Leaching of Nitrogen from Container Plants Grown under Controlled Fertigation Regimes[1]

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Abstract

One-year-old *Weigela* and *Campanula* liners were transplanted into containers and grown outdoors for one season. Nutrient solutions with high conductivity (EC: 2.0 dS/m), intermediate conductivity (EC: 1.25 dS/m) or low conductivity (EC: 0.95 dS/m) were applied at each irrigation. The nitrogen concentrations of the solutions were 220, 110 and 55 g N/m^3, respectively. Fertigation frequency was controlled by the use of tensiometers placed in the growing medium. Growth and the amount of N leached from the containers and the N content of the shoot were measured. The respective amounts of N leached from *Weigela* were 40, 6 or 3 kg N/ha, whereas in *Campanula* 88, 45 or 17 kg N/ha was leached. The recovery of nitrogen applied was between 53% to 73% in *Weigela* and 41% to 56% in *Campanula*. The amount of non-recovered nitrogen was substantially higher in treatments 1.25 dS/m and 0.95 dS/m than in 2.0 dS/m. Fresh and dry weights of both plant species and the number of flowers in *Campanula* were reduced when the plants were grown at low conductivity.

Index words: conductivity, nitrate, nutrient solution, N-recovery.

Species used in this study: Weigela (*Weigela* Thunb. ’Bristol Ruby’); Carpathian bluebell (*Campanula carpática* Jacq. ’Dark Blue’).

Significance to the Nursery Industry

This experiment demonstrated that leaching of nitrogen from container plants can be minimized if fertigation is controlled. When a constant moisture tension in the growing medium is maintained, and conductivity of the nutrient solution is controlled, nitrogen leaching can be reduced and the risk of environmental pollution avoided.

Introduction

Nursery plants grown in containers outdoors are subject to loss of nutrients because of precipitation and extensive use of water and fertilizers (5, 18). Controlled-release fertilizers (CRF) have been used to reduce leaching of nitrogen, but nutrient release of these depends on temperature, which cannot be controlled outdoors. Moreover, leaching of nitrogen from CFR may be substantial at the beginning of the growth period when nutrient uptake by the plants is low (6, 8). Controlling irrigation using a low-leaching fraction can reduce nitrogen leaching (21), but low leaching fraction has been found to have a negative effect on plant dry weight (DW) (15, 17). A high irrigation frequency maintaining a low moisture deficit minimizes leaching more so than con-

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Table 1. **Mean concentration of macronutrients in fertigation solutions (g/m^3) in treatments 2.0, 1.25 and 0.95 dS/m in *Weigela* and *Campanula*.**

	Treatment		
	2.0 dS/m	1.25 dS/m	0.95 dS/m
	Nutrient conc. (g/m^3)		
NO_3-N	210 ± 33^z	105 ± 14	54 ± 16
NH_4-N	10 ± 4	5 ± 2	1 ± 0.3
P	22 ± 3	9 ± 5	3 ± 2
K	207 ± 26	94 ± 15	31 ± 5
Ca	184 ± 46	132 ± 32	120 ± 29
Mg	39 ± 7	19 ± 4	15 ± 5
SO_4	61 ± 12	45 ± 11	45 ± 11

^{z}Standard deviation. Micronutrients (g/m^3) 1.00 Fe, 0.50 Mn, 0.30 Zn, 0.13 Cu, 0.30 B, 0.04 Mo, 45 Cl.

tinuous irrigation (7, 10, 13, 16), and fairly constant moisture tensions can be obtained in the growing medium by using tensiometers linked to a computer-controlled irrigation system (20, 23). Most experiments are carried out in greenhouses, whereas nursery stock is grown outdoors where precipitation makes it difficult to maintain nutrient levels at a constant moisture level. The objective of the present experiment was to determine the influence of three conductivity levels in the substrate on plant quality for container-grown species using tensiometers to control fertigation frequency.

