Influence of Aminoethoxyvinylglycine on Pecan Fruit Retention

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Abstract. Insufficient fruit retention limits profitability of certain pecan [*Carya illinoensis* (Wangenh.) K. Koch] cultivars. The present study examined efficacy of aminoethoxyvinylglycine (formulated as ReTain[®]; Valent BioSciences, Libertyville, IL), a natural ethylene inhibitor, for increasing crop-load through increased fruit retention in pecan trees grown at three distinct locations within the U.S. pecan belt. Several years of field studies found that timely postpollination ReTain[®] sprays [132 mg·L⁻¹ a.i. (11.7 oz./acre)] to canopies could increase fruit retention of ‘Desirable’ and increase crop yield by 16% to 38% in trees carrying a “moderate to heavy” crop. ReTain[®] did not detectably increase fruit retention on trees carrying a “light” crop-load. The ReTain[®]-associated increase in yield of “heavy” crop-load trees did not necessarily decrease subsequent year yield. ReTain[®] appears to offer commercial potential as a crop-load management tool for ‘Desirable’ through regulation of Stage II drop (i.e., June-drop), but may not be efficacious for all cultivars.

Insufficient crop-load, as a result of excessive fruit-drop, can reduce pecan orchard profitability. Four fruit-drops typically occur between flowering and fruit ripening (Hamilton, 1942; Romberg and Smith, 1946; Sparks and Heath, 1972; Woodruff et al., 1928). The vast majority of dropped flowers/fruit occur early season as “Stage I” (bloom-drop) or “Stage II” drops (the first postpollination drop, i.e., June-drop) (Sparks and Madden, 1985). Stage I drop appears to be largely the result of poor pistillate flower development because of insufficient access to carbohydrate and/or mineral nutrient reserves (Yates and Sparks, 1994). Stage II drop is complete within ≈3 to 5 weeks (usually by mid-June) after stigmas of pistillate flowers lose receptivity and fruit begin an elongation growth phase before rapid fruit enlargement. The causes of Stage II drop are uncertain and likely varied, but Stage II drop sometimes appears as a result of abnormal ovule development (i.e., integument, parenchymal nucellus cell layers, embryo sac)

(Yates and Sparks, 1994). Evidence indicates that “Stage II,” “Stage III,” and “Stage IV” drops are often associated with absence of zygotes, deficiencies in cellular endosperm, and retarded embryo development, respectively (Yates and Sparks, 1995). Although Stage II drop can be beneficial in excessively heavy crop-load years, it is typically considered undesirable by orchard managers, especially when crop-load is low to moderate. The magnitude of drop varies among cultivars and years but is usually substantial for ‘Desirable’, a major commercial cultivar producing large nut meats.

Regardless of the cause of Stage II drop, evidence implicates an important role for ethylene in that fruit exposure to ethylene during this period can cause drop (Kays et al., 1975; Wood, 1983). This ethylene link raises the possibility that timely use of chemical agents affecting either ethylene biosynthesis or ethylene receptors offer a means of regulating Stage II drop. Aminoethoxyvinylglycine (AVG) {[S]-trans-2-amino-4-(2-aminoethoxy)-3-butenic acid hydrochloride, a naturally occurring plant growth regulator produced by fermentation; formulated as ReTain[®] at 15% a.i.; EPA Reg. No. 73049-45; Valent BioSciences, Libertyville, IL}, is a commercially available product capable of preventing or reducing ethylene biosynthesis in certain plants by competitively inhibiting 1-aminocyclopropanecarboxylate synthase (i.e.,

ACC synthase; Yu et al., 1979), which is the rate-limiting enzyme in what appears to be the primary ethylene anabolic pathway of higher plants. Therefore, ReTain[®] affects ethylene-associated plant processes such as fruit abscission, maturation, and ripening through inhibition of ACC synthase. ReTain[®] has subsequently proven useful as a horticultural tool for managing crop-load or fruit ripening in certain walnut (*Juglans regia* L. cv. Serr) (Anderson et al., 2006; Beede and Polito, 2003; Buchner et al., 2006) and tree-fruit cultivars (Belding and Lokaj, 2002; Bregoli et al., 2002; Byers, 1997, 1998a, 1998b; Clayton et al., 2000; Dal-Cin et al., 2008; Greene, 2002, 2005, 2006; Greene and Schupp, 2004; Hayama et al., 2008; Hu et al., 2002; Rath et al., 2006; Salazar-García et al., 2006; Schupp and Greene, 2004; Shafer et al., 1997; Webster et al., 2006; Williams, 1980).

