Optimizing Molybdenum Levels in Sub-Irrigation Floriculture Systems

Water Adaptation Management and Quality Initiative Project #11

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Executive Summary

Original recommendations for fertiliser rates in floriculture greenhouses were based on top feeding (irrigation) systems that were inherently open: leachate was captured by a strategically placed subsurface drainage system systematically installed beneath the production area discharging to the environment. Since the 1990's, many greenhouse flowering potted plant producers have switched to sub-irrigation, where the nutrient solution is supplied from below in a trough-style or flood-floor system. Nutrient feedwater not absorbed through capillary action is returned to a holding tank where it is stored for reused (closed systems) during the next irrigation cycle. If this water no longer has value to the indoor crop, it can be land applied under the *Nutrient Management Act*; however, molybdenum (Mo) levels may trigger a flag in the NMAN system (program that determines appropriate land application rates based on the composition of the wastewater to be applied). This project studied Mo requirements for a Mo-sensitive crop to determine if the fertiliser rates can be decreased given that much of the potted flowering plants are produced using sub-irrigation where no leaching of nutrients occurs from the media in the container. Preliminary results comparing Mo levels of 0-100% of the typical fertiliser rate revealed no difference in the quality of the plant material by the time of harvest (early December), indicating that substantially decreasing the Mo concentration in the feed water after establishment may have negligible effect in the production of saleable plants while allowing land application of nutrient feedwater with fewer restrictions.

Poinsettias sub-irrigated (after spacing) without molybdenum after potting showed no evidence of Mo deficiency

Introduction

At certain points in greenhouse production, it may be desirable to refresh the nutrient feed solution and dispose of the re-circulated water (in open systems, nutrient solution is discharged continuously). The expansion of the *Ontario Water Resources Act* to allow land application of nutrient feedwater (excess or waste nutrient solution from greenhouses) following the guidelines of the *Nutrient Management Act* provides a sustainable solution for disposing of this excess water. However, a TOGA study (SRG, 2012) revealed that levels of molybdenum (Mo) and boron (B) in floriculture greenhouse nutrient feedwater exceeded the allowable rates in the NMAN program, indicating that full application of this solution on land would be limited under the NMAN program. Excess B and Mo released into surface water can affect aquatic life, as well as plant growth (CCME 2009, Gupta 1993, Kaiser et al. 2005). Molybdenum in particular can cause toxicity in ruminant animals if it builds up in the soil to levels

exceeding 5 ppm (CCME 1999).

Molybdenum, the least abundant essential micronutrient (Kaiser et al. 2005), is required for plant growth, metabolism of nitrogen and reproduction (OMAFRA 2010). This trace element is considered to be of intermediate mobility, meaning that it can move within the xylem and phloem, and that low levels within the plant do not immediately lead to deficiency symptoms. Sink regions, such as flowers, fruit, and new foliage can obtain this nutrient, at least in part, from older parts of the plant as required. However the movement of Mo in plants is not always clear (Kaiser et al. 2005). At some point, however, the amount of available nutrient can be limiting and Mo deficiency appears first in the recently matured leaves as interveinal chlorosis and mottling, cupping, curling and deformation, and necrotic spots on tips and margins of leaves (Arreola et al. 2008, Gupta 1993). Rates of fertilisation in commercial greenhouse floriculture operations that have adopted sub-irrigation systems, have significantly decreased in practice, since experience has shown that previously recommended rates based on top-irrigated open systems are much higher than crops require for optimal growth, often leading high soluble salts in the media, root rot issues and increased use of plant growth retardants to control plant height. Despite this decrease, Mo levels are still at rates higher than desired for land application from an outdoor growing perspective.

Fertiliser recommendations for floriculture greenhouse crops are over 40 years old

This project tested a range of concentrations of Mo in the nutrient feed solution (from the maximum commercially available rate to zero) to determine the lowest, yet optimal level for plant growth, bloom yield, and overall plant quality. The experiment was performed at the Vineland Research and Innovation Centre research greenhouse complex using Mo-sensitive potted poinsettia plants over the course of one growing cycle (August through December 2014). Using sensitive plants ensured that the results could be transferred to other flower species.

While there are technologies developed to remove nitrogen and phosphorus, salts, and other key compounds in greenhouse effluents (e.g. denitrifying woodchip biofilters, constructed wetlands, radial deionization, and nanofiltration), there are currently no readily available and cost-effective technologies for removing essential microelements such as Mo from solution. In top irrigated recirculating systems using rockwool or coir, undesirable salts (Na, Cl and sulphates) can become limiting for these crop production systems. Greenhouse vegetable and cut gerbera flower production are typical examples

where crops have long crop cycles and when a recirculation system is used then the salts can build up over time as other elements critical for plant growth are selectively taken up by the plants. However, most other elements (such as Mo) do not accumulate sufficiently to influence plant growth. In open systems, the composition of the discharge water is critical, and requires removal of macro- and micro-elements to decrease the impact on the environment. Ultimately, it is best for producers to minimize the use of nutrients, if possible, providing there are no negative impacts on their crop yield and post-harvest quality.

