Characterization of Nutrient Disorders of *Lilium longiflorum* 'Nellie White' and *Lilium* Hybrid 'Brunello'

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Abstract

***Lilium longiflorum* 'Nellie White' and *Lilium* hybrid 'Brunello' plants were grown in silica sand culture to induce and photograph symptoms of nutritional disorders. Plants were grown with a complete modified Hoagland's all nitrate solution: (macronutrients in mM) 15 NO_3-N, 1.0 PO_4-P, 6.0 K, 5.0 Ca, 2.0 Mg, and 2.0 SO_4-S, plus μM concentrations of micronutrients, 72 Fe, 18 Mn, 3 Cu, 3 Zn, 45 B, and 0.1 Mo. The treatments causing nutrient deficiency symptoms were induced with a complete nutrient formula minus one of the nutrients. Boron toxicity was also induced by increasing the element 10× higher than the complete nutrient formula. Reagent grade chemicals and deionized water of 18-mega ohms purity were used to formulate treatment solutions. The solution drained from the bottom of the pot was captured for reuse. A complete replacement of nutrient solutions was done weekly. Plants were monitored daily to document and photograph sequential series of symptoms as they developed. Typical symptomology of nutrient disorders and critical tissue concentrations are presented. Symptoms of nitrogen, sulfur, boron, and iron deficiencies and boron toxicity were the first disorders documented in lilies, and these disorders may be a more likely problem encountered by a grower.**

INTRODUCTION

Easter lilies (*Lilium longiflorum* Thunb., *Liliaceae*) and hybrid lilies are important floriculture crops grown as potted plants and as cut flowers (Dole and Wilkins, 2005). To produce a superior crop, growers need to be well versed on the nutritional requirements and the problems that occur.

Nitrogen (N) deficiency appeared initially as lower leaf yellowing and leaf loss particularly at flowering (IFBC, 2008; Seeley, 1950; Hamrick, 2003; Niedziela et al., 2008). Smaller leaves (IFBC, 2008; Seeley, 1950), short stems (Seeley, 1950), stems weighing less, and low flower numbers were other symptoms (IFBC, 2008).

For phosphorus (P), Seeley (1950) observed no P deficiency symptoms in Easter lily, yet the IFBC (2008) reported P deficient plants were short and smaller with a dull pale green leaves and with brownish-red leaf tips. Niedziela et al. (2008) described the progression of phosphorus deficiency symptoms in Easter lily which begins with the plant being stunted and the leaves being a normal green. Over time the lowest leaves developed a uniform chlorosis of the entire leaf, which progressed to a tan-brown necrosis. Their work was done with one-year-old scale bulblet plants.

For potassium (K), Seeley (1950) observed no symptomology on plants grown under K deficiency and theorized that the bulb had an adequate amount of K or that because sodium (Na) was added to the solution, the plant might be using Na in the place of K. IFBC (2008) notes that K deficient plants are smaller, stockier, and grow slower than the control plants. A yellow-green coloration with a brown discoloration covered the upper leaves except for the leaf tips, and necrotic white spots covered the entire leaf. In the advanced stage, leaves became necrotic. With one-year-old Easter lily bulblet plants, symptoms of potassium deficiency began on the leaves of the upper half of the plant as dark brown pigmented streaks and over time progressed to necrosis and desiccation of the

entire leaf (Niedziela et al., 2008).

Calcium (Ca) deficiency symptoms included smaller plants (Seeley, 1950; IFBC, 2008), smaller root systems (IFBC, 2008; Seeley, 1950) with short and stubby roots (Seeley, 1950), light to very pale green with white spots on the leaves, downward leaf tip curl with occasional tip browning (IFBC, 2008), blasting of flower buds, smaller flowers, and flowers that did not open completely (Seeley, 1950).

