Bulking Duration and Daminozide Affect Growth and Flowering of *Achillea* ×'Coronation Gold'[1]

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Abstract

A study was conducted to determine the effects of bulking duration and the plant growth retardant daminozide on plant growth and flowering of greenhouse-grown 'Coronation Gold' yarrow (*Achillea* ×'Coronation Gold'). Single-shoot liners of yarrow were transplanted on October 14 and December 2, 2010, into 15 cm (6 in) containers and bulked for 4, 6, 8, or 10 weeks prior to exposure to night-interrupted lighting (NIL). Increasing the bulking duration increased the number of shortened, thickened stems of rosette-like appearance, or offsets, that had developed from the base of the main stem by the end of bulking by 100 to 367% and reduced days to first and five open inflorescences, hereafter referred to as flowers, from the beginning of NIL by 13 to 16 days and 10 to 20 days for the October and December potting dates, respectively. Increasing the bulking duration increased flower and flower bud number by 67 and 25% in the October 14 and December 2 potting dates, respectively. Therefore, more flowers and flower buds formed on yarrow when potted early, compared to late potting. Lengths of the first five open flower stems were inconsistent and minimally affected by bulking duration. In a repeat of the experiment potted on December 2 using the same bulking treatments, 5,000 ppm of daminozide was applied as a foliar spray when half the plants in a bulking duration had begun to elongate and was reapplied 1 week later. Daminozide application decreased stem length at first open flower by 20 to 43%, but increased days to first flower and five open flowers by 6 and 8 days, respectively. As in the first experiment, increasing the bulking duration increased the number of offsets and flower and flower bud number and reduced days to first and five open flowers.

Index words: yarrow, plant growth regulator.

Chemicals used in this study: B-Nine (daminozide) [butanedioic acid mono (2,2-dimethylhydrazide)].

Species used in this study: 'Coronation Gold' yarrow (*Achillea filipendulina* Lam. ×*Achillea clypeolata* Sibth. & Sm. 'Coronation Gold').

Significance to the Horticulture Industry

'Coronation Gold' yarrow is a widely grown herbaceous perennial that has potential as a flowering potted crop for greenhouse production. Numerous references have been made in production literature to the importance of early fall transplanting of herbaceous perennial liners into final containers to allow sufficient time for vegetative growth before plants are exposed to photo-inductive conditions, a practice known as bulking. This increase in the size of the root system and crown is speculated to promote more shoots of sufficient developmental size to respond to inductive photoperiods, resulting in an increase in flowering shoots. In this study, increasing the bulking duration increased the number of offsets at the end of bulking and flower and flower bud number and reduced days to flower from the beginning of NIL of 'Coronation Gold' yarrow, without affecting plant height. At first flower, plants in all bulking treatments not treated with daminozide (B-Nine) were considered tall for the production containers. However, two foliar applications of daminozide suppressed flower stem length 20 to 43%. Plants bulked longer and treated with daminozide were considered more marketable as a potted crop.

Introduction

Bulking is a term often used to describe the growth period before a perennial is forced into flower, such as by an inductive photoperiod. It can be used to ensure a plant has passed through the juvenile phase and is mature enough to flower (Keever et al. 2014, Pilon 2013b, Whitman et al. 2012); to increase plant size, regardless of juvenility requirement, to one more suitable for forcing (Pilon 2013a, Pilon 2013c, Pilon 2013d); or to increase the root system, allowing the plant to become well established (Chong et al. 2000, Pilon 2006). Increasing the bulking duration has recently been shown to increase the number of shoots of *Rudbeckia fulgida* Ait. 'Goldsturm' ('Goldsturm' black-eyed Susan) and *Coreopsis verticillata* L. 'Moonbeam' ('Moonbeam' coreopsis) of sufficient developmental size to respond to inductive photoperiods, resulting in more flowers and/or flowering shoots (Keever et al. 2014).

