Pinching, Bulking Duration, and Plant Growth Retardant Effects on Growth and Flowering of Greenhouse-grown *Achillea* ×'Coronation Gold' and *Coreopsis verticillata* 'Moonbeam'

by

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Abstract

Achillea ×'Coronation Gold' ('Coronation Gold' achillea) and *Coreopsis verticillata* L. 'Moonbeam' ('Moonbeam' coreopsis) are popular herbaceous perennials that are widely grown under nursery and greenhouse conditions. Herbaceous perennials are considered to be of high quality if they are well branched and full in appearance, with multiple flowers that open simultaneously. A balance between container size and plant size is also necessary to achieve high perceived quality.

One study was conducted to determine the effects of a soft pinch on the offset from propagation and the plant growth retardant, daminozide (B-Nine), on growth and flowering of 'Coronation Gold' achillea. Pinching decreased inflorescence stem length by 6.4%, but increased the number of flowering offsets and total offsets by 33.3% and 9.1%, respectively. Daminozide decreased inflorescence stem length and the number of flowering offsets by 7.9% and 40%, respectively, but increased the time to first open inflorescence and the number of non-flowering offsets by 6 days and 28.6%, respectively. Pinching at 7 weeks resulted in the highest number of flowering, non-flowering, and total offsets and the lowest days to flower and intermediate flower stem length. Pinching at 7 weeks after potting resulted in the most improvements in plant qualities related to marketability with the fewest drawbacks.

Another study was conducted to determine the effects of bulking duration and daminozide on growth and flowering of 'Coronation Gold' achillea and 'Moonbeam' coreopsis. Increasing bulking duration increased flower and flower bud number of both plants for the early fall potting

date, but only increased flower and flower bud number of 'Coronation Gold' achillea for the late fall potting date. There were much more flowers and flower buds for the early potting date than the late potting date over all bulking durations for both plants. Daminozide suppressed 'Moonbeam' coreopsis plant height at first open flower by 31-49% and suppressed 'Coronation Gold' achillea first open flower stem height by 20-43%, but increased the time to first open flower for both plants. Daminozide also increased flower and flower bud number of coreopsis by 13% over all plants, but decreased flower and flower bud number of achillea slightly.

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Table of Contents

List of Tables

CHAPTER I

Literature Review

Herbaceous perennials have become popular crops for forcing in containers in nurseries and greenhouses (Cameron et al., 2003 and Latimer, 2006). They are most marketable when in flower, especially when flowering occurs in spring to early summer, the peak garden plant market period for much of the United States. However, many of the most popular herbaceous perennials naturally flower during other times of the year. Greenhouse production of herbaceous perennials requires a significant effort to control size of some very vigorous plants and to force them into flower out-of-season. Herbaceous perennials are considered to be of high quality if they are well branched and full in appearance, with multiple flowers that open simultaneously. A balance between container size and plant size is also necessary to achieve high perceived quality (Latimer, 2004 and Olrich et al., 2003).

Coreopsis verticillata L. 'Moonbeam' and *Achillea* ×'Coronation Gold' are popular herbaceous perennials that are widely grown under nursery and greenhouse conditions and have been investigated as possible flowering potted crops for greenhouse production. 'Moonbeam' coreopsis is a fast growing, durable herbaceous perennial well adapted to bright, warm areas of the United States, especially where periodic summer drought may occur (Armitage, 1997). It grows 46–61 cm (18–24 in) tall in the garden and bears single, light yellow flowers repeatedly throughout the summer and even into the fall months in some areas. 'Coronation Gold' achillea is a hybrid cross between *Achillea filipendulina* Lam. and *Achillea clypeolata* Sibth. & Sm. It is probably the best-known garden achillea and is suitable as a garden perennial or cut flower

(Hamrick, 2003). Plants grow 76 cm (2.5 ft) to 91 cm (3 ft) tall with tight clusters of 7.6 cm (3 in) to 10 cm (4 in) inflorescences that are composed of golden yellow florets. The foliage is finely dissected, gray-green, and aromatic (Nau, 1996).

Photoperiod

Flowering is a complex physiological process controlled by many factors including photoperiod (Thomas and Vince-Prue, 1997). In the floriculture industry, photoperiod is a reliable environmental signal for flower induction that has been artificially manipulated by greenhouse growers to keep plants vegetative or to induce flowering. Plants can be categorized as short-day, long-day, or day neutral. A short day plant initiates flowers when the day length is shorter than the critical day length for that species. Day lengths longer than the critical result in vegetative growth. A long day plant initiates flowers when the day length is longer than the critical day length for that species. Day lengths shorter than the critical result in vegetative growth. Short-day and long-day plants can be further subdivided into qualitative or quantitative photoperiod responses. Qualitative photoperiodic plants require a specific photoperiod for flowering, i.e., flowering does not occur without it. Quantitative photoperiodic plants benefit from a specific photoperiod, i.e., the plants will eventually flower under short days or long days, but flowering is faster or more flowers are produced under the required photoperiod. Day-neutral plants do not respond to photoperiod for flowering.

Under natural short days, night-interrupted lighting (NIL) from 10:00 p.m. to 2:00 a.m. from incandescent lamps providing a minimum 10 ft-c is recommended to induce flowering of long-day plants (Armitage, 1996a and 1996b), including the qualitative long-day plants, *Coreopsis verticillata* ‘Moonbeam’ (Iversen and Weiler, 1994), *Coreopsis grandiflora* Hogg ex Sweet ‘Early Sunrise’ (Cameron et al., 1996), and *Achillea millefolium* L. ‘Summer Pastels’

(Zhang et al., 1996). In general, NIL more effectively induces flowering than the same quantity or duration of light added to the end of the photoperiod (Thomas and Vince-Prue, 1997). Durations of NIL longer than 4 hr may not improve flowering: a 7 hr NIL induced flowering similar to that induced by a 4 hr NIL in six species of herbaceous perennials (Hamaker et al., 1996a). In quantitative long-day plants, long days are not required to induce flowering but are beneficial in either hastening the rate of flowering or increasing the number of flowers (Armitage, 1996a and 1996b). Quantitative long-day herbaceous perennials include *Coreopsis grandiflora* 'Sunray' and *Salvia* ×'Blue Queen' (Cameron et al., 1996).

'Moonbeam' coreopsis (Hamaker et al., 1996b) and 'Cloth of Gold' achillea (Cameron et al., 1996) have an obligate requirement for long photoperiods to flower that can be a 14 hr or longer photoperiod or 4 hr NIL. 'Coronation Gold' achillea responds in much the same way. Nausieda et al. (2000) reported that 'Coronation Gold' achillea flowered fastest when provided at least a 16 hr photoperiod or a 4 hr NIL that also resulted in an increase in the number of lateral shoots in greenhouse production. Keever et al. (2001, 2006) reported application of NIL to 'Coronation Gold' achillea and 'Moonbeam' coreopsis grown outdoors under nursery conditions accelerated flowering by 2–11 days and 7-36 days and increased flower and flower bud counts by 82-100% and 20-244%, respectively.

Juvenility

Many herbaceous perennials undergo a juvenile phase following seed germination. A period of juvenility was described as a physiologically based time when a plant is insensitive to conditions that promote floral initiation (Bernier et al., 1981). Many photoperiodic herbaceous species pass through juvenility gradually, characterized by a period of increased sensitivity to day length rather than a total inability to flower, such as *Coreopsis grandiflora* 'Early Sunrise'

(Damann and Lyons, 1993), and *Gaillardia pulchella* Foug. and *Rudbeckia hirta* L. (Bourke, 1990). Time to flower for these plants decreased as their age at exposure to inductive long-day photoperiods increased. Leaf or node number usually is used to measure plant age because it is more constant than other measurements, such as time (Holdsworth, 1956). Yuan et al. (1997) concluded that the juvenile phase of coreopsis, gaillardia, heuchera and rudbeckia ended when they had approximately 8, 16, 19 and 10 nodes, respectively.

Bulking

Bulking is a term often used to describe the growth period before a perennial is forced into flowering, such as by a photo-inductive photoperiods. It can be used to ensure a plant has passed through the juvenile phase and is mature enough to flower; to build the plant, regardless of juvenility requirements, to a size more suitable for forcing; or to build the root system, allowing the plant to become well established. The increase in the size of the root system is believed to result in a greater number of shoots of sufficient developmental size to respond to photo-inductive photoperiods, possibly resulting in more flowers and/or flowering shoots (Pilon, 2006).

Perennials are bulked under non-flower inducing conditions, keeping them in the vegetative phase. The length of the bulking period varies for each cultivar, but often averages 2 to 4 weeks. It is often determined by the initial size of the plants being bulked and the size of the finished container it is intended for. For example, a 72-cell plug transplanted into a 1L (1 qt.) container will require less bulking time than a 72-cell transplanted into a 3.8L (1 gal.) pot. Pilon (2008) reported that several perennials, including *Aquilegia* spp. (columbine), *Dianthus gratianopolitanus* Vill. (cheddar pink) and *Phlox subulata* L. (creeping phlox), must be potted in early fall to properly bulk them up in the final container so they will have adequate foliage for a full, marketable container, and plants will grow well and be marketable. It was recommended that if growers choose to force plants, such as ‘Moonbeam’ coreopsis and ‘Coronation Gold’ achillea, into flower for spring sale, plants must be bulked under short days so that roots can fully developed throughout the pot prior to inducing flowers (Hamrick, 2003).

Plant Growth Retardants

Rapid growth of plants under greenhouse 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 and 2008).

Plant growth regulators are chemical compounds or plant hormones that control plant growth and development (McAvoy, 1989). They can increase or retard plant height, prolong or break bud dormancy, promote rooting, and increase branching and/or flowering (Larson, 1985; McAvoy, 1989). Plant growth regulators that are used to reduce plant height are commonly called plant growth retardants (PGR). PGRs used to control plant height are gibberellin (GA) synthesis inhibitors (Latimer, 2004). The gibberellins are natural plant hormones that cause the elongation of cells in the plant. They are present in the greatest quantities in those tissues that are elongating the most rapidly, usually stems, petioles, and, in some crops, flower inflorescences. The application of PGRs to potted plants can result in shorter, more rigid stems and darker green foliage; characteristics that increase the value of the plant (Gianfagna, 1995). PGRs consist of several older compounds that were introduced to floriculture in the 1960s and 70s like B-Nine (daminozide), Cycocel (chlormequat chloride) and A-Rest (ancymidol). These products are still commonly used in the industry. In the 1980s, a new class of compounds was introduced, the triazoles, including Bonzi (paclobutrazol) and Sumagic (uniconazole). These products are much more potent than the older chemistries.

Burnett et al. (2000a) treated *Coreopsis rosea* Nutt. ‘American Dream’, or pink coreopsis, with four PGRs: B-Nine from 2500 to 7,500 ppm, Cutless from 25 to 150 ppm, Sumagic from 10 to 40 ppm, or Bonzi from 25 to 100 ppm. Application of B-Nine, Cutless, or Sumagic suppressed plant growth by 13–31% at first flower and increased plant quality ratings by 52-67% when compared to controls. Plants also had greater compactness and more branches with darker green foliage and more flowers. Times to first flower and to a marketable stage were minimally affected by PGR application, and no phytotoxicity was observed. Bonzi did not control growth or affect flowering of pink coreopsis.

Plants of ‘Moonbeam’ coreopsis received PGRs treatments in two experiments consisting of one application of A-Rest or Bonzi medium drenches at 0, 2, 4, or 6 ppm; B-Nine sprays at 0, 2550, 5100, or 7650 ppm; Bonzi sprays at 0, 12, 24, 36, 48, or 60 ppm or Cutless sprays at 0, 25, 50, 75, 100, 150, or 200 ppm in the first experiment and sprays of B-Nine at 0, 2550, 5100, or 7650 ppm; Bonzi at 0, 60, or 120 ppm; B-Nine/Bonzi combinations at 0, 2550/16, 2550/32, 2550/48, or 2550/64 ppm, Cycocel at 0, 767, 1534, or 2301 ppm; or B-Nine/Cycocel combinations at 0, 1275/1534, 2550/1534, 3825/1534, or 5100/1534 ppm in the second experiment (Kessler and Keever, 2007). In the first experiment, there was a linear decrease in shoot height, growth index, and lateral shoot length with increasing rates of A-Rest and Bonzi drenches and Cutless sprays while B-Nine decreased growth quadratically. Only B-Nine increased the number of days from treatment to flower with increasing rates. Quality ratings increased with increasing rates of A-Rest, B-Nine, and Cutless with the highest ratings found at the two highest rates of B-Nine and Cutless. Bonzi sprays did not affect the parameters measured.

