table 2).

Leaf Total N and Mineral nutrients. 'Samish' leaves were higher in K, Fe, Al, and total cations than leaves of 'Florida Broadleaf' (Table 3). Lithium addition reduced these mineral nutrients and total cations.

Table 1. Agronomic response of spinach and mustard greens grown under ambient and reduced light to soil type and lithium application.

Main effect means	Total plant FW	Leaf number	Area / leaf	Plant leaf DW	Root DW
	(g)		(cm^2)	(g)	(g)
Ambient light level					
Greens:					
Samish	34.1 b	21.6 a	26.6 b	8.97 a	2.04 b
Florida Broadleaf	50.4 a	8.1 b	111.5 a	9.08 a	2.69 a
	**[Z]	**	**	NS	**
Soil type:					
Hebbronville	34.8 b	13.7 b	62.8 b	8.01 b	1.93 b
Hidalgo	49.7 a	16.0 a	75.4 a	10.03 a	2.80 a
	**	**	**	**	**
Lithium:					
No	41.2 a	14.7 a	67.6 a	8.68 b	2.28 a
Yes	43.3 a	14.9 a	70.6 a	9.37 a	2.45 a
	NS	NS	NS	*	NS
Signif. Interactions:					
cultivar x soil	NS	**	NS	*	NS
soil x lithium	NS	NS	NS	*	NS
Reduced light level					
Greens:					
Samish	30.6 b	20.5 a	26.8 b	8.02 a	1.55 b
Florida Broadleaf	55.5 a	7.9 b	139.5 a	8.36 a	2.36 a
	**	**	**	NS	**
Soil type:					
Hebbronville	36.2 b	12.9 b	78.5 b	7.40 b	1.65 b
Hidalgo	49.8 a	15.4 a	87.9 a	8.98 a	2.25 a
	**	*	*	**	**
Lithium:					
No	39.8 b	13.4 a	83.3 a	7.69 b	1.86 a
Yes	46.3 a	14.9 a	83.0 a	8.69 a	2.05 a
	**	NS	NS	*	NS
Signif. Interactions:					
soil x lithium	*	NS	NS	**	*
cultivar x soil x lithium	NS	NS	NS	*	NS

[z] NS, *, ** = Not significant or significant at $P = 0.05$ or $P = 0.01$, respectively.

Interactions. Calcium levels were highest in Hebbronville-grown 'Florida Broadleaf' leaves compared to other soil x greens combinations. Phosphorus levels were highest inHidalgo-grown 'Samish' leaves and lowest in Hidalgo-grown 'Florida Broadleaf' leaves, whereas leaves of the other soil x greens combinations were similar. Magnesium leaf levels were higher in Hidalgo-grown 'Samish' compared to leaves from 'Samish' plants grown in Hebbronville soil, which in turn were both higher than Mg levels in 'Florida Broadleaf' leaves from plants grown in both soil types. Hidalgo-grown 'Samish' leaves contained higher Na levels than Hidalgo-grown 'Florida Broadleaf' leaves, whereas leaf Na levels were similar in both greens grown in Hebbronville soil. Leaf Mn levels were higher in Hidalgo-grown 'Samish' compared to other greens x soil combinations. Leaf B levels were similar in 'Samish' grown in both soil types, but Hidalgo-grown 'Florida Broadleaf' leaf B levels were lower than those from plants grown in Hebbronville soil. Leaf total N was lowered by supplementing 'Samish' plants with Li, whereas 'Florida Broadleaf' did not respond to Li. Lithium addition suppressed Mn leaf levels in 'Florida Broadleaf', but not in 'Samish' plants. Leaf S levels in 'Samish' plants grown in either soil and supplied with or without Li were similar, whereas S leaf levels were improved by Li addition to 'Florida Broadleaf' plants, particularly those grown in Hebbronville soil. Leaf Zn levels were highest in Hebbronville-grown 'Samish' without Li addition, whereas 'Florida Broadleaf' plants showed no change in leaf Zn levels in either soil, with or without Li addition. Leaf Li levels were dramatically increased by supplementing with Li, with leaves of 'Florida Broadleaf' plants having higher concentrations than leaves of 'Samish', particularly when grown in Hebbronville soil.

Greens Grown Under Reduced Light.

