Influence of Paclobutrazol on Shoot Growth and Flowering in a High-density Pecan Orchard

Haijun Zhu^{1,3} and Eric T. Stafne²

ADDITIONAL INDEX WORDS. *Carya illinoensis*, pistillate inflorescences, size controlling

SUMMARY. Paclobutrazol (PBZ) was applied to 6-year-old pecan (*Carya illinoensis*) trees as a basal trunk drench (0, 30, 90, and 150 mg·cm⁻² trunk cross-sectional area) in Dec. 2012. Terminal shoot growth was retarded for 1 year after a single application of PBZ. The total number of current season shoots showed a significant increase with 30- and 90-mg·cm⁻² PBZ treatments. After PBZ application at 30, 60, and 90 mg·cm⁻², the percentage of very short shoots (<5 cm) was 32.3%, 36.3%, and 32.3%, respectively, compared with 22.4% on control trees; the percentage of short shoots (5–15 cm) increased to 36.0%, 38.1%, and 43.5%, respectively. The percent of long shoots (>30 cm) was decreased to 7.4%, 5.1%, and 7.6%, respectively, after PBZ application, compared with 18.7% with control. Shoots varying from 5 to 30 cm in length accounted for at least 63.3% of all pistillate inflorescences the following spring.

Due to the strong vegetative nature of relatively young pecan trees and the absence of dwarfing rootstocks or cultivars, controlling tree size is a major problem in high-density pecan orchards. Paclobutrazol, an effective inhibitor of gibberellin biosynthesis, offers a superior method of tree size control of pecan compared with traditional and generally unsuccessful pruning or hedging methods (Sparks, 1979). Previous research indicated the strong effect of PBZ on pecan seedlings grown in a greenhouse (Marquard, 1985; Wood, 1984), young trees in the field (Andersen and Aldrich, 1987; Gash and David, 1989; Wood, 1986, 1988a), and large pecan trees (Wood, 1988b; Worley et al., 1996). However, there are differential cultivar responses depending on tree size and age and on the balance between vegetative and reproductive growth (Gash and David, 1989; Wood, 1988a; Worley et al., 1996).

A well-maintained carbohydrate and nitrogen balance within certain levels is essential for pecan flower formation (Gourley and Howlett, 1941). Terminal growth is related to the amount of stored carbohydrates and is an outward expression of the nutritional and physiological condition of the tree (Crane, 1930; Gossard, 1954; Sparks and Brack, 1970). It is also the most common characteristic observed by growers, who associate it with tree vigor and nutrition. There can be a large variation in shoot growth on the same tree or different trees. Old trees tend to produce short shoots while young trees produce longer shoots (Crane, 1930). In mature trees, longer shoots produce more leaf area and carbohydrates (Sparks, 1969), but excess vegetative growth resulted in little or no blossoming and nut production (Gossard, 1954). Trees with short and weak shoots were less likely to fruit the following year than shoots within the optimal growth range for fruiting. Heavy nut production is associated with shoots of medium length (Isbell, 1928).

Different cultivars have a wide shoot-length range for optimal fruit production (Amling, 1959; Isbell,

1928). The optimal shoot length ranges for fruiting in ‘Western Schley’, ‘Burkett’, ‘Stuart’, and ‘Success’ were on shoots 4 to 15, 4 to 18, 4 to 9, and 2.5 to 8 inches, respectively (Taylor, 1959). Gossard (1954) suggested that the best range for terminal growth was 4 to 8 inches. The general recommendation for pecan fertilization is to keep annual terminal growth on mature bearing pecan trees to 4 to 8 inches long. A significant positive relationship was found between yield and percentage of fruiting shoots (Sparks and Heath, 1972; Sparks, 1975). Young pecan trees usually produce few lateral branches due to aggressive vegetative growth, which contributes to relatively low yields (Thompson, 1981). Increased lateral branching may increase the potential number of sites for nut initiation (Andersen and Aldrich, 1987). Chemical applications (Malstrom and McMeans, 1977, 1978) and pruning (Kuykendall and Tate, 1970) may be potential methods to promote lateral shoots.

This experiment was carried out to 1) evaluate the effects of paclobutrazol on inhibiting pecan vegetative growth and increasing the number of different shoot lengths and 2) investigate the relationship between shoot length and number of pistillate inflorescences.

Materials and methods

Six-year-old ‘Mahan’ trees (Lulang Pecan Ranch, Nanjing, China; lat. 31.78°N, long. 118.62°E) spaced 5 × 7.5 m were used in this study. The site has a freeze-free growing period of 230 d with annual precipitation of 1053 mm. Trees appeared to be crowding as limbs began to intermesh within rows.

