graphic survey. Ann. Missouri Bot. Garden 54:103–137.
15. Schmidt, D.R. 1971. Comparative yields and composition of eight tropical leafy vegetables grown at two soil fertility levels. Agron. J. 63:546–550.
16. Schmidt, D.R., H.A. MacDonald, F.E. Brockman. 1971. Oxalate and nitrate contents of four tropical leafy vegetables grown at two soil fertility levels. Agron. J. 63:559–561.
17. Stafford, W.L., J.S. Mugerwa, and R. Bwabye. 1976. Effects of method of cooking, application of nitrogen fertilizer and maturity on certain nutrients in the leaves of *Amaranthus hybridus* subspecies hybridus (Green Head). Plant Foods for Man 2:7–13.
18. Thomas, R.L., R.W. Sheard, and J.R. Moyer. 1967. Comparison of conventional and automated procedures for nitrogen, phosphorus, and potassium analysis of plant material using a single digestion. Agron. J. 59:240–243.
19. Watt, B.K. and A.L. Merrill. 1963. Composition of Foods. USDA Agr. Hdbk. 8.

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Paclobutrazol Suppresses Vegetative Growth of Large Pecan Trees

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Abstract. **The desirability of controlling growth of large pecan [*Carya illinoensis* (Wangenh.) C. Koch] trees prompted the evaluation of paclobutrazol (PBZ) for growth suppression. PBZ was applied to 75-year-old 'Stuart' pecan trees via trunk injection (rates of 0, 50, 100, and 200 mg·cm^{-1} trunk diameter) or as a spray to the orchard floor (rates of 0, 19, 38 and 76 g/tree). Terminal-shoot growth and leaf area were reduced during 4 years after treatment in both studies. In-shell nut yield was reduced the third and fourth years after PBZ injection, but was increased the second year after soil application. PBZ can reduce terminal-shoot growth in large trees, but higher doses may produce a decline of nut production. Chemical name used: β-[(4-chlorophenyl)methyl]-α-(1,1-dimethylethyl)-1*H*-1,2,4-triazole-1-ethanol (paclobutrazol).**

Tree size control is a major problem associated with pecan culture. A large portion of the pecans marketed in the United States is produced by large (≥ 60-year-old) trees growing at orchard spacings generally ranging from 12 × 12 m to 30 × 30 m. Even at these relatively low densities, pecan trees may encroach upon one another, resulting in an eventual decline of productivity (7). The current practice in such orchards is to reduce tree size and competition by removing trees (2), removing major limbs over a period of several years, or by hedge pruning (10). Tree removal creates a large area of unused orchard space, resulting in a substantial loss in orchard productivity that lasts from several years to decades after thinning (2). The duration of this problem is largely dependent on the prethinning tree spacing. Removal of major limbs and hedging can reduce tree size; however, both methods are expensive (10).

Use of a growth retardant to reduce tree growth may have potential when trees have nearly filled their allotted space. Paclobutrazol (PBZ) (ICI Americas, Goldsboro, N.C.), a potent inhibitor of gibberellin biosynthesis (3), has been reported to be an effective retardant of vegetative growth of apple (6, 8) and peach (4) trees and pecan seedlings (5, 9) and young pecan trees (1). The effectiveness of paclobutrazol for controlling growth of mature pecan trees under orchard conditions is unknown.

The objectives of this study were to assess the effectiveness of PBZ for controlling vegetative growth of large mature pecan trees and to evaluate the influence of PBZ on nut production and quality.