Agronomic. 'Florida Broadleaf' plants were higher in total fresh wt., area per leaf, and root dry wt., but lower in leaf number than 'Samish' (Table 1.). Greens grown in Hidalgo soil had more leaves per plant and greater area per leaf than those grown in Hebbronville soil. Lithium addition improved the fresh plant wt. and root dry wt. of plants grown only in the Hidalgo soil. Leaf dry wt. was increased by Li addition only in 'Florida Broadleaf' plants grown in Hidalgo soil.

Leaf greenness and pigments. 'Samish' leaves had higher SPAD values, chlorophyll a:b ratio, but lower C:C ratio compared to leaves of 'Florida Broadleaf' (Table 2). Leaf chlorophyll and carotenoid levels were higher in Hidalgo-grown 'Samish' leaves compared to 'Samish' leaves from plants grown in Hebbronville soil. Pigment levels in 'Florida Broadleaf' leaves were not influenced by soil type. Lithium application reduced the leaf chlorophyll a:b ratio.

Leaf ascorbic acid. Total ascorbate levels were 2.7 times higher in 'Florida Broadleaf' than in 'Samish' leaves (Table 2). Ascorbate leaf levels were 12% higher in Hidalgo-grown 'Florida Broadleaf' leaves compared to 'Florida Broadleaf' leaves from plants grown in Hebbronville soil.

Leaf total organic acids (as oxalates). 'Samish' leaves had lower levels of total organic acids compared to leaves of 'Florida Broadleaf' (Table 2). Total leaf organic acid levels were higher in leaves of plants grown in Hebbronville soil that were given supplemental Li. Added Li did not affect leaf total organic acid levels in plants grown in the Hidalgo soil.

Leaf Total N and Mineral nutrients. 'Samish' leaf levels of K, Fe, Zn, Al, and total cations were greater than those in leaves of 'Florida Broadleaf' (Table 3). Leaf levels of these nutrients were not affected by added Li.

Interactions. Hidalgo-grown 'Samish' was higher in total leaf N compared to Hebbronville-grown 'Samish'. Leaf P levels were highest in Hidalgo-grown 'Samish' and lowest in Hidalgo-grown 'Florida Broadleaf'. Leaf Na levels were highest in Hidalgo-gown 'Samish', followed by Hidalgo-grown 'Florida Broadleaf' and lowest (similar) in both greens grown in Hebbronville soil. Leaf Mn levels were lower in Hebbronville-

Table 2. Leaf greenness, pigments, ascorbate, and total organic acids (as oxalate) (all dry wt. basis) as affected by greens type, soil type, and added lithium when grown under ambient and reduced light conditions.

Main effect means	SPAD Reading	Chlorophyll Total	Chlorophyll a:b Ratio	Total carotenoids	Chlorophyll: carotenoid ratio	Total ascorbate	Total organic Acids
		($mg \cdot g^{-1}$)		($mg \cdot g^{-1}$)		($mg \cdot 100g^{-1}$)	(%)
Ambient Light level							
Greens:							
Samish	46.5 a	7.00 a	2.82 a	1.96 a	3.56 b	153 b	0.80 b
Florida Broadleaf	23.0 b	2.24 b	2.78 b	0.58 b	3.84 a	371 a	1.14 a
	**[Z]	**	.07[Y]	**	**	**	**
Soil type:							
Hebbronville	34.0 a	4.19 b	2.83 a	1.18 b	3.62 b	264 a	1.02 a
Hidalgo	35.6 a	5.04 a	2.77 b	1.36 a	3.77 a	260 a	.92 b
	NS	*	*	.06	**	NS	.06
Lithium:							
No	34.0 a	4.76 a	2.81 a	1.32 a	3.67 a	260 a	1.02 a
Yes	35.6 a	4.47 a	2.79 a	1.22 a	3.72 a	264 a	0.92 a
	NS	NS	NS	NS	NS	NS	NS
Signif. Interactions:							
cultivar x soil	NS	*	NS	*	NS	NS	**
Reduced Light level							
Greens:							
Samish	46.5 a	8.94 a	2.78 a	2.33 a	3.82 b	135 b	0.88 b
Florida Broadleaf	24.6 b	3.02 b	2.70 b	0.74 b	4.05 a	375 a	1.30 a
	**	**	**	**	**	**	**
Soil type:							
Hebbronville	34.2 b	5.62 b	2.75 a	1.46 b	3.91 a	246 a	1.11 a
Hidalgo	36.9 a	6.34 a	2.74 a	1.62 a	3.95 a	265 a	1.07 a
	*	.07	NS	*	NS	NS	NS
Lithium:							
No	35.2 a	6.11 a	2.77 a	1.57 a	3.93 a	252 a	1.07 a
Yes	35.9 a	5.84 a	2.72 b	1.50 a	3.93 a	258 a	1.11 a
	NS	NS	*	NS	NS	NS	NS
Signif. Interactions:							
cultivar x soil	NS	*	NS	*	NS	*	NS
soil x lithium	NS	NS	NS	NS	NS	NS	*