ReTain[®]’s success with other tree crops indicates potential for managing crop-load in pecan. We report that appropriate ReTain[®] use can indeed increase fruit retention in ‘Desirable’ by reducing Stage II drop without necessarily reducing the return crop; therefore, ReTain[®] merits commercial-level evaluation as a horticultural tool for regulating crop-load in commercial orchards of certain pecan cultivars.

Materials and Methods

Characteristics of test orchards. Study orchards were located at three different geographic locations of the United States—i.e., Georgia, Texas, and New Mexico—covering humid to arid climatic zones. The Georgia site is lat. 32°39′54″ N, long. 83°44′31″ W at an elevation of ≈+156 m (509 ft) with a fine, kaolinitic, thermic Typic Kandiodult soil (FoA). The New Mexico site is lat. 32°13′30″ N, long. 106°45′13″ W at an elevation of ≈+1176 m (3858 ft) with a mixed, thermic Typic Torripsamment soil (Br) soil. The Texas site is lat. 29°32′48″ N, long. 97°03′06″ W at an elevation of ≈+86 m (283 ft) with a Branyon clay type, 0 to 1% slope (BrA) soil.

The test scion cultivar in Georgia was ‘Desirable’ grafted to an open-pollinated ‘Elliott’ rootstock with test trees being ≈25 years old. The test scion cultivars in the New Mexico study were ‘Western’ (syn. ‘Western Schley’) and ‘Ideal’ (known locally in New Mexico as ‘Bradley’) grafted to an open-pollinated ‘Riverside’ rootstock with trees being ≈30 years old. In Texas, trees were 28 years old ‘Desirable’ grafted to an unknown rootstock. Experimental trees were spaced 9.1 m × 18.2 m (30 × 60 ft) in Georgia, at 10.7 × 10.7 m (35 × 35 ft) in New Mexico, and at 15 × 15 m (50 × 50 feet) in Texas. The Georgia site has a freeze-free growing period of ≈240 d with annual precipitation of ≈1.17 m (46 inches); the New Mexico site has a freeze-free growing period of ≈212 d with average annual precipitation of ≈0.23 m (9 inches); and the Texas site has a freeze-free growing period of ≈267 d

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with average annual precipitation of ≈ 1.14 m (45 inches).

Experimental trees at each geographic location were managed as commercial orchards according to the Georgia (Hudson et al., 2007), New Mexico (New Mexico State University Cooperative Extension Service, 2009), or Texas (Texas Agricultural Extension Service, 2007) Extension Services guidelines for pests, fertilizers, and so on, respectively. Georgia trees received subsurface drip irrigation with drip emitters rising to the soil surface at 1-m intervals to supplement tree water needs. Parallel irrigation lines run the length of tree rows positioned ≈ 1.2 m on either side of tree trunks. Drip emitters delivered water at $3.78 \text{ L}\cdot\text{h}^{-1}$ for ≈ 8 to $12 \text{ h}\cdot\text{d}^{-1}$, depending on water needs, throughout the growing season. Irrigation lines were within a herbicide strip maintained in a bare state using glyphosate (Monsanto, St. Louis, MO). Trees received annual broadcast applications of nitrogen (N), potassium (K), phosphorous (P), magnesium, calcium, and magnesium as needed, based on previous July leaf analysis, at principal leaf development growth Stage "11" (Finn et al., 2007). Canopies also received foliar sprays of zinc sulfate (Zn), as needed, during canopy expansion (growth Stage 11 to 17) each spring. Fertilizer application rates were determined based on July-sampled leaf analysis from the previous season. Orchard management included routine foliar sprays of pesticides to control pecan scab disease and various arthropod pests as prescribed by the Georgia Extension Service recommendations for commercial orchards (Hudson et al., 2007). Pest management practices produced nuts with little or no pecan scab damage and little or no fruit-drop or fruit damage by arthropod pests.

The Texas trees were irrigated using surface irrigation at 10- to 20-d intervals, depending on rainfall and tree needs. On each irrigation date, the orchard received ≈ 200 mm (8 inches) of water during a 24-h period. Trees were fertilized with N, P, K, Zn, and sulfur early May, early June, and mid-July based on July-sampled leaf analysis from the previous season and did not exhibit evidence of nutrient stress. Pest management was such that there was no damage to fruit by arthropod or disease pests.