Objectives:

- Research greenhouse (i.e. laboratory) study of a sensitive floriculture crop (Poinsettia) grown using a sub-irrigation system to determine minimal Mo application rates without negatively impacting bloom yield and plant quality
- Correlate tissue levels of Mo with the presence/absence of deficiency symptoms
- Communicate results to the sector and fertiliser manufacturers/suppliers

Materials & Methods

Three hundred rooted Poinsettia "Christmas Day" cuttings were generously supplied by Linwell Gardens, a local commercial greenhouse rooting station, in production week 31 for planting. Cuttings had been rooted in peat-based Ellegaard style plugs. Rooted cuttings were planted into 16.5 cm plastic azalea pots filled with Sunshine #1 soilless media courtesy of SunGro Horticulture, on July 31, 2014 and placed on an expanded metal bench in a glass greenhouse compartment at the Vineland Research and Innovation Centre research greenhouse complex and watered with clear water until moist. During the establishment phase the following set points were established: D/N heat 22^{o}C, venting at 24^{o}C; shading was triggered based on light and/or temperature (600 W/m2 from 10:00-17:00h or 26^{o}C). Cuttings were pinched to 7/8 nodes 2 weeks after planting. The cuttings were fertilised overhead by hand beginning one week after transplanting using Plant Prod 20-8-20 at 100 ppm N with each irrigation event (roughly 2x per week). Refer to Table 1 for more detailed cropping schedule.

Table 1 – 2014 Vineland Cropping Schedule for the Reduced Molybdenum Trial

Activity	Week	Date	Comments
Planting of cuttings	31	July 30-31	Christmas Day – Selecta variety All rooted in ellegaard-type plug
Growing Media			Sunshine #1 in 6.5 ITML plastic azalea pots. All were grown pot-to-pot until spacing.
Shading	31-35 36/37	July 30 – Aug 30 Aug 31 – Sept 15	Shade closed at 600 W/m2 (10-17:00 h) or 26°C Shade closed at 700 W/m2 (11-15:00 h) or 26°C
Nutrition	31-36 37-50	Aug 7- Sept 5 Sept 7 –Dec 1	20-8-20 @ 1.0 EC – 100 ppm N – 1 wk after plant until spacing out onto troughs *150 ppm N – 4 levels fo Mo – 100%, 50%, 25%, 0%* *Agral 90* added monthly to improve H_2O uptake
Lights on/off (photoperiod) **Use of Blackout**	No Yes	 Beginning Sept 29	No night break lighting used To prevent stray HPS light B/O open/closed 30 minutes after/before sunrise/sunset
Pinching	33	Aug 13	Soft pinch to 7-8 nodes + top leaf removal
Spacing	36 40 44	Sept 5&6 Oct 4 Oct 30	Initial 12”x12” Respaced Spaced as required
PGR Applications ***B-Nine/Cycocel Extra***	33-1 35-1 35-6	Aug 10 Aug 24 Sept 5	B-Nine/ CCC spray (1000/1000 ppm) All PGR applied with HV sprayer
PGR Applications ***Cycocel Extra***	35-5 37-3 38-4 39-6 40-6 41-5 42-6	Aug 29 Sept 10 Sept 18 Sept 27 Oct 4 Oct 10 Oct 18	Spray at 1000 ppm (2.2 mL/L) Spray @ 1000 ppm (sprayed to glisten) Spray @ 1000 ppm Spray @ 1000 ppm Spray @ 1000 ppm Spray @ 1000 ppm Spray @ 1000 ppm
Fungicide Application(s) for Pythium Root Rot Control	38 40	Sept 15 Oct 3	*Subdue Maxx* + wetting agent sub-irrigated @ 0.4g/L *Subdue Maxx* + wetting agent sub-irrigated @ 0.4g/L
Temperature (heat/vent) Set Points	31 36 38 40 42 46 48 50 51	Jul 31 Sept 2 Sept 16 Oct 1 Oct 16 Nov 3 Nov 16 Dec 1 Dec 8	D/N Heat 22°C D/N Vent 24°C D/N Heat 21°C D/N Vent 22.5°C D/N Heat 20°C D/N Vent 22°C D/N Heat 20°C D/N Vent 21°C D/N Heat 19°C D/N Vent 21°C D/N Heat 18°C D/N Vent 20°C D/N Heat 18°C D/N Vent 19°C D/N Heat 17°C D/N Vent 18°C D/N Heat 15°C D/N Vent 16°C

Table 2 – 2014 Average Weekly Greenhouse Climate and Total Solar Radiation for each Compartment during the Reduced Molybdenum Trial

	Hse 10 (pot to pot)				
Week #	**Avg 24 h Temp °C**	**Avg 24 h RH%**	**Heat Set points D/N °C**	**Vent Set Points °C D/N**	**Total Solar Radiation J/cm²**
31	25.1	73	22/22	24/24	14,158
32	25.5	71			14,635
33	24.4	69			13,106
34	25.3	75			12,743
35	26.5	70			13,651
36	25.1	74	21/21	22.5/22.5	11,558
	Hse 20 (spaced on sub-irrigation)				
37	21.7	70			7,041
38	22.1	69	20/20	21/21	10,562
39	22.8	77			12,424
40	20.8	62	18/18	21/21	5,851
41	20.8	66			9,874
42	21.8	73			4,408
43	20.2	66			5,149
44	19.4	64	18/18	20/20	3,411
45	18	67	17/17	20/20	3,935
46	18.5	61			4,003
47	18.2	58	15/15	16/16	3,775
48	18.3	64			3,211
49	18.2	59			3,211
50	18.1	66			1,771
51	15.3	75			1,972