Perennials are bulked under non-flower inducing conditions, keeping them in the vegetative phase. The length of the bulking period may vary among species, but is often determined by the initial size of the plant being bulked and the size of the finishing container. For example, a 72-cell plug for a 1 L (1 qt) container requires less bulking time than a 72-cell intended for a 3.8 L (1 gal) container. Pilon (2008) reported that several perennials, including *Aquilegia* L. spp. (columbine), *Dianthus gratianopolitanus* Vill. (cheddar pink) and *Phlox subulata* L. (creeping phlox), must be potted in early fall to provide time for root and shoot growth to be marketable in spring when in flower. It was recommended that if growers choose to force plants, such as 'Coronation Gold' yarrow, into flower for spring sale, plants must be bulked under short days so that roots can fully develop throughout the pot prior to inducing flowers (Hamrick 2003).

Rapid growth of plants under greenhouse and nursery conditions can be a problem for perennial plant growers, leading to excessively tall, leggy plants that are often unmarketable and difficult to ship (Amling et al. 2005, Kessler and Keever 2007, 2008). Plant growth retardants (PGRs) are commonly used in greenhouse production to control plant height. Crops treated with PGRs often have shorter, more rigid stems and

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darker green foliage, characteristics that increase their value (Gianfagna 1995). Latimer (2001) reported that height of *Achillea* ×'Moonshine' and *Achillea millefolium* L. 'Summer Pastels' was suppressed by four spray applications of daminozide at 5,000 ppm, and height of *Achillea millefolium* 'Paprika' by multiple spray applications of daminozide at 5,000 ppm, but details of treatments and methods were not reported. Burnett et al. (2000) applied daminozide at 2,500, 5,000, or 7,500 ppm to 'Coronation Gold' yarrow in a nursery setting over 2 years. In 1998, daminozide provided little growth suppression of 'Coronation Gold' yarrow; however in 1999, when plants were pruned just prior to treatment and were thus less reproductively developed, height at the most effective concentration of 7,500 ppm was reduced by 33% when compared to untreated plants. In another study, 7,650 ppm daminozide reduced shoot height and growth index of 'Coronation Gold' yarrow by 36 and 26%, respectively, and delayed flowering by 5 days without affecting inflorescence diameter (Kessler and Keever 2008).

'Coronation Gold' yarrow, a hybrid between *Achillea filipendulina* Lam. and *Achillea clypeolata* Sibth. & Sm, is a widely grown herbaceous perennial that has potential as a flowering potted crop for greenhouse production. Suitable as a garden perennial or cut flower, 'Coronation Gold' yarrow matures at 76 to 91 cm (2.5 to 3.0 ft) tall with tight clusters of 7.6 to 10 cm (3 to 4 in) inflorescences composed of golden yellow florets (Nau 1996). *Achillea filipendulina* 'Cloth of Gold' has an obligate requirement for long days and vernalization to flower, but must attain a minimum age or number of leaves to be responsive to flower-inductive treatments (Cameron et al. 1996a, 1996b). 'Coronation Gold' yarrow has responded similarly to photoperiod in unpublished trials at Auburn University, although others reported that *Achillea* ×'Anthea', 'Coronation Gold', and 'Moonshine' yarrow were facultative long-day plants that didn't require vernalization; these cultivars flowered fastest when provided with at least a 16-hour photoperiod or 4 hours of NIL (Nausieda et al. 2000). Application of NIL to 'Coronation Gold' yarrow grown outdoors under nursery conditions accelerated flowering by 2 to 12 days and 7 to 36 days and increased flower and flower bud counts by 82 to 100% and 20 to 244% in two studies (Keever et al. 2001, 2006). The objective of this study was to investigate the effects of four bulking durations and daminozide applications on growth and flowering of 'Coronation Gold' yarrow liners following transplanting into final containers.