The New Mexico trees grew in flood-irrigated, laser-leveled basins with each irrigation event delivering 7.6 to 10.2 cm (3 to 4 inches) of water so as to sufficiently wet the soil to a depth of ≈ 1 m. Irrigations were scheduled at 10- to 20-d intervals depending on rainfall and tree needs. Trees received annual broadcast applications of N, P, and K. Micronutrients, including Zn, manganese, iron, copper, and nickel, were applied foliarly each spring. Fertilizer application rates were determined based on July-sampled leaf concentrations from the previous season. Timely application of glyphosate ensured a weed-free orchard floor. Timely application of insecticides ensured that pecan nut casebearer (*Acrobasis nuxvorella* Neunzig) and

other arthropod pest populations were minimal such that they did not influence fruit-drop. No fungicide was used because foliar and fruit diseases are not a concern for pecan in the arid southwestern United States. Pest management was such that there was no damage to fruit by arthropod pests.

Study 1: Effect of spray concentration of ReTain® on fruit retention. This experiment evaluated whether foliar sprays of branches and floral clusters of 'Desirable' trees with ReTain® increases fruit retention. This was done in Georgia in 2005, after preliminary studies in 2003, using major limbs with treatments applied twice through foliar sprays. The crop-load of test trees was moderate ($\approx 50\%$ of shoots fruiting). The first application was ≈ 2 weeks before staminate flower maturity (i.e., pollination) and the second ≈ 1 week after conclusion of stigma receptivity (i.e., after full bloom). ReTain® was applied using a handgun sprayer delivering droplets similar to that of air-blast sprayers used in pecan management. Treated limbs (greater than 12 cm diameter with at least 25 flowering shoots) were uniformly sprayed until leaf drip, ensuring thorough coverage of flowers and fruit. Twenty-five flower clusters were assessed for number of florets per cluster before spraying and again during early July after completion of Stage I and Stage II fruit-drops but before onset of Stage III drop.

The hypothesis was tested using two separate studies, each with ReTain® and unsprayed treatments. The first study assessed ReTain® at a spray concentration of $250 \text{ mg}\cdot\text{L}^{-1}$ a.i. (equivalent to 22.3 oz/acre), whereas the second study assessed ReTain® at $500 \text{ mg}\cdot\text{L}^{-1}$ a.i. (equivalent to 44.6 oz/acre). These concentrations are substantially greater than those typically used for late-season fruit retention of tree-fruit crops (i.e., roughly $132 \text{ mg}\cdot\text{L}^{-1}$ a.i.) and were applied to assess both efficacy and phytotoxicity. A nonionic surfactant (Biosurf; Lonza, Allendale, NJ), was added at $0.53 \text{ mL}\cdot\text{L}^{-1}$ in all ReTain® treatments. The experimental design for each of the two studies had two treatments structured as randomized complete blocks (RCB; with single trees as blocks) and single major limbs as experimental units ($n = 10$ per experiment). Treatment limbs were selected from the lower one-third of the canopy and adjacent to each other on the southern exposed canopy but with a buffer limb between treatment limbs. Measured parameters were number of prespray pistillate flowers per cluster and number of fruit present per cluster in mid-July. These data from 25 fruit clusters were used to calculate percentage drop in each experimental unit. Treatments in this, and in all subsequent studies, were inspected for phytotoxicity. Statistical analysis was by two-way analysis of variance (ANOVA) at $P \leq 0.05$.

Study 2: Effect of ReTain® on retention as a function of treatment relative to flowering stage. This study tests the ability of a single application of ReTain® to increase fruit retention depending on application time and crop-load. In Georgia, the experimental pro-

tolocol was as in previously described Study 1. Single trees served as replicates, and major limbs served as treatment experimental units. There were five treatments: nontreated versus ReTain® (at $132 \text{ mg}\cdot\text{L}^{-1}$ a.i./L) applied at ≈ 7 d prebloom, at 10% bloom, at 100% bloom, and 7 d postbloom. Percentage bloom is based on the approximate percentage of stigmas that had become receptive to pollen (i.e., pollen sticking to surface exudates). All ReTain® treatments included a nonionic surfactant (Silwet L-77, an organosilicone surfactant; Helena Chemical Co., Memphis, TN) at 0.025% v/v. The first experiment used 'Desirable' trees with a "light crop" (≈ 300 to $700 \text{ kg}\cdot\text{ha}^{-1}$ of in-shell nuts; $\approx 10\%$ to 30% of shoots bearing flowers). The second experiment used 'Desirable' trees in a separate orchard at the same Georgia location with a "moderate crop" (greater than ≈ 1000 to $1300 \text{ kg}\cdot\text{ha}^{-1}$ in-shell nuts; $\approx 50\%$ of shoots bearing flowers). The design of each experiment consisted of five treatments to major limbs structured as a randomized complete block consisting of five single-tree blocks ($n = 25$ per experiment). Measured parameters were number of prespray pistillate flowers per cluster and number of immature fruit per cluster in late June; data used to calculate percentage drop (or retention) was based on a mean of 25 fruit clusters per experimental unit. After arcsine transformation of percentages, statistical analysis was by two-way ANOVA at $P \leq 0.05$. Mean separation was by Tukey's honestly significant difference (HSD) using SAS software (SAS Institute Inc., Cary, NC).