In Week 38 (September 10, 2014) young plants were spaced into another glass greenhouse for the remainder of the trial, maintained without supplemental lighting and initially at 21°C, and later as the plants matured at 19°C. The plants were placed in 12 rows (troughs) of 24 plants each, and 3 of the 4 treatments (0%, 50%, 100% Mo) were randomly assigned to each trough with the exception of the 25% Mo treatment. Each trough had its own nutrient solution tank and pump to supply the randomly selected treatment. The 25% Mo treatment was assigned to the 2 outside rows, and the third row was inserted into the centre of the ten rows. Because the outside rows could potentially experience an edge effect, the decision was made to use the 25% Mo fertiliser solution on these plants and if there

appeared to be no significant edge effect, then this treatment could be used in the results. If an effect was noted, the treatment would be removed from the final results. Replication for the four treatments were as follows: 23 biological reps, 3 blocks (1 genus * 1 element * 4 rates * 23 plants * 1 light regime * 1 pH levels * 3 blocks) = 276 plants per experiment (an additional row of buffer plants was placed at the beginning and end of each greenhouse trough as guards and these plants were discarded not included in the final harvest measurements (December 9th). Once plants were set out on the troughs treatment at the 4 levels of Mo was initiated (September 11, 2014). For this phase of the study, the nutrient solutions were made using an A/B stock tank system based on mmol/L for supplying the macronutrients and the standard rates of micronutrients based on micromole/L. All the macro and micronutrients remained the same for all treatments except Mo. Table 3 below outlines the nutrient levels supplied.

Table 3 – Fertiliser levels for Reduced Molybdenum Trial 2014

Macronutrients	**Mmol/L**	**PPM nutrient**
$HCO3^{-1}$	1.0	61
$H2PO4^{-1}$ –P	1.0	31
$SO4^{-2}$ – S	1.0	32
$NO3-^{1}$ –N	9.5	133
Ca^{+2}	3	120
Mg^{+2}	1.25	30
$NH4^{+1}$- N	2	14
K^{+1}	3	117
Micronutrient	**Micromol/L**	
Fe (13% EDTA)	25	
Mn (manganese sulphate -25%)	5	
Zn (zinc sulphate 35%)	3.5	
B (borax -15%)	2.0	
Cu (copper sulphate -25%)	0.8	
Mo (sodium molybdate – 39%)	0.5 (100%), 0.25 (50%), 0.125 (25%)	

The four treatments were continued until December 1, 2014. The fertiliser solution was applied via sub-irrigation to all plants with the same volumes (i.e. each trough received the same volume of it's particular feed solution), with the recirculating feed solution passing by the pots for a period of 20 minutes. There were 4 separate B concentrate tanks set up, containing 0%, 25%, 50%, and 100% of the recommended Mo rate and one A concentrate tank. Weekly, the required amount of concentrate from each of the four B concentrate tanks and from the A tank were blended with fresh water and added to replenish the individual recirculating tanks connected to each of the three troughs assigned to that Mo

rate of fertilisation. At the end of each trough, a barrel collected the feed solution that was recirculated within that same trough, with the barrels requiring weekly top-up from the concentrate tank. Typically 20 L of nutrient solution was added weekly. On occasion the two perimeter 25% Mo treatment plants required additional fresh water irrigation because they were drier than the outside plants. This occurred approximately once every two weeks. The greenhouse technician (Cathy Gray, University of Guelph) and the OMAFRA floriculture specialist (Wayne Brown) maintained humidity and temperature throughout the research trial through attentive care and venting as required. The Silverleaf Whitefly population was controlled using biweekly introductions of *Amblyseius cucumeris*, *Amblyseius swirski* and *Encarsia* to prevent the possibility that foliar applied pesticides might have an influence on the levels of Mo measured in the associated plant tissue at the conclusion of the trial.

Figure 1 – Design of trough system in greenhouse H20, with troughs sloped to empty into barrels at the end of each row for recirculating.

Measurements/Sampling Plan:

- Initial sampling of the growing medium (SGS Agri-food Laboratories, Guelph) on September 10th, 2014, as well as a tissue sample (University of Guelph Laboratory Services, Guelph) of 50 newly mature leaves taken randomly from the trial plants.
- Tissue/Medium/Fertiliser analyses included Mo, and nutrients such as N, B and Ca, which serve as markers for phloem mobile and immobile elements
- Biweekly tissue sampling of recently mature leaves (one from each of the 23 plants in a specific row/trough, so a total of 12 samples representing each row) between September 30 and December 9, 2014 for tissue analysis.

- Monthly water sampling of the concentrate tanks to verify feed solutions contained the appropriate amount of Mo (sent to ALS Environmental, Waterloo).
- Yield/Size measurements, including: final total heights (from soil level to tip) of all 276 plants, plus total fresh and dry weights for leaves, inflorescence (bracts and cyathia) and stems. Note that since the flower portion of the poinsettia is so small, the entire bract portion (the inflorescence) plus flowers was included in the bract sample. Only bracts (which are modified leaves) that were fully coloured were included in the 'bract' sample, while any leaves that were partially red (transitional) were included in the 'leaf' sample.
- Final sampling of three tissue parts for nutrient analysis: leaves, bracts and stems for the 276 plants.
- Visual observations of plant growth, bloom yield and overall plant quality were made throughout and at the end of the trial.
- Plant quality was of particular importance (appearance of visual symptoms of nutrient deficiency or imbalance, leaf and inflorescence development).

Statistical analysis of the data was limited to calculation of means and standard deviation where appropriate. Analysis of variance (ANOVA) is planned for the full tissue analysis data set.

Results & Discussion

Initial results (September 10, 2014):

Molybdenum level in the aggregate growing media sample from early September was 0.01 ppm, yet in the tissue, the Mo was determined to be 0.59 ppm dry weight. Nitrogen and calcium levels in the mature leaves were found to be 4.07% and 0.979% dry weight, respectively. At this time, the plants were spaced in the greenhouse in a random manner, and appeared healthy, with a fresh green colour (Figure 2). The level of Mo in the plants after the initial establishment period is particularly important, as tissue and physical appearance of the plants by the end of the study suggest movement of the internal Mo levels to sink regions to maintain overall plant quality.