Materials and Methods

Bulking duration. Plugs (72-cell) of 'Coronation Gold' yarrow were transplanted into 15 cm (6 in) plastic pots containing a growing medium (Fafard Mix No. 4P, Sun Gro Horticulture, Agawam, MA) on October 14 and December 2, 2010. There were forty pots per potting date. Plants were spaced on raised benches so that foliage didn't overlap in an unshaded, polycarbonate-covered (8 mm twin-wall) greenhouse with a heat set point of 18.3 C (65 F) and a ventilation set point of 25.5 C (78 F) under natural photoperiods (12.2 to 10.9 hours and 11.1 to 11.8 hours over the 10-week bulking durations in the first and second runs, respectively). Liquid fertilization was applied throughout the study based on a pour-through soluble salt target rate of 1 to 2.5 $dS \cdot m^{-1}$ beginning 10 days after potting using a 20N-4.4P-16.6K (Pro Sol 20-10-20, Frit Industries, Inc., Ozark, AL) fertilizer formulation at 150 ppm N. Plants were watered or fertilized by hand when the medium appeared dry, but before plants wilted.

At 4, 6, 8, or 10 weeks after both potting dates, ten plants were moved to a bench under night-interrupted lighting (NIL) from 10:00 P.M. to 2:00 A.M. using a minimum of 10 ft-c from incandescent lamps (60W) until the end of the experiment. Plants were spaced on greenhouse benches 22.9 cm (9 in) on center. Offset numbers were recorded at the end of each bulking duration. By early January 2011 plants were pot-bound and maintaining hydration was more difficult. On January 13, 2011, plants from both potting dates were repotted into 20.3 cm (8 in) pots of the same substrate. At first open flower, when all florets on an inflorescence were showing color, the date was recorded. When five flowers were fully opened, the date, flower and flower bud numbers, and the heights of the tallest and shortest flowering shoots were recorded. Stem length at five open flowers was an average of the tallest and shortest flowering shoots. Days to first and five open flowers were counted from the end of each bulking period.

An analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.3 (SAS Institute, Cary, NC). The experimental design was a split plot with potting date as the main plot and bulking duration as the sub-plot. Where residual plots and a significant COVTEST statement using the HOMOGENEITY option indicated heterogeneous variance, a RANDOM statement with the GROUP option was used to correct heterogeneity. Differences between potting date least squares means were determined using the Shaffer Simulated Method. Linear and quadratic trends over bulking durations were tested using orthogonal polynomials in the CONTRAST statements. All significances were at $\alpha = 0.05$.

Bulking duration by daminozide. A second experiment was conducted at the same time as the first using similar methodology, including bulking durations, unless otherwise noted. Eighty plugs of yarrow were transplanted on December 2, 2010, only. When half the 20 plants in a bulking duration treatment had elongated a minimum of 2 cm (0.8 in), two foliar spray applications of 5,000 ppm daminozide were applied 1 week apart to 10 plants. The first daminozide applications were made 25 days after the end of each bulking duration. Ten plants in a bulking duration were not treated with daminozide. Spray treatments were applied uniformly in a volume of 0.2 $L \cdot m^{-2}$ (equivalent to 2 $qt \cdot 100\ ft^{-2}$) using a pressurized CO_2 sprayer with a flat spray nozzle (XR TeeJet 8003 VK, TeeJet Technologies, Wheaton, IL) calibrated at 138 kPa (20 psi). The experimental designs were a completely randomized design for offset number at the end of bulking and split plots for the remaining responses with bulking duration as the main plot and daminozide treatment as the sub-plot. Differences between daminozide treatments least squares means were determined using the Shaffer Simulated Method.

Results and Discussion

Bulking duration. The bulking duration by potting date interactions were significant for all responses (Table 1). There were quadratic increases in offset number at the end of bulking with increasing bulking duration for both potting dates, with up to 11 and 3 offset increases for the October 14 and December 2 potting dates, respectively. Similarly,

Table 1. The effects of bulking duration before the beginning of night-interrupted lighting (NIL) and two potting dates on plant size and flowering of container-grown *Achillea* ×'Coronation Gold'.