Materials and Methods

Experimental design. Two experiments were performed in 1998 at Aarslev (55°18'N, 10°27'E). One-year-old liners of *Weigela* 'Bristol Ruby' and *Campanula carpática* 'Dark Blue' were transplanted in peat into 3.5 liter and 0.67 liter polyethylene containers, respectively. The plants were placed on polyethylene trays topped with 1 cm sand as drainage at a density of 11 plants/m^2 (*Weigela*) and 40 plants/m^2 (*Campanula*). According to nursery practice, *Campanula* was transplanted on May 12 and harvested on October 3, while *Weigela* was transplanted on June 11 and harvested on September 29. The peat (particle size of 0–20 mm) had following amounts of nutrients and lime added by company (Pindstrup Mosebrug, Ryomgård, Denmark) (gram/m^3): 72 NO_3-N, 13 NH_4-N, 75 P, 134 K, 18 Mg, 13.7 Fe, 3.7 Mn, 3.0 Zn, 7.7 Cu, 0.8 B, 2.8 Mo, 2 × 10^3 lime and 40 × 10^3 clay.

The treatments consisted of three levels of complete nutrient solutions supplied at each irrigation with high (EC: 2.0 dS/m), intermediate (EC: 1.25 dS/m) and low conductivity (EC: 0.95 dS/m) (Table 1). Each experiment was carried out in a complete randomized block design with four replicates, 30 plants in each replicate.

Conductivity of the soil solution was measured three times a week by taking press-samples of the potsoil. If conductivity increased or decreased by more than 0.5 dS/m, conductivity of the fertigation solution was subsequently decreased or increased by this same amount within the limit of concentrations shown in Table 1.

Tap water was used and pH was maintained between 5.5–6.0 by adding HNO_3 (the amount included in the solutions in Table 1) to neutralize the HCO_3^- in the tap water. A slope (1%) on the trays provided that the leachate from the containers including precipitation on each tray could be collected in polyethylene tanks. The tanks were emptied every week or more after heavy rainfall, and samples of the leachate were refrigerated for analysis later.

Control of fertigation. For each species, five tensiometers (Steck-Tensio 100 KV1, Tensio-Technik, Geisenheim, Germany) were placed in different pots among the treatments, with the ceramic cup at a depth of 4 cm from the top of the growing medium. The tensiometers were connected to a datalogger (Datataker 600, Data Electronics, UK) and controlled fertigation frequency. Fertigation was initiated when the tension of three of the five tensiometers had increased to 50 hPa and lasted for one minute. Leaching fraction was low (<0.05). Fertilizer was added to the irrigation water using an AMI 5000 (DGT-Volmatic, Denmark) and the fertigation solution was supplied to the plants through a non-recirculated drip-irrigation system at a rate of 2 liter/h with two drips in Weigela and one in Campanula (Netafim, Israel). Quantity of fertigation and precipitation during the experimental periods are shown in Table 2.

Chemical analysis. Concentration of nitrate and ammonium in the nutrient solution and in the leachate was measured by spectrophotometer (2, 9). Nitrate in the potsoil was extracted with acetic acid (0.01 M) before measuring as above. Nitrogen added to the plants was estimated from the concentration of nitrate and ammonium in the fertigation solution and time and amount per minute. Nitrogen recovery was calculated from the N measured in the shoot, in the leachate and in the soil (nitrate-nitrogen). Ammonium-N and

Table 2. **Fertigation and precipitation (mm) in *Weigela* and *Campanula* during the experiments.**

	Weigela			Campanula	
Days from transplanting	Fertigation mm	Precipitation mm	Days from transplanting	Fertigation mm	Precipitation mm
0–20	28	39	0–20	36	18
21–40	25	56	21–40	34	52
41–60	55	31	41–60	26	44
61–80	102	31	61–80	22	55
81–100	70	40	81–100	34	18
101–110	23	0	101–120	38	29
			121–144	4	43
Total	303	197		194	259

