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Greenhouse Conditioning Affects Landscape Performance of Bedding Plants[1]

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Abstract

Conditioning treatments were evaluated for effects on growth of bedding plants during greenhouse production and carryover effects on plant performance in the landscape. Treatments included two fertilization regimes using a complete water soluble fertilizer applied three times/week at 500 ppm N, designated 'high N', or at 50 ppm N, designated the 'low N' treatment. Other treatments included: ebb and flow irrigation, drought stress for up to 2 h wilt/day, 5000 ppm B-Nine (daminozide), 45 ppm Bonzi (paclobutrazol; 180 ppm on columbine), and brushing (40 strokes twice daily). Unless otherwise noted all plants, including controls, were maintained well-irrigated and fertilized with 250 ppm N three times/week. Marigolds and New Guinea impatiens grown under low N during greenhouse production exhibited reduced plant height and width relative to control plants at 4 weeks after planting (WAP) in the landscape. Plant quality ratings of all species conditioned with low N were lower than those of controls 2 and 4 WAP. Plant height of New Guinea impatiens conditioned with high N was greater than that of controls 4 WAP in the landscape. Marigolds subjected to drought in the greenhouse were still shorter than controls 2 and 4 WAP. Persistent height reductions in the landscape in response to B-Nine were observed in ageratum 2 and 4 WAP and to Bonzi in New Guinea impatiens through 8 WAP. Brushing reduced the height of all species except ageratum in the greenhouse, but had no carryover effect on plant growth in the landscape. At 4 weeks after treatment, plant height of columbine treated with low or high N, drought, brushing, or B-Nine was reduced relative to controls, but all plants were similar in size in the landscape.

Index words: growth regulators, stress, brushing, drought, Bonzi, B-Nine.

Species used in study: columbine (*Aquilegia* x *hybrida* Sims 'McKana Giants'); New Guinea impatiens (*Impatiens* x *hybrida* L. 'Agadoo'); marigold (*Tagetes erecta* L. 'Little Devil Mix'); ageratum (*Ageratum Houstonianum* L. Mill. 'Blue Puffs').

Chemicals used in this study: B-Nine (daminozide), butane-dioic acid mono(2,2-dimethylhydrazide); Bonzi (paclobutrazol), β-[(4-chlorophenyl)methyl]-α-(1,1-dimethylethyl)-1*H*-1,2,4-triazole-1-1-ethanol.

Significance to the Nursery Industry

Cultural practices and/or chemical growth regulators are commonly used during greenhouse production to control bedding plant height. However, the carryover effects of these practices on landscape performance are seldom examined. Landscape performance affects customer satisfaction and therefore, repeat business. This paper emphasizes the reduction in plant height and quality of ageratum and New Guinea impatiens in the landscape when the bedding plants were produced under a low N fertilization regime (50 ppm N, 3×/week). Landscape quality ratings of marigold bedding plants produced under low N levels also were reduced, with no reduction in plant height during greenhouse production. A high N fertilization regime (500 ppm N, 3×/wk) increased height of only one species, ageratum, in the greenhouse, but increased the height of New Guinea impatiens 4 WAP in the landscape, relative to their respective controls. Production of ageratum under ebb-and-flow conditions increased plant height in the greenhouse, but reduced plant quality ratings in the landscape. Rates of chemical plant growth regulators (PGRs) must be carefully selected to avoid persistent growth reduction in the landscape. Management of cultural conditions to produce healthy vigorous bedding plants in the greenhouse provides the best plants for optimum landscape performance.

Introduction

Management of plant growth during greenhouse production generally involves a combination of cultural and chemi-

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cal regulation of plant processes. The ultimate goal is to control plant growth in the greenhouse but prepare, i.e., condition, the plant to better tolerate the handling and stresses involved in shipping, marketing, planting, and landscape establishment. Fertilization practices control plant growth and affect subsequent postproduction plant performance (3). Although most bedding plant growers still use overhead irrigation, use of ebb-and-flow or flood technologies for irrigation is increasing, especially in the midwestern United States (P.A. Hammer, personal communications). Use of nonlethal water deficits has also been effective in growth regulation and the improvement of plant response to subsequent stresses (4, 13). Chemical plant growth regulators (PGRs) are commonly used on bedding plants during greenhouse production, and persistent effects in the landscape have been noted (9, 11). Mechanical conditioning has been very effective in controlling height of vegetable transplants during greenhouse production without affecting crop yield (12). Brushing has been used on some ornamental bedding plants during greenhouse production (1, 6), but landscape performance was not evaluated.