Plants grown under magnesium (Mg) deficient conditions, tip yellowing or browning areas on the leaf near the petiole that collapsed and resulted in the leaf hanging downward also occurred (Seeley, 1950). Seeley (1950) then reported leaves turned brown but did not abscise from the plant, and the leaf symptomology progressed upward on the plant. Leaves were smaller and exhibited a light green coloration and bent downward (IFBC, 2008) or had a light green mottling with a grayish cast. Stems manifested a brownish-white spotting (IFBC, 2008) and became light green that advanced to a brown coloration (Seeley, 1950). IFBC (2008) reported older leaves exhibited the worst symptomology.

Upper leaf interveinal chlorosis was reported as the initial symptom of iron (Fe) deficiency. As the severity of the deficiency increased, the plants became more yellow, but the veins remained green (IFBC, 2008; Seeley, 1950).

Manganese (Mn) deficiency has been reported to not severely impact plant growth. Young leaves had a lighter coloration, and leaf tips were yellow or light brown in coloration. This deficiency can be prevented with application of chelated Mn or $MnSO_4$ (IFBC, 2008).

Boron (B) toxicity was reported to manifest on the leaf tips as white or brown areas on the leaves, and symptoms were most obvious on the upper leaves (IFBC, 2008).

Nutrient disorders have been described for N, P, K, Ca, Mg, Fe, and Mn deficiencies and for B and Mn toxicities. However, a complete characterization of the nutrient disorders of lilies has not been done. For example, Seeley (1950) also grew Easter lilies under B deficient conditions, and noted that no symptoms appeared, and suggested that the bulb contained enough B reserves (Roh and Wilkins, 1976). Therefore, this study was performed to document the symptomology of nutrient disorders of Easter and hybrid lilies and to obtain critical tissue values.

MATERIALS AND METHODS

'Nellie White' Easter lily bulbs (9-10 cm in circumference) were planted singly into 12.3 cm diameter (1.77 L) pots containing acid washed silica-sand (Millersville #2 (0.8 to 1.2 mm diameter) from Southern Products and Silica Co., Hoffman, NC) on 18 December 2009. This experiment was conducted in a glass greenhouse in Raleigh, NC at 35°N latitude. Plants were grown at 18°C day and 15°C night temperature set points. Treatments started immediately upon planting. An automated, recirculating irrigation system was constructed out of 10.2 cm diameter PVC pipe (Charlotte Plastics, Charlotte, NC).

The system consisted of 18 separate irrigation lines (each 1.82 m long). Each line contained 8 openings (12.7 cm diameter) that held the eight pots for the elemental treatment. Thirteen lines contained the disorder treatments, and 5 lines contained the control. Pipes were randomly assigned as a control or treatment after the system was constructed. Control plants were grown with a complete modified Hoagland's all nitrate solution: (macronutrients in mM) 15 NO_3-N, 1.0 PO_4-P, 6.0 K, 5.0 Ca, 2.0 Mg, and 2.0 SO_4-S (Hoagland and Arnon, 1950), plus micronutrients in μM 72 Fe, 18 Mn, 3 Cu, 3 Zn, 45 B, and 0.1 Mo. Nutrients originated from the salts of KNO_3, $Ca(NO_3)_2 \cdot 4H_2O$, KH_2PO_4, $MgSO_4 \cdot 7H_2O$, FeDTPA, $MnCl_2 \cdot 4H_2O$, $ZnCl_2$, $CuCl_2 \cdot H_2O$, H_3BO_3, and $Na_2MoO_4 \cdot 2H_2O$.NaOH was added to adjust the pH to 5.8. Reagent grade chemicals and deionized water of 18-mega ohms purity were used to formulate treatment solutions (Pitchay, 2002) and the plants were irrigated as needed (Barnes, 2010).

In order to induce nutrient deficiency treatments, the plants were irrigated with complete nutrient solution excluding one of the nutrients. For macronutrients salt cations

were replaced with Na, and anions were replaced with Cl (Barnes, 2010). For micronutrients the salt was omitted from the solution. The B toxicity treatment was conducted by increasing B concentration (450 μM) in the Hoagland's solution.