In New Mexico, the experiment was conducted in 2006. Like with the Georgia experiment, single trees served as replicates, and major limbs served as treatment experimental units. The orchard was in the "off" season of its biennial bearing cycle in 2006 and each of the trees possessed a light crop. For 'Western', limbs on 10 trees received one of four treatments: nontreated versus ReTain® (at $132 \text{ mg}\cdot\text{L}^{-1}$ a.i.) applied (using a backpack sprayer to runoff) at $\approx 10\%$ bloom (26 Apr.), $\approx 90\%$ bloom (1 May), and ≈ 7 d postbloom (12 May). For 'Ideal', limbs on three trees received one of three treatments: nontreated versus ReTain® (at $132 \text{ mg}\cdot\text{L}^{-1}$ a.i.) applied (using a backpack sprayer to runoff) at $\approx 10\%$ bloom (1 May) and postbloom (12 May). All ReTain® treatments included a nonionic surfactant (Agri-Dex; Helena Chemical Co., Collierville, TN). Shoots were spaced apart enough to prevent drift and cross-contamination during treatment application. In July, the number of persistent fruit and the number of fruit (or pistillate flower) drop scars were counted on 30 terminals per experimental unit for the 'Western' cultivar and 45 terminals per experimental unit for the 'Ideal' cultivar. Analysis of variance was performed on arcsine transformed fruit set data and mean separation was by Tukey's HSD at $P \leq 0.05$ using SAS proc GLM (SAS Institute Inc.).

The Texas experiment used single-tree replicates. Five branches, similar in bloom

load, diameter, and size, were selected in the lower one-third of the canopies of 10 single-tree blocks. Shoots were spaced apart enough to prevent drift and cross-contamination during treatment application. Treatment application ($132 \text{ mg}\cdot\text{L}^{-1}$ a.i.) was done using a backpack sprayer to runoff. All treatments included a nonionic surfactant (Baron™; Estes Inc., Wichita Falls, TX) at 0.05% v/v. Treatments were randomized within the five branches and included an untreated control and ReTain® applications at four developmental stages: prebloom (i.e., between early pollen shed and stigma receptivity stages), 10% bloom, 100% bloom, and postbloom. In 2006 (“off” year), applications were done on 15, 25, and 29 Apr. and 6 May for prebloom, 10% bloom, 100% bloom, and postbloom, respectively. Applications were always made between 0630 and 0730 HR (solar time) with air temperature ranging between 18.6 and 24.5 °C and relative humidity (RH) between 84.5% and 90.8% . In 2007 (“on” year), treatment application was repeated using the same branches used in 2006. Applications were done on 19 Apr., 4, 9, and 15 May, for prebloom, 10% bloom, 100% bloom, and postbloom, respectively. Air temperature was 18.0 to 23.3 °C and RH between 76% and 93.4% . Measured parameters were number of prespray pistillate flowers per cluster and number of immature fruit per cluster in early July (after completion of Stage II drop); these data were used to calculate percentage drop (or retention) based on a mean of 25 fruit clusters per experimental unit (branch). The experimental design was a RCB design with 10 single-tree blocks. After arcsine transformation of percentages, data were subjected to ANOVA and means were separated using Fisher’s least significance difference at $P \leq 0.05$ using SAS software (SAS Institute Inc.).

Study 3: Comparison of the effects of a single versus double application of ReTain® on fruit retention. This study, conducted in Georgia, tested whether number of ReTain® applications influences fruit retention. The experimental protocol is as described in Study 1. Single trees served as a replication unit, and major limbs served as experimental units for treatments with buffer limbs between treated limbs. There were three treatments: nontreated versus ReTain® (at $132 \text{ mg}\cdot\text{L}^{-1}$ a.i.) applied either once at ≈ 3 d after termination of stigma receptivity or twice (at 3 d and again 14 d later). All ReTain® treatments included a nonionic surfactant (Silwet L-77; Helena Chemical Co., Memphis, TN) at 0.025% v/v. The ‘Desirable’ trees had a “heavy crop” (in-shell nuts greater than $\approx 2000 \text{ kg}\cdot\text{ha}^{-1}$; greater than 75% of shoots bearing fruit). The experimental design consisted of three treatments to major limbs structured as a RCB consisting of eight single-tree blocks ($n = 24$). Measured parameters were number of prespray pistillate flowers per cluster and number of immature fruit per cluster in early July (after completion of Stage II drop); and these data were used to calculate percentage or retention based on a mean of 25 fruit clusters per

experimental unit. Statistical analysis was by two-way ANOVA at $P \leq 0.05$ with mean separation by Tukey’s HSD.