The influence of PBZ on vegetative growth and nut characteristics of mature trees was assessed on 75-year-old 'Stuart' pecan trees spaced at 18 × 22 m. Two studies were performed, one involving the application of PBZ via trunk injection and the other to the orchard floor. The injection study consisted of pressure injection (11 kg·cm^{-2}) of technical grade (95%) PBZ (dissolved in 100% methanol) at six equally spaced points around the tree trunk ≈60 cm above soil level. The check consisted of both noninjected trees and trees injected with methanol, the PBZ carrier. PBZ doses used were 50, 100, and 200 mg a.i./cm of trunk diameter (≈ 0, 3.4, 6.8, and 13.6 g a.i./tree) in Oct. 1982 using a total injection volume of 10 ml/cm of trunk diameter. The average trunk diameter was ≈ 66 cm. The experimental design was a randomized complete block with nine single-tree replicates per treatment. Trees were measured annually for terminal shoot growth (20 random shoots per tree sampled at mid-crown), in-shell nut yield (total crop harvested), percent kernel (based on 100 nuts), and leaf characteristics (10 terminals per tree). Trees were managed for optimum fertility and pest control according to Georgia Cooperative Extension Service recommendations (2) and were not irrigated.

Evaluation of PBZ applied to the orchard floor was carried out under the same cultural, tree age, and cultivar conditions as described in the first experiment. PBZ was applied to the orchard floor at 0, 19, 38, or 76 mg/tree using a 50% wettable powder formulation (ICI-GFU029). PBZ was applied in 7 liters of solution using a hand sprayer to the portion of the orchard floor beneath the tree crown in Feb. 1983. The experimental design was a randomized complete block with three single-tree replicates per treatment. The soil type for both experiments was a Norfolk loamy fine sand (siliceous, thermic typic Paleudult). Trees were measured annually as described previously and data analyzed using the SAS statistical package (SAS Institute, Raleigh, N.C.).

Although injection points were equally spaced around the tree trunk in an effort to obtain uniform distribution, some major limbs showed no effects of PBZ for the duration of the study. Closer examination of such limbs revealed that the injection point usually was positioned between the groups of xylem vessels leading to two major limbs, suggesting that PBZ exhibited little lateral movement. The injection points did not appear to be injured by the PBZ carrier (methanol), but developed depressed areas ≈15 cm in diameter by 4 years after treatment. Visual evaluation of the phloem and cork cambium at these sites indicated that these tissues were alive and appeared healthy, but were depressed due to the differential growth between the tissues at the injection site and adjacent tissues.

Paclobutrazol injection treatments did not influence nut volume or percent kernel (Table 1). In-shell nut yield was unaffected the first 2 years after treatment but declined considerably with increasing PBZ treatment the third and fourth years after injection.

Injected PBZ retarded growth of terminal shoots for 4 years after treatment in 1982

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Table 1. Terminal shoot growth, in-shell nut production, and nut characteristics of 75-year-old 'Stuart' pecan trees after a single pressure injection of technical-grade paclobutrazol in Oct. 1982.

Paclobutrazol treatment ($mg \cdot cm^{-1}$ of trunk diameter)[z]	Terminal shoot growth (cm)				In-shell nut production				Kernel[y] (%)	Nut volume[y] (cm^3)
	1983	1984	1985	1986	1983	1984	1985	1986		
0	12	12	10	10	51	50	27	86	50	9
Methanol	12	12	10	9	49	54	30	89	50	9
50	9	10	9	9	41	64	28	83	51	9
100	7	8	7	7	36	44	16	71	51	9
200	7	7	6	7	39	52	16	61	52	9
Significance[x]:	LQ	L	LQ	LQ	NS	NS	L	LQ	NS	NS
r^2:	0.64	0.60	0.27	0.11	---	---	0.20	0.20	---	---

[z]Paclobutrazol was dissolved in methanol and pressure-injected at six sites around the trunk. A check was injected with methanol only.
[y]Average of 4 years of data.
[x]NS, L, Q, represents nonsignificant or significance of linear (L) or quadratic (Q) components at $P \leq 0.05$ (n = 36), respectively. Coefficient of determination (r^2) for best-fit model.

Table 2. Influence of trunk-injected paclobutrazol on foliage characteristics of terminal shoots of 75-year-old 'Stuart' pecan trees.