When the initial deficient symptom of each element was observed, 3 plants showing symptoms were sampled and the remaining 5 plants were grown to document the symptoms. Fully expanded leaves were sampled to evaluate the critical tissue concentration for each element. Harvested leaves were washed in a solution of 0.5 N HCl for 1 min and rinsed with deionized water. The remaining shoot tissue was harvested separately. Both sets of tissue were dried at 70°C for at least one week, and the weights were recorded. The tissue was analyzed for nutritional concentrations (Barnes, 2010). Plants were sampled on three separate dates.

The experiment was terminated on 20 March 2009, and plants of copper, potassium, manganese, molybdenum, phosphorus, and zinc treatments that showed no symptoms were sampled for dry weight and nutrient levels. All the data were subjected to the analysis of variance (ANOVA) using PROC ANOVA SAS program (SAS Inst., Cary, N.C.). Where the F test is significant, LSD ($P \leq 0.05$) was used to compare between means. Deviations in dry weight were calculated on a percentage basis from the controls.

Lilium hybrid 'Brunello' bulbs (12-14 cm in circumference) were grown under the same conditions by planting on 8 January 2010 and terminating on 22 March.

RESULTS AND DISCUSSION

Values for percentage difference in plant dry weights are presented if control and treatment tissues were significantly different. Unless otherwise noted, values for tissue concentrations presented were significantly different. Values obtained from this experiment were compared with optimum values published by Mills and Jones (1996) for *Lilium longiflorum* and Dole and Wilkins (2005) for *Lilium* (Table 1), except for Mo since values were not reported in these two studies. Symptomology was similar for *Lilium* hybrid 'Brunello', therefore, tissue and dry weight values are reported in Table 2, but not discussed.

Nitrogen

Plants grown under nitrogen (N) deficient conditions were 40% less in dry weight than the control plants. Control plants had a concentration of 3.19% N and N deficient plants 2.36% N. As symptoms progressed, the lower leaves were yellow, leaf loss occurred, and overall the leaf size was smaller. Nitrogen contents of the leaves in the low and middle part of stems was reduced (<1.74%) when leaves were collected on 5 August as compared to those (<2.15%) when leaves were collected on 20 July (Roh and Wilkins, 1976).

Calcium

Calcium deficiency manifested as brown spots on the distal tips of the upper leaves. Control tissue Ca concentration was 0.80%, and Ca deficient tissue concentration was 0.02%. As the disorder progressed, the spots grew larger. Also, some young flower buds become brown and aborted and large flower buds abscised. Affected leaves then developed a purple-brownish coloration. The brown discoloration on the tips and flower bud blasting match descriptions by IFBC (2008) and Seeley (1950), but none of the other symptoms they describe of smaller plants and smaller root systems (IFBC, 2008; Seeley, 1950). Short and stubby roots (Seeley, 1950), light to very pale green leaf coloration, white spots on the leaves, downward leaf curl (IFBC, 2008), or smaller flowers (Seeley, 1950) were observed.

Sulfur

Upper leaves developed a yellowish-green coloration on plants grown under sulfur (S) deficiency. The coloration was present over the entire leaf, and some of the veins appeared to be a darker green color. The tissue S concentration in the control plants was

0.19% while S deficient tissue concentration was 0.12%. Symptomology has not been previously reported for S deficiency. No additional symptoms were observed for this deficiency.

Boron

Plants with B deficiency symptoms weighed 47% less than the control in dry weight. The B concentration of the control plants was 22.0 $mg \cdot kg^{-1}$ (ppm) while B deficient plants had a concentration of 0.2 $mg \cdot kg^{-1}$. Seeley (1950) observed no symptoms for B deficiency, but our B deficient plants were smaller than the control.