Potting date	4	6	8	10	Sign.[y]
Bulking duration (weeks)[z]					
Offset number at the end of bulking[x]					
10/14/2010	3ns[w]	10ns	13a	14a	Q***
12/2/2010	6	9	9b	9b	Q**
Days to first open flower from the end of bulking[v]					
10/14/2010	73a	74a	76a	60a	Q***
12/2/2010	61b	53b	51b	48b	L***
Flower and flower bud number at five open flowers					
10/14/2010	9ns	11a	14a	15a	L***
12/2/2010	8	8b	11b	10b	L**
Stem length at five open flowers (cm)[u]					
10/14/2010	52.5b	55.4b	61.3ns	61.0ns	L***
12/2/2010	66.8a	64.6a	63.0	61.1	L***

[z]The potting date by bulking duration interaction was significant for all responses at $\alpha = 0.05$.

[y]Significant (Sign.) linear (L) or quadratic (Q) trends using orthogonal polynomials at $\alpha = 0.01$ (**) or 0.001 (***).

[x]NIL was started at the end of bulking.

[w]Least-squares means comparison in columns (lower case letters) using Shaffer Simulated method at $\alpha = 0.05$, ns = not significant.

[v]Open flower was when all florets on an inflorescence were showing color.

[u]Stem length at five open flowers was the average of the longest and shortest flower stems.

leaf counts of black-eyed Susan increased linearly with progressively longer bulking durations (Keever et al. 2014). No differences were found in offset number between the two potting dates after 4 and 6 weeks of bulking, but differences of 4 to 5 offsets were found after 8 and 10 weeks of bulking with the highest offset number from the October 14 potting date. For the October 14 potting date, bulking occurred from mid-October to mid-December, while bulking for the December 2 potting date occurred from early December to early February. The higher offset number at the end of 8 and 10 weeks of bulking for the October 14 potting date when compared to the December 2 potting date was possibly due to higher light intensities and longer photoperiods during the bulking periods, although the same differences in environmental conditions would have been present during the shorter bulking periods (Fig. 1).

There was a quadratic change and a linear decrease in the number of days to first open flower with increasing bulking duration for the October 14 and December 2 potting dates, respectively (Table 1). Plants potted on October 14 and December 2 and bulked for 10 weeks flowered 13 to 16 days and 3 to 13 days, respectively, quicker than those bulked for shorter durations. These results agree with the acceleration in flowering with increased bulking duration reported in 'Goldsturm' black-eyed Susan and 'Moonbeam' coreopsis (Keever et al. 2014), and may result from an increase in daily solar radiation during the flowering of plants bulked for 10 weeks in the first run and a continuous increase in daily solar radiation in the second run as plants bulked for longer periods flowering at progressively later periods in spring (Fig. 1). The number of days to first open flower was higher for the October 14 than the December 2 potting date for all bulking durations with differences of 12 to 25 days. Plants from the December 2 potting date flowered from