Study 4: Effect of postpollination ReTain® applications on fruit retention of trees with a light crop. The efficacy of ReTain® for increasing fruit retention on trees possessing a “light” crop-load (less than 30% of shoots bearing fruit), conducted in Georgia, was assessed as described in Study 3 except that application was at one of two concentrations (i.e., 66 or $132 \text{ mg}\cdot\text{L}^{-1}$ a.i.) and at either of three application frequencies (i.e., once, twice, or three times). The first application was 7 d postbloom, whereas the second and third applications were at 21 and 35 d postbloom, respectively. The experimental design consisted of six treatments to major limbs structured as a RCB consisting of eight single-tree blocks ($n = 48$). Measured parameters were number of prespray immature flowers per cluster and number of immature fruit per cluster in early July (after completion of Stage II drop); and these data were used to calculate percentage drop (or retention) based on a mean of 25 fruit clusters per experimental unit. Statistical analysis was by two-way ANOVA at $P \leq 0.10$.

Study 5: Effect of postpollination ReTain® applications on nut yield during an ‘on’ year and in the subsequent ‘off’ year. This study at Byron, GA, tested whether two postreceptivity applications of ReTain® increase fruit retention and nut yield. The study also assessed impact of previous season ReTain® use in a “heavy crop-load” (greater than 70% of shoots bearing) year on subsequent “off” (less than 40% of shoots bearing) season crop yield. Trees received ReTain® through an air-blast sprayer delivering $934 \text{ L}\cdot\text{ha}^{-1}$ (100 gal/acre). ReTain® was applied to the entire tree canopy at $132 \text{ mg}\cdot\text{L}^{-1}$ a.i. with a nonionic surfactant (Silwet L-77; Helena Chemical Co., Memphis, TN) at $0.50 \text{ mL}\cdot\text{L}^{-1}$. The second treatment was a nonsprayed control. ReTain® was applied twice with the first being 7 d after the end of stigma receptivity and the second 14 d after the first application. The experimental design consisted of two treatments structured as a RCBk, with eight blocks comprised of six trees per experimental unit ($n = 16$, using 96 trees). Measured parameters were in-shell nut yield and percent kernel. Statistical analysis was by two-way ANOVA at $P \leq 0.05$.

The influence of ReTain® on crop retention during the “on” year investigated in-shell yield and percent kernel from the same trees after the second growing season posttreatment. Statistical analysis was by two-way ANOVA at $P \leq 0.05$.

Results

Study 1: Effect of spray concentration of ReTain® on fruit retention. The potential for increasing fruit retention by pecan trees using ReTain® is apparent when used at a relatively high concentration of 250 or $500 \text{ mg}\cdot\text{L}^{-1}$ a.i. (Fig. 1). ReTain® at either spray concentration substantially reduced fruit-drop of ‘De-

sirable’ trees when applied twice with the first application ≈ 14 d before flowering and the second ≈ 7 d postreceptivity (Fig. 1). ReTain®, at $250 \text{ mg}\cdot\text{L}^{-1}$ a.i., increased retention over the nontreated control (67% for ReTain® versus 49% for the nontreated control) by 37% ; the $500 \text{ mg}\cdot\text{L}^{-1}$ a.i. treatment also increased retention over the nontreated control (63% for ReTain® versus 46% for the nontreated control) by 37% ; thus, maximum fruit retention of ‘Desirable’ pecan is attainable using a ReTain® concentration of $\approx 250 \text{ mg}\cdot\text{L}^{-1}$ a.i. ReTain® at either concentration substantially increased fruit retention and demonstrates potential for use on pecan as has been observed for certain walnut cultivars (Anderson et al., 2006; Beede and Polito, 2003; Buchner et al., 2006). The fruit retention of nontreated fruit clusters was $\approx 45\%$ to 50% , a bit higher than the 30% to 40% fruit retention more commonly observed in many commercial orchards. There was no evidence of phytotoxicity at the lower treatment concentration, but $500 \text{ mg}\cdot\text{L}^{-1}$ a.i. caused chlorosis at margins of leaflets, thus bracketing the upper concentration limit as being between ≈ 250 and $500 \text{ mg}\cdot\text{L}^{-1}$ a.i. Although the two experiments were not statistically comparable, the results indicate that there is no added benefit from using a much higher concentration than the relatively high concentration necessary for improving fruit retention.