In the second experiment, Cycocel sprays did not affect the parameters measured, but when combined with increasing rates of B-Nine, there was a linear decrease in shoot height, growth index, and lateral shoot length and an increase in the number of days to flower. B-Nine alone resulted in a linear increase in the number of days to flower, but with no effect on quality rating. The higher rates of Bonzi than were used in the first experiment decreased shoot height and lateral shoot length with no effect on growth index, the number of days to flower, or quality rating. Overall, the best quality ratings and the most compact plants resulted from spray applications of B-Nine at 5100 ppm or 7650 ppm and Cutless at 150 ppm or 200 ppm.

Also, Amling et al. (2005) reported that B-Nine was more effective in controlling plant height of ‘Moonbeam’ coreopsis and ‘Goldsturm’ rudbeckia than Cycocel or B-Nine/Cycocel combinations. B-Nine alone suppressed height of coreopsis by 26–52%, in contrast to a 17–41% height suppression when B-Nine was combined with Cycocel. Cycocel alone suppressed height of coreopsis by 6–16%. Also, B-Nine suppressed height of rudbeckia by 20–40%.

Latimer (2001, 2003) reported that multiple applications of B-Nine at 5000 ppm reduced plant stem length of *Achillea* ×‘Moonshine’, *Achillea millefolium* L. ‘Summer Pastels’, and *Achillea millefolium* ‘Paprika’, but details on treatments and methods were not reported. Burnett et al. (2000b) applied B-Nine at 2500, 5000, or 7500 ppm to ‘Coronation Gold’ achillea in a nursery setting over 2 years. In 1998, B-Nine provided little growth suppression of achillea; 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, plants of ‘Coronation Gold’ achillea treated with B-Nine at 0, 2550, 5100, or 7650 ppm; Cycocel at 0, 767, 1534, or 2301 ppm; B-Nine/Cycocel at 0, 1275/1534, 2550/1534, or 3825/1534 ppm; Sumagic at 0, 11, 22, 33, 44, or 55 ppm; Bonzi at 0, 32, 64, 96, 128, or 160 ppm; or Cutless at 0, 40, 80, or 120 ppm as a spray. B-Nine, Cycocel, B-

Nine/Cycocel, Sumagic, Bonzi, and Cutless reduced shoot height and growth index by 36 and 26%, 39 and 27%, 61 and 41%, 75 and 52%, 52 and 36%, and 75 and 51%, respectively, with the highest rate of each (Kessler and Keever, 2008). B-Nine, Cycocel, B-Nine/Cycocel, and Sumagic, but not Bonzi or Cutless, increased the number of days to open inflorescence by 3–5 days at the highest rates. Sumagic, Bonzi, and Cutless reduced inflorescence diameter by up to 15, 18, and 14%, respectively, but not B-Nine, Cycocel, or B-Nine/Cycocel. The highest quality ratings of 2.8 to 3.0 were found with B-Nine/Cycocel at 3825/1534 ppm, Sumagic at 22 and 33 ppm, and Bonzi at 64 ppm. The highest B-Nine rate of 7650 ppm reduced shoot height by 36%, but increased time to first open inflorescence by 5 days when compared to controls.

B-Nine inhibits gibberellin synthesis. Similar to prohexadione-Ca, daminozide is a structural mimic of 2- oxoglutaric acid that is required in processes that oxidize GA12-aldehyde into other gibberellins. Daminozide specifically inhibits the process when GA_{20}, an inactive form of GA, is converted to GA_1 (Brown et al., 1997). It is labeled for use on herbaceous perennials under greenhouse and nursery conditions (OHP, Inc., 2011). In general, it is not phytotoxic, and has a short-term effect that seldom results in excess growth suppression of treated plants. Due to the low activity of B-Nine and its lack of soil activity, it is less likely to suppress excessively than the newer, more potent PGR chemistries. The low activity also means that B-Nine may need to be applied more frequently to maintain control over vigorous crops. Generally, foliar sprays of 5000 ppm are applied every 7 to 14 days as necessary. Application frequency may need to be increased to weekly for more vigorous cultivars grown outdoors (Latimer, 2001).

Apical Dominance

‘Coronation Gold’ achillea is propagated from single offsets. An offset is a shortened, thickened stem of rosette-like appearance that develops from the base of a main stem or crown in certain plants (Hartmann et al., 1997). During vegetative growth offsets arise from the crown and root system. It has been observed that at flowering, the original "propagation" offset elongates more than secondary offsets and is taller than the surrounding floral canopy, which decreases perceived quality. This phenomenon is named apical dominance, which is defined as the control exerted by the shoot apex over the outgrowth of lateral buds (Cline, 1994). Thimann and Skoog (1934) found that decapitated *Vicia faba* plants allowed lateral bud growth, but treatment of the apical stump with auxin prevented lateral bud development. Apical dominance is regulated by auxin, which diffuses basipetally from terminal buds and inhibits the development of lateral buds (Tamas, 1987). In contrast, cytokinin application to lateral buds often overcomes the apical dominance, and initiated lateral bud development (Cline, 1991). Lateral bud growth is generally prevented by a correlative signal from the apical meristem, and removal of the apical bud eliminates this signal and allows lateral bud growth (Mok and Mok, 1994). Cline (1997) divided apical dominance and its release into four stages, based on differential response to hormones. In stage one, cytokinin promotes lateral bud formation. In stage two, apical dominance is imposed by auxin, produced in terminal buds and shoots. If buds enter stage three (resulting from a compromised apical meristem due to injury, removal or loss of apical dominance) lateral bud elongation is attributed to increased cytokinin levels. In stage four, auxin and gibberellin promote the further elongation of the lateral bud into a branch. Therefore, to develop well-branched plants, apical dominance must be disrupted (Cline, 1991).

Pinching

Pinching the central shoot apex, which removes apical dominance and stimulates the development of lateral shoots, often results in well-branched plants and improved plant aesthetics. Many species require growers to apply a manual pinch. Lateral shoot growth and plant morphology of *Euphorbia pulcherrima* Willd. ex Klotzsch (poinsettia) were influenced by the pinching technique used for apical meristem removal (Berghage et al., 1989). Plants were pinched in one of four ways: 1) soft pinch-removal of the apical meristem plus stem and leaf tissue associated with leaves less than or equal to 2 cm long; 2) medium pinch-removal of the apical meristem plus stem and leaf tissue associated with leaves up to 7 cm long; 3) hard pinch-removal of the apical meristem plus stem and leaf tissue associated with all immature leaves; or 4) leaf removal-soft pinch as defined above plus removal of all immature leaves, but not the associated stem tissue (LR). Initial growth of lateral shoots on soft and some medium-pinched plants was less than initial growth of lateral shoots on hard- or LR-pinched plants. Shorter lateral shoots and longer primary stems at anthesis on soft-pinched plants resulted in vertical plant architecture. Hard- and LR-pinched plants had a more horizontal plant architecture. The average height : width ratio of soft-, hard-, and LR-pinched plants at anthesis was 0.77, 0.68, and 0.63, respectively. Of 10 commercial cultivars tested in 1987, 48% of the inflorescences on soft-pinched plants developed below the bract canopy when compared with 27% and 31% for hard- and LR-pinched plants, respectively. These results show that the use of a soft pinch to increase inflorescence number in the bract canopy is productive if immature leaves are removed on the plant when pinching. The soft pinch is recommended in most cases because, as the name implies, it removes the least amount of tissue from the stem tip. Most soft pinches remove the growing tip and one or more leaf nodes below the pinch, depending on the crop species. The timing of a soft pinch usually occurs during the second or third week following transplant. This provides enough time for the root system to develop so it may support active shoot growth and development. A time-tested rule is to pinch when roots are visible at the sides and bottom of the medium after removing the plant from its pot (Hamrick, 2003).

Plants of *Rhododendron* 'Molly Ann', 'Paprika Spiced', and 'Travis' pruned by pinching, top-pruning, or root-pruning were compared to non-pinched plants (Lohr and Sudkamp, 1989). Pruning treatments were applied 7 weeks after potting in a greenhouse and were no growth removed ('non-pinched'), top 1 cm (0.4 in) of the shoot tip removed ('pinched'), top half of the shoot removed ('top-pruned'), or the outer half of the root mass removed and replaced with potting medium ('root-pruned'). Removal of the shoot apex by pinching or top-pruning increased shoot number in the three cultivars. Shoot heights and dry weights were significantly lower in the plants pruned by any of the three methods than in non-pinched plants.

In another study, seedlings of flame azalea [*Rhododendron calendulaceum* (Michx.) Torr] were given the following manual pinching treatments at the 10-, 12-, 14-, or 16-leaf stage: no pinching, removal of the terminal two nodes [approximately 1.25 cm (0.5 in)], or removal of terminal growth [approximately 2.5-5.0 cm (1-2 in)] leaving six nodes (Malek et al., 1992). The greatest number of lateral shoots (5.3) was produced by removing the terminal two nodes at the 16-leaf stage. Generally, the number of lateral shoots increased with an increase in the leaf stage at which manual pinching was imposed. Removal of terminal growth, leaving six nodes, resulted in the lowest leaf, stem and root dry weights at each leaf stage.

Plants of *Delphinium ×belladonna* 'Völkerfrieden' received a hard pinch (removal of apex and all stem and leaf tissue associated with leaves ≤10 cm long), soft pinch (removal of apex and all stem and leaf tissue associated with leaves ≤4 cm long), or no pinch (Garner et al., 1997). Stem length increased with an increasing degree of tissue removal. Stems of soft- and hard-pinched plants were 18% and 34%, respectively, longer than those of non-pinched plants. Time from planting to harvest was longer in pinched plants than in non-pinched plants, but was similar for the two pinched groups. At 30 days after the commencement of harvest, yield of flowering stems for hard-pinched plants was 213% higher than that for non-pinched plants, while yield for soft-pinched plants was similar to that for non-pinched plants.

Yields of flowering stems for pinched and non-pinched plants were similar when measured over the entire 90-day harvest of the experiment.

The combinations of pinching and PGRs can produce compact, well-branched potted plants that are more aesthetically pleasing. Forty-two chrysanthemum cultivars were grown in 15 cm (6-inch) diameter containers on raised beds in a polypropylene shade house by Wilfret (1989). Cultural procedures included planting four rooted cuttings per pot, manually pinching the plant terminals after 10 days, night-interrupted lighting from the time of planting to 5 days after pinching, and making two applications of daminozide at 2500 ppm foliar sprays at 7days or 14 days after lighting. Plant height, which was influenced by the two daminozide applications, ranged from 25.2 cm (9.9 in) to 36.8 cm (14.5 in) in ‘Gold Champ’ and ‘Dark Parasol’, respectively. Ideal plant height was determined to be from 27.9 cm (11 in) to 33.0 cm (13 in) above the pot rim. Thirty-two of the cultivars were within this range. Several of the cultivars, such as ‘Applause’, ‘Envy’, and ‘Solo’ were slightly shorter than desired, indicating that one daminozide application would be sufficient for these cultivars. The number of laterals that developed following the pinch and the number of floral buds per lateral determined the flower potential of each plant. ‘Lamplight’ produced the fewest laterals (14/pot) while ‘Songster’ produced the most (35/pot). ‘Brightlight’ had only 5 floral buds per lateral while ‘Lucido’ had 11. When the flower potential per pot was calculated, ‘Echo’ produced the highest number (318) while ‘Envy’ had the least (104). Although the ideal floral display was determined by both flower number and flower size, cultivars that had a flower potential less than 160 appeared sparse. Only eight of the forty-two cultivars exhibited a flower potential below this minimum.

Židovec (2002) reported pinching and plant growth retardant effects on plant height and the number of lateral branches of *Lavandula angustifolia* Mill. (lavender). Plants were pinched at the beginning of the growing period and/or treated twice with Alar 85(85% daminozide) sprays at 0.1% (1000 ppm) or 0.2% (2000 ppm) at an interval of 15 days. The first treatment was control plants with no pinching or daminozide application. The second was pinched plants without daminozide application. The third and fourth combinations were daminozide at a 0.1% solution, with the third one having no pinch, and the fourth one being pinched. The fifth and sixth combinations were daminozide at a 0.2% solution, also without and with pinching. Non-pinched plants were taller (27.5%) than pinched plants regardless of the daminozide treatment. Plants treated with a 0.2% daminozide solution were shorter than untreated plants. The shortest plants received pinching and application of daminozide at 0.1% solution. Plants that were not treated with daminozide had the highest number of lateral branches (6.0% more) while plants treated with a 0.1% daminozide solution had the lowest number of lateral branches (2.2% less). Regardless of the daminozide treatment, pinched plants had a higher number of lateral branches (2.3% more) when compared to non-pinched plants.