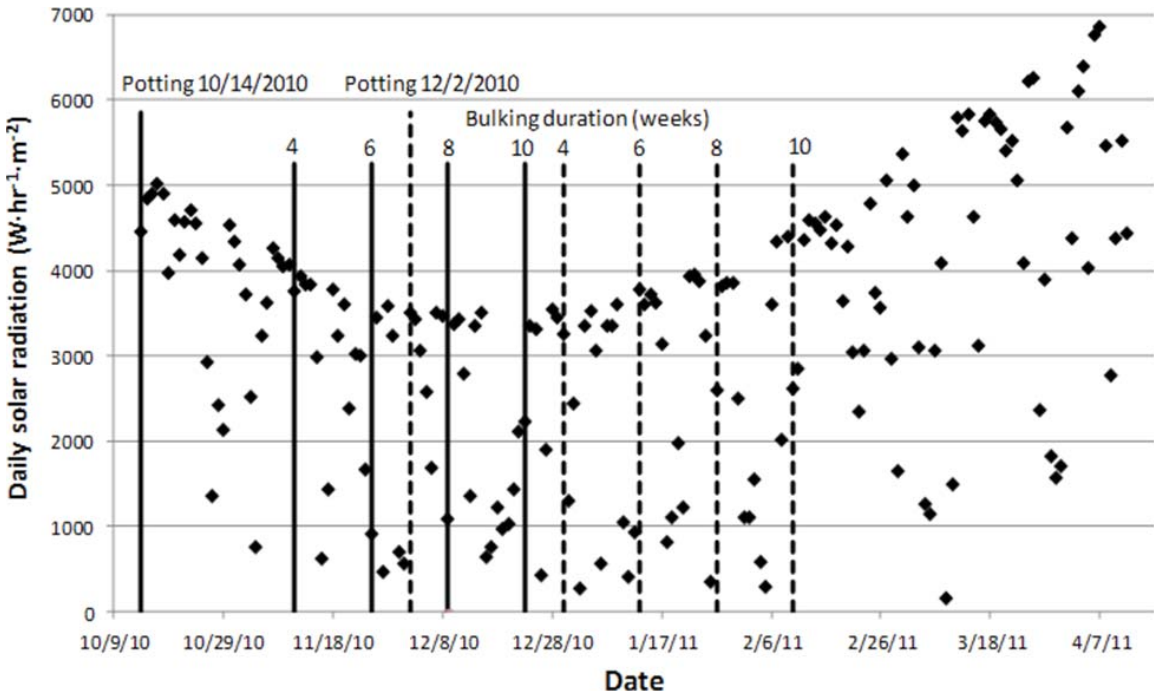

Fig. 1. Daily solar radiation (AWIS Weather Services, Inc.) for Auburn, AL, from October 10, 2010, to April 12, 2011, indicating the two potting dates and 4, 6, 8 or 10 weeks of bulking for *Achillea* ×'Coronation Gold'. Solid and dashed vertical lines represent the ends of the four bulking durations for the October 14 and December 2 potting dates, respectively.

mid-February to early April while those from the October 14 potting date flowered from mid-January to early March. The differences in days to first open flower were likely due to higher light intensities and longer photoperiods in the later potting date. These differences are reflected in the average daily solar radiations values, which were 438, 774, 869, and 1,175 $W \cdot hr^{-1} \cdot m^{-2}$ higher for plants potted on December 2 and bulked 4, 6, 8 and 10 weeks, respectively, compared to plants potted on October 14 (Fig. 1). Similar trends were found for number of days to five open flowers (data not shown).

There was a linear increase in flower and flower bud number with increasing bulking duration with a 6 and 2 flower and flower bud number increase for the October 14 and December 2 potting dates, respectively (Table 1). Similar results were observed with different herbaceous perennial species outdoors under nursery conditions (Keever et al. 2014). Higher flower and flower bud number, particularly after 8 and 10 weeks of bulking, likely resulted from the higher offset numbers at the end of bulking. Stem length at five open flowers for the October 14 potting date increased linearly, up to 16%, and decreased linearly, up to 9%, for the December 2 potting date with increasing bulking duration. These differences were not considered of horticultural significance. Generally, flowering stems were longer for the December 2 potting dates than the October 14 potting date, especially after 4 and 6 weeks bulking, and were likely due to greater stem elongation from lower light intensities and shorter photoperiods in the mid-January to mid-February period as compared to the mid-February to mid-March period (Fig. 1).