Study 2: Effect of ReTain® on set as a function of treatment relative to flowering stage. ReTain®’s efficacy appears to vary with crop-load. In light crop trees, use of ReTain® at $132 \text{ mg}\cdot\text{L}^{-1}$ a.i. failed to increase fruit retention in both Georgia (‘Desirable’; Table 1) and New Mexico [‘Western’ and ‘Ideal’ (data excluded as a result of nonsignificant differences among treatments within each cultivar—average retention for ‘Western’ was $\approx 90\%$ and $\approx 60\%$ for ‘Ideal’)]. However, ReTain® use on trees with a moderate crop-load in Georgia (‘Desirable’; Table 1) and Texas (‘Desirable’; Table 2) did increase fruit retention with amount of increase varying with time of application relative to bloom date. Under conditions of this study, in the Georgia and Texas trials, ReTain® was most efficacious when applied ≈ 7 d after completion of stigma receptivity. In Texas, the prebloom application was also effective, but only in the “off” year. Overall, it appears that within the period studied, the later the application of ReTain®, the greater the potential for increasing fruit retention. It is unknown how efficacy varies when ReTain® is used during the latter phase of the Stage II drop stage. An associated study assessing fruit retention found that drop occurs ≈ 5 to 7 d after fruit receive drop-inducing damage (Wood and Reilly, 1999; unpublished data); thus, fruit appear to require ≈ 1 week from the induction of an abscission-inducing signal until actual drop.

In the Texas trial, there were no differences among treatments in the number of pistillate flowers/cluster in either year (Table 2). In 2006, clusters had an average of 2.8 pistillate flowers/cluster. In 2006, Stage II drop caused approximately one fruit/cluster to fall off, and

Fig. 1. Influence of foliar sprays of ReTain® on fruit retention of ‘Desirable’ pecan trees supporting a moderate crop-load (i.e., ≈50% of shoots bearing fruit). Treatments were nontreated controls and ReTain® at either 250 or 500 mg·L⁻¹ a.i. ReTain® applied twice to runoff with the first application being ≈14 d before bloom (i.e., pollination or receptivity) and the second application ≈7 d after conclusion of stigma receptivity. Two different experiments were used to test efficacy of these two ReTain® concentrations. Fruit retention was assessed in mid-July after completion of Stage I (bloom-drop) and Stage II drop (June-drop). Treatment effects assessed by analysis of variance with means followed by different letters within each concentration class being different at $P \leq 0.05$.

Table 1. Influence of ReTain® on fruit retention by ‘Desirable’ pecan trees grown in Byron, GA, in 2005.^z

Treatment	Fruit retention	
	Light crop (%)	Moderate crop (%)
Nontreated control	59 a ^y	46 b
ReTain® at 7 d prebloom	60 a	52 ab
ReTain® at 10% bloom	54 a	52 ab
ReTain® at 100% bloom	58 a	57 ab
ReTain® at 7 d postbloom	59 a	62 a

^zA single application of ReTain® at 132 mg·L⁻¹ a.i. was sprayed on tree shoots at one of several stages of bloom (i.e., stigma receptivity). Tests were done on trees of two crop-load classes—i.e., trees possessed a “light” (≈10% to 30% of terminals bearing flowers) or a “moderate” (≈50% of terminals bearing flowers) fruit crop.

^yMeans followed by the same letter are not significantly different at $P \leq 0.05$ by Tukey’s honestly significant difference.

differences among treatments were observed (Table 2). Number of set fruits/cluster in pre- and postbloom-treated branches was greater, although differences were very small (0.2 fruit/cluster) than in control and the 10% bloom application. Return bloom in 2007 was unaffected by ReTain® application in 2006. In 2007, fruit retention was greater than in the previous year, because each cluster had an average of three pistillate flowers. The

greater return bloom, combined with greater fruit retention (on average 0.5 pistillate flowers or fruit abscised from each cluster), led to increased yield in 2007. Like in 2006, differences were observed among ReTain® treatments, but only the postbloom applications resulted in greater fruit retention.

Study 3: Comparison of the effects of a single versus double application of ReTain® on fruit retention. ReTain® increased fruit retention by 22% in heavy crop-load trees as a consequence of either a single or double postbloom application when applied at a spray concentration of 132 mg·L⁻¹ a.i. (Fig. 2); hence, one application 3 d after stigma receptivity is adequate to improve percent fruit retention. The 45% fruit retention exhibited by the nontreated control was higher than is often observed for heavy crop-load ‘Desirable’ trees.