In another study, potted rooted cuttings of *Euphobia pulcherrima* (poinsettia) were treated with a single pinch, and/or a double pinch, and/or Cycocel and/or B-Nine applications (Karunananda and Peiris, 2010). The first pinch was applied 14 days after transplanting, leaving five to six nodes on plants and allowing the side shoots to develop. The second pinch was applied 14 days after the first pinch by removing the apical bud on all the developing buds after the first pinch, leaving five nodes. Cycocel was applied at a rate of 1,500 ppm 14 days after the second pinch. B-Nine was applied at a rate of 5,000 ppm 7 days after the Cycocel application.

The most stem height control was obtained from a double pinch plus Cycocel and B-Nine or a double pinch plus Cycocel. Results showed that there was no effect of B-Nine for control of stem elongation when used in combination with pinching and Cycocel. This was also evident between the results of double pinch plus B-Nine and double pinch only. Single pinch plus Cycocel and B-Nine, single pinch plus Cycocel, and single pinch plus B-nine produced the same plant height. Cycocel resulted in the best height reduction when combined with pinching. Cycocel with double pinching gave better results than Cycocel with a single pinch. Cycocel only was no different from the control. However, Cycocel was better at keeping plants at a prefered height than B-Nine. Pinching, Cycocel and B-Nine, when applied singly did not reduce plant height.

The highest number of plant lateral shoots was produced by a double pinch plus Cycocel and B-Nine or a double pinch plus Cycocel, indicating that there was no effect of B-Nine for increasing shoot number when used in combination with pinching and Cycocel. However, when B-Nine was applied to double pinched plants, the shoot number was higher than double pinch only. This indicated that either Cycocel or B-Nine can contribute to higher shoot number after the double pinch was applied. Results showed that plants receiving a double pinch had a higher number of shoots than those receiving a single pinch when combined with Cycocel and/or B-Nine. Combining single pinch with Cycocel resulted in a higher number of shoots than for any individual treatment only or than the control.

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CHAPTER II

Effects of pinching and plant growth retardant on growth and flowering of *Achillea* ×'Coronation Gold'.

Abstract

A study was conducted to determine the effects of pinching and the plant growth retardant, daminozide (B-Nine), on plant size and flowering of *Achillea* ×'Coronation Gold'. Plants grown in a greenhouse were not pinched or were pinched by removing the apical bud from propagation offsets 3, 5 or 7 weeks after potting. One week after pinching, plants were provided night-interrupted lighting (NIL). Five weeks after pinching, daminozide was applied at 5000 ppm to half the pinched and non-pinched plants. Pinching decreased inflorescence stem length by 6.4%, and increased the number of flowering and total offsets by 33.3% and 9.1%, respectively. Daminozide decreased inflorescence stem length and the number of flowering offsets by 7.9% and 40%, respectively, but increased the time to first open inflorescence and the number of non-flowering offsets by 6 days and 28.6%, respectively. Pinching at 7 weeks after potting resulted in the highest number of flowering, non-flowering, and total offsets and the fewest days to flower and intermediate flower stem length. In a second experiment, the effects of beginning NIL at different times after pinching the offset from propagation on offset production and flowering were evaluated. All plants were uniformly pinched and NIL was started 0, 1, 2, 3, or 4 weeks after pinching. Starting NIL a 4 weeks after pinching resulted in the fewest days to flower, the highest flowering offset number, and a flower stem length about equal to all other NIL treatments.

Index words: plant growth regulator, greenhouse production, yarrow.

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

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

Significance to the Nursery Industry

‘Coronation Gold’ achillea is a popular herbaceous perennial that is widely grown under nursery and greenhouse conditions and has been investigated as a possible flowering potted crop for greenhouse production. However, it often outgrows its pots, becomes top-heavy and topples over under greenhouse production. Additionally, excessively tall plants are of lower quality and cost more to ship. This study found that pinching increased flowering, non-flowering, and total offset number and decreased flower stem length without affecting days to flower, but decreased inflorescence diameter. Pinching at 7 weeks after potting resulted in the highest number of flowering, non-flowering, and total offsets and the fewest days to flower and intermediate flower stem length. Although pinching increased the number of flowering, non-flowering, and total offsets, it does appear to be minimal economically. Daminozide decreased flower stem length without affecting inflorescence diameter or total offset number, but increased days to flower. Results of the effects of beginning NIL at different times after pinching the offsets from propagation indicate that starting NIL at 4 weeks after pinching resulted in the fewest days to flower, the highest flowering offset number, and a flower stem length about equal to all other NIL treatments.

Introduction

‘Coronation Gold’ achillea (*Achillea* ×‘Coronation Gold’) is a hybrid cross between *Achillea filipendulina* Lam. and *Achillea clypeolata* Sibth. & Sm. It is probably the best-known achillea and is suitable as a garden perennial or cut flower. Plants grow 76 cm (2.5 ft) to 91 cm (3 ft) tall with tight clusters of 7.6 cm (3 in) to10 cm (4 in) inflorescences composed of golden yellow florets. The foliage is finely dissected, gray-green, and aromatic (Nau, 1996).

Flowering is a complex physiological process controlled by many factors including photoperiod (Thomas and Vince-Prue, 1997). In the floriculture industry, photoperiod is a reliable environmental signal for flower induction that has been artificially manipulated by greenhouse growers to keep plants vegetative or to induce flowering. Under natural short days, night-interrupted lighting (NIL) from 10:00 p.m. to 2:00 a.m. from incandescent lamps providing a minimum 10 ft-c is recommended to induce flowering of long-day plants (Armitage, 1996a and 1996b). *Achillea filipendulina* 'Cloth of Gold' has an obligate long-day requirement to flower that can be met by a 14 hr or longer photoperiod or 4 hr NIL (Cameron et al., 1996). Nausieda et al. (2000) reported that 'Coronation Gold' achillea flowered fastest when provided at least a 16 hr photoperiod or a 4 hr NIL that also resulted in an increase in the number of lateral shoots in greenhouse production. Keever et al. (2001) reported application of NIL to 'Coronation Gold' achillea grown outdoors under nursery conditions accelerated flowering by 2–11 days and increased flower and flower bud counts by 82-100%.

'Coronation Gold' achillea is propagated from single offsets. An offset is a shortened, thickened stem of rosettelike appearance that develops from the base of a main stem or crown in certain plants (Hartmann et al., 1997). During vegetative growth offsets arise from the crown and root system. It has been observed that at flowering, the original propagule elongates more than secondary offsets formed following propagation and is taller than the surrounding floral canopy, which decreases perceived quality. This phenomenon is an example of apical dominance, the control exerted by the shoot apex over the outgrowth of the lateral buds (Cline, 1994). Apical dominance is regulated by auxin, which diffuses basipetally from terminal buds and inhibits the development of lateral buds (Tamas, 1987). In contrast, cytokinin application to lateral buds often overcomes the apical dominance, and resulting in lateral bud outgrowth (Cline, 1991). Lateral bud growth is generally prevented by a correlative signal from the apical meristem, and removal of the apical bud eliminates this signal and allows shoot development (Mok and Mok, 1994). Therefore, to develop well-branched plants, apical dominance must be disrupted (Cline, 1991).

Pinching the central shoot apex, which removes apical dominance and stimulates the development of lateral shoots, often results in well-branched plants and improved plant aesthetics. Many species require growers to apply a manual pinch (Hamrick, 2003). Pinching induced branching in *Rhododendron* 'Molly Ann', 'Paprika Spiced', and 'Travis' (Lohr and Sudkamp, 1989); *Euphorbia pulcherrima* Willd. ex Klotzsch (poinsettia) (Berghage et al., 1989); *Delphinium ×belladonna* 'Völkerfrieden'(Garner et al., 1997); and flame azalea [*Rhododendron calendulaceum* (Michx.) Torr] (Malek et al., 1992).

Plant growth regulators (PGR) are chemical compounds or plant hormones that control plant growth and development (McAvoy, 1989). They can increase or retard plant height, prolong or break bud dormancy, promote rooting, and increase branching and/or flowering (Larson, 1985; McAvoy, 1989). Plant growth regulators used to reduce height are commonly called plant growth retardants. Application of plant growth retardants to potted plants often results in shorter, more rigid stems and darker green foliage; characteristics that increase the value of the plant (Gianfagna, 1995). Latimer (2004) concluded that the primary chemicals used to control plant height are gibberellin (GA) synthesis inhibitors. The gibberellins are natural plant hormones that cause cell elongation in plants. They are present in the greatest quantities in those tissues that are elongating rapidly, usually stems, petioles, and, in some crops, flower inflorescences. The plant growth retardant, B-Nine (daminozide), is labeled for use on herbaceous perennials under greenhouse and nursery conditions (OHP, Inc., 2011). Generally, foliar sprays of 5000 ppm are applied every 10 to 14 days as necessary. Frequency of application may need to be increased to weekly for more vigorous cultivars grown outdoors (Latimer, 2006).

Latimer (2001, 2003) reported that multiple applications of B-Nine at 5000 ppm reduced plant stem length of *Achillea* ×'Moonshine', *Achillea millefolium* L. 'Summer Pastels', and 'Paprika', but details on treatments and methods were not reported. Burnett et al. (2000) applied B-Nine at 2500, 5000, or 7500 ppm to 'Coronation Gold' achillea in a nursery setting over 2 years. In 1998, B-Nine provided little growth suppression of achillea; however in 1999, when plants were pruned just prior to treatment and thus were less reproductively developed, height at the most effective concentration of 7,500 ppm was reduced 33% when compared to untreated plants. Increasing B-Nine rates from 2550 ppm to 7650 ppm resulted in a linear decrease in shoot height, a linear increase in the number of days to first open flower, but had no effect on flower diameter or quality rating of 'Coronation Gold' achillea. The highest B-Nine rate of 7650 ppm reduced shoot height by 36% but increased time to first open inflorescence by 5 days when compared to controls (Kessler and Keever, 2008).

The combinations of pinching and PGRs can produce compact, well-branched potted plants that are more aesthetically pleasing. Forty-two chrysanthemum cultivars were grown in 15 cm (6 in) diameter containers on raised beds in a polypropylene shade house by Wilfret (1989). Cultural procedures included planting four rooted cuttings per pot, manually pinching the plant terminals after 10 days, night-interrupted lighting from the time of planting to 5 days after pinching, and making two foliar applications of 2500 ppm daminozide at 7 and 14 days after lighting. Plant height, which was influenced by the two daminozide applications, ranged from 25.2 cm (9.9 in) to 36.8 cm (14.5 in) in ‘Gold Champ’ and ‘Dark Parasol’, respectively. Ideal plant height was determined to be from 27.9 cm (11 in) to 33.0 cm (13 in) above the pot rim. Thirty-two of the cultivars were within this range. Several of the cultivars, such as ‘Applause’, ‘Envy’, and ‘Solo’ were slightly shorter than desired, indicating that one daminozide application would be sufficient for these cultivars. The number of laterals that developed following the pinch and the number of floral buds per lateral determined the flower potential of each plant. ‘Lamplight’ produced the fewest laterals (14/pot) while ‘Songster’ produced the most (35/pot). ‘Brightlight’ had only five floral buds per lateral while ‘Lucido’ had 11. When the flower potential per pot was calculated, ‘Echo’ produced the highest number (318) while ‘Envy’ had the least (104). Although the ideal floral display was determined by both flower number and flower size, cultivars that had a flower potential less than 160 appeared sparse. Only eight of the forty-two cultivars exhibited a flower potential below this minimum.

Židovec (2002) reported pinching and plant growth retardant effects on plant height and the number of lateral branches of *Lavandula angustifolia* Mill. (lavender). Plants were pinched at the beginning of the growing period and/or treated twice with Alar 85(85% daminozide) sprays at 1000 or 2000 ppm at a 15-day interval. The control treatment was plants with no pinching or daminozide application. The first treatment was pinched plants without daminozide application. The third and fourth combinations were 1000 ppm daminozide, with the third one having no pinch, and the fourth one being pinched. The fifth and sixth combinations were 2000 ppm daminozide, also without and with pinching. Non-pinched plants were taller (27.5%) than pinched plants regardless of the daminozide treatment. Plants treated with a 2000 ppm daminozide solution were shorter than untreated plants. The shortest plants received pinching and application of 1000 ppm daminozide. Plants that were not treated with daminozide had the highest number of lateral branches (6.0% more) while plants treated with1000 ppm daminozide had the fewest lateral branches. Regardless of the daminozide treatment, pinched plants had more lateral branches (2.3%) when compared to non-pinched plants.

In another study, potted rooted cuttings of *Euphobia pulcherrima* (poinsettia) were treated with a single and/or double pinch, Cycocel and B-Nine applications (Karunananda and Peiris, 2010). The first pinch was applied 14 days after transplanting, leaving five to six nodes and allowing the side shoots to develop. The second pinch was applied 14 days after the first pinch, leaving five nodes. Cycocel was applied at a rate of 1,500 ppm 14 days after the second pinch. B-Nine was applied at a rate of 5,000 ppm 7 days after the Cycocel application.