Bulking duration by daminozide. Offset number of *Achillea* ×'Coronation Gold' at the end of bulking increased linearly by up to 4 offsets, or 67%, as bulking duration increased, which agrees with the first experiment (Table 2). Only the daminozide and bulking duration main effects were significant for days to first open flower. Application of daminozide delayed first open flower by 6 days (55 vs 61) and time to five open flowers by 8 days, regardless of bulking duration (data not shown). This delay in flowering is similar to that in an earlier study using daminozide on 'Coronation Gold' yarrow (Kessler and Keever 2008) and to delays in flowering reported in other crops (Kahar 2008, Wang and Hsu 1994). Days to first open flower decreased linearly by 9 days with increasing bulking duration, a trend similar to that found in the first experiment. Similar trends were found for number of days to five open flowers (data not shown). As in the first experiment, there was a linear increase in flower and flower bud number with increasing bulking duration, but no effect from daminozide applications. There was a daminozide by bulking duration interaction for stem length at five open flowers. Flowering stems at five open flowers of plants treated with daminozide were 43, 20, 29, and 33% shorter than those of plants without daminozide application when bulked for 4, 6, 8, and 10 weeks, respectively. Daminozide-treated plants were more proportional to their pots than those not treated, although they were still considered tall for 20 cm (8 in) pots. Stem length at five open flowers changed quadratically with increasing bulking duration with daminozide applications, but not without. The range in flower stem length across all bulking durations was less than 4 cm (1.6 in) in the absence of daminozide, but 13 cm (5.1 in) when daminozide was applied. These changes in the absence of daminozide were similar to the 16% increase in the flower stem length for the October transplanting and the 9% decrease for the December transplanting. In a previous study, plant height at first flower of 'Goldsturm' black-eyed Susan increased linearly as bulking duration increased based on potting date, but did not differ when trended across NIL start dates, and effects of bulking duration on plant height of 'Moonbeam' coreopsis were inconsistent (Keever et al. 2014).

Overall, the response of 'Coronation Gold' yarrow to increasing bulking duration was similar in the two experiments. Increasing bulking duration generally increased the number of offsets and flower and flower bud numbers and reduced days to first and five open flowers. Flower stem lengths at five open flowers were minimally affected by bulking duration. More flowers and flower buds formed on yarrow when potted early, compared to late potting. Daminozide application decreased stem lengths at five open flowers by 20 to 43%, but increased days to first and five open flowers by 6 and 8 days, respectively. Kessler and Keever (2008) reported daminozide applied at 5,100 ppm suppressed 'Coronation Gold' yarrow first open flower stem length by 17%, but increased days to flower by 2 days. Burnett et al. (2000) reported daminozide applied at 5,000 ppm suppressed 'Coronation Gold' yarrow plant height by 16 to 30% from 14–70 days after treatment; however, flower and flower bud number was not reported for these studies.

Table 2. The effects of bulking duration before the beginning of night-interrupted lighting (NIL), and two applications of daminozide (B-Nine) at 5,000 ppm 1 week apart on plant size and flowering of container-grown *Achillea* ×'Coronation Gold'.

Bulking duration (weeks)	Offset number[z]	Days to first open flower[y]	Flower and bud number[x]
4	6	62	4
6	8	58	6
8	9	60	8
10	10	53	10
Significance[w]	L***	L***	L***

Stem length at five open flowers (cm)[v]

Bulking duration (weeks)	Daminozide	
	No	Yes
4	60.3a[u]	34.4b
6	59.1a	47.4b
8	61.7a	43.8b
10	58.1a	38.7b
Significance	NS	Q***

[z]Recorded at the end of bulking. The bulking duration main effect was significant at $\alpha = 0.05$.

[y]Counted from the end of bulking. The bulking duration main effect was significant at $\alpha = 0.05$. Open flower was when all florets on an inflorescence were showing color. NIL was started at the end of bulking.

[x]At five open flowers. The bulking duration main effect was significant at $\alpha = 0.05$.

[w]Not significant (NS) or significant linear (L) or quadratic (Q) trends using orthogonal polynomials at $\alpha = 0.001$ (***).

[v]The daminozide by bulking duration interaction was significant at $\alpha = 0.05$. Stem length at five open flowers was an average of the longest and shortest flower stems.

[u]Least-squares means comparison in rows using Shaffer Simulated method at $\alpha = 0.05$.

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