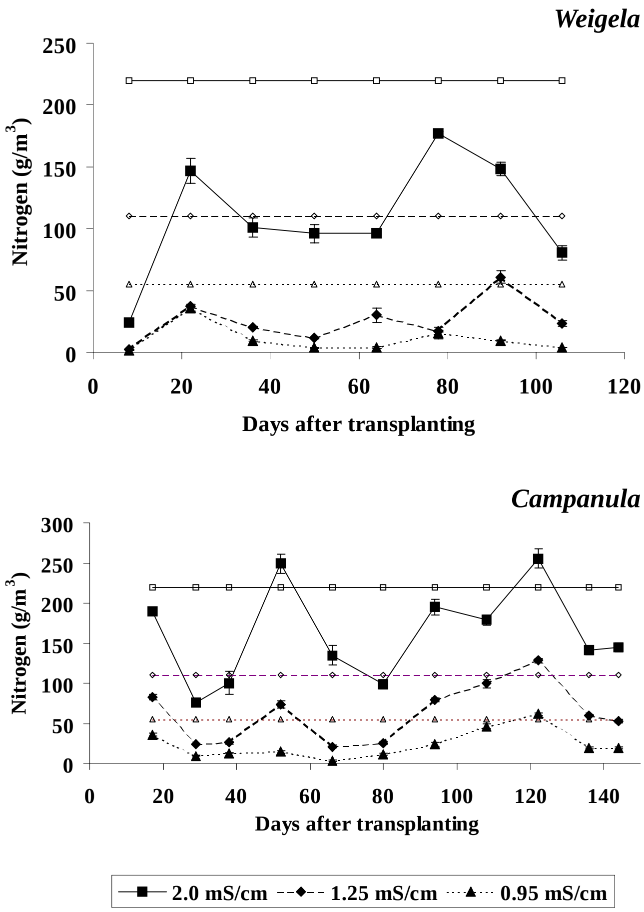

Fig. 1. **Concentration of nitrogen in the leachate (g N/m³) (closed symbol) during the experiment and the mean concentration of nitrogen in the fertigation solution (g N/m³) (open symbol) in *Weigela* and *Campanula* grown at 2.0 (◆), 1.25 (■) or 0.95 (▲) dS/m. Error bars represent standard error (n=12).**

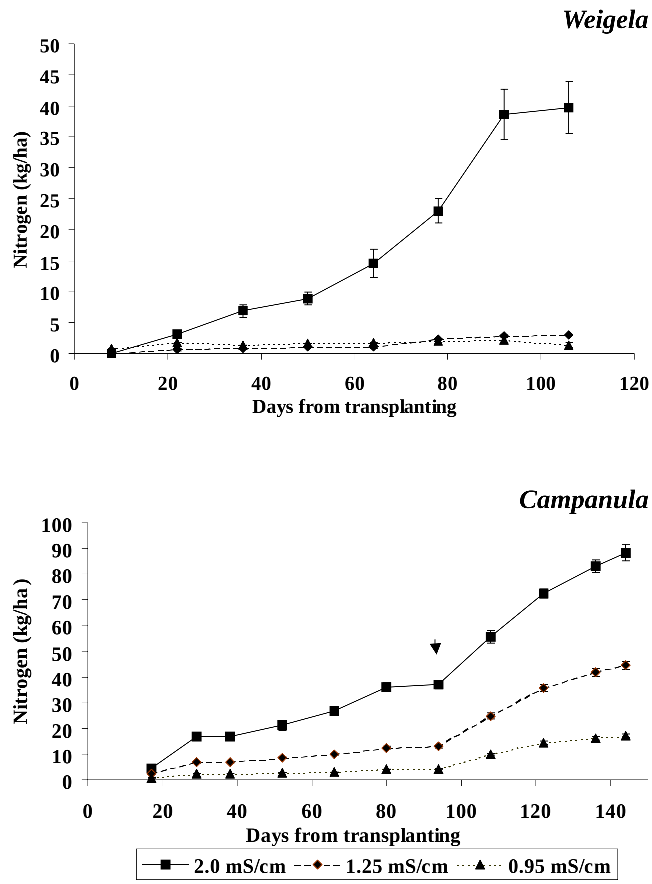

Fig. 2. **Accumulation of nitrogen leached (kg N/ha) during the experimental period in *Weigela* and *Campanula* grown at 2.0 (◆), 1.25 (■) or 0.95 (▲) dS/m. The end of flowering in *Campanula* is marked. Error bars represent standard error (n = 12).**

organic-N in the soil were not analysed. Total N in the shoot dry matter (DM) was measured using the Kjeldahl procedure.