The most stem height control was obtained from a double pinch plus Cycocel and B-Nine or a double pinch plus Cycocel. There was no effect of B-Nine on stem elongation when used in combination with pinching and Cycocel. This was also evident when comparing double pinch plus B-Nine and double pinch only. Single pinch plus Cycocel and B-Nine, single pinch plus Cycocel, and single pinch plus B-nine resulted in similar plant height. Cycocel resulted in the most height reduction when combined with pinching. Cycocel with double pinching reduced plant height more than Cycocel with a single pinch. Cycocel only was no different from the control. However, Cycocel was better at keeping plants at a preferred height than B-Nine. Pinching, Cycocel and B-Nine applied singly did not suppress plant height when compared to the control.

The most plant lateral shoots were produced by a double pinch plus Cycocel and B-Nine or a double pinch plus Cycocel, indicating that there was no effect of B-Nine for increasing shoot number when used in combination with pinching and Cycocel. However, when B-Nine was applied to double pinched plants, the shoot number was higher than double pinch only. This indicated that either Cycocel or B-Nine can contribute to higher shoot number after the double pinch was applied. A double pinch resulted in a higher number of shoots than a single pinch when combined with Cycocel and/or B-Nine. Combining single pinch with Cycocel resulted in more shoots than any individual treatment only and the control.

The objective of the first experiment was to determine the effects of a soft pinch on the offset from propagation before the beginning of NIL and daminozide application on growth, offset number, and flower number of ‘Coronation Gold' achillea. Also, because the optimal timing of beginning NIL after pinching is not known, the objective of the second experiment was to determine the effects of beginning NIL at different times after pinching the offset from propagation of ‘Coronation Gold’ achillea on offset production and flowering.

Materials and Methods

Experiment 1, 2011. Offsets of ‘Coronation Gold’ achillea were removed from stock plants on January 14, 2011 and stuck in 72 cell flats [6.1 cm (2.4 in) depth, 70 cm^3 (4.7 in^3) volume] containing germinating medium (Fafard Super Fine Germinating Mix, Sun Gro Horticulture, Agawam, MA). Offsets were removed by cutting just below the medium surface with a knife. Offsets were rooted under intermittent mist propagation set initially to 5 sec on every 5 min in a shaded (72% light reduction), glass-covered greenhouse with a heating set point of 23.3C (74F) and a ventilation set point of 26.7C (80F) under natural photoperiods. Adjustments for changing environmental conditions were made as needed to maintain turgid foliage. Bottom heat was provided at 29.4C (85F) during propagation using electric heating mats.

Rooted offsets were removed from propagation on February 4, 2011, and were grown in an unshaded, polycarbonate-covered (8 mm twin-wall) greenhouse with a heat set point of

18.3C (65F) and a ventilation set point of 25.5C (78F). One hundred twenty offsets were transplanted into 16 cm (6.3 in) round, plastic pots [11 cm (4.3 in) depth, 1475 cm^3 (90.0 in^3) volume] containing growing medium (Fafard Mix No. 4-P, Sun Gro), and initially spaced pot-to-pot on a greenhouse bench on February 11, 2011 for a first replication of the experiment, and a second group of one hundred twenty offsets from the same propagation were transplanted on February 25, 2011 for a second replication of the experiment.

Throughout the experiment liquid fertilization was applied two out of every three times the plants required water at 150 ppm N using a 20N-4.4P-16.6K (Pro Sol 20-10-20, Frit Industries, Inc., Ozark, AL) fertilizer formulation. Fertilizer applications began when roots appeared on the sides and bottom for each container. Plants were watered or fertilized by hand when the medium appeared dry, but before plants wilted.

At three, five, and seven weeks after potting, twenty randomly selected plants were given a soft pinch on the offset from propagation using small scissors and twenty remained un-pinched. Difficulty was encountered in removing the apical buds because of the close spacing of the nodes in vegetative offsets of ‘Coronation Gold’ achillea. Two to three days after initial pinching, many plants had to be re-pinched because new leaves were emerging, indicating that complete removal of the apical bud had not been accomplished. The 20 plants were exposed to night-interrupted lighting (NIL) from 10:00 p.m. to 2:00 a.m. using a minimum of 10 fc from incandescent lamps (100 W) beginning 1 week after 10 plants in that group were pinched. Plants were spaced on greenhouse benches 22.9 cm (9 in) on center. Five weeks after each pinching treatment, B-Nine was applied at 5000 ppm to half the pinched and non-pinched plants. Temperature and relative humidity were 19.4 C (67 F) and 97.4% on April 8, 27.8C (82 F) and 45% on April 22, and 21.7 C (71 F) and 86% on May 6. Spray treatment was applied uniformly at a rate of 0.2 liter/m^2 (equivalent to 2 qt/100 ft^2) using a pressurized CO_2 sprayer with a flat spray nozzle (XR TeeJet 8003 VK, Bellspray, Inc., Opelousas, LA) calibrated at 138 kPa (20 psi).

Leaf number on the offset from propagation and total offset number per pot were recorded at pinching. At the time of first fully opened inflorescence, the date, first open inflorescence stem length, inflorescence diameter at the widest point, flowering offset number, and non-flowering offset number were recorded. Flowers were considered fully open when all florets on an inflorescence were showing gold color.

An analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.2 (SAS Institute, Cary, NC). The experimental design was a split-plot with pinch and daminozide in the main plot and pinch timing in the subplot. Either initial leaf number or initial offset numbers were used as a covariate in the models. The choice of which covariate to use and its linear or quadratic correlation to a response variable was determined by linear regression and by choosing the model that minimized the AIC (Akaike Information Criteria) fit statistic. Experiment replication was treated as a random variable in the model. 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. Linear and quadratic trends over pinch dates were tested using orthogonal polynomials in CONTRAST statements. Differences in pinch and B-Nine treatments were based on the main effects F-test. All significance were at $\alpha = 0.05$.

Experiment 2, 2011. Methodology similar to the first experiment was used unless otherwise noted. Forty rooted offsets of ‘Coronation Gold’ achillea were potted, 20 for a first replication of the experiment, and a second group of 20 offsets from the same propagation were potted for a second replication of the experiment.

On March 11, 2011, the offset from propagation of all plants were uniformly pinched. Four plants from each replication were moved under NIL 0, 1, 2, 3, or 4 weeks after pinching and provided NIL immediately until the end of the experiment.

Treatments were arranged in a completely randomized design. Experiment replication was treated as a random variable in the model. Linear and quadratic trends over pinch dates were tested using orthogonal polynomials in CONTRAST statements. All significances were at $\alpha = 0.05$.

Results and Discussion

Experiment 1, 2011. The pinch main effect was significant for first open inflorescence diameter, first open inflorescence stem length, flowering offset number, and total offset number (Table 1). At the time of first fully opened flower, pinching decreased flower stem length and inflorescence diameter by 6.4% and 8.9%, respectively, but increased the number of flowering offsets and total offsets number by 33.3% and 9.1%, respectively, when compared to non-pinched plants without affecting days to first open inflorescence or non-flowering offset number. These results agree with reports that pinching increased lateral shoots and decreased plant height in *Rhododendron* 'Molly Ann', 'Paprika Spiced', and 'Travis' (Lohr and Sudkamp, 1989); *Euphorbia pulcherrima* Willd. ex Klotzsch (poinsettia) (Berghage et al., 1989; Karunananda and Peiris, 2010); *Delphinium ×belladonna* ‘Völkerfrieden’(Garner et al., 1997); and *Lavandula angustifolia* Mill. (lavender) (Židovec, 2002).

Daminozide main effects were significant for days to first open inflorescence, first open inflorescence stem length, flowering offset number, and non-flowering offset number. Daminozide treated plants had decreased flower stem length and flowering offset number by 7.9% and 40%, respectively, but increased days to first open inflorescence and number of non-flowering offsets by 6 days and 28.6%, respectively, when compared to non-treated plants without affecting first open inflorescence diameter or total offset number. Daminozide application may have delayed or prevented some shoots from flowering because its application decreased flowering shoot number while increasing non-flowering shoot number. In agreement with Kessler and Keever (2008), daminozide applied at 5100 ppm to ‘Coronation Gold’ achillea reduced stem length by 17.4% without affecting inflorescence diameter, but increased days to first open inflorescence by 2 days when compared to non-treated plants. Also, increasing daminozide rates from 2550 ppm to 7650 ppm resulted in a linear decrease in stem length, and a linear increase in the number of days to first open flower, but offset production was not reported. Burnett et al. (2000) did not find a difference in stem length of ‘Coronation Gold’ achillea in 1998 using daminozide at 5000 ppm, but stem length reductions were found in 1999. Unlike in this study, Burnett et al. (2000) found no difference in number of days to first open inflorescence in either year. Karunananda and Peiris (2010) found a small reduction in stem length of *Euphorbia pulcherrima* using daminozide at 5000 ppm, but when plants received daminozide after pinching, stem length decreases were larger. However, daminozide was less effective than pinching in stem length reduction. Likewise, there was no difference in shoot production by using daminozide. Židovec (2002) found when *Lavandula angustifolia* received Alar 85 (85% daminozide) at 2000 ppm, plant height was reduced, but much less than when pinched. After plants were pinched, there was not much effect of daminozide in reducing plant height. Unlike this study, when plants received daminozide at 1000 ppm or 2000 ppm, the number of lateral shoots decreased.

The number of weeks after potting that pinching was applied main effects were significant for all responses except for first open inflorescence diameter. Increasing the number of weeks after potting that pinching was applied resulted in a quadratic change in the number of days to first open inflorescence with the highest at 5 weeks and the lowest at 7 weeks, a difference of 10 days; a quadratic change in flower stem length with the longest at 5 weeks and the shortest at 3 weeks, a difference of 7.9 cm; a quadratic change in flowering offset number with the highest at 5 and 7 weeks and the lowest at 3 weeks; and a linear increase in the number of non-flowering offsets and in the number of total offsets.

Pinching at 3 weeks resulted in the shortest flower stem lengths, but the lowest number of flowering, non-flowering, and total offsets and an intermediate days to flower; pinching at 5 weeks resulted in the highest number of flowering and total offsets, and intermediate number of non-flowering offsets, but the lowest flower stem length and highest days to flower; pinching at 7 weeks resulted in the highest number of flowering, non-flowering, and total offsets and the lowest days to flower and intermediate flower stem length. Pinching at 7 weeks after potting resulted in the most improvements in plant qualities related to marketability with the fewest drawbacks.

Experiment 2, 2011. Increasing the number of weeks between pinching to begin NIL resulted in a quadratic change in first open flower stem length with the longest at 4 weeks and the shortest at 0 week (Table 2); a quadratic change in flowering offset number with the highest at 3 and 4 weeks and the lowest at 0 week; a quadratic change in total offset number with the highest at 2 weeks and the lowest at 0 week; and a quadratic change in the number of days to first open flower with the highest at 2 weeks and the lowest at 4 weeks.

Stems were the shortest when NIL was started immediately after pinching, but changed little with later start dates. Flowering offset number was highest when NIL was started 3 or 4 weeks after pinching while total offset number was highest when NIL was started 2 weeks after pinching and decreased at 3 and 4 weeks at the same time flowering offset number were highest. This indicates that more offsets flowered by a 3 or 4 weeks start time. Days to first open flower were highest when NIL was started 2 weeks after pinching and lowest at 4 weeks. Starting NIL at 4 weeks after pinching resulted in the fewest days to flower, the highest flowering offset number, and a flower stem length about equal to all other NIL treatments.

In this study, foliar spray of daminozide was effective on ‘Coronation Gold’ achillea in improving plant attributes. Daminozide decreased flower stem length without affecting inflorescence diameter or total offset number, but increased days to flower, all responses that should enhance marketability. However, daminozide may have delayed or prevented some shoots from flowering because its application decreased flowering offset number while increasing non-flowering offset number. Pinching decreased flower stem length nearly as daminozide, but decreased inflorescence diameter. Although pinching increased the number of flowering, non-flowering, and total offsets, it does appear to be minimal economically. Also, it was impractical to pinch the short offsets from propagation because plants were often over-pinched by hand and it was labor intensive.

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Table 1. The effects of pinching the offset from propagation at different times before the beginning night-interrupted lighting (NIL) and daminozide application on offset production and flowering of *Achillea* ×'Coronation Gold'.