Study 4: Effect of postpollination ReTain® applications on fruit retention of trees with a light crop. Fruit retention of ‘Desirable’ trees, possessing a light crop-load, was not increased when treated with ReTain® at 66 or 132 mg·L⁻¹ a.i. regardless of number of applications (data not included as a result of lack of statistical differences). Fruit retention of the control and treatments was ≈60% to 68%, which is much higher than is normally for ‘Desirable’ trees possessing heavy crop-loads. Because fruit-drop on “light” crop-

load trees is much more significant to orchard managers than is drop from “heavy” crop-load trees, this apparent lack of ReTain® efficacy on “light” crop-load trees is a major limitation in the commercial potential for ReTain® in commercial pecan production.

Study 5: Effect of postpollination ReTain® applications on nut yield during an ‘on’ year and in the subsequent year. Treatment of “on” ‘Desirable’ trees, with two postreceptivity air-blast sprays of ReTain®, increased nut yield the year of application (Table 3). This in-shell yield increase was 38% (i.e., 46.3 kg/tree for nonsprayed trees versus 64 kg/tree for ReTain®-treated trees). ReTain® treatment also increased nutmeat, or kernel, yield by 16.3% over the nontreated control (i.e., 22.7 kg/tree versus 26.4 kg/tree) during the year of treatment but did not detectably influence in-shell nut weight or percentage of kernel mass per nut. It is especially noteworthy that the ReTain®-associated yield increase showed no evidence of decreasing yield or quality characteristics in the crop year after initial treatment when trees were in their “off” fruiting phase (Table 3). Thus, the standard notion that increasing crop-load in an “on” phase year proportionally decreases crop-load in the next “off” phase year is not always valid, although it might be true in “on” phase years when trees have an exceedingly heavy crop-load. The “on” phase ‘Desirable’ trees in this study yielded ≈1536 kg·ha⁻¹ of in-shell nuts, thus indicating that the yield threshold leading to subsequent season yield loss is likely greater than 1536 kg·ha⁻¹.

Discussion

As has been observed for certain cultivars of walnut (Anderson et al., 2006; Beede and Polito, 2003; Buchner et al., 2006), avocado (Salazar-Garcia et al., 2006), and grape (Hu et al., 2002), timely ReTain® application to canopies increases fruit retention in ‘Desirable’ pecan. The ability of ReTain®, or AVG, to influence Stage II fruit-drop in pecan is consistent with the evidence that ethylene plays a key role in the abortion of developing fruit as has been previously implicated by others (Kays et al., 1975; Wood, 1983). The fact that ReTain®-treated fruit continued to develop and ripen, possessing fully developed kernels, indicates that a portion of the fruit abortion occurring in certain ‘Desirable’ orchards, possessing “moderate to heavy” crop-load, is either the result of ReTain® blocking fruit aborting physiological stress factors from triggering drop or somehow ensures continued development of otherwise impaired zygotic tissues. ‘Desirable’ typically exhibits relatively mild alternate-bearing intensities in commercial orchards (Conner and Worley, 2000), which is attributed to a major Stage II drop of developing fruit (commonly referred to as self-thinning). Although the magnitude of Stage II drop in ‘Desirable’ may indeed be a primary factor influencing alternate bearing intensity and desirability as a commercial cultivar, the

Table 2. Number of flowers and retained fruit per cluster, counted on 25 clusters per branch, of ‘Desirable’ pecan trees grown in Komensky, TX, and treated with ReTain® in 2006 and 2007.^z

Treatment	2006			2007		
	Flowers/ cluster	Set fruit/cluster	Fruit retention (%)	Flowers/ cluster	Set fruit/cluster	Fruit retention (%)
Nontreated	2.8 a ^y	1.7 b	60 c	3.1 a	2.4 b	78 a
Prebloom	2.8 a	1.9 a	64 ab	3.0 a	2.4 b	80 a
10% bloom	2.7 a	1.7 b	63 bc	2.9 a	2.2 b	75 a
100% bloom	2.7 a	1.8 ab	65 abc	3.1 a	2.5 ab	78 a
Postbloom	2.8 a	1.9 a	67 a	3.1 a	2.9 a	77 a

^zFruit retention reflects the percentage of the initial fruit set remaining after Stage II drop and ReTain® application.

^yMeans followed by the same letter are not significantly different at $P \leq 0.05$ by Fisher’s least significant difference honestly significant difference.