Plant analysis. At harvest, shoot fresh weight (FW), including stem and leaves, of 5 plants from each replicate ~ 20 plants per treatment, was determined. After drying at 70C (158F) for 24–48 hours, DW was determined. The number of flowers and buds in Campanula was counted on day 90. Roots could not be separated from the peat and hence were not analyzed.

Statistical analysis. Analysis of variance procedures (General Linear Model procedure of SAS (1)) and comparison of means using Duncan´s multiple-range test ($p < 0.05$) were used to evaluate the effects of treatments.

Results and Discussion

Control of fertigation. The tensiometers controlled fertigation frequency throughout the experiments in both *Weigela* and *Campanula*. In some periods during the experiments precipitation was higher than fertigation (Table 2).

Leaching of nitrogen. The leachate N concentration was constantly lower than in the applied nutrient solution in all three treatments in *Weigela* (Fig. 1a). Nitrogen uptake by the plants in the 0.95 and 1.25 dS/m treatments may have reduced the leachate N concentration to values between 0 and 50 g N/m³, which is in accordance with observations by Cabreara et al. (3). Very low total leaching (3–6 kg/ha) was observed in these two treatments, whereas 40 kg N/ha was leached at 2.0 dS/m treatment (Fig. 2a). Previous experiments have revealed leaching above 200 kg N/ha when fertigation frequency was controlled by measurements of evapotranspiration (12).

In *Campanula*, N concentration in the leachate in 2.0 dS/m treatment was higher than the N concentration in the solution applied on two occasions, indicating that the N uptake by the plants was low (Fig. 1b). Leachate N concentration increased after flowering from day 90 in all three treatments, maybe because N uptake in the plants decreased in this period. The amount of N (kg/ha) leached from *Campanula* was generally higher than in *Weigela*. Total N leached was 90 kg N/ha in 2.0 dS/m treatment, 45 kg N/ha in 1.25 dS/m treatment and 17 kg N/ha in 0.95 dS/m treatment (Table 3).

N-balance in Weigela. *Weigela* plants grown at 0.95 dS/m contained half the amount of nitrogen in the shoot mass of that of plants grown at 2.0 dS/m (Table 3). N concentration in the shoot DM was significantly ($p < 0.05$) reduced under

Table 3. N-balance regarding nitrogen added and recovered in shoot, soil and leachate, and not recovered (kg N/ha and % of applied) in *Weigela* and *Campanula* plants grown at fertigation solutions of 2.0, 1.25 or 0.95 dS/m for 110 or 144 days and at 11 pl/m² or 40 pl/m², respectively.

	Treatment					
	2.0 dS/m		1.25 dS/m		0.95 dS/m	
	Nitrogen (kg/ha and %)					
Weigela:						
N added	397 ± 18[z]	(100.0%)	287 ± 13	(100.0%)	199 ± 9	(100.0%)
N in shoot	223 ± 7	(56.2%)	146 ± 5	(50.9%)	102 ± 1	(51.3%)
N leached	40 ± 4	(10.1%)	6 ± 1	(2.1%)	3 ± 1	(1.5%)
N in growing medium[y]	25	(6.3%)	2	(0.7%)	1	(0.5%)
N recovered	288 ± 13	(72.5%)	154 ± 10	(53.7%)	106 ± 6	(53.3%)
N not-recovered	109 ± 7	(27.5%)	133 ± 8	(46.3%)	93 ± 8	(46.7%)
Campanula:						
N added	226 ± 11	(100.0%)	147 ± 8	(100.0%)	80 ± 4	(100.0%)
N in shoot	33 ± 1	(14.6%)	27 ± 1	(18.4%)	15 ± 1	(18.8%)
N leached	88 ± 3	(38.9%)	45 ± 1	(30.6%)	17 ± 1	(21.3%)
N in growing medium[y]	6	(2.7%)	2	(1.4%)	1	(1.3%)
N recovered	127 ± 8	(56.2%)	74 ± 5	(50.3%)	33 ± 3	(41.3%)
N not-recovered	99 ± 6	(43.8%)	73 ± 3	(49.7%)	47 ± 4	(58.7%)

[z]Standard error (n = 12).