Figure 2 – Initial layout of the poinsettia crop (September 10, 2014) in greenhouse A20, and a close up of one of the plants to illustrate colour/appearance.

Biweekly results (September 30 through December 9):

Table 4 details the levels of Mo in mature leaves over the treatment period for each row of plants (three replicates of the four fertiliser rates). Nearly every row of plants (composite leaf samples) experienced a reduction in Mo levels over the 13.5-week period, suggesting that Mo was being mobilized from older mature leaves after the bracts began to develop (late October, see Figure 3) and even more so after the fertiliser source was discontinued (December 1). On average (average of the 3 rows of the same treatment), over the crop cycle the 0% Mo-treated plants had a reduction in leaf Mo levels of 35% (if Row 4 data is removed, the decrease averages 57%), the 25% Mo-treated plants a 52% reduction, and the 50 and 100% treatments had reductions of 26% and 21%, respectively. By December 9th, Mo levels in the mature leaves for the 0 and 25% treatments were slightly lower than the 50 and 100% treatments (0.20 ppm compared to 0.26 ppm, respectively). Averaging the data over the entire treatment period showed no difference among treatments or replicate blocks (troughs) of the same treatment. An analysis of Mo levels throughout the plant on a monthly basis throughout the trial would have provided more information regarding the mobility of Mo and allowed a mass balance, but this was not within the scope of the study. Notably, all the Mo levels measured in mature leaves throughout this study are generally considered to be within the sufficiency range for Mo (0.1-2 ppm).

Nitrogen (N) levels increased in mature leaves by approximately 25% over the trial period, whereas calcium (Ca) and boron (B) levels increased by approximately 100%. Note that the fertiliser levels of these essential elements were supplied at the full (recommended) rates up to December 1, 2014.

Table 4 – Mo (ppm dry weight) levels in mature leaves from September 10, 2014 through the growing cycle, followed by results of nitrogen, calcium and boron.

Summary results for Molybdenum (ppm) in mature leaves of Poinsettia

	1st day	Row 1- 25%	Row 2- 50%	Row 3- 100%	Row 4- 0%	Row 5- 0%	Row 6- 100%	Row 7- 50%	Row 8- 25%	Row 9- 100%	Row 10- 0%	Row 11- 50%	Row 12- 25%
10-Sep	0.59												
30-Sep		0.34	0.31	0.28	0.31	0.32	0.34	0.38	0.35	0.38	0.35	0.42	0.46
14-Oct		0.46	0.55	0.40	0.61	0.48	0.58	0.53	0.41	0.49	0.42	0.45	0.39
28-Oct		0.32	0.35	0.29	0.38	0.25	0.38	0.31	0.24	0.32	0.20	0.32	0.25
11-Nov		0.48	0.41	0.25	0.37	0.37	0.25	0.30	0.22	0.34	0.17	0.54	0.54
25-Nov		0.31	0.46	0.31	0.44	0.25	0.46	0.31	0.22	0.36	0.19	0.34	0.24
09-Dec		0.21	0.31	0.22	0.34	0.15	0.34	0.25	0.16	0.22	0.14	0.24	0.17

Summary results for Nitrogen (% dry weight) in mature leaves of Poinsettia

	1st day	Row 1- 25%	Row 2- 50%	Row 3- 100%	Row 4- 0%	Row 5- 0%	Row 6- 100%	Row 7- 50%	Row 8- 25%	Row 9- 100%	Row 10- 0%	Row 11- 50%	Row 12- 25%
10-Sep	4.07												
30-Sep		4.48	4.50	4.55	4.30	4.69	4.48	4.30	4.15	4.24	3.98	4.62	4.37
14-Oct		4.74	4.71	5.22	5.31	5.03	5.31	4.98	5.14	4.90	4.49	5.08	5.11
28-Oct		4.57	4.69	4.79	5.28	4.93	5.31	4.82	4.62	5.24	4.90	4.93	4.87
11-Nov		5.03	4.74	5.23	5.05	5.06	5.07	5.39	5.04	5.32	5.23	4.98	4.72
25-Nov		5.17	5.40	5.36	5.2	5.46	5.26	5.38	5.28	4.74	5.51	4.86	5.18
09-Dec		4.48	4.90	4.86	4.83	4.94	4.97	4.91	4.86	4.89	5.05	5.00	4.62

Summary results for Calcium (% dry weight) in mature leaves of Poinsettia

	1st day	Row 1- 25%	Row 2- 50%	Row 3- 100%	Row 4- 0%	Row 5- 0%	Row 6- 100%	Row 7- 50%	Row 8- 25%	Row 9- 100%	Row 10- 0%	Row 11- 50%	Row 12- 25%
10-Sep	0.98												
30-Sep		1.29	1.09	1.24	1.21	1.35	1.14	1.12	1.15	1.37	1.18	1.16	1.18
14-Oct		0.92	1.11	1.39	0.97	1.09	1.10	1.05	1.18	1.11	1.27	1.13	1.19
28-Oct		1.01	1.10	1.07	1.06	1.16	1.06	1.07	1.09	1.11	1.06	1.10	1.18
11-Nov		1.23	1.19	1.26	1.18	1.19	1.17	1.16	1.17	1.21	1.26	1.12	1.20
25-Nov		1.46	1.51	1.44	1.43	1.48	1.41	1.48	1.46	1.43	1.48	1.56	1.47
09-Dec		1.77	1.76	1.67	1.57	1.75	1.72	1.64	1.69	1.74	1.69	1.71	1.75

Summary results for Boron (mg/kg dry weight) in mature leaves of Poinsettia

	1st day	Row 1- 25%	Row 2- 50%	Row 3- 100%	Row 4- 0%	Row 5- 0%	Row 6- 100%	Row 7- 50%	Row 8- 25%	Row 9- 100%	Row 10- 0%	Row 11- 50%	Row 12- 25%
10-Sep	21												
30-Sep		20	21	20	19	19	19	21	22	19	20	21	18
14-Oct		24	25	23	25	27	24	25	26	26	27	25	25
28-Oct		25	23	23	23	24	22	22	23	23	23	25	26
11-Nov		29	28	26	26	25	26	25	26	27	26	27	29
25-Nov		36	35	33	33	35	32	33	34	37	35	38	38
09-Dec		40	42	42	37	39	39	38	41	42	38	40	42

Figure 3 – Poinsettia crop (November 3, 2014) in greenhouse #20, to illustrate colour/appearance as the bracts start to form and plants enter the flowering stage.