Days to first open inflorescence[z]				First open inflorescence diameter (cm)[y]	
Daminozide[x]		Weeks after potting		Pinch	
No	71b[w]	3	74	No	5.6a
Yes	77a	5	78	Yes	5.1b
		7	68		
Sign.[v]			Q***		

First open inflorescence stem length (cm)[u]					
Pinch		Daminozide		Weeks after potting	
No	56.3a	No	56.7a	3	49.9
Yes	52.7b	Yes	52.2b	5	58.0
				7	55.5
Sign.					Q***

Flowering offset number					
Pinch		Daminozide		Weeks after potting	
No	3b	No	5a	3	3
Yes	4a	Yes	3b	5	4
				7	4
Sign.					Q*

Non-flowering offset number[z]				Total offset number[t]			
Daminozide		Weeks after potting		Pinch		Weeks after potting	
No	7b	3	7	No	11b	3	11
Yes	9a	5	8	Yes	12a	5	12
		7	9			7	12
Sign.			L***				L**

[z]Only the daminozide and weeks after potting main effects were significant at $\alpha = 0.05$. Open inflorescence was when all florets on an inflorescence were showing color.

[y]Only the pinch main effect was significant at $\alpha = 0.05$.
[x]Daminozide (B-Nine) was applied once (Yes) as a foliar spray at 5,000 ppm 4 weeks after the beginning of NIL or not applied (No).
[w]Least squares means comparison using the main effect F-test at $\alpha = 0.05$.
[v]Significant (Sign.) linear (L) or quadratic (Q) trends using orthogonal polynomials at $\alpha = 0.05$ (*), 0.01 (**), or 0.001 (***).
[u]Only the pinch, daminozide, and weeks after potting main effects were significant at $\alpha = 0.05$.
[t]Only the pinch and weeks after potting main effects were significant at $\alpha = 0.05$.

Table 2. The effects of beginning night-interrupted lighting (NIL) at different times after pinching the offset from propagation of *Achillea* ×'Coronation Gold' on offset production and flowering.

Weeks after pinching					
0	1	2	3	4	Significance[z]
Days to first open inflorescence after beginning NIL[y]					
68[x]	77	80	70	65	Q**
First open inflorescence stem length (cm)					
49.1	59.9	60.8	58.1	61.0	Q**
Flowering offset number					
2	5	5	6	6	Q**
Total offset number					
8	10	12	11	10	Q*

[z]Significant quadratic (Q) trends using orthogonal polynomials at $\alpha = 0.05$(*) or 0.01 (**).
[y]Open inflorescence was when all florets on an inflorescence were showing color.
[x]Least squares means.

CHAPTER III

Effects of bulking duration and plant growth retardant on growth and flowering of *Achillea* ×'Coronation Gold' and *Coreopsis verticillata* 'Moonbeam'.

Abstract

Studies were conducted to determine the effects of bulking duration and the plant growth retardant, daminozide (B-Nine), on plant size and flowering of greenhouse-grown 'Coronation Gold' achillea (*Achillea* ×'Coronation Gold') and 'Moonbeam' coreopsis (*Coreopsis verticillata* 'Moonbeam'). The first experiment was conducted to determine the effects of 4, 6, 8, or 10 weeks of bulking, following transplanting liners into final containers and prior to the onset of night-interrupted lighting (NIL) on plant size and flowering of 'Coronation Gold' achillea and 'Moonbeam' coreopsis. Liners of 'Coronation Gold' achillea and 'Moonbeam' coreopsis were potted into 15 cm (6 in) and 10 cm (4 in) containers, respectively, on October 14 and December 2, 2010. After bulking, 10 plants of each species were moved under NIL. Increasing bulking duration increased flower and flower bud number of both plants for the early potting date, but only increased flowering of 'Coronation Gold' achillea for the late potting date. There were more flowers and flower buds for the early potting date than the late potting date over all bulking durations for both plants. Treatments in second experiment were the same as in the first experiment except in addition daminozide was applied when half the plants in a bulking duration had begun to elongate. Two foliar applications of daminozide were made at 5000 ppm, 1 week apart to 10 plants each of each species. Daminozide decreased 'Moonbeam' coreopsis plant height at first open flower by 31-49% and decreased 'Coronation Gold' achillea first open flower

stem length by 20-43%, but increased number of days to flower for both species. Daminozide also increased flower and flower bud number of coreopsis by 13% over all bulking durations, but decreased flowering slightly in achillea.

Index words: Thread-leaf coreopsis, yarrow, plant growth regulator.

Species used in this study: ‘Coronation Gold’ achillea (*Achillea filipendulina* Lam. ×*Achillea clypeolata* Sibth. & Sm. ‘Coronation Gold’); ‘Moonbeam’ coreopsis (*Coreopsis verticillata* L. ‘Moonbeam’)

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

Significance to the Nursery Industry

‘Moonbeam’ coreopsis and ‘Coronation Gold’ achillea are popular herbaceous perennials that are widely grown under nursery and greenhouse conditions and have been investigated as possible flowering potted crops for greenhouse production. Numerous references have been made in production literature to the importance of early fall transplanting of herbaceous perennials liners into final containers to allow sufficient time for vegetative growth before plants are exposed to photo-inductive conditions. This increase in the size of the root system and crown is believed to result in a greater number of shoots of sufficient developmental size to respond to photo-inductive photoperiods, thus a larger number of flowers and/or flowering shoots. In these studies, increasing bulking duration increased flowering of both ‘Moonbeam’ coreopsis and ‘Coronation Gold’ achillea for the early fall potting. A longer bulking period also resulted in taller plants whose quality may suffer under the low light conditions present during winter. Daminozide decreased ‘Moonbeam’ coreopsis plant height at first open flower by 31-49% and decreased ‘Coronation Gold’ achillea first open flower stem length by 20-43%. However, differences between the results of this study and earlier studies highlight the impact of differences in environments and possible differences in the stage of development when plant growth retardants are applied.

Introduction

'Moonbeam' coreopsis and 'Coronation Gold' achillea are popular herbaceous perennials that are widely grown under nursery and greenhouse conditions and have been investigated as possible flowering potted crops for greenhouse production. 'Moonbeam' coreopsis is a fast growing, durable herbaceous perennial well adapted to bright, warm areas of the United States, especially where periodic summer drought may occur (Armitage, 1997). It grows 46–61cm (18–24 in) tall in the garden and bears single, light yellow flowers repeatedly throughout the summer and into the fall months in some areas. 'Coronation Gold' achillea is a hybrid cross between *Achillea filipendulina* Lam. and *Achillea clypeolata* Sibth. & Sm. It is probably the best-known garden achillea and is suitable as a garden perennial or cut flower. Landscapers love it because plants are maintenance free (Hamrick, 2003). It is the best achillea for landscaping, as plants get 76 cm (2.5 ft) to 91 cm (3 ft) tall with tight clusters of 7.6 cm (3 in) to 10 cm (4 in) blooms, which are composed of golden yellow florets. Also, it has finely dissected, gray-green, aromatic foliage (Nau, 1996).

Flowering is a complex physiological process controlled by many factors including photoperiod (Thomas and Vince-Prue, 1997). In the floriculture industry, photoperiod is a reliable environmental signal for flower induction that has been artificially manipulated by greenhouse growers to keep plants vegetative or to induce flowering. Plants can be categorized as short-day, long-day or day neutral. A short day plant initiates flowers when the day length is shorter than the critical day length for that species. Day lengths longer than the critical photoperiod result in vegetative growth. A long day plant initiates flowers when the day length is longer than the critical day length for that species. Day lengths shorter than the critical photoperiod result in vegetative growth. Short-day and long-day plants can be further subdivided into qualitative or quantitative photoperiod responses. Qualitative photoperiodic plants require a specific photoperiod for flowering, i.e., flowering does not occur without it. Quantitative photoperiodic plants benefit from a specific photoperiod, i.e., the plants will eventually flower under short days or long days, but flowering is faster or more flowers are produced under the required photoperiod. Day-neutral plants do not respond to photoperiod for flowering.

Under natural short days, night-interrupted lighting (NIL) from 10:00 p.m. to 2:00 a.m. from incandescent lamps providing a minimum 10 ft-c generally is recommended to induce flowering of long-day plants (Armitage, 1996a and 1996b), including the qualitative long-day plants, *Coreopsis verticillata* ‘Moonbeam’ (Iversen and Weiler, 1994), *Coreopsis grandiflora* Hogg ex Sweet ‘Early Sunrise’ (Cameron et al., 1996), and *Achillea millefolium* L. ‘Summer Pastels’ (Zhang et al., 1996). In general, NIL more effectively induced flowering than the same quantity or duration of light added to the end of the photoperiod (Thomas and Vince-Prue, 1997). Durations of NIL longer than 4 hr may not improve flowering: a 7 hr NIL induced flowering similar to that induced by a 4 hr NIL in six species of herbaceous perennials (Hamaker et al., 1996a). In quantitative long-day plants, long days are not required to induce flowering but are beneficial in either hastening the time to flower or increasing the number of flowers (Armitage, 1996a and 1996b). Quantitative long-day herbaceous perennials include *Coreopsis grandiflora* ‘Sunray’ and *Salvia* ×‘Blue Queen’ (Cameron et al., 1996).

‘Moonbeam’ coreopsis (Hamaker et al., 1996b) and ‘Cloth of Gold’ achillea (Cameron et al., 1996) have an obligate requirement for long photoperiods to flower, which is a 14 hr photoperiod or a 4 hr NIL. ‘Coronation Gold’ achillea responds in much the same way. Nausieda et al. (2000) reported that ‘Coronation Gold’ achillea flowered fastest when provided at least a 16 hr photoperiod or 4 hr NIL that also resulted in an increase in the number of lateral shoots in greenhouse production. Keever et al. (2001, 2006) reported application of NIL to ‘Coronation Gold’ achillea and ‘Moonbeam’ coreopsis grown outdoors under nursery conditions accelerated flowering by 2–11 days and 7-36 days and increased flower and flower bud counts by 82-100% and 20-244%, respectively.

Many herbaceous perennials undergo a juvenile phase following seed germination. A period of juvenility was described as a physiologically-based time when a plant is insensitive to conditions that promote floral initiation (Bernier et al., 1981). Many photoperiodic herbaceous species pass through juvenility gradually, characterized by a period of increased sensitivity to day length rather than a total inability to flower, such as *Coreopsis grandiflora* ‘Early Sunrise’ (Damann and Lyons, 1993), and *Gaillardia pulchella* Foug. and *Rudbeckia hirta* L. (Bourke, 1990). Time to flower for these plants decreased as their age at exposure to inductive long-day photoperiods increased. Leaf or node number usually is used to measure plant age because it is more constant than other measurements, such as time (Holdsworth, 1956). Yuan et al. (1997) concluded that the juvenile phase of coreopsis, gaillardia, heuchera and rudbeckia ended when they had approximately 8, 16, 19 and 10 nodes, respectively.

Bulking is a term often used to describe the growth period before a perennial is forced into flower, such as by a photo-inductive photoperiods. It can be used to ensure a plant has passed through the juvenile phase and is mature enough to flower; to build the plant, regardless of juvenility requirements, to a size more suitable for forcing; or to build the root system, allowing the plant to become well established. The increase in the size of the root system is believed to result in a greater number of shoots of sufficient developmental size to respond to photo-inductive photoperiods, possibly resulting in more flowers and/or flowering shoots (Pilon, 2006).

Perennials are bulked under non-flower inducing conditions, keeping them in the vegetative phase. The length of the bulking period varies for each cultivar, but is often 2 to 4 weeks. It is often determined by the initial size of the plant material being bulked and the size of the finishing container. For example, a 72-cell plug for a 1L (1 qt.) container required less bulking time than a 72-cell intended for a 3.8L (1 gal.) container. Pilon (2008) reported that several perennials, including *Aquilegia* spp. (columbine), *Dianthus gratianopolitanus* Vill. (cheddar pink) and *Phlox subulata* L. (creeping phlox), must be potted in early fall to properly bulk them up in the final container so they will have adequate foliage for a full, marketable container, and plants will grow well and be marketable. It was recommended that if growers choose to force plants, such as 'Moonbeam' coreopsis and 'Coronation Gold' achillea, into flower for spring sale, plants must be bulked under short days so that roots can fully developed throughout the pot prior to inducing flowers (Hamrick, 2003).

Rapid growth of plants under greenhouse 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 and 2008).

Plant growth regulators, which are chemical compounds or plant hormones that control growth and development of plants (McAvoy, 1989), can increase or retard plant height, prolong or break bud dormancy, promote rooting, and increase branching and/or flowering (Larson, 1985; McAvoy, 1989). The plant growth regulators that are used to reduce plant height are commonly called plant growth retardants (PGR). PGRs used to control plant height are gibberellin (GA) synthesis inhibitors (Latimer, 2004). The gibberellins are natural plant hormones that cause the elongation of cells in the plant. They are present in the greatest quantities in those tissues that are elongating the most rapidly, usually stems, petioles, and, in some crops, flower inflorescences. The application of PGRs to potted plants can result in shorter, more rigid stems and darker green foliage; characteristics that increase the value of the plant (Gianfagna, 1995). PGRs consist of several older compounds that were introduced to floriculture in the 1960s and 70s like B-Nine (daminozide), Cycocel (chlormequat chloride), and A-Rest (ancymidol). These products are still commonly used in the industry. In the 1980s, a new class of compounds was introduced, the triazoles, including Bonzi (paclobutrazol) and Sumagic (uniconazole). These products are much more potent than the older chemistries.

