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**Optimizing supply and timing of nitrogen application for
subirrigated potted chrysanthemums**

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23 **Abstract**

24 Two disbudded, potted chrysanthemum cultivars were subirrigated with 9.25, 12.3 and
25 18.5 mM N during vegetative, but not reproductive growth. At commercial harvest,
26 visible symptoms of N deficiency or differences in plant/inflorescence quality were
27 minimal, whereas N uptake efficiency was dramatically improved at 9.25 and 12.3 mM
28 N.

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30 *Key words:* greenhouse floriculture, nitrogen use efficiency, nitrogen uptake efficiency,
31 remobilization
32

33 **Introduction**

34 Greenhouse floriculture operations can pose significant environmental risk due to the
35 large fertilizer inputs for the different crops, in part because leaching and run-off of
36 nutrients such as nitrate and phosphorous pollute surface and ground waters (MacDonald
37 et al., 2013). Closed subirrigation systems, which recirculate water and nutrients, are
38 gaining popularity as environmentally friendly strategies for managing the nutrition of
39 popular ornamental potted plants (MacDonald et al., 2013; Ferrarezi et al., 2015) such as
40 chrysanthemum (MacDonald et al., 2014a, b). However, the original recommendations
41 for fertilizer rates are based on overhead and drip irrigation systems that are inherently
42 open.

43 Nitrogen is considered to be a strongly mobile nutrient in plants, meaning that it
44 readily moves within both xylem and phloem, and that low levels within the plant do not
45 immediately lead to deficiency symptoms (Marschner, 1995). Thus, sink regions such as

46 inflorescence, fruit and new foliage can obtain N from older parts of the plant as required.
47 At some point, however, the amount of available nutrient becomes limiting and N
48 deficiency appears first in the older leaves as interveinal chlorosis. The goal of our
49 research is to optimize the timing and application rates of soluble N to important
50 commercial cultivars of subirrigated potted chrysanthemum in order to maximize N use
51 efficiency (NUE; expressed as utilization or uptake, Good et al., 2004) without reducing
52 plant and inflorescence quality.

53 Commercial fertilizer N guidelines for greenhouse-grown potted chrysanthemums
54 suggest feeding 17.9 to 28.6 mM N, primarily in the nitrate form using soilless media
55 (Dole and Wilkins, 2005). Green Leaf Plants (2015), a major supplier of chrysanthemum
56 cuttings, recommends 21.4-28.6, 14.3-17.9 and 3.6-7.2 mM N, followed by clean water,
57 respectively, for the first 40-50% and the next 20-25%, 20-25%, and the last 10% of the
58 crop cycle. In our initial studies, we modified the management of N by simply
59 interrupting the supply (18.5 mM N) at inflorescence emergence, essentially the mid-
60 point of the crop cycle for subirrigated potted chrysanthemum ('Yellow Favour'), and
61 thereby promoting the remobilization of N from the lower stems/petioles/leaves during
62 the reproductive phase and improving the N utilization efficiency at commercial harvest
63 (MacDonald et al. 2014a). In the present study, we determined the impact of a range of N
64 levels supplied over the duration of the vegetative phase, on the morphology and NUE of
65 two modern chrysanthemum cultivars at commercial harvest.

