Effects of Apogee on Growth and Whole-canopy Photosynthesis in Spur ‘Delicious’ Apple Trees

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Abstract. This study examines the effect of multiple spray applications of Apogee on shoot growth and whole-canopy photosynthesis (WCPn) rate in young, bearing apple trees. Apogee increased fruit numbers and reduced shoot growth and inconsistently reduced leaf area but the reduction in photosynthetic area did not result in reduced WCPn or a detrimental effect on the fruit number:fruit size relationship. Since WCPn was not affected by Apogee treatment, it suggests a greater photosynthetic efficiency of leaves on Apogee treated trees due to reduced shading. The use of Apogee for canopy management may produce a side-effect of increasing fruit set, which may be managed through a crop thinning program.

Vegetative growth management is essential in a modern high density apple planting. Rootstocks are commonly used to dwarf the tree and facilitate higher density plantings. However, dwarfing rootstocks may not suppress shoot extension growth, eventually resulting in overcrowding in the orchard. Excess vegetative growth and overcrowding reduce light and spray penetration into the canopy, which lowers fruit quality and may reduce return bloom. In addition pruning costs are increased by excessive vegetative growth.

Plant growth regulators have been used since the 1960s (Miller, 1988) to inhibit shoot elongation and help maintain apple tree canopies within the allotted planting space. Daminozide and ethephon are two growth regulators that received widespread attention and use for growth control in apple during the late 1960s and 1970s (Miller, 1988). Later work with triazole derivatives, such as paclobutrazol and uniconazole, demonstrated that these compounds had strong vegetative growth controlling properties in apple (Davis and Curry, 1991). Registration for the use of daminozide to control vegetative growth in apple was cancelled in 1989 because of controversial health issues and environmental concerns. Ethephon has not been registered for growth control in bearing apple trees because of problems with fruit abscission (Byers, 1993). Paclobutrazol was not registered for tree fruit crops in the U.S. because of concerns related to the strong residual nature of the compound.

Recently, a new class of compounds, the acyloxyhexanediones, has been shown to exhibit strong shoot growth inhibiting properties (Rademacher et al., 1992). Like daminozide and paclobutrazol, these compounds inhibit the production of growth-active gibberellins, thereby retarding shoot elongation. Prohexadione-calcium (Apogee), a compound in this class, has demonstrated excellent vegetative growth controlling properties in a number of plant species (Miyazawa et al., 1991) including apple (Evans et al., 1999; Greene, 1999; Miller, 2002; Unrath, 1999). Growth response to foliar sprays of Apogee is visible in apple shoots about 20 to 14 d after application (Greene, 1999), with response to a single application lasting about 3 to 4 weeks (Evans et al., 1999; Miller, 2002; Unrath, 1999). In addition to retarding shoot growth in apple, Apogee has been reported to increase fruit set (Greene, 1999; Unrath, 1999).

Fig. 1. Whole canopy photosynthesis chambers enclosing apple trees.
and 721 g·ha\(^{-1}\) in 2001. Actual spray volume on net Pn of greenhouse grown apple trees when sprayed at rates up to 4000 mg·L\(^{-1}\) did not have an effect on the Pn or transpiration of leaves of potted apple trees grown in a growth chamber. Wieland and Wample (1985) reported no significant effect on Pn rate or transpiration rate from soil or stem applied paclobutrazol. In contrast, Huang et al. (1995) increased spur leaf Pn in 4-year-old ‘Aki Fuji’ apple trees grown in the field and treated with soil-applied paclobutrazol. They partially attributed the increased Pn to higher light levels within the canopy that resulted from the growth retarding effect of paclobutrazol. Working with uniconazole, another triazole growth regulator, Steffens and Zimmerman (1992) reported a seasonal increase in Pn of young tissue-cultured and budded apple trees. There were no differences in Pn between foliar spray applications or soil trunk drench treatments. Apogee treatments increased whole canopy photosynthesis (WCPn) of 2-year-old potted apple trees in 2 of 3 years and increased water use efficiency in 1 of 3 years (Sabatini et al., 2003).

The objectives of this study were to examine the effect of multiple spray applications of Apogee on shoot growth and WCPn rate in young bearing apple trees.