Burnett et al. (2000a) treated *Coreopsis rosea* Nutt. ‘American Dream’, or pink coreopsis, with four PGRs: B-Nine from 2500 to 7,500 ppm, Cutless from 25 to 150 ppm, Sumagic from 10 to 40 ppm, or Bonzi from 25 to 100 ppm. Application of B-Nine or Sumagic suppressed plant growth by 13-31% at first flower and increased plant quality by 52-67% when compared to controls. Plants also were more compact and had more branches with darker green foliage and more flowers. Times to first flower and to a marketable stage were minimally affected by PGR application, and no phytotoxicity was observed. Bonzi did not control growth or affect flowering of pink coreopsis.

Plants of ‘Moonbeam’ coreopsis received PGRs treatments in two experiments consisting of one application of A-Rest or Bonzi medium drenches at 0, 2, 4, or 6 ppm; B-Nine sprays at 0, 2550, 5100, or 7650 ppm; Bonzi sprays at 0, 12, 24, 36, 48, or 60 ppm or Cutless sprays at 0, 25, 50, 75, 100, 150, or 200 ppm in the first experiment and sprays of B-Nine at 0, 2550, 5100, or 7650 ppm; Bonzi at 0, 60, or 120 ppm; B-Nine/Bonzi combinations at 0, 2550/16, 2550/32, 2550/48, or 2550/64 ppm, Cycocel at 0, 767, 1534, or 2301 ppm; or B-Nine/Cycocel combinations at 0, 1275/1534, 2550/1534, 3825/1534, or 5100/1534 ppm in the second experiment (Kessler and Keever, 2007). In the first experiment, there was a linear decrease in shoot height, growth index, and lateral shoot length with increasing rates of A-Rest and Bonzi drenches and Cutless sprays while B-Nine decreased growth quadratically. Only B-Nine increased the number of days from treatment to flower with increasing rates. Quality ratings increased with increasing rates of A-Rest, B-Nine, and Cutless with the highest ratings found at the two highest rates of B-Nine and Cutless. Bonzi sprays did not affect the parameters measured.

In the second experiment, Cycocel sprays did not affect the parameters measured, but when combined with increasing rates of B-Nine, there was a linear decrease in shoot height, growth index, and lateral shoot length and an increase in the number of days to flower. B-Nine alone resulted in a quadratic change in growth index and lateral shoot length and a linear increase in the number of days to flower, but with no effect on quality rating. The higher rates of Bonzi than were used in the first experiment decreased shoot height and lateral shoot length with no effect on growth index, the number of days to flower, or quality rating. Overall, the best quality ratings and the most compact plants resulted from spray applications of B-Nine at 5100 ppm or 7650 ppm and Cutless at 150 ppm or 200 ppm.

Also, Amling et al. (2005) reported that B-Nine was more effective in controlling plant height of ‘Moonbeam’ coreopsis and ‘Goldsturm’ rudbeckia than Cycocel or B-Nine/Cycocel combinations. B-Nine alone suppressed height of ‘Moonbeam’ coreopsis by 26–52%, in contrast to a 17–41% height suppression when B-Nine was combined with Cycocel. Cycocel alone suppressed height of coreopsis by 6–16%. Also, B-Nine suppressed height of ‘Goldsturm’ rudbeckia by 20–40%.

Latimer (2001, 2003) reported that *Achillea* ×'Moonshine' responded to four applications of B-Nine at 5000 ppm, *Achillea millefolium* L. 'Summer Pastels' responded to four applications of B-Nine at 5000 ppm, and *Achillea millefolium* 'Paprika' responded to multiple applications of B-Nine at 5000 ppm, but details on treatments and methods were not reported. Burnett et al. (2000b) applied B-Nine at 2500, 5000, or 7500 ppm to 'Coronation Gold' achillea in a nursery setting over 2 years. In 1998, B-Nine provided little growth suppression of 'Coronation Gold' achillea; 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, plants of 'Coronation Gold' achillea treated with B-Nine at 0, 2550, 5100, or 7650 ppm; Cycocel at 0, 767, 1534, or 2301 ppm; B-Nine/Cycocel at 0, 1275/1534, 2550/1534, or 3825/1534 ppm; Sumagic at 0, 11, 22, 33, 44, or 55 ppm; Bonzi at 0, 32, 64, 96, 128, or 160 ppm; or Cutless at 0, 40, 80, or 120 ppm as a spray, B-Nine, Cycocel, B-Nine/Cycocel, Sumagic, Bonzi, and Cutless at the highest rate reduced shoot height and growth index by 36 and 26%, 39 and 27%, 61 and 41%, 75 and 52%, 52 and 36%, and 75 and 51%, respectively (Kessler and Keever, 2008). B-Nine, Cycocel, B-Nine/Cycocel, and Sumagic, but not Bonzi or Cutless, increased the number of days to open inflorescence by 3–5 days at the highest rates. Sumagic, Bonzi, and Cutless reduced inflorescence diameter by up to 15, 18, and 14%, respectively, but not B-Nine, Cycocel, or B-Nine/Cycocel. The highest quality ratings of 2.8 to 3.0 were found with B-Nine/Cycocel at 3825/1534 ppm, Sumagic at 22 and 33 ppm, and Bonzi at 64 ppm. The highest B-Nine rate of 7650 ppm reduced shoot height by 36%, but increased time to first open inflorescence by 5 days when compared to controls.

B-Nine inhibits gibberellin synthesis. Similar to prohexadione-Ca, daminozide is a structural mimic of 2- oxoglutaric acid that is required in processes that oxidize GA12-aldehyde into other gibberellins. Daminozide specifically inhibits the process when GA_{20}, an inactive form of GA, is converted to GA_1 (Brown et al., 1997). It is labeled for use on herbaceous perennials under greenhouse and nursery conditions (OHP, Inc., 2011). In general, it is not phytotoxic, and has a short-term effect that seldom results in overstunting of treated plants. Due to the low activity of B-Nine and its lack of soil activity, it is easier to apply consistently than the newer, more potent PGR chemistries. Generally, foliar sprays of 5000 ppm are applied every 7 to 14 days as necessary. Application frequency may need to be increased to weekly for more vigorous cultivars grown outdoors (Latimer, 2001).

The objective of the first experiment was to investigate the effects of four bulking durations, and in the second experiment daminozide applications, following transplanting ‘Coronation Gold’ achillea and ‘Moonbeam’ coreopsis liners into final containers prior to the beginning of NIL on growth and flowering.

Materials and Methods

Experiment 1, 2010. Plugs (72-cell) of ‘Moonbeam’ coreopsis and ‘Coronation Gold’ achillea were transplanted into 10 cm(4 in) and 15 cm(6 in) plastic pots, respectively, containing growing medium (Fafard Mix No. 4-P, Sun Grow Horticulture, Agawam, MA) on October 14, and December 2, 2010. 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 18.3C (65F) and a ventilation set point of 25.5C (78F) under natural photoperiods. Liquid fertilization throughout the experiment was applied based on pour-through soluble salt target rate 1-2.5 $dS*m^{-1}$ 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 first potting date, ten plants of each cultivar were provided NIL by lighting from 10:00 pm to 2:00 am using a minimum of 10 fc from incandescent lamps (60W) until the end of the experiment. Plants were spaced on greenhouse benches 22.9 cm (9 in) on center. At 4, 6, 8, and 10 weeks after the second potting date, ten plants of each cultivar were treated with the same NIL mentioned above. Any flowers present on ‘Moonbeam’ coreopsis were removed at the start of NIL.

Data recorded at the end of each bulking duration were basal shoot number and plant height on coreopsis and offset number on achillea. Data recorded at first fully opened flower were date, flower and flower bud number, plant height of coreopsis and first open flower stem length of achillea, and basal shoot number on coreopsis. Data recorded at five fully opened flowers were date on achillea only. Flowers were considered fully open when ray florets on an inflorescence were fully reflexed on coreopsis and when all florets on an inflorescence were showing color on achillea.

An analysis of variance was performed on all responses using PROC GLIMMIX in SAS version 9.2 (SAS Institute, Cary, NC). The experimental design was a completely randomized design with bulking durations and potting dates in a complete factorial treatment design. 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 dates least squares means were determined using Tukey's test. Linear and quadratic trends over bulking durations were tested using orthogonal polynomials in the CONTRAST statement. All data presented are least squares means. All significances were at $\alpha = 0.05$.

Experiment 2, 2010. This experiment conducted at the same time as the first experiment used methodology similar, unless otherwise noted. Daminozide was applied in two foliar applications of 5000 ppm 1 week apart to 10 plants of each speicies within each bulking duration when half the plants in a bulking duration treatment had begun to elongate. Ten plants in a bulking duration were not treated with daminozide. Spray treatment was applied uniformly at a rate of 0.2 liter/m^2 (equivalent to 2 qt/100 ft^2) using a pressurized CO_2 sprayer with a flat spray nozzle (XR TeeJet 8003 VK, Bellspray, Inc., Opelousas, LA) calibrated at 138 kPa (20 psi).

In addition to the analysis from the first experiment, differences between daminozide least squares means were determined using Tukey's test at $\alpha = 0.05$.

Results and Discussion

Experiment 1, 2010. Coreopsis verticillata 'Moonbeam'. Only the main effect, potting date, was significant for basal shoot number at the end of bulking (Table 1). Basal shoot number at the end of bulking was higher for the October 14 than for the December 2 potting date, but there were no differences in bulking durations. The bulking duration by potting date interactions were significant for all other responses. There was a linear increase in plant height at the end of bulking with increasing bulking duration for the October 14 potting date, but no trend for the December 2 potting date. Plants were also taller at the end of bulking for the October 14 than the December 2 potting date over all bulking durations. Higher basal shoot number and plant height for the October 14 potting date was likely due to higher light intensities and temperatures and longer day lengths in the mid-October to mid-December bulking period than the early December to early February bulking period for the December 2 potting date.

There was a linear increase in basal shoot number at first open flower with increasing bulking duration for the October 14 potting date, but no trend for the December 2 potting date. Plants also had more basal shoots for the October 14 than the December 2 potting date over all bulking durations with larger differences in the longer bulking duration. Higher basal shoot number at first open flower from the October 14 potting date than the December 2 potting date for all bulking durations likely resulted from differences in basal shoot number at the end of bulking. Higher light intensities and temperatures for the October 14 potting date in the mid-October to mid-December bulking period than the early December to early February bulking period for the December 2 potting date may have also contributed to the large differences in basal shoot number at first open flower between the two potting dates. The same patterns of differences were found for flower and flower bud number as for basal shoot number at first open flower. The lowest difference was 55 flowers and flower buds in 4 weeks bulking duration and the largest difference was 149 flowers and flower buds in 10 weeks bulking duration.

There was a quadratic change and a linear decrease in the number of days to first open flower from the beginning of NIL with increasing bulking duration for the October 14 and December 2 potting dates, respectively. Plants from the October 14 potting date flowered from late December to late February while those from the December 2 potting date flowered from late February to late April. There were more days to first open flower in the December 2 than the October 14 potting dates after 4 or 6 weeks bulking, but there were no differences for 8 and 10 weeks bulking. There was a linear increase in plant height at first open flower with increasing bulking duration for the October 14 potting date, but no trend for the December 2 potting date. Plants in bulking for 4 and 6 weeks were shorter in the October 14 than the December 2 potting date, but there were no differences for 8 and 10 weeks bulking. There was very little growth during the bulking period for the December 2 potting date in terms of shoot numbers and plant height at the end of bulking likely a result of low light intensities, shorter day lengths, and lower temperatures than the October 14 potting date. There was only one basal shoot at the end of bulking for the December 2 potting date when compared to four for the October 14 potting date. Reduced growth during the bulking period resulted in more days to first flower and higher plant height at first flower after 4 and 6 weeks bulking. During the later parts of the 8 and 10 weeks bulking periods light intensities and durations were likely more similar in the two potting dates resulting in similar days to first flower and plant height.

Achillea ×'Coronation Gold'. The bulking duration by potting date interactions were significant for all responses (Table 2). There were linear increases in offset number at the end of bulking with increasing bulking duration for both potting dates with 11 and 3 offset increases for the October 14 and December 2 potting dates, respectively. 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 bulking for the October 14 potting date when compared to the December 2 potting date was likely due to higher light intensities and durations, and temperatures during the bulking period.

Likewise, there was a linear increase in flower and flower bud number with increasing bulking duration for both potting dates with a 6 and 2 flower and flower bud number increase for the October 14 and December 2, respectively. Higher flower and flower bud number, particularly after 8 and 10 weeks bulking, likely resulted from the higher offset numbers at the end of bulking.