66

67 **Materials and Methods**

68 Rooted cuttings of *Chrysanthemum morifolium* Ramat ('Olympia' and 'Covington')
69 were produced in a commercial setting (Kuyvenhoven Greenhouses, Halton Hills, ON)
70 essentially as described by Green Leaf Products (2015). Briefly, the base of each cutting
71 was dipped in 19.7 mM indole butyric acid and then enclosed in a Jiffy Plug (Model CF
72 Hort. Plug 343040-26, Jiffy Products (N.B.) Ltd., Shippagan, New Brunswick, Canada)
73 filled with peat moss and placed on a misting bench in a naturally-lighted greenhouse,
74 wherein the dark period was interrupted daily with supplemental lighting (one 100-w
75 incandescent lamp per 2 m²) from 2200-0200 h. On day 13, the misting tent was removed
76 and the cuttings received 20/8/20 fertilizer solution (17.8 mM N) every 2 d thereafter
77 until day 21. Then the cuttings were transferred to the University of Guelph by car and
78 individually grown in 10-cm plastic pots filled with a custom mixture of peat moss and
79 perlite (50:50 by volume) at a pH of 5.4-6.2 (Berger, Specialties Robert Legault Inc.,
80 Boisbriand, QC, Canada). The potted cuttings were placed in one of eight troughs (445 x
81 11 x 4.7 cm, Farm Tek HydroCycle 6" Pro NFT Series, Dyerville, IA, USA) located on a
82 custom-designed, computer-controlled bench with a four-sided frame (455 x 109 x 160
83 cm) over the cuttings. The bench was located in a naturally-lighted greenhouse set at
84 23°C day/night temperatures during the study period (May-July 2015). Beginning 1 wk
85 after transplanting, short days (10 h:14 h L:D cycle) were imposed 1 h before sundown
86 by automatically closing the top and four sides of the bench. In general, the nutrient
87 feedwater was supplied every 2 d until inflorescence emergence (4.5 wks), and deionized
88 water was supplied every day thereafter; border plants received nutrient feedwater
89 continuously. The nutrient feedwater (completely replenished once over the crop cycle)
90 or deionized water for each trough was housed in an adjacent 50-L tank and recycled

91 using an ebb-and-flow subirrigation system, wherein pumping occurred at 1100 h for 2.5
92 min, allowing the troughs to fill to an approximate depth of 2 cm, and then to drain over a
93 20-min period. Over the growing period, all auxiliary buds and branches were removed
94 by hand to ensure that each plant had only a single stem with an inflorescence.

95 A balanced split-plot experiment was conducted with nitrate-N treatment (18.5, 12.3
96 and 9.25 mM N) as the main plot and cultivar as the sub-plot, and the main plots were
97 arranged as a randomized complete block design of two blocks. The outside two rows
98 contained border plants receiving 18.5 mM N for the entire growing period. With the
99 exception of the nitrate salts, the composition of feedwaters was essentially as described
100 earlier (MacDonald et al. 2014a), except that KCl and CaCl₂ were used to maintain a
101 consistent macronutrient supply over the N range and to minimize differences in
102 electrical conductivity among the feedwaters as much as possible. There were 10 plants
103 (disbudded) per treatment replicate, and all plants were harvested and divided at the end
104 of the crop cycle (9 wks under our experimental conditions) to rapidly assess visual
105 symptoms and plant characteristics, and then dried at 70 °C for 3 d. Two plants were
106 randomly combined for total N analysis (i.e., five biological replicates per treatment
107 replicate) by a combustion method (AOAC International 2005) performed with a Leco
108 FD-428 Nitrogen Analyzer. All statistical analyses were conducted using SAS 9.4 (SAS
109 Institute Inc., NC) at $\alpha = 0.05$ level. Effects of block, cultivar and N treatment were
110 analyzed using ANOVAs (proc mixed method) with Fisher's protected least significant
111 difference test. The dry mass (DM) and N contents of the flower and plant were used to
112 calculate N uptake efficiency (shoot N content/N supply) and N utilization efficiency

(inflorescence DM/shoot N content), respectively, as specific indices for the efficiency of N absorption and remobilization (Good et al. 2004; MacDonald et al., 2013)

Results

The morphological characteristics of ‘Olympia’ at commercial harvest were not affected by N supply, whereas with ‘Covington’ plant DM yield, plant N content and plant height were approximately 17, 20, and 8% less at 9.25 and 12.3 mM N than 18.5 mM N (Table 1, Supplementary Table S1). Visible symptoms of N deficiency were absent in both cultivars at these N levels (Supplementary Fig. S1). N uptake efficiency was improved by 47-87% and 25-71% in ‘Olympia’ and ‘Covington’, respectively, with decreasing N supply, but N utilization efficiency was unchanged.