[z] NS, *, ** = Not significant or significant at $P = 0.05$ or $P = 0.01$, respectively.
[Y]Prob. > 'F' value.

grown 'Samish' compared to the other greens x soil combinations. The influence of the Hidalgo soil on greens leaf B was reversed: higher in 'Samish' and lower in 'Florida Broadleaf'. Leaf Ca levels were highest in 'Florida Broadleaf' plants given no supplemental Li. Leaf Mg was highest in 'Samish'greens given supplemental Li. Leaf Mn levels were higher in 'Samish' plants given supplemental Li, but similar in 'Florida Broadleaf' leaves grown with or without added Li. There was a strong tendency for added Li to improve leaf S levels in all soil x greens combinations, but it was significantly higher in leaves of Hebbronville-grown 'Florida Broadleaf' plants which were given added Li. Leaf Li levels were similar in Hidalgo and Hebbronville-grown 'Samish', but higher in Hebbronville-grown 'Florida Broadleaf' leaves compared to Hidalgo-grown 'Florida Broadleaf' when plants were grown with supplemental Li.

Light Level Comparisons.

Agronomic. Reducing light intensity to ca. 50% of ambient had no effect on total plant fresh weight, but decreased leaf number per plant, plant leaf and root dry weight, and increased area per leaf.

Leaf greenness and pigments. Light level had no affect on SPAD readings taken 53 DAP but total leaf chlorophyll (at harvest), total carotenoids and the C:C ratio were increased and the chlorophyll a:b ratio was decreased in ambient light. 'Samish' leaves had higher SPAD readings, total chlorophyll and carotenoid content, but lower a:b and C:C ratios than did leaves of 'Florida Broadleaf'.

Leaf ascorbic acid. Total ascorbic acid was not influenced by light level.

Leaf total organic acids (as oxalates). Plants grown under reduced light intensity had greater organic acid levels compared to those grown under ambient light. 'Florida Broadleaf' leaves had higher organic acid levels compared to 'Samish' leaves, particularly 'Florida Broadleaf' plants grown in Hebbronville soil.

Leaf Total N and Mineral nutrients. Plants grown under reduced light had higher leaf concentrations (dry wt. basis) of N, K, Mg, S (Florida Broadleaf, only), Na, Fe, Li and total cations.

Porometry. At 54 DAP, PAR levels and leaf temperatures for the ambient and reduced environments (between 1115 and 1245 hrs) were 1200 vs. 676 μMol./s/m^2 and 22.8 vs. 21.9° C, respectively (P values <0.01). Under ambient light, leaves of 'Samish' had lower transpiration rates (5.4 vs 6.8 μg H_2O/s/cm^2), but higher leaf temperatures (23.0 vs 22.6° C) than did leaves of 'Florida Broadleaf' (P<0.01). Lithium application to Hidalgo-grown plants increased leaf transpiration in greens (P<0.01) whereas Li application to Hebbronville-grown greens, decreased leaf transpiration (P<0.05). Under reduced light, 'Samish' leaf transpiration was 4.3 vs 6.2 μg H_2O/s/cm^2 compared to leaves of 'Florida Broadleaf'. There were no leaf temperature differences between greens type under reduced light. No other main effect differences or interactions were observed at either light level.

Linear correlations. Leaf total sulfur was the only mineral nutrient found to be correlated with leaf Li (r=0.415, P<0.02 in 'Samish'; and r= 0.826, P<0.01 in 'Florida Broadleaf'). Total chlorophyll vs total carotenoids were well correlated (r=0.979 in 'Samish' and r=0.991 in 'Florida Broadleaf', both P<0.01), but other relationships were not consistent between greens type. Leaf Li and S were correlated (P<0.01) in plants grown in both ambient (r=0.692; n=32) and reduced (r=0.620; n=32) light.