The objective of these tests was to evaluate the effect of individual cultural or chemical methods of growth regulation of herbaceous perennial and annual bedding plants on growth in the greenhouse and subsequent performance in the landscape.

Materials and Methods

Shade plants used in the study were columbine and New Guinea impatiens and sun plants were marigold and ageratum. Plugs (cell size for 72s: 3.8 × 3.8 × 6.0 cm) for each species were obtained from a commercial grower and planted into 10 cm × 10 cm (4 in) plastic pots (volume 580 cm^3 (35.4 cu. in.)) filled with Metro-Mix 300 (Scotts, Marysville, OH). New Guinea impatiens plugs were planted on March 17, marigold and ageratum on March 25, and columbine on April 6, 1994.

Conditioning treatments were initiated on each crop at 7 days after planting to allow plant establishment and resumption of growth. Control plants were maintained well-watered with overhead irrigation and received 250 ppm N three times per week using a 20N–4.4P–16.6K (20–10–20) water soluble fertilizer.

Two fertilization rates were selected to represent extreme ends of the normal range. 'Low N' designates the water soluble fertilizer applied at 50 ppm N three times per week, while 'high N' designates the same fertilizer applied at 500 ppm N three times per week.

Two irrigation treatments were tested. Ebb-and-flow irrigation was used to maintain plants well watered but undisturbed. Drought stress was imposed by withholding water daily until plants exhibited visible wilt symptoms for up to 2 h. The drought treatment was imposed as soon as the plants were large enough to deplete the water in the media between the fertilizer applications. The drought treatment was moderate and most uniform in the last 2 weeks of greenhouse production.

Chemical growth regulation was evaluated with a single application of 5000 ppm B-Nine (daminozide, Uniroyal Chemical Co., Middlebury, CN) or a single application of 45 ppm Bonzi (paclobutrazol, Uniroyal) applied to all species except columbine which was treated with 180 ppm Bonzi. Mechanical conditioning was applied by brushing the top one-third of the shoots with a wooden bar 40 strokes twice daily.

All plants not assigned to low N or high N treatments were fertilized with 250 ppm N three times per week. Each plant species was arranged in a randomized complete block design with three plants per experimental unit and five replications. Plant height (from rim of pot to top of plant) and width (average of width at widest point and width perpendicular to widest point) of all plants (n = 15) were measured at 2 and 4 weeks after treatment (WAT) initiation.

At 4 weeks after initiation of conditioning treatments, plants were planted in 50% shade (columbine and New Guinea impatiens) or full-sun (marigold and ageratum) landscape beds (Cecil sandy loam, Typic Halpludult) at the Griffin Campus, maintaining the randomized complete block design used in the greenhouse. Plants were irrigated with drip tubes and mulched with hardwood chips. One plant per treatment was used as an outside border plant which was not measured. Plant height and width were measured on the two remaining plants per treatment/replication (n = 10) at 2, 4, and 8 weeks after planting (WAP) to determine long-term effects of conditioning treatments on plant performance. Plant quality, based on aesthetic appearance, was rated on a continuous scale from 0 (dead) to 100 (mounded, proportional plant form covered with flowers) at 2 and 4 WAP.

Statistical analyses. All data were subjected to analyses of variance using SAS's general linear models procedure (SAS Institute, Cary, NC) and mean separation was by protected least significant difference test (LSD), P < 0.05.

Table 1. Effect of conditioning treatments on growth of 'McKana Giants' columbine and 'Agadoo' New Guinea impatiens 2 and 4 weeks after treatment in the greenhouse.