There was a quadratic change or a linear decrease in the number of days from the beginning of NIL to first open flower with increasing bulking duration for the October 14 and

December 2 potting dates, respectively. The number of days to first open flower was higher for the October 14 than the December 2 potting dates for all bulking durations with 12-25 days differences. Plants from the December 2 potting date flowered from 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 durations, and temperatures in the later potting date. Similar trends were found for number of days from the beginning of NIL to five open flowers (data not shown).

There was a linear decrease in stem length at first open flower for the October 14 potting date, but no trend for the December 2 potting date. Generally, longer stem lengths for the October 14 than the December 2 potting dates, especially after 4 and 6 weeks bulking, were likely due to greater stem elongation from lower light intensities and durations in the mid-January to mid-February period as compared to the mid-February to mid-March period.

Experiment 2, 2010. Only the main effect, potting date, was significant for basal shoot number in *Coreopsis verticillata* 'Moonbeam' at the end of bulking (Table 3). Basal shoot number at the end of bulking was higher for the October 14 than the December 2 potting date, but there were no differences in bulking durations. The bulking duration by potting date interactions was significant for plant height at the end of bulking. There was a linear increase in plant height at the end of bulking with increasing bulking duration for the October 14 potting date, but no trend for the December 2 potting date. Plants were also taller at the end of bulking for the October 14 than the December 2 potting date over all bulking durations. Higher basal shoot number and plant height for the October 14 potting date were likely due to higher light intensities and durations, and temperatures in the mid-October to mid-December bulking period than the early December to early February bulking period for the December 2 potting date.

The bulking duration by potting date interaction was significant for basal shoot number at first open flower. There was a quadratic change in basal shoot number at first open flower with increasing bulking duration for the October 14 potting date with the fewest 7 basal shoots at 6 weeks bulking, but no trend for the December 2 potting date. Plants also had more basal shoots for the October 14 than the December 2 potting date over all bulking durations. Higher basal shoot number at first open flower from the October 14 potting date than the December 2 potting date for all bulking durations likely resulted from differences in basal shoot number at the end of bulking.

There was a bulking duration by potting date interaction and the daminozide main effect was significant for flower and flower bud number. The same patterns of differences in the interaction of bulking duration by potting date were found for flower and flower bud number as for basal shoot number at first open flower. Plants with daminozide applications had 20 more flowers and flower buds than those without.

There were significant bulking duration by potting date, bulking duration by daminozide, and daminozide by potting date interactions for days to first open flower. Days to first open flower increased linearly for the October 14 potting date with increasing bulking durations, but decreased linearly for the December 2 potting date. Plants in bulking for 4 and 6 weeks reached first flower earlier in the October 14 than the December 2 potting date, but reached first flower earlier in the December 2 than the October 14 potting date after 8 and 10 weeks bulking. Days to first open flower were likely fewer after 8 and 10 weeks bulking because of higher light intensities and temperatures and longer day lengths in the mid-March to late April period for the December 2 potting date than the mid-February to late March period for the October 14 potting date. Days to first open flower increased linearly or changed quadratically with the lowest 64 days at 8 weeks bulking duration with increasing bulking duration for the non-treated daminozide or treated daminozide plants, respectively. Days to first open flower were higher for treated daminozide plants than non-treated daminozide plants at all bulking durations. Days to first open flower were higher for both potting dates when plants with daminozide applications than without, however without daminozide applications days to first open flower was higher for the December 2 potting date but the reverse was found with daminozide applications.

There was a bulking duration by potting date by daminozide interaction for plant height at first open flower (Table 4). At both potting dates, application of daminozide resulted in shorter plants than without over all bulking durations. Without daminozide application, plants from the December 2 potting date were taller than those from the October 14 potting date after 4, 6, and 8 weeks bulking, but there was no difference after 10 weeks. With daminozide application, there were no differences in plant height between the two potting dates after 4, 8, and 10 weeks bulking, but a small difference after 6 weeks bulking. Plant height increased linearly by 12% with increasing bulking duration when no daminozide was applied for the October 14 potting date; however the height change was quadratic with daminozide application with the shortest plants resulting from 4 weeks bulking. Plant height changed quadratically with increasing bulking duration when no daminozide was applied for the December 2 potting date with the shortest plants resulting from 10 weeks bulking. A similar trend was found when daminozide was applied, but the shortest plants resulting from 6 weeks bulking.

Overall, results were similar to the first experiment except for daminozide application. Daminozide applications increased flower and flower bud number by 13% over all plants, increased days to first open flower by 21days for the October 14 and by 14 days for the

December 2 potting dates, and over all bulking durations with 1-28 days difference, but suppressed first open flower stem length by 31-49% for both potting dates and over all bulking durations. Kessler and Keever (2007) reported daminozide applied at 5100 ppm suppressed ‘Moonbeam’ coreopsis first open flower stem length by 21%, but increased days to flower by 3 days. Amling (2005) reported daminozide applied at 5000 ppm suppressed ‘Moonbeam’ coreopsis plant height by 38-43% from 1-5 weeks after initial treatment, but increased days to flower by 6 days. However, flower and flower bud number was not reported by these studies.

There was a bulking duration by potting date interaction for offset number in *Achillea* ×‘Coronation Gold’ at the end of bulking (Table 5). Offset number at the end of bulking increased quadratically or linearly by 11 and 4 offsets for the October 14 and December 2 potting dates, respectively. Plants after 6, 8, and 10 weeks bulking had more offset for the October 14 than the December 2 potting dates, but the reverse was found after 4 weeks bulking. 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 6, 8, and 10 weeks bulking for the October 14 potting date when compared to the December 2 potting date was likely due to higher light intensities and temperatures and longer day lengths during the bulking period.

There was a bulking duration by potting date by daminozide interaction for days to first open flower. At both potting dates, application of daminozide resulted in higher number of days to first open flower than without daminozide over all bulking durations except 8 weeks bulking for the October 14 potting date. Regardless of daminozide application, days to first open flower were higher for the October 14 than the December 2 potting date over all bulking durations except no daminozide application and 4 weeks bulking. Days to first open flower changed quadratically with the lowest 61 days at 4 weeks bulking with increasing bulking duration for the October 14 potting date and no daminozide application, but decreased linearly with increasing bulking duration with daminozide application for the October 14 potting date and with and without daminozide application for the December 2 potting date.

There was a bulking duration by potting date by daminozide interaction for flower and flower bud number. At the October 14 potting date, flower and flower bud numbers were lower with daminozide application than without after 8 and 10 weeks bulking, but were not different after 4 and 6 weeks bulking. At the December 2 potting date, flower and flower bud numbers were lower with daminozide application than without after 10 weeks bulking, but were not different after 4, 6 or 8 weeks bulking. Regardless of daminozide application, flower and flower bud number were higher for the October 14 than the December 2 potting date over all bulking durations except with daminozide application and 8 weeks bulking. Flower and flower bud number increased linearly with increasing bulking duration with and without daminozide application for the October 14 potting date and without daminozide application for the December 2 potting date, but the change over bulking duration was quadratic with the highest number 11 at 8 weeks bulking with daminozide application for the December 2 potting date.

There was a bulking duration by potting date by daminozide interaction for first open flower stem length. At the October 14 potting date, plants were shorter with than without daminozide application after 10 weeks of bulking, but there were no differences after 4, 6, or 8 weeks. However at the December 2 potting date, plants were shorter with than without daminozide application over all bulking durations. Without daminozide applications, plants were shorter after 4 and 6 weeks bulking for the October 14 than the December 2 potting dates, there was no difference in potting dates after 8 weeks bulking, and plant height was shorter after 10 weeks bulking for the December 2than the October 2 potting dates. With applications of daminozide, plants were shorter for the December 2 than the October 14 potting dates over all bulking durations. First open flower stem length increased linearly with increasing bulking duration without daminozide applications for the October 14 potting date, changed quadratically with increasing bulking duration with daminozide applications for both potting dates, but was not affected by bulking duration without daminozide applications for the December 2 potting date.

Overall, results were similar to the first experiment except for daminozide application. Daminozide applications increased days to first open flower by 4-17 days for both potting dates and most bulking durations, but decreased flower and flower bud number slightly by 2-3 after the longer bulking durations for both potting dates. Daminozide applications also suppressed first open flower stem length by 20-43% after all bulking durations for the December 2 potting date, but only decreased stem length by 16% after 10 weeks bulking for the October 14 potting date. Kessler and Keever (2008) reported daminozide applied at 5100 ppm suppressed ‘Coronation Gold’ achillea first open flower stem length by 17%, but increased days to flower by 2 days. Burnett et al. (2000b) reported daminozide applied at 5000 ppm suppressed ‘Coronation Gold’ achillea plant height by 16-30 % from 14-70 days after treatment, but increased days to flower by 1 day. However, flower and flower bud number was not reported by these studies.

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Table 1. The effects of bulking duration before the beginning of night-interrupted lighting (NIL) and two potting dates on growth and flowering of *Coreopsis verticillata* 'Moonbeam'.

Basal shoot number at the end of bulking[z]					
10/14/2010	4a[y]				
12/2/2010	1b				
	Bulking duration (weeks)[x]				
Potting date	4	6	8	10	Sign.[w]
	Plant height at the end of bulking (cm)				
10/14/2010	7.9a[v] Oct 14-Nov 11	8.4a Oct 14-Nov 25	5.8a Oct 14-Dec 9	5.8a Oct 14-Dec 23	L***
12/2/2010	4.8b Dec 2-Dec 30	3.9b Dec 2-Jan 13	4.1b Dec 2-Jan 27	4.5b Dec 2-Feb 10	NS
	Basal shoot number at first open flower[u]				
10/14/2010	7a	8a	10a	10a	L***
12/2/2010	4b	3b	3b	3b	NS
	Flower and flower bud number				
10/14/2010	176a	175a	186a	241a	L*
12/2/2010	121b	96b	95b	92b	NS
	Days to first open flower after beginning NIL				
10/14/2010	53b Dec 29-Jan 6[t]	56b Jan 18-Jan 25	61ns Feb 14-Feb 21	56ns Feb 17-Feb 28	Q***
12/2/2010	65a Feb 26-Mar 11	65a Mar 14-Mar 22	61 Mar 25-Apr 6	61 Apr 4-Apr 25	L*
	Plant height at first open flower (cm)				
10/14/2010	53.1b	58.3b	57.0ns	60.4ns	L**
12/2/2010	62.4a	64.8a	62.0	60.3	NS

[z]Only the main effect, potting date, was significant at α = 0.05.
[y]Least squares mean difference using the main effect F-test at α = 0.05.
[x]The bulking duration by potting date interactions were significant at α = 0.05.
[w]Not significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends using orthogonal polynomials at α = 0.05(*), 0.01 (**), or 0.001 (***).
[v]Least squares means comparison in columns (lower case letters) using Tukey's test at α = 0.05.

Date range for bulking in 2010-2011.
[u]Open flower was when ray florets on an inflorescence were fully reflexed.
[t]Date range for first open flower in 2011.

Table 2. The effects of bulking duration before the beginning of night-interrupted lighting (NIL) and two potting dates on growth and flowering of *Achillea* 'Coronation Gold'.

	Bulking duration (weeks)[z]				
Potting date	4	6	8	10	Sign.[y]
	Offset number at the end of bulking				
10/14/2010	3b[x] Oct 14-Nov 11	10ns Oct 14-Nov 25	13a Oct 14-Dec 9	14a Oct 14-Dec 23	L***
12/2/2010	6a Dec 2-Dec 30	9 Dec 2-Jan 13	9b Dec 2-Jan 27	9b Dec 2-Feb 10	L***
	Flower and flower bud number at first open flower				
10/14/2010	9ns	11a	14a	15a	L***
12/2/2010	8	8b	11b	10b	L**
	Days to first open flower after beginning NIL[w]				
10/14/2010	73a Jan 14-31[v]	74a Feb 2-11	76a Feb 2-28	60a Feb 8-Mar 7	Q***
12/2/2010	61b Feb 23-Mar 4	53b Feb 23-Mar 14	51b Mar 10-25	48b Mar 13-Apr 7	L***
	First open flower stem length (cm)[u]				
10/14/2010	59.6a	50.3a	45.2ns	44.8ns	L***
12/2/2010	46.6b	45.6b	42.1	43.0	NS

[z]The bulking duration by potting date interaction was significant for all responses at $\alpha = 0.05$.
[y]Not significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends using orthogonal polynomials at $\alpha = 0.01$ (**) or 0.001 (***).
[x]Least squares means comparison in columns (lower case letters) using Tukey's test at $\alpha = 0.05$, ns = not significant. Date range for bulking in 2010-2011.
[w]Open flower was when all florets on an inflorescence were showing color.
[v]Date range for first open flower in 2011.
[u]First open flower stem length was the average of the longest and shortest flower stems.