DISCUSSION

The effect of reduced light to increase leaf area, pigment concentration, soluble oxalates, and mineral accumulation has been observed in vegetable amaranth (Makus and Hettiarachchy, 2001) and snap bean leaves (Makus, 2001). In a previous study, when mustard green cultivars Florida Broadleaf and Tendergreen were grown in light and heavy textured soils, heavier textured soils improved most leaf nutrient concentrations except P and Fe (Makus and Lester, 2002). In the present study about one-half of the leaf nutrient concentrations were improved when grown in the heavier soil. 'Samish' leaves were twice as high as 'Florida Broadleaf' leaves in total cations, when grown under both light regimes, suggesting that 'Samish' leaves were more nutrient dense compared to those of mustard greens. At 48 DAP, a Ca or Mg deficiency was observed in 'Florida Broadleaf' leaves. At 50 DAP Mg Metalosate (5%, v:v) was applied to run-off to all greens. The deficiency symptoms lingered through harvest and the low Mg leaf concentrations reported in Table 3 for 'Florida Broadleaf' reflect this.

Soil test S levels reported for the Hebbronville soil were one- twentieth the levels found in Hidalgo soil (Makus and Lester, 2002). However, even at the low S soil test levels found in Hebbronville soil, 'Florida Broadleaf' plants given Li addition had the numerically highest leaf S levels of all possible treatment combinations when grown in ambient light. Under reduced light, Hebbronville-grown 'Florida Broadleaf' leaves had twice the leaf S content when Li was added, compared to when none was added. Lithium, which is reported to suppress Ca uptake in bush beans (Wallace and Shear, 1979), reduced Ca levels in 'Florida Broadleaf', but not in 'Samish' leaves. Therefore, species differences appear to be important in the way lithium addition affects both S and Ca uptake. Reduced light moderated the effect of added Li on reducing the levels of several leaf mineral nutrients (none in shade vs eight under ambient light), with the exception of leaf S and Li levels, which were increased under both light levels.

In a field experiment in soil ranging from 1.4 to 2.4 ppm Li, addition of 1 kg Li / ha increased potato tuber citric and malic acids (Vlasyuk, et al., 1973). In the present experiment, there was no consistent Li effect on total titratable acidity (soluble oxalic acid) in either greens. In a hydroponic experiment, solution Li concentrations to 12 ppm, increased cucumber fruit yield, fruit sugar, and ascorbic acid, but Li did not accumulate in the fruit (Rusin, 1979). In the present study, lithium addition had no affect on ascorbic acid leaf levels. Tomato and bush bean plants grown in solutions up to 0.5 mM Li accumulated Li in roots, leaves and fruits/pods; yields were reduced by Li solution levels greater than 0.1 mM (Patel, et al., 1980). In the present study, the greatest leaf Li concentrations were found in mustard greens grown in Hebbronville soil (324 μg/g in shade; 344 μg/g in ambient light).

The effect of light intensity on ascorbate levels in *Brassica juncea* and *Spinacia oleracea* leaves were consistent with those in other plants. Mozafar (1994), in a review of the literature, concluded that light duration and/or intensity can increase

Table 3. Total leaf N and mineral nutrients as affected by greens type, soil type, and added lithium grown under ambient and reduced light.