Species / Treatment	2 WAT[z] Plant height (cm)	4 WAT Plant height (cm)	4 WAT Plant width (cm)
Columbine			
Control	12.4a	24.4a	35.2a
Low N (50 ppm)	10.3abc	17.5cd	25.9d
High N (500 ppm)	11.4ab	20.7bc	33.3ab
Ebb-and-flow	12.2a	25.6a	30.9abc
Drought	9.9bcd	20.6bc	32.8ab
Brushing	8.2cd	15.9d	27.0cd
B-Nine (5000 ppm)	7.7d	18.6cd	30.0bcd
Bonzi (180 ppm)	10.7ab	22.8ab	32.4ab
F-test[y]	***	***	**
New Guinea impatiens			
Control	8.2 bc	13.1ab	—
Low N (50 ppm)	8.1bc	11.5cd	—
High N (500 ppm)	8.5ab	13.8a	—
Ebb-and-flow	8.9a	13.3ab	—
Drought	7.7c	12.3bc	—
Brushing	7.7c	10.5d	—
B-Nine (5000 ppm)	8.1bc	12.6b	—
Bonzi (45 ppm)	6.6d	7.4e	—
F-test	***	***	—

[z]WAT = weeks after treatment initiation.

[y]NS,**,***: Not significant or significant at P < 0.01 or 0.001, respectively. Mean separation by protected LSD, P < 0.05.

Table 2. **Effect of conditioning treatments on plant quality ratings of 'McKana Giants' columbine 2 and 4 weeks after planting in the landscape.**

Treatment	Plant quality rating[z] 2 WAP[y]	4 WAP
Control	74ab	85ab
Low N (50 N)	51d	76ab
High N (500 N)	77a	88a
Ebb-and-flow	53cd	69b
Drought	66abcd	73ab
Brushing	75a	86ab
B-Nine (5000 ppm)	63abcd	77ab
Bonzi (180 ppm)	68abc	82ab
F-test[x]	**	*

[z]Continuous rating scale 0 = dead to 100 = excellent plant form with good flower coverage.

[y]WAP = weeks after planting.

[x]NS, *,**: Not significant or significant at P < 0.05 or 0.01, respectively. Mean separation by protected LSD, P < 0.05.

Results and Discussion

Columbine. At 2 and 4 weeks after initiation of conditioning treatments (WAT), plant height of columbine treated with drought, brushing, or B-Nine was less than that of control plants (Table 1). At 4 WAT, plants conditioned with low (50 ppm) or high (500 ppm) N also were shorter than the controls which had received the same complete fertilizer at the same frequency but at a rate of 250 ppm N over the treatment period. Width of plants treated with low N, brushing, or B-Nine was less than that of controls 4 WAT. Brushing was most effective in height reduction with treated plants 35% shorter than controls at 4 WAT. However, there were no significant differences in columbine plant height or width at 2, 4, or 8 WAP in the landscape (data not presented). Quality ratings of columbine produced under low N or ebb-and-flow conditions were lower than those of controls 2 WAP, but quality ratings were similar to controls 4 WAP in the landscape (Table 2). The goal in conditioning bedding plants is to control plant height in the greenhouse while improving the plant's ability to perform in the landscape. Through consultation with landscape professionals, we determined that treated plants

Table 3. **Effect of conditioning treatments during greenhouse production on growth and quality ratings of bedding plants after planting in the landscape.**

