Effects of Contrasting Climate and Paclobutrazol on the Growth and Water Use of Two Container-Grown Landscape Plants[1]

John M. Ruter[2] and Chris A. Martin[3]
University of Georgia
Department of Horticulture
Coastal Plain Experiment Station
Tifton, GA 31793-0748

Abstract

A study was conducted under contrasting climates [southwestern Georgia (humid, temperate) and central Arizona (arid, Sonoran desert)] to evaluate the effects of paclobutrazol on the growth and water use of container-grown *Feijoa Sellowiana* O. Berg and *Ligustrum japonicum* Thunb. Plants grown in Georgia were taller, had approximately twice as many leaves and five times more canopy leaf area, a lower shoot:root ratio, and generally higher water use compared to plants grown in Arizona. Differences in meteorological factors such as higher maximum and minimum temperatures and increased solar radiation in Arizona compared to Georgia were coincident with smaller plant size and lower water use of plants grown in Arizona compared to those grown in Georgia. Paclobutrazol inhibited height growth of plants grown in Arizona; however, this growth inhibition was not affected by application concentration. In Georgia, paclobutrazol inhibited height growth of all plants; however, *Ligustrum* treated with 250 ppm paclobutrazol appeared to begin to overcome growth suppression after five months. Paclobutrazol reduced canopy leaf area and water use for all plants except for Arizona *Feijoa*.

Index words: growth regulator, container production, climatic comparisons.

Chemicals used in this study: Paclobutrazol [(2RS,3RS)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-y1)pentan-3-o1].

Species used in this study: *Feijoa Sellowiana* O. Berg and *Ligustrum japonicum* Thunb.

Significance to the Nursery Industry

The climate of the arid southwestern United States is drastically different from the more humid, temperate, southeastern United States. During summer, nursery operators in the desert Southwest contend with extreme high temperatures which sometimes exceed 43°C (110°F), high irradiance levels, and low relative humidities. In contrast, nursery operators in the Southeast United States contend with summer temperatures which regularly exceed 32°C (9O°F), high relative humidities, and frequent afternoon thundershowers. In this study, same-source plants were grown under identical production schemes at Tempe, AZ, or Tifton, GA, and treated with 0, 250, 500, or 750 ppm paclobutrazol, a growth regulator. Plants grown in Georgia were generally taller, more branched, had a larger canopy area and lower shoot:root (S:R) ratio, and had higher water use than plants grown in Arizona. Paclobutrazol inhibited shoot elongation of all plants; however, this inhibition was not related to application concentration except Georgia *Ligustrum* treated with 250 ppm paclobutrazol which appeared to begin to overcome growth suppression after five months. Plants treated with paclobutrazol also had lower water use compared to untreated plants, except for *Feijoa* grown in Arizona. Growth regulators such as paclobutrazol appear to offer more potential benefit to nursery operators in the southeastern United States for restricting container plant growth and/or decreasing container plant water use during critical periods of the growing season than for nursery operators in the southwestern United States because of increased plant growth and higher plant water use.

Introduction

Understanding relationships between container plant growth and water use is important in the southeastern and southwestern United States because of growing public concerns about future adequacy of fresh water supplies and water quality. Nursery irrigation schedules are determined largely by climate, plant species and time of year (15). Container plant water use will vary in different geographic locations because of differences in environmental variables such as temperature, rainfall, relative humidity, light intensity and wind speed.

Paclobutrazol is a triazole compound which interferes with gibberellin biosynthesis (4) and reduces growth of several container-grown landscape plants (7, 8, 14, 20). In addition to restricting plant growth, plants treated with triazole growth regulators often transpire less water than untreated plants (5, 16, 19). Triazole-treated plants often have a higher water potential compared to untreated plants (5, 17) and may be able to better withstand drought conditions. Chemical growth regulators and pruning can be used to reduce water use by reducing leaf area. Research has not shown clearly whether lower transpiration by plants treated with growth regulators is due to less canopy leaf area, changes in stomatal density, or alterations in stomatal conductance (5). The objectives of this study were to determine the effects of contrasting climate and growth regulator application con-

[1]Received for publication April 12, 1993; in revised form October 28, 1993. Technical assistance of Bruce Tucker and Tina Divis is gratefully acknowledged. This research is supported in part by the nursery industry through contributions to the Horticultural Research Institute, 1250 I Street, N.W., Suite 500, Washington, DC 20005.