Plants grown at B level designed to cause a toxicity exhibited yellowing on the lower leaf tips. Plants grown in the B toxicity regime were 17% smaller in dry weight than the controls. Control tissue had a B concentration of 22.0 $mg \cdot kg^{-1}$, and plants grown in elevated B levels contained 168.0 $mg \cdot kg^{-1}$. Over time, the yellowing progressed inward on the leaf toward the stem. The lowest leaves became completely yellow. Leaves in the middle then began exhibiting symptoms.

Iron

Iron deficiency symptoms were manifested in the upper leaves; they became yellowish-green. The coloration was present over the entire leaf, and some of the veins appeared to be a darker green color. Tissue concentrations were not significantly different. This lack of significance occurred because one of the control values was a lower outlier, and one of the Fe deficient samples was a higher outlier. With the outliers removed, control Fe tissue concentration was 59.0 $mg \cdot kg^{-1}$, and Fe deficient tissue was 43.8 $mg \cdot kg^{-1}$. Our symptoms match those previously reported, but the veins were not as dark green (IFBC, 2008).

Asymptomatic Elements

After 13 weeks of growth when the plants had reached full bloom, plants grown under P, K, Mg, Cu, Mn, Mo, and Zn deficient conditions exhibited no visual symptoms. These asymptomatic plants were sampled and analyzed for dry mass and tissue concentration to determine if non-visual differences were evident. Molybdenum (Mo) values were neither reported for the control nor the Mo deficient plants because concentrations were below the detectable limit of 0.5 $mg\ kg^{-1}$.

Tissue concentrations between the control and plants without P, K, Mg, and Mn were significantly different. The control tissue P concentration was 0.20% while P deficient tissue concentration was 0.12% P. The K concentrations of control and K deficient plants were 3.44 and 2.41%, respectively. Control plants had Mg concentration of 0.27% while deficient plants had a concentration of 0.08% Mg. Control tissue contained 27.9 $mg \cdot kg^{-1}$ Mn, and Mn deficient tissue contained 9.4 $mg \cdot kg^{-1}$.

Two nonsymptomatic treatments did not have significantly different tissue concentrations. For the Cu treatment, control tissue was 7.3 $mg \cdot kg^{-1}$ Cu while the deficient tissue had 7.9 $mg \cdot kg^{-1}$ Cu. The control tissue Zn concentration was 23.8 $mg \cdot kg^{-1}$ while the Zn deficient tissue concentration was 21.1 $mg \cdot kg^{-1}$.

Of the 7 treatments that exhibited no symptomology, 4 - P, K, Mg, and Mn - have published symptomolgy. All four had significantly different tissue values at the end of the experiment which indicates that tissue concentrations were reduced in the plants. It has been hypothesized that some symptoms do not appear because the bulb may be considered to be the source of these elements (Seeley, 1950). Therefore, symptoms in this experiment may not have been observed for P, K, Mg, and Mn because levels in the plant had not dropped below the point where growth would be interrupted to induce a deficiency symptom. This hypothesis is supported by the work of Niedziela et al. (2009) in which deficiencies were observed with 0.10% P and 1.05% K in one-year-old plants.

CONCLUSIONS

Symptoms of N, S, B, and Fe deficiencies and B toxicity were some of the first

disorders to manifest in Easter and hybrid lilies. Growers may be more likely to encounter these problems in production. Sulfur deficiency symptom was observed very quickly, but it has not been reported as a problem.

When grown in the nutrient treatment system, lilies exhibited the reported symptoms. Tissue samples were taken when the initial symptoms occurred. The symptomology presented here and critical tissue nutrient levels for the crop will be helpful for commercial growers needing to diagnose lily nutritional problems.

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Tables

Table 1. *Lilium longiflorum* 'Nellie White' plant dry weight and tissue nutrient concentration as affected by deficient or toxic induced nutrient treatments and published optimum concentrations.