Paclobutrazol was applied to trees via soil drench (rates of 0, 30, 90, and 150 mg·cm⁻² trunk cross-sectional area) in Dec. 2012. The four treatments were initially applied in a randomized complete block design with three-single tree replications. Four types of shoots were defined

Received for publication 11 Dec. 2018. Accepted for publication 1 Feb. 2019.

Published online 25 March 2019.

¹Jiangsu Academy of Agricultural Sciences, Institute of Pomology, 50 Zhongling Street, Nanjing, Jiangsu 210014, China

²Coastal Research and Extension Center, Mississippi State University, Poplarville, MS 39470

³Corresponding author. E-mail: zhuhaajun@jaas.ac.cn.

This is an open access article distributed under the CC BY-NC-ND license (<https://creativecommons.org/licenses/by-nc-nd/4.0/>).

<https://doi.org/10.21273/HORTTECH04241-18>

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.3048	ft	m	3.2808
2.54	inch(es)	cm	0.3937
25.4	inch(es)	mm	0.0394
4.3942×10^3	oz/inch ²	mg·cm ⁻²	2.2757×10^{-4}

Table 1. Number of shoots in different length categories in 6-year-old pecan tree canopies after a single application of paclobutrazol (PBZ) at 30, 90, and 150 mg·cm⁻² trunk cross-sectional area.

PBZ (mg·cm ⁻²) ^z	Shoot length (cm) ^z				Total shoots (mean no. ± SE)
	<5	5–15	15–30	>30	
	Shoots [mean no. ± SE (%)]				
0	69 ± 6 b ^y (22.4%)	100 ± 0 b (32.7%)	80 ± 9 b (26.3%)	57 ± 6 a (18.7%)	306 ± 20 b
30	131 ± 7 a (32.3%)	146 ± 6 a (36.0%)	98 ± 10 a (24.3%)	30 ± 6 b (7.4%)	405 ± 4 a
90	104 ± 7 a (36.3%)	109 ± 8 b (38.1%)	59 ± 3 b (20.5%)	15 ± 4 b (5.1%)	285 ± 8 b
150	119 ± 12 a (32.3%)	160 ± 8 a (43.5%)	61 ± 8 b (16.6%)	28 ± 4 b (7.6%)	367 ± 10 a

^z1 mg·cm⁻² = 2.2757 × 10⁻⁴ oz/inch², 1 cm = 0.3937 inch.

^yDifferent letters within a column indicate that the values are significantly different according to Duncan's multiple range test ($P < 0.05$).

for this study: 1) very short shoots (<5 cm), 2) short shoots (5–15 cm), 3) medium shoots (15–30 cm), and 4) long shoots (>30 cm) (Zhang, 1979). Number of shoots of different lengths and pistillate inflorescences were counted in Apr. and May 2014, respectively. Data were subjected to analysis of variance and Duncan's multiple range tests at 5% level using SPSS statistical software (Grad Pack 16; IBM Corp., Armonk, NY).

Results and discussion

The total number of current season shoots per tree in 2013 showed a significant increase with 30- and 150-mg·cm⁻² PBZ treatments, but no difference with 90 mg·cm⁻² PBZ compared with the control (Table 1). Trees treated with 30, 90, and 150 mg·cm⁻² PBZ produced 405, 285, and 367 shoots, respectively, whereas the average number of shoots arising from control trees without PBZ was 306. Similarly, enhanced lateral branching was reported for PBZ-treated apple (*Malus × domestica*) seedlings (Swietlik and Miller, 1983) and pecan (Andersen and Aldrich, 1987). Yield of pecan orchards is related to percentage of fruiting shoots (Sparks, 1975), and the number of shoots, especially fruiting shoots, is an important indicator of future nut production potential.

Reducing vegetative growth of shoots can lead to their transformation into fruiting shoots. In this study, terminal growth was retarded during the first year after a single PBZ treatment. The percent of expanding shoots decreased to 7.4%, 5.1%, and 7.6% for 30, 90, and 150 mg·cm⁻², respectively, after PBZ application compared with 18.7% with control. This is because young 'Mahan' trees

Table 2. Pistillate inflorescences of 6-year-old pecan tree formed the following spring after a single application of paclobutrazol (PBZ) at 30, 90, and 150 mg·cm⁻² trunk cross-sectional area.