Treatment	2 WAP[z] Plant height (cm)	2 WAP Plant width (cm)	2 WAP Plant quality rating[y]	4 WAP Plant height (cm)	4 WAP Plant width (cm)	4 WAP Plant quality rating	8 WAP Plant height (cm)	8 WAP Plant width (cm)
New Guinea impatiens								
Control	14.8ab	24.7a	69ab	18.6bc	32.2ab	81a	25.2a	40.9ab
Low N (50 N)	13.5c	21.8bc	60c	17.1d	27.2d	65b	23.6a	38.0b
High N (500 N)	15.4ab	24.6a	73a	20.5a	32.6a	84a	23.6a	38.1b
Ebb-and-flow	15.0ab	25.0a	70ab	18.8bc	30.1c	81a	24.6a	39.1ab
Drought	15.0ab	23.4ab	69ab	19.2b	30.7bc	81a	24.0a	41.2a
Brushing	14.4bc	20.7c	67b	18.1bcd	30.3c	80a	24.6a	40.0ab
B-Nine (500 ppm)	15.6a	24.4a	70ab	18.9bc	30.7bc	82a	23.8a	38.2ab
Bonzi (45 ppm)	8.8d	16.2d	51d	9.7e	16.3e	36c	12.4b	16.8c
F-test[x]	***	***	***	***	***	***	***	***
Marigold								
Control	17.3ab	21.8	86a	20.2ab	27.4ab	82a	25.5	27.4
Low N (50 N)	14.8d	17.9	70b	17.4c	23.0c	62c	25.5	26.0
High N (500 N)	16.8abc	22.7	89a	21.0a	28.6a	81a	25.2	25.2
Ebb-and-flow	17.6a	22.2	86a	20.7a	27.8ab	81a	23.2	24.9
Drought	14.6d	21.0	89a	16.6c	25.9abc	80a	22.4	24.2
Brushing	15.6bcd	21.2	88a	18.0bc	26.5ab	84a	22.8	24.7
B-Nine (5000 ppm)	15.8abcd	21.5	88a	19.0abc	27.6ab	78ab	23.5	27.6
Bonzi (45 ppm)	15.2cd	20.7	87a	17.8bc	25.3bc	71b	23.1	26.3
F-test	*	NS	***	*	*	***	NS	NS
Ageratum								
Control	14.1a	20.3ab	67ab	14.7abc	23.9ab	71b	15.8	29.6
Low N (50 N)	11.8bc	16.2c	35e	13.4cd	21.0cd	58c	17.6	30.7
High N (500 N)	14.2a	22.3a	77a	15.5a	25.4a	83a	17.2	30.5
Ebb-and-flow	14.2a	21.0a	53c	15.2ab	24.6a	57c	19.6	34.0
Drought	14.4a	21.8a	68ab	15.5a	25.1a	78ab	17.4	29.4
Brushing	13.2ab	20.0ab	57bc	14.0abcd	23.0abc	73b	16.8	29.4
B-Nine (5000 ppm)	11.1c	17.2c	40de	12.6d	19.7d	50c	16.4	27.5
Bonzi (45 ppm)	12.2bc	18.4bc	50cd	13.7bcd	21.6bcd	56c	15.5	29.3
F-test	**	***	***	*	***	***	NS	NS

[z]WAP = Weeks after planting in landscape.

[y]Continuous rating scale 0 = dead to 100 = excellent mounded plant form with good flower coverage.

[x]NS, *, **, *** Not significant or significant at P < 0.05, 0.01, or 0.001 respectively. Mean separation by protected LSD, P < 0.05.

should match the size of control plants within 4 WAP. Although brushing effectively reduces elongation of stems and petioles, the growth inhibition effects dissipate within three days after treatment ceases and the plants generally exhibit accelerated growth (7, 12).

New Guinea impatiens. At 2 WAT, height of New Guinea impatiens was reduced by 45 ppm Bonzi, while ebb-and-flow plants were taller, compared to controls (Table 1). At 4 WAT, plants treated with the low N fertilization regime were shorter than controls, but the height of high N plants was similar to controls. Plants subjected to brushing, or treated with 45 ppm Bonzi, were shorter than controls at 4 WAT.

At 2 and 4 WAP in the landscape, New Guinea impatiens subjected to low N during greenhouse production were still smaller (less plant height and width) than controls (Table 3), but the absolute difference in height was comparable to that seen at 4 WAT in the greenhouse. At 4 WAT height of low N plants was 12% less than that of controls, while at 4 WAP they were only 8% less than controls, suggesting that once nutrition is no longer limiting, the plants exhibit an accelerated growth rate relative to controls. Quality ratings of plants conditioned with low N also were lower than controls 2 and 4 WAP in the landscape. Nell et al. (14) reported species differences in bedding plants 'hardened off' by withholding nutrients. For example, withholding nutrition 2 or 3 weeks prior to planting severely reduced the subsequent landscape growth of vinca (*Catharanthus roseus*), salvia (*Salvia splendens*) and impatiens (*Impatiens wallerana* Hook), but geraniums (*Pelargonium* x *hortorum*) were unaffected.