By looking at the average tissue data for each treatment on a monthly basis (Table 5), it is evident that the Mo levels in mature leaves decrease through the various developmental stages (vegetative state, bract development, and at maturity) at the lower level treatments of 0% and 25% but remain above the published acceptable range for Mo in poinsettia leaf tissue. Figure 4 illustrates the variation in Mo levels over time. Nitrogen (N) levels increased steadily in all treatments (no difference among treatments as expected as all four treatments received the same amount), while the immobile Ca levels actually declined across all treatments during bract development before increasing again at maturity. This result is most interesting, and warrants further investigation. Boron, also partially mobile, demonstrated increased levels in the recently matured leaves at the mature plant stage in late November, compared with the other two developmental growth stages.

Table 5 – Key nutrient levels (ppm) in composite samples of recently mature leaves (raw data taken from Table 4), and averaged by treatment on a monthly basis.

	TREATMENT	veg state 2014-09-30	bract devpt 2014-10-28	maturity 2014-11-25
Mo	0%	0.33	0.28	0.29
	25%	0.38	0.27	0.26
	50%	0.37	0.33	0.37
	100%	0.33	0.33	0.38
N	0%	4.32	5.04	5.39
	25%	4.33	4.69	5.21
	50%	4.47	4.81	5.21
	100%	4.42	5.11	5.12
Ca	0%	1.25	1.09	1.46
	25%	1.21	1.09	1.46
	50%	1.12	1.09	1.52
	100%	1.25	1.08	1.43
B	0%	19	23	34
	25%	20	25	36
	50%	21	23	35
	100%	19	23	34

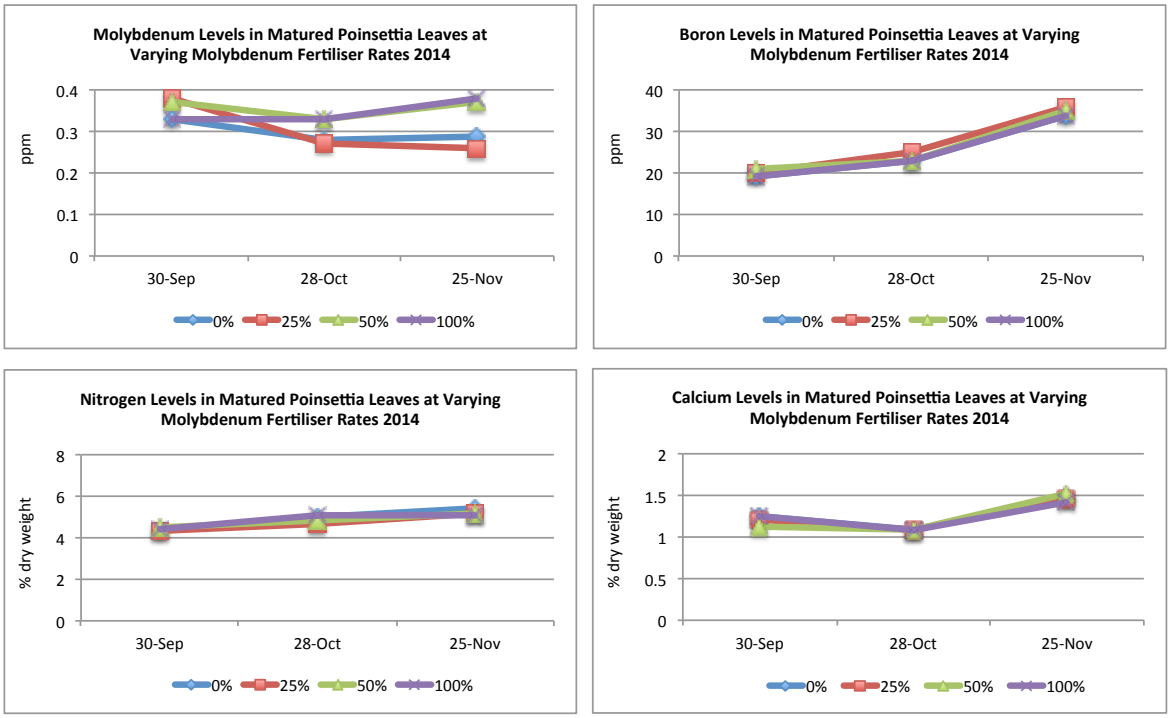

Figure 4 – Levels of key nutrients during Poinsettia plant development from September through late November (data from Table 5).