Discussion

Current commercial guidelines for chrysanthemums recommend that N be supplied continuously (minimum of approximately 18.5 mM) in the feedwater over the growth cycle (Dole and Wilkins, 2005) or decreased in a step-wise fashion over the reproductive phase (Green Leaf Plants, 2015). Our previous research showed that complete removal of the feedwater N supply, as well as other nutrients, from disbudded, potted plants of ‘Yellow Favor’ chrysanthemum at inflorescence emergence promotes sufficient remobilization of nitrate, as well as reduced N, from previously- produced organs/tissues for reduction and/or transport to satisfy the development of the inflorescence and production of commercially acceptable plants (MacDonald et al. 2014a, b). The present study demonstrated that the supply of N to disbudded ‘Olympia’ and ‘Covington’

chrysanthemums could also be reduced by 34-50% during the vegetative phase, compared to current commercial guidelines (i.e., 9.25-12.3 mM N versus 18.5 mM N; Dole and Wilkins, 2005; Green Leaf Products, 2015), with only slight effects on plant and inflorescence quality. However, there were marked increases in N uptake efficiency with decreasing N supply. Overall, these findings suggest that nitrate transporters present in the root plasma membrane of modern chrysanthemum cultivars (Wang et al. 2012) are saturable at lower nitrate levels than are recommended in commercial guidelines, and further suggest that the judicious use of N over the crop cycle (i.e., 25-50% of current commercial recommendations) can improve the efficiency of processes associated with both nitrate absorption and remobilization.

Commercial trials in floricultural operations in Ontario are warranted to firmly establish the minimal N supply for year-round production of subirrigated potted chrysanthemums, which does not negatively influence crop use and postharvest quality (e.g., Nemali and van Iersel, 2004). Optimization of the nutrient supply using the strategies described in this report could result in less nutrient usage and cost and a smaller volume of less concentrated nutrient-rich feedwater for treatment and/or approved discharge, if and when it is not recycled.

Supplementary Materials

Table S1 and Supplementary Fig. S1 are available with the article through the journal Web site.

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Table 1. Impact of N supply prior to inflorescence emergence on DM yield, N accumulation, and indices of N use efficiency in ‘Olympia’ and ‘Covington’ cultivars of potted chrysanthemums grown with subirrigation

N Supply (mM)	S+P+L ^y DM (g plant ⁻¹)	Inflorescence DM (g plant ⁻¹)	Plant DM (g plant ⁻¹)	S+P+L N (mmol plant ⁻¹)	Inflorescence N (mmol plant ⁻¹)	Total N (mmol plant ⁻¹)	NU _p E	NU _t E
‘Olympia’								
9.25	4.46 ^a ^z	1.34 ^a	5.79 ^a	10.32 ^a	1.79 ^b	12.11 ^a	1.31 ^a	9.64 ^a
12.3	3.99 ^a	1.16 ^b	5.14 ^a	11.02 ^a	1.62 ^b	12.64 ^a	1.03 ^b	7.56 ^b
18.5	4.09 ^a	1.26 ^{ab}	5.36 ^a	11.33 ^a	2.01 ^a	13.34 ^a	0.70 ^c	8.23 ^{ab}
‘Covington’								
9.25	2.32 ^b	0.85 ^b	3.17 ^b	5.96 ^b	1.66 ^b	7.62 ^b	0.82 ^a	10.54 ^a
12.3	2.31 ^b	0.82 ^b	3.13 ^b	5.81 ^b	1.56 ^b	7.37 ^b	0.60 ^b	10.64 ^a
18.5	2.71 ^a	1.10 ^a	3.81 ^a	7.00 ^a	2.16 ^a	9.16 ^a	0.48 ^c	12.76 ^a

^zDM yield and N data represent the mean of 10 and five replicates (each derived from two plants), respectively.

^yS+P+L represents stems+petioles+leaves.

a-c Means followed by the same letter within a column for each cultivar are not significantly different ($P \leq 0.05$)