Conversely, New Guinea impatiens grown with high N in the greenhouse were significantly taller than controls 4 WAP (Table 3). New Guinea impatiens are considered to be 'heavy' feeders after plug establishment with recommended rates of 250 ppm N for constant feed (8) or 300 to 350 ppm N at every other watering (5).

Excessive (~50%) reductions in height and width of New Guinea impatiens treated with 45 ppm Bonzi persisted through 8 WAP in the landscape, and reduced landscape quality ratings 2 and 4 WAP. Persistent growth reductions in the landscape due to treatment with Bonzi during crop production have been reported with marigold (8), *Verbena rigida* (2), geranium (15), zinnia (*Zinnia elegans*), impatiens, and marigold (11).

Marigold. Marigold plants that were brushed or treated with B-Nine or Bonzi were shorter than controls at 2 and 4 WAT (Table 4). At 4 WAT, plants conditioned with drought or low N also were shorter than controls. Plant width was reduced only by low N or brushing 4 WAT.

Height of marigold plants conditioned with low N or drought was less than that of control 2 and 4 WAT (Table 3). The differences in the carryover effects of conditioning treatments into the landscape can be seen by comparing the height of marigolds pretreated with low N or drought to that of plants pretreated with brushing. At the time of planting (4 WAT), plants conditioned with low N were 29% shorter than controls, but were 14% shorter than controls at both 2 and 4 WAP. Droughted plants were 22% shorter than controls 4 WAT, but 16% and 18% shorter than controls at 2 and 4 WAP, respectively. In comparison, brushed plants were 21% shorter than controls 4 WAT, and were 10% and 11% shorter at 2 and 4 WAP, respectively, which was not different from controls. The growth rate of all the conditioned plants exceeded that of control plants during the first 2 WAP as indicated by the reduction in the difference in height between treated and control plants, but the plants conditioned with low N or brushing made up the difference more quickly than did plants subjected to drought conditioning. Brushed broccoli (*Brassica oleracea*) transplants had a higher relative growth rate during the first 15 days in the field than did transplants subjected to drought conditioning (8). Width of marigolds conditioned with low N was less than that of controls 4 WAP, but there were no significant differences in plant height at 8 WAP (Table 3). However, plant quality ratings were lower for plants conditioned with low N as compared to controls 2 and 4 WAP in the landscape.

Growth retardant effects of B-Nine did not persist in the landscape, but Bonzi-treated marigolds were shorter than controls 2 WAP, and had a lower quality rating 4 WAP (Table 3). Heights and widths of all plants were similar at 8 WAP.

Ageratum. Ageratum plants grown with ebb-and-flow irrigation were taller than plants in any other treatment 2 WAT, while B-Nine or Bonzi-treated plants were the shortest (Table 4). By 4 WAT, ageratum was exhibiting significant responses to fertilization regime; plants grown with low N were 20% shorter and 23% narrower than controls, while those treated with high N were 11% taller and 10% wider than controls. Plants conditioned with ebb-and-flow irrigation or drought also were taller than controls 4 WAT, while B-Nine and Bonzi reduced plant height and width compared to controls. Ageratum did not respond to brushing as compared to controls.

Table 4. Effect of conditioning treatments on growth of 'Little Devil Mix' marigolds and 'Blue Puffs' ageratum at 2 and 4 weeks after treatment in the greenhouse.