Solution results:

According to traditional fertiliser requirements, the fertiliser solution (at 100% Mo) should include 0.5 µmol/L. The molecular weight of Mo = 95.94, so after converting to mg/L it was determined that 0.04797 mg/L (or ppm) is required for the 100% solution. The concentration in the other treatments was determined based on this calculation, with 0, 25, and 50% of the rate determined above. Initial analysis at A&L Laboratories (London, Ontario) used the ICP process, with a detection limit of 0.02 ppm, insufficient for testing of the individual trough solutions from the recirculation barrels. ALS Environmental (Waterloo, Ontario) tested (with a detection limit of 0.0005 ppm) the stock tank solutions (i.e., the concentrate) on three separate dates (Table 6). Note that the concentration in these tanks was concentrated by 100-fold, and diluted with fresh to achieve the correct fertiliser rate during application. Note that the concentrate tanks did experience some settling, and the difference between the expected rate and actual calculated rate may be due to improper sampling technique.

Table 6 – Mo levels in the concentrate stock tanks (ppm).

Treatment	Oct 29/14	Nov 11/14	Nov 25/14	Target ppm	Actual average ppm inTreatment	Actual Average % of full rate in Treatment
0%	0.12	0.0005	0.0005	0	0.04	0.8%
25%	1.16	1.73	1.69	1.2	1.53	31.8%
50%	3.02	3.9	3.08	2.4	3.33	69.5%
100%	3.41	4.48	4.71	4.797	4.20	87.6%

End of trial results (December 15-16, 2014):

At the end of the trial, there were no visible differences among the rows and treatments, in either colour of leaves or flowers, overall height, apparent bloom yield, and no visible interveinal chlorosis was observed (Figure 5).

Figure 5 – Poinsettia crop (December 9, 2014) in greenhouse A20, to illustrate colour/appearance one week before the crop cycle was completed. Markers at the end of each row identified the treatments; no difference in colour or height was apparent among rows or treatments.

By comparing overall plant height, and fresh weights of the three plant parts (bracts, leaves and stems, see Figure 6), there appeared to be no difference between the 25% Mo treated plants in row 8 (embedded in the treatment area) and the two outside rows. While there might be slight differences apparent in the tissue analysis through the growing cycle (Tables 4 & 5), there was not enough evidence to show an edge effect. Therefore, the 25% treatment was included in the following data analysis.

Figure 6: Harvesting the plants on December 15, 2014, separating plant shoot parts, and weighing leaf and stem portions.

Based on data collected at the December harvest, there were no significant differences among the four treatments (Figure 7). Overall height of the plants (shown as red diamonds), as well as bract, leaf and stem fresh weights (bars) were averaged for all the plants in a treatment row, and across the three replicate rows. The standard deviation was calculated based on the data from those 69 plants (23 plants per row, 3 rows).

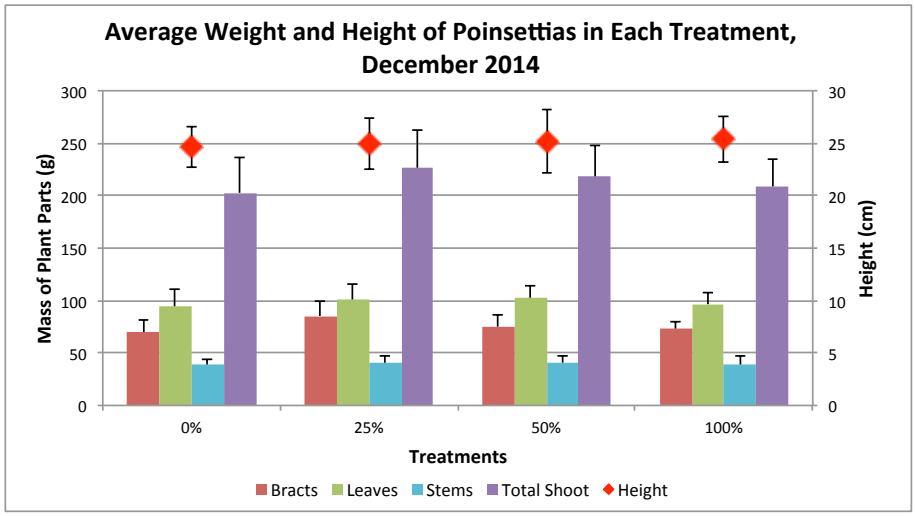

Figure 7: Average fresh weights and heights of the bracts, leaves and stems in each of the four treatments. Note that each bar and point represents the average of 72 plants. Error bars represent the standard deviations.

The distribution of Mo, N, Ca and B in various tissues at maturity was dependent on the element under consideration: however, this distribution was unaffected by the Mo treatments (Table 7 and Figures 8-11). While this result was expected for Ca, N and B (since all plants in the experiment were provided with consistent levels of these elements throughout the study), the Mo levels would be expected to vary if the element becomes limiting (especially at the lower application rates).

Table 7 – Mean Levels of N and Ca (% dry weight) and B and Mo (mg/kg dry weight) in Bract, Leaf and Stem Tissues of Poinsettia after Plants Reached Maturity (December 15, 2014)

	Average within treatment					Std Deviation within treatment				
Trt/Tissue	**N**	**Ca**	**B**	**Mo**	**Dry Wt**	**N**	**Ca**	**B**	**Mo**	**Dry Wt**
0% Bract	3.35	0.555	23	0.22	15.37	0.16	0.064	1	0.05	1.20
0% Leaf	4.42	1.697	44	0.39	21.33	0.19	0.136	3	0.08	2.20
0% Stem	1.84	1.517	13	0.14	13.78	0.16	0.171	1	0.04	1.25
25% Bract	3.23	0.592	23	0.20	17.10	0.17	0.061	1	0.07	1.70
25% Leaf	4.42	1.804	46	0.39	22.17	0.19	0.151	5	0.23	2.17
25% Stem	1.79	1.534	13	0.11	14.20	0.12	0.192	1	0.05	1.57
50% Bract	3.36	0.579	23	0.28	15.77	0.15	0.065	1	0.04	1.15
50% Leaf	4.48	1.724	45	0.42	22.15	0.16	0.134	4	0.08	1.67
50% Stem	1.80	1.554	13	0.17	14.17	0.11	0.194	1	0.06	1.21
100% Bract	3.33	0.593	23	0.24	15.76	0.16	0.141	3	0.07	0.89
100% Leaf	4.47	1.697	43	0.41	21.35	0.16	0.129	5	0.11	1.62
100% Stem	1.82	1.535	13	0.12	13.84	0.19	0.156	1	0.04	1.13