PBZ (mg·cm ⁻²) ^z	Shoot length (cm) ^z			
	<5	5–15	15–30	>30
	Pistillate inflorescences formed [mean ± SE (no.)]			
0	2.7 ± 0.05 c ^y	4.1 ± 0.14 d	4.7 ± 0.06 c	2.4 ± 0.04 a
30	4.2 ± 0.12 a	6.6 ± 0.10 a	7.8 ± 0.16 a	1.6 ± 0.10 c
90	3.7 ± 0.08 b	6.3 ± 0.05 b	7.4 ± 0.18 a	2.2 ± 0.15 b
150	3.8 ± 0.09 b	5.9 ± 0.06 c	6.8 ± 0.10 b	2.7 ± 0.22 a

^z1 mg·cm⁻² = 2.2757 × 10⁻⁴ oz/inch², 1 cm = 0.3937 inch.

^yDifferent letters within a column indicate that the values are significantly different according to Duncan's multiple range test ($P < 0.05$).

have naturally high vigor and mainly produce long and expanding shoots. Also, PBZ increased the proportion of short and very short shoots. Percent of very short shoots with PBZ application at 30, 90, and 150 mg·cm⁻² was 32.3%, 36.3%, and 32.3%, which was significantly higher than 22.4% very short shoots produced on control trees. Percent of short shoots increased with increasing PBZ rate at 30 and 150 mg·cm⁻² but not at the 60-mg·cm⁻² PBZ rate.

PBZ treatments also influenced pistillate inflorescences formed the following spring. The number of pistillate inflorescences formed on shoots under 30 cm increased significantly for all PBZ treatments (Table 2). For shoots under 30 cm, lower rate PBZ treatments produced more pistillate inflorescences than PBZ at 150 mg·cm⁻² and the control. It appears that the pistillate flowers that initiated from different shoots in length have different responses to PBZ applications.

Table 2 shows that the length of shoots was related to pistillate flowering. A large percentage of pistillate inflorescences initiated on shoots varying from 5 to 15 cm in length. This result is consistent with previous research (Gossard, 1954; Taylor,

1959). Shoot growth is related to the amount of carbohydrates stored (Sparks and Brack, 1970). Longer shoots produce more leaf area and carbohydrates (Sparks, 1969), as well as more pistillate flowers on a shoot (Sparks, 1975). However, shoots greater than 30 cm in our study formed few pistillate flowers. Therefore, carbohydrate storage does not appear to explain the few pistillate flowers arising from longer shoots. Other researchers noted that carbohydrates appeared to be an important factor determining the ability to flower (Smith et al., 1986), rather than controlling flower induction on individual shoots (Rohla et al., 2005). A similar mechanism might explain why shoot lengths were negatively related to pistillate inflorescences in this study. Shoot growth potential and number of female blossoms are reduced with the diminishing rate of carbohydrate storage (Arreola-Avila et al., 2006). This is consistent with results from shoots under 5 cm in length that formed few pistillate inflorescences.

As is demonstrated in previous studies (Wood, 1987, 1988a), non-uniform control of tree growth from PBZ applications was still noted in the field. These escaped lammas shoots,

greater than 100 cm long, especially on upper parts of the tree canopy, may have been due to either non-uniform uptake of PBZ by trees or the high vigor nature of 'Mahan'. Further work is needed to refine the optimal rate of PBZ and to address suitable methods to avoid overtreatment.

Conclusions

Because of the early production and quicker returns, many growers in China prefer high-density planting systems that have the potential to break even in 6 to 7 years compared with 10 to 12 years for traditional systems (Zhu, 2018). PBZ application appears to be a method to control pecan tree size and is superior to pruning methods that require a significant amount of labor resources and also results in temporary loss of production. The yield is expected to increase as more pistillate inflorescences produced. Unfortunately, we were not able to collect the yield data because of the owner's preharvesting. As is shown in this study, greater than 35% pistillate inflorescences were produced on shoots 15 to 30 cm long. Thus, maintaining 'Mahan' tree shoot growth within this range tends to be optimal shoot length range for young tree management.