Paclobutrazol treatment ($mg \cdot cm^{-1}$ of trunk diameter)[z]	Area per leaf (cm^2)				No. leaves per shoot				Leaf area per shoot (dm^2)			
	1983	1984	1985	1986	1983	1984	1985	1986	1983	1984	1985	1986
0	173	166	178	161	9.2	9.1	9.4	9.1	16	15	17	15
Methanol	171	172	169	159	9.1	9.3	9.4	9.4	15	15	16	15
50	167	153	151	155	9.2	9.1	9.1	9.2	15	14	14	14
100	149	130	122	124	9.2	8.3	8.4	7.9	13	13	10	10
200	134	121	109	111	8.0	8.1	7.6	7.4	11	10	8	8
Significance[y]:	LQ	LQ	LQ	LQ	NS	LQ	LQ	LQ	LQ	LQ	LQ	LQ
r^2:	0.86	0.80	0.83	0.81	---	0.73	0.89	0.80	0.84	0.80	0.86	0.84

[z]Paclobutrazol was dissolved in methanol and pressure-injected at six sites around the trunk. A check was injected with methanol only. Coefficient of determination (r^2) for best-fit model.
[y]NS, L, Q, represents nonsignificant or significance of linear (L) or quadratic (Q) components at $P \leq 0.05$ (n = 36), respectively.

(Table 1). Methanol alone did not detectably influence any of the parameters evaluated. By the next growing season after treatment, shoot growth was reduced to 58%, 58%, and 75% of the methanol check for the 200, 100, and 50 $mg \cdot cm^{-1}$ treatments, respectively. This retardation had diminished to 78%, 78%, and 100% of the check, for the above respective rates, by the fourth year after treatment. There was little additional reduction in shoot growth by the 200 $mg \cdot cm^{-1}$ treatment over that of the 100-mg rate.

The loss of nut production in the third and fourth years after treatment may have been the result of reduced tree assimilate levels due to an increasing decline in leaf area per compound leaf, leaves per terminal shoot, and leaf area per terminal shoot with increasing PBZ rate (Table 2). Although not measured, there was also a visually obvious reduction in leaf area of lateral shoots without any effect on the number of such shoots. This loss of terminal-shoot leaf area was observed every year after PBZ application, and was most pronounced at the two highest PBZ rates.

Terminal-shoot growth of 75-year-old 'Stuart' trees also was influenced by soil-applied PBZ. As with the injection study, growth retardation was still apparent 4 years after treatment (Table 3). In-shell nut yield increased the second year after application, but not in the first or third years. The trees in the soil-application study received from 1.4- to 6-fold greater PBZ per tree than those in the injection study, but did not exhibit a greater degree of shoot growth inhibition. This lack of response suggests that most of the PBZ applied to the orchard floor was not taken up by the tree. Growth of many grasses and broadleaf species in the orchard ground cover was retarded drastically the first growing season after treatment, but was generally unaffected in subsequent years.

These experiments indicate that certain growth-related physiological processes of large, mature pecan trees are sensitive to PBZ and that PBZ can retard terminal shoot elongation by about 20% without much, if any, loss in nut production. PBZ doses producing greater inhibition of vegetative growth probably would reduce in-shell nut yields in subsequent years, with this reduction presumably due to a decline in leaf area. A 20% reduction in terminal shoot growth may not be enough to justify the use of PBZ on large trees in a commercial orchard system. It may have application, however, if used in combination with pruning, where regrowth after pruning might sufficiently increase leaf area to offset the PBZ-induced loss of leaf area. This approach might help offset any yield loss from using PBZ alone, but has not yet been demonstrated.

Table 3. Influence of soil-applied paclobutrazol on terminal shoot growth and nut production of 75-year-old 'Stuart' pecan trees.