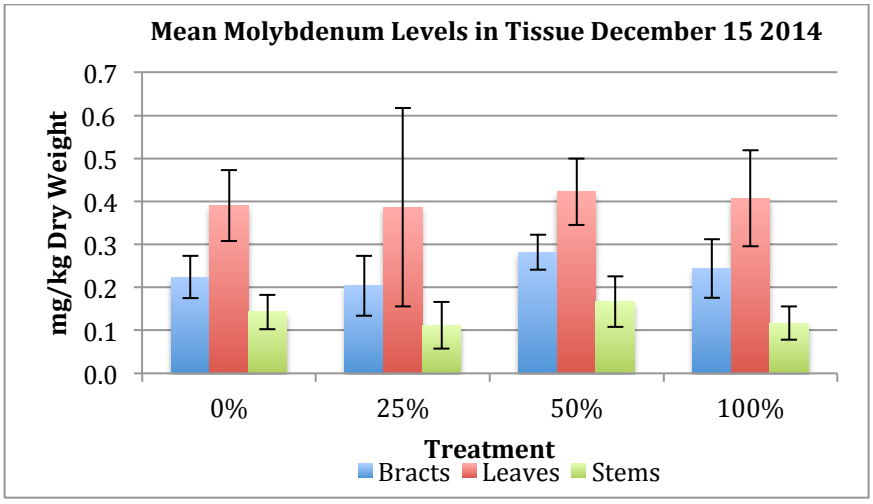

Figure 8: Mean Mo levels in the bracts, leaves and stems in each of the four treatments. Note that each bar and point represents the average of 69 plants. Error bars represent the standard deviations.

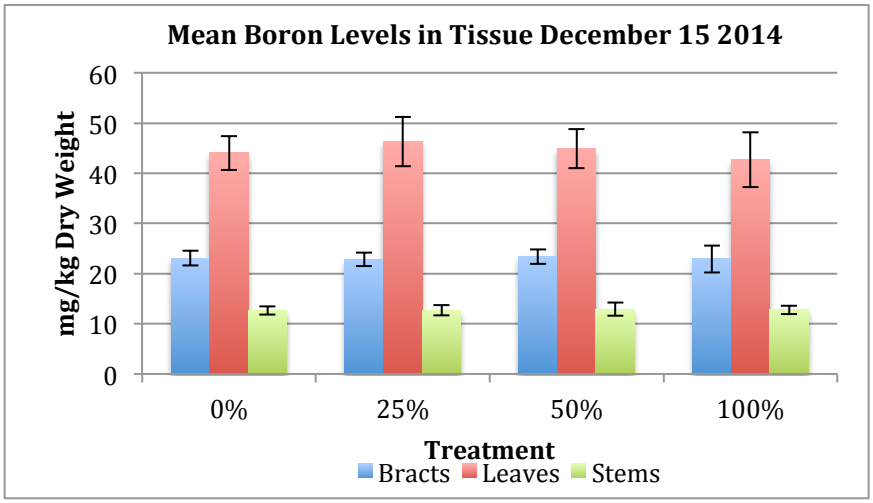

Figure 9: Mean B levels in the bracts, leaves and stems in each of the four treatments. Note that each bar and point represents the average of 69 plants. Error bars represent the standard deviations.

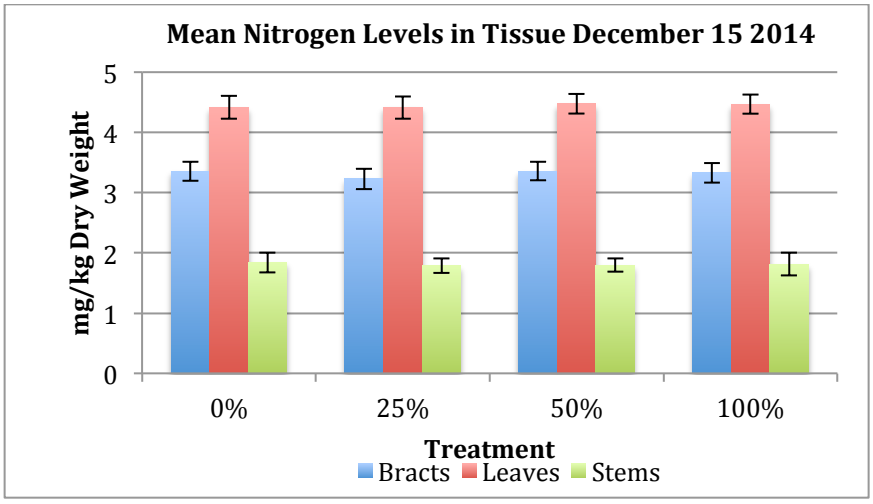

Figure 10: Mean N levels in the bracts, leaves and stems in each of the four treatments. Note that each bar and point represents the average of 69 plants. Error bars represent the standard deviations.