Species Treatment	2 WAT[z] Plant height (cm)	4 WAT Plant height (cm)	4 WAT Plant width (cm)
Marigold			
Control	4.8a	10.8ab	22.6ab
Low N (50 N)	4.5abc	7.7d	17.3d
High N (500 N)	4.5abc	10.3bc	23.0ab
Ebb-and-flow	4.7ab	12.2a	23.2a
Drought	4.2abcd	8.4d	21.0bc
Brushing	4.1bcd	8.5d	19.3cd
B-Nine (5000 ppm)	4.0cd	8.6cd	21.2abc
Bonzi (45 ppm)	3.7d	9.0cd	21.2abc
F-test[y]	*	***	***
Ageratum			
Control	6.7bc	13.1b	20.4bc
Low N (50 N)	6.1c	10.5d	15.7e
High N (500 N)	6.1c	14.5a	22.4a
Ebb-and-flow	7.7a	14.8a	21.0ab
Drought	6.9b	14.0a	22.2a
Brushing	6.4bc	12.3bc	19.4cd
B-Nine (5000 ppm)	4.8e	11.0cd	17.8d
Bonzi (45 ppm)	5.2de	12.0cd	18.7d
F-test	***	***	***

[z]WAT = weeks after treatment initiation.

[y]NS,*,***: Not significant or significant at $P < 0.05$ or 0.001, respectively. Mean separation by protected LSD, $P < 0.05$.

Ageratum conditioned with low N during greenhouse production were still shorter than controls 2 WAP, and narrower than controls 2 and 4 WAP in the landscape (Table 3). Plants conditioned with low N also had lower quality ratings relative to controls 2 and 4 WAP. Plants conditioned with high N were similar to controls in height and width at all measurement dates in the landscape, but plant quality ratings 4 WAP were greater than those of controls. Although treatment with ebb-and-flow irrigation did not affect ageratum growth in the landscape, plant quality ratings were lower than those of controls 2 and 4 WAP. Although only ageratum treated with B-Nine were shorter than controls 2 and 4 WAP, those treated with either PGR had lower quality ratings 2 and 4 WAP compared to controls. There were no differences in plant height or width of ageratum 8 WAP in the landscape.

The goal in conditioning bedding plants is to reduce plant height in the greenhouse while improving the plant's ability to perform when placed in the landscape. The data presented here offer information on the subsequent landscape performance of plants subjected to common cultural or chemical conditioning treatments. In all four species, plants conditioned with low N (50 ppm) fertilization during greenhouse production required more time to attain a size (New Guinea impatiens, marigold) or quality (columbine, New Guinea impatiens, marigold, ageratum) comparable to controls during the landscape evaluation. On the other hand, high N improved the landscape performance of only one species, New Guinea impatiens, which are considered to be 'heavy' feeders (5, 8).

Marigolds were sensitive to drought conditioning, as shown by an 18% height reduction and lower plant quality ratings relative to controls 4 WAP in the landscape. Ebb-and-flow irrigation tends to produce very succulent plants which may result in greater transplant shock during landscape establishment than seen in plants from the other treatments, which in turn may be the reason for the lower plant quality ratings for columbine and ageratum as compared to controls.

Brushing was effective in reducing plant height (relative to controls) of columbine (35%), New Guinea impatiens (20%), and marigold (22%) 4 WAT, but significant height reductions did not persist 2 WAP in the landscape for these crops. On the other hand, ageratum was not responsive to brushing, probably due to the very dense growth habit of this crop. Minor leaf damage from the brushing treatment was observed on ageratum and New Guinea impatiens, while flower damage was significant and unsightly on New Guinea impatiens during greenhouse production. Similar damage was seen on geranium and impatiens in response to brushing (6). The moderate height reduction and lack of persistence have been noted benefits of brushing of vegetable transplants (12).

A single application of 5000 ppm B-Nine provided moderate reductions in plant height (relative to control) of ageratum (16%), marigold (20%), and columbine (24%) 4 WAT in the greenhouse, but resulted in ageratum plants shorter than controls 4 WAP in the landscape. Columbine was not responsive to 180 ppm Bonzi, but 45 ppm Bonzi caused excessive persistence of New Guinea impatiens height reductions in the landscape. Landscape persistence of plant growth retardant effects has been seen with Bonzi (2, 9, 11, 15), but B-Nine has not caused any persistent growth effects on zinnia, marigold or salvia (11).

Conditioning treatments like drought or low N, which result in physiological stress, had the greatest negative impact on bedding plant performance in the landscape. Maintenance of optimum growing conditions combined with brushing or the proper rate of an effective PGR to reduce greenhouse height produces high quality bedding plants for optimum landscape performance.

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