Literature cited

- Amling, H.J. 1959. Shoot growth and pecan fruiting. *Proc. Southeastern Pecan Growers Assn.* 52:45–48.
- Andersen, P.C. and J.H. Aldrich. 1987. Effect of soil-applied paclobutrazol on 'Cheyenne' pecans. *HortScience* 22:79–82.
- Arreola-Avila, J., E. Herrera-Aguirre, R. Trejo-Calzada, A. Flores-Hernández, R. Parra-Quezada, and A. Borja-de la Rosa. 2006. Sunlight availability and nut production after thinning of pecan trees. *Rev. Chapingo Ser. Hort.* 12:177–181.
- Crane, H.L. 1930. Terminal growth in relation to fruiting in the pecan. *Natl. Pecan Assn. Bul.* 29:24–32.
- Gash, D. and I. David. 1989. Paclobutrazol effect on growth and cropping of pecan trees. *Acta Hort.* 239:301–304.
- Gossard, A.C. 1954. Growth and fertilization of pecan trees in relation to regularity of bearing. *Proc. Oklahoma. Pecan Growers Assn.* 24:14–22.
- Gourley, J.H. and F.S. Howlett. 1941. *Modern Fruit Production*. Macmillan, New York, NY.
- Isbell, C.L. 1928. Growth studies of the pecan. *Alabama Agr. Expt. Sta. Bul.* 226.
- Kuykendall, J.R. and H.F. Tate. 1970. Pecan pruning experiments in Arizona. *Proc. Southeastern Pecan Growers Assn.* 63:42.
- Malstrom, H.L. and J.L. McMeans. 1977. A chemical method of pruning young pecan trees. *HortScience* 12:68–69.
- Malstrom, H.L. and J.L. McMeans. 1978. Chemical pruning young pecan trees. *Pecan Qrtly* 12(1):23–24, 26, 28.
- Marquard, R.D. 1985. Chemical growth regulation of pecan seedlings. *HortScience* 20:919–921.
- Rohla, C.T., M.W. Smith, and N.O. Maness. 2005. Effects of cluster size and shoot type on characteristics of pecan nuts. *HortScience* 40:1300–1303.
- Smith, M.W., R.W. McNew, P.L. Ager, and B.C. Cotton. 1986. Seasonal changes in the carbohydrate concentration in pecan shoots and their relationship to flowering. *J. Amer. Soc. Hort. Sci.* 111:558–561.
- Sparks, D. 1969. Some characteristics of shoot growth of pecan trees and their implications to yields. *Proc. Southeastern Pecan Growers Assn.* 62:55–75.
- Sparks, D. 1975. The alternate fruit bearing problem in pecans. *Proc. Northern Nut Growers Assn.* 65:145–157.
- Sparks, D. 1979. Physiology-site, growth, flowering, fruiting, and nutrition, p. 211–239. In: R.A. Jaynes (ed.). *Nut tree culture in North America*. Northern Nut Growers Assn., Hamden, CT.
- Sparks, D. and C.E. Brack. 1970. Effect of removing leaves and fruit on return bloom and fruit set on the Stuart pecan. *Proc. Southeastern Pecan Growers Assn.* 63:69–71.
- Sparks, D. and J.L. Heath. 1972. Pistillate flower and fruit drop of pecan as a function of time and shoot length. *HortScience* 7:402–404.
- Swietlik, D. and S.S. Miller. 1983. The effect of paclobutrazol on growth response to water stress of apple seedlings. *J. Amer. Soc. Hort. Sci.* 108:1076–1080.
- Taylor, G.G. 1959. The relation of terminal growth to fruiting in pecans. MS Thesis, Oklahoma State Univ., Stillwater.
- Thompson, T.E. 1981. Pecan breeding prospects. *Pecan Qrtly* 15:4–11.
- Wood, B.W. 1984. Influence of paclobutrazol on selected growth and chemical characteristics of young pecan seedlings. *HortScience* 19:837–839.
- Wood, B.W. 1986. Influence of paclobutrazol (PP-333), Flurprimidol (EL-500) and Ortho XE-1019 (Chevron) growth retardants on growth and selected chemical and yield characteristics of *Carya illinoensis*. *Acta Hort.* 179:287–288.
- Wood, B.W. 1987. Control of pecan tree size by bioregulating chemicals. *Proc. Southeastern Pecan Growers Assn.* 80:40–45.
- Wood, B.W. 1988a. Paclobutrazol suppresses shoot growth and influences nut quality and yield of young pecan trees. *J. Amer. Soc. Hort. Sci.* 113:374–377.
- Wood, B.W. 1988b. Paclobutrazol suppresses vegetative growth of large pecan trees. *HortScience* 23:341–343.
- Worley, R.E., B.G. Mullinix, and J.W. Daniel. 1996. Selective limb pruning, tree removal, and paclobutrazol growth retardant for crowding pecan trees. *Scientia Hort.* 67:79–85.
- Zhang, W.C. 1979. Research methodology in pomology. China Agriculture Press, Beijing, China.
- Zhu, H.J. 2018. Challenges for the expanding pecan industry in China. *Pecan South* 51(9):16–23.