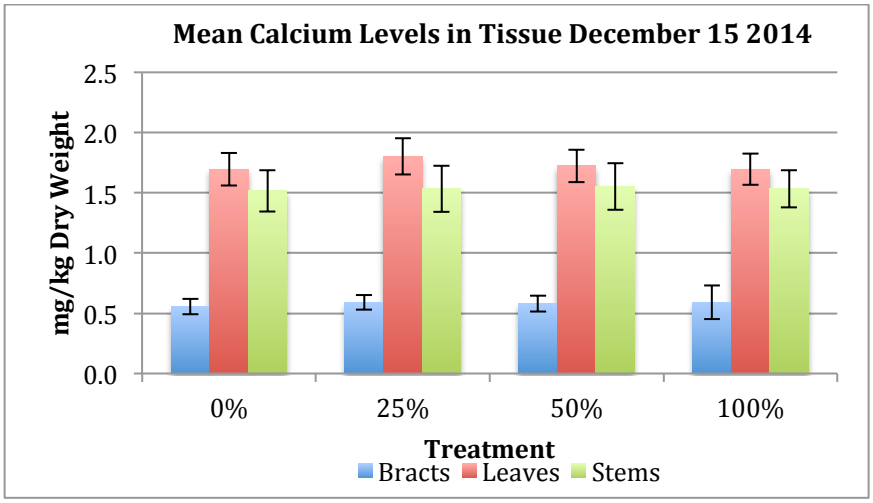

Figure 11: Mean Ca levels in the bracts, leaves and stems in each of the four treatments. Note that each bar and point represents the average of 69 plants. Error bars represent the standard deviations.

When mean Mo and B levels are compared among the four treatments, and also to those of Ca (immobile) and N (mobile), it is possible to explore the level of mobility of these elements between plant parts and test our prediction that these elements have intermediate mobility. Table 8 lists the ratios of the four elements of interest, comparing levels of these elements in the bract to both the leaf and stem tissues (Bract:Leaf, Bract:Stem). Larger numbers suggest greater mobility in the plant. As predicted, calcium has the lowest ratios (0.327-0.386), and nitrogen has the highest ratios (0.731-0.759) for

Bract:Leaf, and 1.804-1.836 for Bract:Stem. Boron and Mo ratios are intermediate and fairly similar for Bract:Leaf indicating some mobility. The Bract:Stem ratios for B and Mo are similar to N, indicating similar mobility. While it is possible that Mo mobility may be decreased by the 0% treatment (less available Mo), it is not likely significant, and there is strong indication that Mo is not in short supply.

Table 8 – Ratios of Bract nutrient levels to Leaf and Stem nutrient levels for Mo, B, N and Ca in Poinsettia Plants at Maturity (December 15, 2014)

Bract : Leaf	Treatment			
Parameter:	**0%**	**25%**	**50%**	**100%**
Mo/Mo	0.573	0.528	0.667	0.599
B/B	0.525	0.493	0.521	0.537
N/N	0.759	0.731	0.750	0.745
Ca/Ca	0.327	0.328	0.336	0.349

Bract : Stem	Treatment			
Parameter:	**0%**	**25%**	**50%**	**100%**
Mo/Mo	1.567	1.824	1.689	2.089
B/B	1.824	1.805	1.810	1.795
N/N	1.821	1.804	1.868	1.836
Ca/Ca	0.366	0.386	0.373	0.386

Outcomes/Recommendations

- Significant decreases in the levels of Mo in fertiliser application rates appear, based on this initial study, to have no impact on the production of saleable *Poinsettia* crops (known to be sensitive to Mo deficiency) when grown using sub-irrigation technology.
- Decreasing the Mo fertilisation by 50% over the current recommended rates based on this one study will not have a negative effect on Mo levels in plant tissues (after the establishment stage) when plants are grown in a closed, sub-irrigation system where no leaching occurs from the substrate in which the plants are grown.
- *Other cultivars of poinsettia may have different responses to Mo rates, so it would be valuable to trial various Mo dose rates before changing production practices*
- Decreased levels of Mo in discharge water could result in levels meeting the Provincial Water Quality Objectives and not be red flagged under land application proposed rules of NMA.
- Post-harvest impacts were beyond the scope of this study.
- Decreasing the level of Mo in fertiliser mixes may decrease the cost to the farmer, although since the amount of Mo in fertiliser is so small (a micronutrient typically supplied at 0.04797 mg/L), the impact on farmer costs will be negligible. The environmental impact of decreasing Mo in open systems is the larger gain resulting from this study.
- Both 0% and 25% Mo treatments decreased the Mo levels in mature leaf tissue over time; however, the decrease in mature leaf Mo levels was insufficient to result in deficiency symptoms during the crop cycle. The level of Mo (and Ca, N, and B) in the bracts, as well as the

mature tissues from the December harvest, might provide clues as to the degree of mobility and ability of the plant to sustain itself beyond the trial period.

- Mo applied through the establishment period (August) may provide sufficient Mo to the plant for the remainder of the growing cycle (September through December), since plants possess some ability to mobilize Mo.
- In open systems, 'waste' nutrient feedwater can be reused on other crops (e.g. outdoor containers) or can be land applied as a beneficial solution under the Nutrient Management Act. Low levels of trace elements are important for plant growth, but cannot exceed the requirements of the receiving crop or land, or result in toxic levels for livestock grazing on receiving crops.
- This research, while not directly applicable to vegetable greenhouse production, will set a precedent for testing similar theories for vegetable Mo requirements. Original recommendations for tomato, pepper and cucumber crops were not based on sub-irrigation/hydroponic systems. However, it may be more complicated to satisfy the Mo demands of fruiting crops.
- Based on this initial study, evaluating the optimal level of micronutrients in standard greenhouse based water-soluble fertilisers when using recirculating sub-irrigation technology is recommended.

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