Main effect means	N	K	Ca	P	Mg	S	Na	Mn	Fe	Zn	B	Al	Li	Total cations
	(%)							(mg•g^{-1})						(%)
Ambient Light Level														
Greens:														
Samish	3.27 a	6.71 a	1.48 b	0.565 a	0.620 a	0.324 b	0.426 a	73.9 a	75.4 a	79.2 a	5.51 a	42.1 a	86 b	8.85 a
Florida Broadleaf	1.39 b	2.12 b	1.97 a	0.396 b	0.191 b	0.354 a	0.125 b	55.6 b	47.5 b	21.2 b	40.9 b	25.2 b	122 a	4.30 b
	**[z]	**	**	**	**	**	**	**	**	**	**	**	**	**
Soil Type:														
Hebbronville	2.25 a	4.56 a	1.93 a	0.506 a	0.377 b	0.329 a	0.082 a	52.8 b	61.2 a	60.8 a	48.6 a	34.6 a	135 a	6.90 a
Hidalgo	2.41 a	4.26 a	1.52 b	0.455 b	0.434 a	0.349 a	0.468 b	76.8 a	61.6 a	39.6 b	47.4 a	32.7 a	73 b	6.24 b
	NS	NS	**	.08[y]	**	NS	**	**	NS	**	NS	NS	**	**
Lithium:														
No	2.42 a	4.60 a	1.86 a	0.516 a	0.420 a	0.298 b	0.282 a	66.7 a	64.3 a	55.9 a	50.4 a	36.9 a	2 b	6.90 a
Yes	2.24 a	4.22 b	1.59 b	0.445 b	0.391 a	0.380 a	0.269 a	62.8 a	58.6 b	44.5 b	45.7 b	30.3 b	206 a	6.25 b
	NS	*	**	*	NS	**	NS	NS	*	**	*	*	**	**
Signif. Interactions														
cultivar x soil	NS	NS	**	**	**	NS	**	**	NS	*	**	NS	**	NS
cultivar x lithium	*	NS	NS	NS	NS	**	NS	*	NS	**	NS	NS	**	NS
soil x lithium	NS	NS	NS	NS	NS	*	NS	NS	NS	**	NS	NS	**	NS
cultivar x soil x lithium	NS	NS	NS	NS	NS	*	NS	NS	NS	**	NS	NS	**	NS
Reduced Light Level														
Greens:														
Samish	4.04 a	7.74 a	1.59 b	0.554 a	0.745 a	0.417 a	0.503 a	61.0 a	93.8 a	70.5 a	59.0 a	49.8 a	119 a	10.1 a
Florida Broadleaf	1.59 b	2.76 b	1.92 a	0.406 b	0.204 b	0.357 b	0.186 b	62.1 a	61.4 b	22.5 b	39.3 b	27.7 b	129 a	4.9 b
	**	**	**	**	**	*	**	NS	**	**	**	**	NS	**
Soil Type:														
Hebbronville	2.72 a	5.61 a	1.89 a	0.453 a	0.443 b	0.356 b	0.109 b	55.0 b	76.2 a	58.7 a	49.5 a	40.6 a	152 a	7.98 a
Hidalgo	2.90 a	4.89 a	1.61 b	0.508 a	0.506 a	0.418 a	0.579 a	68.1 a	78.9 a	34.3 b	48.9 a	36.9 a	96 b	7.04 b
	NS	NS	**	NS	.06[Y]	*	**	*	NS	**	NS	NS	**	*
Lithium:														
No	2.87 a	5.47 a	1.77 a	0.503 a	0.458 a	0.326 b	0.358 a	58.6 a	77.3 a	44.7 a	48.2 a	39.5 a	2 b	7.72 a
Yes	2.76 a	5.02 a	1.74 a	0.457 a	0.492 a	0.448 a	0.330 a	64.6 a	77.8 a	48.3 a	50.1 a	38.0 a	246 a	7.30 a
	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	**	NS
Signif. Interactions														
cultivar x soil	*	NS	NS	NS	NS	NS	**	*	NS	NS	*	NS	*	NS
cultivar x lithium	NS	NS	*	NS	*	NS	NS	*	NS	NS	NS	NS	NS	NS
soil x lithium	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS
cultivar x soil x lithium	NS	NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	*	NS

[z] NS, *, ** = Not significant, significant at $P = 0.05$ or $P = 0.01$, respectively

[Y] Prob. > 'F' value.

ascorbate and that supplemental or adequate soil levels of K, Mn, Mo, Cu, Zn, and Co tend to improve ascorbate levels.

CONCLUSIONS

In a greenhouse pot experiment, soil applied lithium sulfate at a field application equivalent rate of 10 lbs. Li /Ac was readily taken up by greens, but was also modulated by soil type and light intensity. The lighter textured soil and reduced light intensity improved Li uptake. Lithium application increased total plant fresh wt., leaf dry wt. (reduced light, only) and improved total leaf sulfur concentrations by 28 and 37% in ambient and reduced light, respectively. Greens grown under reduced light intensity generally had higher total leaf N, mineral nutrients and plant pigment concentrations. ‘Samish’, a spinach, was more nutrient and pigment dense than was ‘Florida Broadleaf’, a mustard greens.

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