Paclobutrazol treatment (g/tree)[z]	Terminal shoot growth (cm)				In-shell nut production (kg/tree)			
	1983	1984	1985	1986	1983	1984	1985	1986
0	12	11	12	10	44	68	10	---[y]
19	12	9	9	9	49	82	22	---
38	11	9	9	9	62	79	20	---
76	9	7	6	6	46	140	10	---
Significance[x]:	LQ	L	LQ	LQ	NS	LQ	NS	---
r^2:	0.93	0.80	0.94	0.90	---	0.89	---	---

[z]Paclobutrazol was sprayed onto the orchard floor beneath the tree crown at rates of 0, 19, 38, and 76 g/tree in Feb. 1983.
[y]Data not collected.
[x]NS, L, Q represents nonsignificant or significance of linear (L) or quadratic (Q) components at $P < 0.05$ (n = 36), respectively. Coefficient of determination (r^2) for best-fit model.

Literature Cited

1. Andersen, P.C. and J.H. Aldrich. 1987. Effect of soil-applied paclobutrazol on 'Cheyenne' pecans. HortScience 22:79–81.
2. Crocker, T.F. 1986. Commercial pecan production in Georgia. Univ. Ga. Coop. Ext. Serv. Bul. 609.
3. Hedden, P. and J. Graebe. 1985. Inhibition of gibberellin biosynthesis by paclobutrazol in cell-free homogenates of *Cucurbita maxima* endosperm and *Malus pumila* embryos. J. Plant Growth Regulat. 4:111–112.
4. Marini, R.P. 1987. Growth and cropping of 'Redhaven' peach trees following soil ap-

plication of paclobutrazol. J. Amer. Soc. Hort. Sci. 112:18–21.
5. Marquard, R.D. 1985. Chemical growth regulation of pecan seedings. HortScience 20:919–921.
6. Quinlan, J.D. and P.J. Richardson. 1984. Effect of paclobutrazol (PP 333) on apple shoot growth. Acta Hort. 146:105–111.
7. Sparks, D. 1979. Physiology-site, growth, flowering, fruiting, and nutrition, p. 211–239. In: R.A. Jaynes (ed.). Nut tree culture in North America. North Nut Growers Assn. Hamden, Conn.
8. Steffens, G.L., S.Y. Wang, M. Faust, and J.K. Byun. 1985. Growth, carbohydrates and mineral element status of shoot and spur leaves and fruit of 'Spartan' apple trees treated with paclobutrazol. J. Amer. Soc. Hort. Sci. 110:850–855.
9. Wood, B.W. 1984. Influence of paclobutrazol on selected growth and chemical characteristics of young pecan seedlings. HortScience 19:837–839.
10. Worley, R.E. 1984. Effect of pruning on three southeastern pecan cultivars. Southeast. Pecan Growers Assn. 77:105–108.

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Impact of Ten Spray Adjuvants on Leaf Gas Exchange of Pecan, Blueberry, Photinia, and Azalea

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Abstract. **Three separate factorial experiments were designed to evaluate the effect of 10 adjuvants on net CO_2 assimilation rate (A), leaf conductance to water vapor (g_l), and transpiration rate (E) of pecan [*Carya illinoensis* (Wagenh.) C. Koch] 'Elliott', blueberry (*Vaccinium ashei* Reade) 'Chaucer', red top photinia (*Photinia* x *Fraseri* Dress), and azalea (*Rhododendron* x 'Pink Ruffles'). Single applications of Bond, Leaf Act 80A, Nu-Film-17, Ortho X-77, Penetrator 3, Plyac, Sorba Spray ZNP, Sun Spray 7E, Triton CS-7, or Triton B-1956 at recommended rates did not affect A, g_l, or E compared to a water spray. The main effect of plant species was highly significant in all three studies without adjuvant–species interactions. A significant adjuvant effect on A occurred with a second application of Nu-Film-17, Plyac, and Triton B-1956. The only significant effect, when treatments were analyzed separately by species, was that A of Plyac-treated blueberry was less than the control.**

Adjuvants are a diverse group of compounds added to pesticide sprays that are imprecisely classified according to their purported effect (i.e., spreader, wetting agent, surfactant, emulsifier, sticker-extender, activator, compatability agent, acidifying agent, etc.) (13, 15).