**Materials and Methods**

Five-year-old ‘Washington Spur Delicious’ apple trees on Malling Merton111 (MM.111) rootstock growing at the Appalachian Fruit Research Station, Kearneysville, W.Va., were used for this study. Trees were planted at a spacing of 3 × 5.5 m, trained to a central leader form, and had cropped the season prior to the initiation of experimental treatments. Ten trees of uniform size and vigor were selected for treatment in 2000. Five trees were sprayed with Apogee 27.5 DF (BASF Corp., Research Triangle Park, N.C.) and five trees were designated as nonsprayed controls. Three Apogee sprays were applied beginning at petal fall and repeated at 2-week intervals. Treatments were repeated on a different set of trees in 2001. Sprays were applied at a rate of 45 g Apogee 27.5 DF per 100 L (equivalent to a 6 oz./100 gal label rate) of spray solution adjusted for tree-row-volume of canopy per hectare (Sutton and Unrath, 1984). The calculated tree-row-volume for the test block was 1309 L·ha\(^{-1}\) (140 gal/acre) in 2000 and 1785 L·ha\(^{-1}\) (191 gal/acre) in 2001. The final Apogee rate applied was 593 g·ha\(^{-1}\) in 2000 and 721 g·ha\(^{-1}\) in 2001. Actual spray volume applied to achieve wetness ranged from 704 to 728 L·ha\(^{-1}\). A nonionic adjuvant, Regulaid (Kalo Inc., Overland Park, Kan.), was included in all sprays at 0.125% (v/v) along with spray grade ammonium sulfate (AMS) as a water conditioner on a weight basis equivalent to the weight of Apogee in the spray solution. The final spray solution was adjusted to pH 6.3 with distilled white vinegar (National Fruit Products Co., Winchester, Va.). Sprays were applied with a backpack hand-wand sprayer to wet the tree to the point of spray drip. Treatments were arranged in a randomized complete block design with five replications.

Trees were harvested when most fruit reached a commercially acceptable stage of maturity and stored at a temperature of 1 to 3 °C for analysis. A single fruit was harvested from each tree for determination of fruit number per tree, yield per tree, yield per hectare (Williams, 1972) following treatment and Hoffman, 1965; Williams, 1972) and (Batjer et al., 1964; Byers, 1993; Edgerton and Hoffman, 1965; Williams, 1972) following treatment with various growth retardants suggest a possible increase in apple tree Pn. However, data supporting this thesis are limited. Halfacre et al. (1968) reported reduced Pn when potted 1-year-old apple trees were sprayed with 1000 to 4000 mg·L\(^{-1}\) daminozide. Dozier and Barden (1971) found no effect of ethephon on net Pn of greenhouse grown apple trees when sprayed at rates up to 4000 mg·L\(^{-1}\), Ferree and Hall (1978) reported that a single application of daminozide (2000 mg·L\(^{-1}\) or ethephon (1000 mg·L\(^{-1}\) had no effect on the Pn or transpiration of leaves of potted apple trees grown in a growth chamber. Wieland and Wample (1985) reported no significant effect on Pn rate or transpiration rate from soil or stem applied paclobutrazol. In contrast, Huang et al. (1995) increased spur leaf Pn in 4-year-old ‘Aki Fuji’ apple trees grown in the field and treated with soil-applied paclobutrazol. They partially attributed the increased Pn to higher light levels within the canopy that resulted from the growth retarding effect of paclobutrazol. Working with uniconazole, another triazole growth regulator, Steffens and Zimmerman (1992) reported a seasonal increase in Pn of young tissue-cultured and budded apple trees. There were no differences in Pn between foliar spray applications or soil trunk drench treatments. Apogee treatments increased whole canopy photosynthesis (WCPn) of 2-year-old potted apple trees in 2 of 3 years and increased water use efficiency in 1 of 3 years (Sabatini et al., 2003).

The objectives of this study were to examine the effect of multiple spray applications of Apogee on shoot growth and WCPn rate in young bearing apple trees.
Table 1. Effect of three prohexadione-calcium (Apogee) sprays on shoot growth, total yield, and fruit size in 5-year-old ‘Washington Spur Delicious’/MM.111 apple trees.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Terminal shoot length (cm)</th>
<th>Number fruit per tree</th>
<th>Yield per tree (kg)</th>
<th>Mean fruit diam (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000 Control</td>
<td>50.0 ab</td>
<td>151 b</td>
<td>33.1 a</td>
<td>8.2 a</td>
</tr>
<tr>
<td>Apogee</td>
<td>24.6 b</td>
<td>221 a</td>
<td>40.1 b</td>
<td>7.6 b</td>
</tr>
<tr>
<td>2001 Control</td>
<td>66.6 a</td>
<td>146 b</td>
<td>31.9 b</td>
<td>7.6 a</td>
</tr>
<tr>
<td>Apogee</td>
<td>21.4 b</td>
<td>336 a</td>
<td>56.2 a</td>
<td>7.0 b</td>
</tr>
</tbody>
</table>

*Initial spray applied at petal fall; two successive sprays applied at 2-week intervals. Apogee sprays applied at 45 g·L⁻¹ based on canopy tree-row-volume.

*Mean separation within columns based on Duncan’s new multiple range test $P \leq 0.05$.