Table 3. The effects of two potting dates, bulking duration before the beginning of night-interrupted lighting (NIL), and two applications of daminozide at 5,000 ppm 1 week apart on growth and flowering of *Coreopsis verticillata* ‘Moonbeam’.

	Bulking duration (weeks)						
Pot date	4	6	8	10	Sign.[z]	Basal shoot number at the end of bulking[x]	
	Plant height at the end of bulking (cm)[y]						
10/14/2010	8.1a[w] Oct 14- Nov 11	8.5a Oct 14- Nov 25	5.4a Oct 14- Dec 9	5.4a Oct 14- Dec 23	L***	3a[v]	
12/02/2010	4.8b Dec 2- Dec 30	3.8b Dec 2- Jan 13	3.8b Dec 2- Jan 27	3.8b Dec 2- Feb 10	NS	1b	
	Basal shoot number at first open flower						
10/14/2010	10a	7a	8a	10a	Q**		
12/02/2010	3b	4b	3b	2b	NS		
	Flower and flower bud number[u]					Daminozide	
10/14/2010	180a	163a	224a	305a	Q***	–	+
12/02/2010	130b	117b	142b	84b	NS	158b	178a
						Daminozide	
	Days to first open flower[t]					–	+
10/14/2010	68b Dec 30- Feb 14[r]	62b Jan 2- Feb 21	73a Feb 11- Mar 6	77a Feb 28- Mar 28	L***	60bB[s]	81aA
12/02/2010	74a Feb 28- Apr 1	74a Mar 7- Apr 6	64b Mar 23- Apr 13	67b Apr 4- Apr 28	L***	63aB	77bA
Daminozide							
–	57b	60b	63b	65b	L***		
+	85a	76a	64a	79a	Q**		

[z]Not significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends bulking duration using orthogonal polynomials at $\alpha = 0.01$ (**) or 0.001 (***).
[y]The bulking duration by potting date interaction was significant at $\alpha = 0.05$.
[x]Only the potting date main effect was significant at $\alpha = 0.05$.
[w]Least squares means comparisons potting dates (lower case letters in columns) using Tukey's test at $\alpha = 0.05$.
[v]Least squares means comparisons using the main effect F-test at $\alpha = 0.05$.
[u]The bulking duration by potting date interaction and the daminozide main effect were significant at $\alpha = 0.05$.
[t]The bulking duration by potting date, the bulking duration by daminozide, and the daminozide by potting date interactions were significant at $\alpha = 0.05$.
[s]Least squares means comparisons among potting dates (lower case letters in columns) and plus or minus daminozide (upper case letters in rows) using Tukey's test at $\alpha = 0.05$.
[r]Date range for first open flower in 2011.

Table 4. The effects of two potting dates, bulking duration before the beginning of night-interrupted lighting (NIL), and two applications of daminozide at 5,000 ppm 1 week apart on plant height (cm) at first open flower of *Coreopsis verticillata* 'Moonbeam'.[z]

Potting date	10/14/2010		12/02/2010	
	Daminozide			
Bulking duration (weeks)	–	+	–	+
4	52.0aB[y]	33.3bNS	62.7aA	36.2b
6	56.4aB	38.7bA	63.3aA	32.9bB
8	55.0aB	37.7bNS	66.9aA	34.2b
10	58.2aNS	35.2bNS	59.7a	39.8b
Signficance[x]	L*	Q*	Q*	Q*

[z]The bulking duration by potting date by daminozide interaction was significant at α = 0.05.
[y]Least squares means comparisons between plus or minus daminozide (lower case letters in rows) and between the two potting dates (upper case letters in rows) using Tukey's test at α = 0.05. NS = not significant.
[x]Significant linear (L) or quadratic (Q) trends over bulking duration using orthogonal polynomials at α = 0.05 (*).

Table 5. The effects of two potting dates, bulking duration before the beginning of night-interrupted lighting (NIL), and two applications of daminozide at 5,000 ppm 1 week apart on growth and flowering of *Achillea* ×'Coronation Gold'.

Offset number at the end of bulking[z]					
	Bulking duration (weeks)				
Potting date[y]	4	6	8	10	Sign.[x]
Oct 14	3b[w] Oct 14- Nov11	12a Oct 14- Nov 25	13a Oct 14- Dec 9	14a Oct 14- Dec 23	Q***
Dec 2	6a Dec 2- Dec 30	8b Dec 2- Jan 13	9b Dec 2- Jan 27	10b Dec 2- Feb 10	L***

	Days to first open flower[v]				Flower and flower bud number			
Potting date	Oct 14		Dec 2		Oct 14		Dec 2	
Bulking duration (weeks)	Daminozide				Daminozide			
	–	+	–	+	–	+	–	+
4	61bNS[u]	86aA	59b	65aB	9nsA	10A	7nsB	8B
6	76bA	84aA	56bB	60aB	11nsA	11A	8nsB	8B
8	78nsA	80A	57bB	63aB	14aA	11bNS	10nsB	11
10	68bA	78aA	50bB	56aB	15aA	13bA	11aB	9bB
Sign.	Q***	L*	L***	L***	L***	L***	L***	Q*

	First open flower stem length (cm)			
Potting date	Oct 14		Dec 2	
Bulking duration (weeks)	Daminozide			
	–	+	–	+
4	47.9nsB	51.6A	60.3aA	34.4bB
6	51.3nsB	52.6A	59.1aA	47.4bB
8	61.7nsNS	61.1A	61.7a	43.8bB
10	62.6aA	52.3bA	58.1aB	38.7bB

Sign.	L***	Q***	NS	Q***

[z]The bulking duration by potting date interaction was significant at α = 0.05.
[y]Plants were potted on 10/14/2010 and 12/02/2010.
[x]Not significant (NS) or significant (Sign.) linear (L) or quadratic (Q) trends over weeks after potting using orthogonal polynomials at α = 0.05 (*), 0.01 (**) or 0.001 (***).
[w]Least squares means comparisons among potting dates using Tukey's test at α = 0.05.
[v]The bulking duration by potting date by daminozide interaction was significant at α = 0.05.
[u]Least squares means comparisons between plus or minus daminozide (lower case letters) and between potting dates 1 and 2 (upper case letters) using Tukey's test at α = 0.05. NS (ns) = not significant.

CHAPTER IV

Final Discussion

This research evaluated the effects of pinching, bulking duration, and plant growth retardant on growth and flowering of *Coreopsis verticillata* 'Moonbeam' and *Achillea* ×'Coronation Gold'.

Results from chapter 2 evaluated pinching and plant growth retardant, daminozide, effects on growth and flowering of 'Coronation Gold' achillea. The pinch main effect was significant for first open inflorescence diameter, first open inflorescence stem length, flowering offset number, and total offset number. At the time of first fully opened flower, pinching decreased flower stem length and inflorescence diameter by 6.4% and 8.9%, respectively, but increased the number of flowering offsets and total offsets number by 33.3% and 9.1%, respectively, when compared to non-pinched plants without affecting days to first open inflorescence or non-flowering offset number. These results agree with reports that pinching increased lateral shoots and decreased plant height in *Rhododendron* 'Molly Ann', 'Paprika Spiced', and 'Travis' (Lohr and Sudkamp, 1989); *Euphorbia pulcherrima* Willd. ex Klotzsch (poinsettia) (Berghage et al., 1989; Karunananda and Peiris, 2010); *Delphinium ×belladonna* 'Völkerfrieden'(Garner et al., 1997); and *Lavandula angustifolia* Mill. (lavender) (Židovec, 2002).

The daminozide main effect was significant for days to first open inflorescence, first open inflorescence stem length, flowering offset number, and non-flowering offset number. Daminozide treated plants decreased flower stem length and flowering offset number by 7.9% and 40%, respectively, but increased days to first open inflorescence and number of non-flowering offsets by 6 days and 28.6%, respectively, when compared to non-treated plants without affecting first open inflorescence diameter or total offset number. Daminozide application may have delayed or prevented some shoots from flowering because its application decreased flowering shoot number while increasing non-flowering shoot number. In agreement with Kessler and Keever (2008), daminozide applied at 5100 ppm to ‘Coronation Gold’ achillea suppressed stem length by 17.4% without affecting inflorescence diameter, but increased days to first open inflorescence by 2 days when compared to non-treated plants. Also, increasing daminozide rates from 2550 ppm to 7650 ppm resulted in a linear decrease in stem length, and a linear increase in the number of days to first open flower, but offset production was not reported. Burnett et al. (2000) did not find a difference in stem length of ‘Coronation Gold’ achillea in 1998 using daminozide at 5000 ppm, but stem length reductions were found in 1999. Unlike in this study, Burnett et al. (2000) found no difference in number of days to first open inflorescence in either year. Karunananda and Peiris (2010) found a small reduction in stem length of *Euphorbia pulcherrima* using daminozide at 5000 ppm, but when plants received daminozide after pinching, stem length decreases were larger. However, daminozide was less effective than pinching in stem length reduction. Likewise, there was no difference in shoot production by using daminozide. Židovec (2002) found when *Lavandula angustifolia* received Alar 85 (85% daminozide) at 2000 ppm, plant height was reduced, but much less than when pinched. After plants were pinched, there was not much effect of daminozide in reducing plant height. Unlike this study, when plants received daminozide at 1000 ppm or 2000 ppm, the number of lateral shoots decreased.

Chapter 3 evaluated two potting dates, bulking duration, and plant growth retardant, daminozide, effects on growth and flowering of 'Moonbeam' Coreopsis and 'Coronation Gold' achillea.

Coreopsis verticillata 'Moonbeam'. Higher basal shoot number at first open flower from the October 14 potting date than the December 2 potting date for all bulking durations likely resulted from differences in basal shoot number at the end of bulking. Higher light intensities and durations, and temperatures for the October 14 potting date in the mid-October to mid-December bulking period than the early December to early February bulking period for the December 2 potting date may have also contributed to the large differences in basal shoot number at first open flower between the two potting dates. The same patterns of differences were found for flower and flower bud number as for basal shoot number at first open flower.

Daminozide applications increased flower and flower bud number by 13% over all plants, increased days to first open flower by 21days for the October 14 and by 14 days for the December 2 potting dates, and over all bulking durations with 1-28 days difference, but suppressed first open flower stem length by 31-49% for both potting dates and over all bulking durations. Kessler and Keever (2007) reported daminozide applied at 5100 ppm suppressed 'Moonbeam' coreopsis first open flower stem length by 21%, but increased days to flower by 3 days. Amling et al. (2005) reported daminozide applied at 5000 ppm suppressed 'Moonbeam' coreopsis plant height by 38-43% from 1-5 weeks after initial treatment, but increased days to flower by 6 days. However, flower and flower bud number was not reported by these studies.

Achillea ×'Coronation Gold'. The higher offset number at the end of 8 and 10 weeks bulking for the October 14 potting date when compared to the December 2 potting date was likely due to higher light intensities and durations, and temperatures during the bulking period.

Likewise, there was a linear increase in flower and flower bud number with increasing bulking duration for both potting dates with a 6 and 2 flower and flower bud number increase for the October 14 and December 2, respectively. Higher flower and flower bud number, particularly after 8 and 10 weeks bulking, likely resulted from the higher offset numbers at the end of bulking.

Daminozide applications increased days to first open flower by 4-17 days for both potting dates and most bulking durations, but decreased flower and flower bud number slightly by 2-3 after the longer bulking durations for both potting dates. Daminozide applications also suppressed first open flower stem length by 20-43% after all bulking durations for the December 2 potting date, but only decreased stem length by 16% after 10 weeks bulking for the October 14 potting date. Kessler and Keever (2008) reported daminozide applied at 5100 ppm suppressed 'Coronation Gold' achillea first open flower stem length by 17%, but increased days to flower by 2 days. Burnett et al. (2000) reported daminozide applied at 5000 ppm suppressed 'Coronation Gold' achillea plant height by 16-30 % from 14-70 days after treatment, but increased days to flower by 1 day. However, flower and flower bud number was not reported by these studies.

In these studies, although pinching increased the number of flowering, non-flowering, and total offsets, it does appear to be minimal economically. Pinching decreased flower stem length nearly as daminozide application, but decreased inflorescence diameter. Also, it was impractical to pinch the short offsets from propagation because plants were often over-pinched by hand and it was labor intensive. Increasing bulking durations resulted in a greater number of shoots of sufficient developmental size to respond to photo-inductive photoperiods, thus resulting in more flowers and/or flowering shoots. Daminozide application suppressed plant height growth for both cultivars; increased flowering of coreopsis, but had no effective impact on achillea, and increased time to first open flower for both cultivars. The applications of pinching, bulking duration, and daminozide are beneficial for compactness and more flowers, characteristics that increase the value of the plants.

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