Certain pesticides applied to apple (*Malus domestica* Borkh) (3, 5, 6), sour cherry (*Prunus cerasus* L.) (9), orange (*Citrus sinensis* L.) (15), peach (*Prunus persica* L. Batsch) (2), pecan (17, 18), lettuce (*Lactuca sativa* L.) (13), strawberry (*Fragaria ananassa* Duch.) (8), and chrysanthemum (*Chrysanthemum morifolium* Ramot) (7) have been reported to affect photosynthesis and/or transpiration. Yield reductions have occurred with the following crop/pesticide combinations: apple, benomyl and oil (11); lettuce, methyl parathion (13); grapes (*Vitis labruscana* L.), Bordeaux mixture (12); grapefruit (*Citrus paradisi* Macf.), various oil sprays (4); and strawberry, formetanate hydrochloride and propargite (8). However, the effects of the components of a pesticide mixture on plant physiology rarely have been isolated.

Although oil and emulsifiable concentrate formulations have been reported to depress photosynthesis more than wettable powder formulation of a given pesticide (3, 5, 17), few studies have assessed the effects of adjuvants alone on photosynthesis (5).

The objective of this study was to compare the effect of 10 adjuvants on leaf gas exchange of pecan, blueberry, photinia, and azalea.

The following container-grown plant material was used in all experiments: 'Elliott' pecan, 'Chaucer' blueberry, 'Fraiser' photinia, and 'Pink Ruffles' azalea. The plants were obtained from local nurseries and were subjected to standard culture and management practices. All plants were in an active state of growth, except pecan, which had ceased growth in mid-summer. Plants were placed on plastic mulch in direct sun and were irrigated with 1.5 cm of water daily.

Ten adjuvants were applied at recommended rates (Table 1) in three separate experiments during September and October Abaxial and adaxial leaf surfaces were sprayed to runoff with a Solo backpack sprayer between 8:00 and 10:00 AM. Nu-Film-17, Plyac, Triton B-1956, and water were sprayed in the first study on 11 Sept. and again on 23 Sept. 1986. Bond, Ortho X-77, Triton CS-7, and water were applied in the second study on 23 Sept. 1986. Leaf Act 80A, Penetrator 3, Sorba-Spray ZNP, Sunspray 7E, and water were applied in the third study on 7 Oct. 1986.

Leaf CO_2 and H_2O vapor exchange were measured on abaxial leaf surfaces on one or two mature fully expanded leaves per plant between 10:00 AM and 2:00 PM, as described previously (2). New CO_2 assimilation rate (A) was measured with a portable open-system LCA-2 Analytical Development Corporation (ADC Hoddesdon, U.K.) infrared gas analyzer. Leaf conductance to water vapor (g_l), transpiration rate (E), leaf temperature, air temperature, relative humidity, and photosynthetic photon flux were determined with a LI-COR 1600M steady-state diffusion porometer on the same leaf immediately after CO_2 exchange measurements. Preliminary experiments have shown that CO_2 exchange measurements did not significantly affect subsequent determinations of H_2O vapor exchange.

Each adjuvant/species combination was replicated four times, with one replication represented in each of four blocks. Leaf gas exchange was measured on one or two leaves of each plant. Data were analyzed as a 4 × 4 factorial (studies 1 and 2) or 5 × 4 factorial (study 3) by SAS (Cary, N.C.). When a significant treatment effect occurred, treatment means were compared to the control by Dunnett's *t* test.

Phytotoxicity symptoms did not occur as a result of any adjuvant spray on any species. The first application of Nu-Film-17, Plyac, and Triton B-1956 did not significnatly affect A, g_l, or E of any plant species (Table 2). Species differences in leaf gas exchange were highly significant. Net CO_2 assimilation rate, g_l, and E were highest for pecan, intermediate for photinia, and lowest for blueberry and azalea in this and the two studies to follow. The second application of the same compounds resulted in a significant adjuvant effect ($P < 0.022$) on A when all species were combined. When species were analyzed separately, the only significant effect was that the A of Plyac-treated blueberries was less than the control. No significant

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