Fig. 2. Influence of either one or two applications of ReTain® on fruit retention of ‘Desirable’ pecan with a heavy crop-load (greater than 75% of shoots bearing fruit) when applied 3 d after the end of stigma receptivity. The second application was 14 d after the first. Means followed by different letters are statistically different using Tukey’s honestly significant difference at $P \leq 0.05$.

observation of substantial return yield the year after ReTain® treatment, at least as great as the nontreated control, is evidence that self-thinning of ‘Desirable’ trees is often excessive. Thus, in certain cases, increasing

fruit retention with ReTain® can increase yields without triggering severe alternate bearing. However, this is not likely to be true in all cases.

ReTain® (at 132 mg·L⁻¹ a.i.) was initially tested in 2003 for efficacy regarding fruit retention in ‘Desirable’ trees with a “light” crop-load, but efficacy was not detected. Again, in the current study, ReTain® (at 132 mg·L⁻¹ a.i.) did not increase fruit retention in Georgia on ‘Desirable’ trees with a “light” crop-load (Table 1) or New Mexico on ‘Western’ and ‘Ideal’ trees with a “light” crop-load (data not presented). Thus, ReTain® is least effective for increasing pecan fruit retention when the potential financial incentive is greatest for commercial pecan producers, i.e., in years when pistillate flower numbers are low. Furthermore, the lack of efficacy of ReTain® for increasing fruit retention on pecan trees with low crop-load indicates that ReTain® does not possess potential as a tool that pecan producers can readily use to mitigate biennial bearing intensity of orchards.

Our data indicate that future ReTain® trials on different pecan cultivars, or even other crops, should consider the possibility of a “ReTain® × crop-load” interaction to avoid mistakenly concluding that the product is nonefficacious or to identify crop-load situations in which use is cost-effective. The apparent lack of efficacy in “light” crop-load trees, although there is efficacious activity in “moderate” to “heavy” crop-load trees, indicates that there are likely at least two different Stage II drop-inducing factors interacting with crop-load. It is therefore postu-

lated that Stage II fruit-drop in “light” crop ‘Desirable’ trees can be dominated by non-physiological stress factors (e.g., problems with development of the zygote involving the integument, parenchymal nucleellus cell layers, or embryo sac), whereas drop in “moderate to heavy” crop trees can be dominated by one or more physiological stressors. This apparent “stress-drop” interaction merits further research to include approaches addressing the potential for managing stressors through cultural practices rather than totally relying on use of commercial plant growth regulators.

In summary, treatment of the expanding pecan canopy with ReTain® at 132 mg·L⁻¹ a.i. can substantially increase fruit retention of ‘Desirable’ trees possessing moderate, or greater, crop-loads. Efficacy appears greatest when applied within ≈1 week after conclusion of pistillate flower receptivity. This early-season retention of fruit translates into a roughly equivalent percentage increase in harvested yield. Efficacy for increasing fruit retention appears to vary depending on crop-load and time of application relative to fruit development. Efforts to optimize efficacy might focus on identifying the fruit-load threshold in which use will not increase crop retention, how this threshold varies among the important commercial cultivars, and how it interacts with tree stress. Efficacy of ReTain® on ‘Western’ and ‘Ideal’, two important cultivars of arid regions, remains problematic, hence requiring more testing to assess efficacy as a function of crop-load. In conclusion, depending on the cost of application versus economic returns, ReTain® may offer commercial potential for increasing yields of ‘Desirable’ pecan trees in certain situations and merits further evaluation on other cultivars.

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Table 3. Influence of two postpollination applications of ReTain® at 132 mg·L⁻¹ a.i. (11.7 oz/acre) on yield characteristics of ‘Desirable’ pecan grown in Byron, GA.^z

Treatment	In-shell yield (kg/tree)	In-shell nut wt (g/nut)	Kernel (%)	Kernel yield (kg/tree)
<i>‘On’ year</i>				
Nontreated control	46.3 b ^x	8.3 a	49 a	22.7 b
ReTain [®]	64.0 a	8.5 a	49 a	26.4 a
<i>‘Off’ year</i>				
Nontreated control	26.3 a	8.4 a	54 a	14.1 a
ReTain [®]	29.0 a	8.8 a	55 a	16.0 a

^zReTain® was applied using an air-blast sprayer 7 d after stigma desiccation and again 14 d later. Application was in a heavy “on” (greater than 70% of shoots bearing) year. Crop characteristics were also assessed the second year, a moderately “off” (less than 40% of shoots bearing) year, after ReTain® treatment the previous year, to assess side effects of a heavier crop on subsequent year yield.

^yA heavy “on” year is one with an in-shell yield of greater than ≈2000 kg·ha⁻¹. Conversely, the moderate “off” year is an in-shell yield of 1000 to 1300 kg·ha⁻¹.

^xYield parameter means within a column and within years are different by analysis of variance at $P \leq 0.05$ when the two means are followed by different letters.

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