[y]Nitrate-N.

Table 4. Nitrogen concentration (%) in shoot dry matter (DM) in *Weigela* and *Campanula* grown at fertigation solutions of 2.0, 1.25 or 0.95 dS/m for 110 and 144 days, respectively. Columns followed by the same letter are not significantly different among each species.

	Weigela	Campanula
Treatment (dS/m)	N (% DM)	
2.0	1.57a[z]	3.76a
1.25	1.52a	3.64a
0.95	1.27b	3.71a

[z]Mean separation within columns by Duncan's multiple range test ($p < 0.05$)

Table 5. Final shoot fresh (FW) and dry (DW) weight (gram per plant) in *Weigela* and *Campanula* and number of flowers and buds in *Campanula* plants grown at fertigation solutions of 2.0, 1.25 or 0.95 dS/m for 110 and 144 days, respectively. Columns followed by the same letter are not significantly different among each species.

	Weigela		Campanula		
Treatment (dS/m)	FW (g)	DW (g)	FW (g)	DW (g)	Flowers[z] (no)
2.0	526a[y]	136.9a	5.9a	2.05a	64a
1.25	405b	85.6b	5.1a	1.79a	56b
0.95	306c	77.3b	3.2a	1.05b	33c

[z]Flowers and buds on day 90.

[y]Mean separation within columns by Duncan's multiple range test ($p < 0.05$).

the same conditions implying that the N supply had been limiting to growth in 0.95 dS/m treatment (Table 4). Leaching of nitrogen as a percentage of the amount applied was low (1.5–10%) in all three treatments (Table 3) and lower than observed (12–25%) from the use of CRF outdoors (13, 19) or of liquid fertilizer (22–56%) (3, 11). In the 1.25 and 0.95 dS/m treatments a larger proportion of the applied N was not recovered (Table 3). A part of this N might have been lost to the atmopshere (5) or remained in the potsoil as only nitrate-N was analyzed. Another part of the N could have been in the roots, as Catanzaro et al. (4) found more of the applied N (22%) in roots when plants were grown at low nutrient level than at high.

N-balance in Campanula. Uptake of N in *Campanula* plants showed practically the same relationship as observed in *Weigela*, although uptake was very low in all three treatments (Table 3). In *Campanula*, N concentration in the DM was not different between the three treatments (Table 4). Presumably, the N concentration in the nutrient solution was not limiting to growth in accordance with the relatively high concentration of N found in the leachate (Fig. 1b). Nitrogen leaching constituted 21% to 39% in 0.95 dS/m and 2.0 dS/m as registered in other experiments (3, 4, 11). The percentage of applied N found in the shoot was low (<20%) in all three treatments. The percentage of non-recovered N was high in all three treatments, most pronounced at low conductivity, perhaps because of allocation of N to the rhizomes (4) or loss of N to the atmosphere (5).

Plant growth. For *Weigela* both FW and DW were lower ($p < 0.05$) at 1.25 and 0.95 dS/m compared to 2.0 dS/m (Table 5). Nitrogen concentration in these two treatments might have been limiting in accordance with the low leachate N concentration. These results are in accordance with results in other species by Ku and Hershey (16) and Lang and Pannkuk (18).

In *Campanula*, shoot FW and DW were lower ($p < 0.05$) only at the 0.95 dS/m compared to the other two treatments (Table 5). Conductivity level had a major influence on flowering, which was reduced 50% at 0.95 dS/m and 10% to 20% at 1.25 dS/m (Table 5). As N concentration in the DM did not differ between the treatments, other nutrients may have been limiting to growth. Moreover it was observed during the experiments that roots developed out of the containers into the sand, especially at 0.95 dS/m and 1.25 dS/m which may imply that DM allocation from the shoot to the roots was higher at low conductivity level (4, 14).

Our results indicate that it is possible to reduce leaching from container plants grown outdoors by controlling fertigation. After flowering in *Campanula*, N leaching increases and N addition might be reduced in this period. Plant quality of the shoot can be affected if conductivity in the nutrient solution is low, probably because of N concentration in the nutrient solution is limiting or because DM allocation is changed from shoot to root at low conductivity.

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