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Table 2. Effect of three prohexadione-calcium (Apogee) sprays on shoot leaf area and leaf area index in 5-year-old ‘Washington Spur Delicious’/MM.111 apple trees.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Leaf area (m²)</th>
<th>Leaf area index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apogee</td>
<td>14.9</td>
<td>3.35</td>
</tr>
<tr>
<td>Control</td>
<td>22.6*</td>
<td>2.60</td>
</tr>
</tbody>
</table>

*Apogee 27.5 DF foliar sprays (45 g/100 L adjusted for tree-row-volume) applied at petal fall and repeated twice at 2-week intervals.

*Mean separation within columns based on $t$ test, $P \leq 0.05$.

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Fig. 2. Effect of three prohexadione-calcium (Apogee) sprays on the relationship of average fruit weight and fruit number in 5-year-old ‘Washington Spur Delicious’/MM.111 apple trees during three growing seasons.

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Results and Discussion

Three Apogee sprays, beginning at petal fall and continued at 2-week intervals, reduced shoot growth in ‘Washington Spur Delicious’/MM.111 apple trees in each of the two years (Table 1). Apogee sprays reduced terminal shoot extension growth an average of 59% compared to controls. This level of shoot growth suppression is similar to that reported previously by Miller (2002) and by others (Byers and Yoder, 1999; Greene, 1999). Treatment (Table 1), however the relationship of fruit number to fruit size indicated no significant difference due to Apogee treatment (Fig. 2) in 2000, 2001 or 2002 when no treatments were applied. Greene (1999) reported that fruit set on ‘McIntosh’ increased and fruit size was also decreased by Apogee treatment in 2001. Apogee had no effect on the length to diameter (L/D) fruit ratio or percent surface color (data not shown).

Apogee application reduced leaf area and leaf area index in 2000 but not in 2001 (Table 2). Our findings agree with Guak et al. (2001), who reported a reduction in total leaf area of potted M.26 trees from a single Apogee spray applied at 250 mg L⁻¹. Specific leaf weight was not affected by the treatments (12.0 and 12.5 mg·cm⁻² for treated and control, respectively, pooled for both years), indicating no morphological effect on leaf structure. These specific leaf weight results are in contrast to those reported by Guak et al. (2001), however, their studies utilized potted M.26 liners and not field grown trees as in this study. Apogee increased water use efficiency (WUE) one of 3 years in potted apples (Sabantini et al. 2003). In the present study, isotopic carbon discrimination indicated no treatment effect (19.46 vs. 19.60 for treated and control respectively, pooled for both years). Isotopic carbon discrimination results indicate that the Apogee treatments did not affect WUE of the trees. Isotopic discrimination of carbon-13 is a method of measuring season-long WUE. Isotopic discrimination of carbon-13 has been correlated with WUE in field crops (Ehleringer, 1993; Farquhar and Richards, 1984; Farquhar et al., 1989) and tree fruit crops (Bongi et al., 1994; Glenn et al., 2000, 2003).

Most studies designed to examine the effect of vegetative growth retardants on fruit tree Pn have used potted trees grown in a greenhouse (Dozier and Barden, 1971; Ferree and Hall, 1978; Guak et al., 2001; Sabatini et al. 2003; Wieland and Wample, 1985). In addition, these greenhouse studies and reported field studies (DeJong and Doyle, 1984; Sabatini et al. 2003; Steffens and Zimmerman, 1992) have focused on single leaf Pn measurements rather than WCp measurements. In the present study, whole canopy Pn measurements of field grown apple trees indicated that there were no differences (P ≤ 0.05) between treatments, years, or time of day (Fig. 3). Despite the reduced leaf area and LAI of Apogee treated trees in 2000, no effect on WCpN was measured at any time. In several of the previous studies with growth retardants [ethephon (Dozier and Barden, 1971) and paclobutrazol (DeJong and Doyle, 1984; Steffens and Zimmerman, 1992)], when the authors found no effect on Pn rate, they suggested that WCpN may be reduced because of the reduction in leaf area. In the present study, we did not find this prediction to be true. Overall, the partitioning of carbon to fruit was not altered by the Apogee treatments.
(Fig. 2) and there was no carry-over effect on fruit size in 2002.

In conclusion, the application of Apogee increased fruit set, as demonstrated by others, which may increase the potential for alternate bearing. Our results indicate that the effect of Apogee on fruit size is likely due to increased fruit number, not a direct effect of the Apogee spray. Apogee consistently reduced shoot growth and inconsistently reduced leaf area, but the reduction in photosynthetic area did not result in reduced WCPn or a detrimental effect on the fruit number:fruit size relationship. Since WCPn was not affected when leaf area was reduced by Apogee treatment, it suggests a greater photosynthetic efficiency of leaves on Apogee treated trees due to reduced shading. The use of Apogee for canopy management may have a side-effect of increasing fruit set, which may be managed through a crop thinning program.

**Literature Cited**


Fig. 3. Relationship of whole canopy carbon assimilation to intercepted photosynthetically active radiation (PAR) for 5-year-old field-grown ‘Washington Spur Delicious’/MM111 apple trees treated in 2000 and 2001.