Treatment	-N	-P	-K	-Ca	-Mg	-S	-B[1]	++B[1]	-Cu	-Fe	-Mn	-Mo	-Zn
							Dry weight (g)						
Element	N	P	K	Ca	Mg	S	B	B	Cu	Fe	Mn	Mo	Zn
Complete control	12.15	20.65	20.65	11.02	11.02	12.15	12.15	12.15	20.70	12.15	20.65	20.65	20.65
Treatment	7.34	20.05	19.42	11.72	9.14	11.56	6.40	10.09	17.80	13.67	17.15	17.66	16.95
p-value[2]	***	NS	NS	NS	NS	NS	***	*	NS	NS	NS	NS	NS
				Tissue nutrient concentration (%)						Tissue nutrient concentration (mg kg^{-1})			
Element	N	P	K	Ca	Mg	S	B	B	Cu	Fe	Mn	Mo	Zn
Complete control	3.19	0.20	3.44	0.80	0.27	0.19	22.0	22.0	7.3	59.0[3]	27.9	-[4]	23.8
Treatment	2.36	0.12	2.41	0.02	0.08	0.12	0.2	168.0	7.9	43.8[3]	9.4	-[4]	21.1
p-value[2]	***	*	*	***	**	**	***	***	NS	NS	***	-[4]	NS
Sufficiency range for *Lilium longiflorum*[5]	3.30-4.80	0.25-0.70	3.30-5.00	0.60-1.50	0.20-0.70	0.25-0.70	25-75	25-75	8-50	60-200	35-200	No data	20-200
Sufficiency range for *Lilium*[6]	2.4-4.0	0.1-0.7	2.0-5.0	0.2-4.0	0.3-2.0	No data	20-25	20-25	5-25	100-250	50-250	No data	30-70

[1] Boron deficiency and toxicity treatments indicated by -B and ++B, respectively.
[2] *, **, or *** indicates statistically significant differences between sample means based on *F* test at P≤0.05, P≤0.01, or P≤0.001, respectively. NS (not significant) indicates the F test difference between sample means was P≥0.05.
[3] Concentration listed is averaged between two samples.
[4] Concentrations were below the detectable limit of 0.5 mg kg^{-1}.
[5] Mills and Jones, 1996.
[6] Dole and Wilkins, 2005.

Table 2. *Lilium* hybrid 'Brunello' plant dry weight and tissue nutrient concentration as affected by deficient or toxic nutrient treatments and published optimum concentrations.

Treatment	-N	-P	-K	-Ca	-Mg	-S	-B[1]	++B[1]	-Cu	-Fe	-Mn	-Mo	-Zn
	Dry weight (g)												
Element	N	P	K	Ca	Mg	S	B	B	Cu	Fe	Mn	Mo	Zn
Complete control	5.60	14.42	14.42	11.66	11.66	11.66	14.42	10.99	14.42	10.99	14.42	14.42	14.42
Treatment	3.59	11.59	11.60	8.63	10.66	9.60	10.92	9.62	12.53	9.74	14.28	14.79	13.93
p-value[2]	**	*	*	*	NS	*	**	NS	NS	NS	NS	NS	NS
	Tissue nutrient concentration (%)						Tissue nutrient concentration (mg kg^{-1})						
Element	N	P	K	Ca	Mg	S	B	B	Cu	Fe	Mn	Mo	Zn
Complete control	3.69	0.28	4.24	1.27	0.25	0.34	65.5	40.8	11.1	98.6	73.6	-[3]	42.4
Treatment	2.79	0.18	2.27	0.04	0.06	0.14	6.9	398.7	10.3	37.5	13.9	-[3]	40.5
p-value[2]	NS	**	**	***	***	***	***	*	NS	**	***	-[3]	NS

[1] Boron deficiency and toxicity treatments indicated by -B and ++B, respectively.
[2] *, **, or *** indicates statistically significant differences between sample means based on *F* test at P≤0.05, P≤0.01, or P≤0.001, respectively. NS (not significant) indicates the F test difference between sample means was P≥0.05.
[3] Concentrations were below the detectable limit of 0.5 mg kg^{-1}.