[2]Assistant Professor

[3]Assistant Professor, Arizona State University, Department of Botany, Tempe AZ 85287-1601

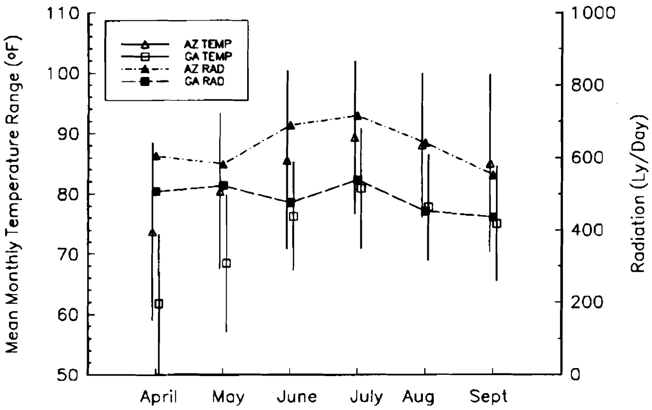

Fig. 1. **Mean monthly temperature range and mean daily radiation for Arizona (AZ TEMP and AZ RAD), respectively, and Georgia (GA TEMP and GA RAD) during Spring and Summer, 1992.**

centration on the growth and whole-plant transpiration of two container-grown landscape plants.

Materials and Methods

Experiments were conducted outdoors under full sun at the University of Georgia Coastal Plain Experiment Station in Tifton (32N 83W) and at the Arizona State University Horticultural Resource Center in Tempe (33.5N 112W). Uniform rooted liners of *Feijoa Sellowiana* and *Ligustrum japonicum* were transplanted into 2.8 1 (#1) containers on March 2, 1992. The rooting medium consisted of a milled pine bark, peat moss and sand (3:1:1 by vol) amended with micronutrients at 0.9 kg/m^3 (1.5 lb/yd^3). Individual containers were topdressed with 18N-2.6P-9.9K (18-6-12) controlled-release fertilizer in March and August, 1992 at the rate of 1.2 kg N/m^3 (2.0 lb N/yd^3). Plants were irrigated daily to container capacity at the rate of 1.3 cm (0.5 in) water per irrigation using overhead irrigation at both locations so as to not allow development of plant water stress.

On March 25, 1992, paclobutrazol sprays of 0 (deionized water control), 250, 500, and 750 ppm in a volume of 4 ml per pot were applied uniformly using a hand-held spray bottle to the shoots of both species at both locations. Beginning in April, 1992, plant height and lateral branch number (> 1.0 cm) were measured monthly. Diurnal canopy transpiration was determined monthly using pre- and post irrigation lysimetry. Five replications per treatment combination were preselected for transpiration measurements which resulted in the same plants being sampled on each measurement date. At both locations, plants were irrigated at 10 AM. The container of each plant was sealed within a plastic bag drawn around the plant stem at 11 AM leaving the shoot uncovered for a 24-hr period to determine diurnal canopy transpiration. At the termination of the study in September, 1992, canopy leaf number and leaf area, and shoot and root dry weight for the five replicates used for transpiration measurements were determined. In Georgia, a LI-3100 area meter was used to determine leaf area in contrast to an Ag Vision computer imaging system used in Arizona.

Meteorological variables of daily maximum and minimum air temperature and integrated daily radiation were collected at each location and averaged for each month (Fig. 1). Mean daily maximum temperatures in Arizona were consistently 7.2 to 8.3°C (13 to 15°F) higher than in Georgia, while minimum daily temperatures were 1.5 to 5.5°C (3 to 10°F) higher in Arizona. Mean daily solar radiation in Arizona averaged 100 to 200 Ly/day[1] higher than in Georgia. Total rainfall during the study period was 18.7 and 42.3 cm (7.5 and 16.9 in) for the Arizona and Georgia locations, respectively.

The experiment was a 2 location × 2 species × 4 treatment factorial arranged in a randomized complete block design with 18 replicates which equaled 72 plants per species at each location. General linear models procedures were used to test for significant responses of the variables. Repeated measures analysis with contrast statements were used to compare changes in plant height and diurnal canopy transpiration over time as affected by treatments.

Results and Discussion

All measured variables were affected significantly by an interaction of species and paclobutrazol treatment with location so the data are presented after statistical analysis by location.

Height of all Arizona-grown plants increased quadratically over time (Table 1). For height growth, there was no interaction between species and paclobutrazol treatment. In Arizona, the height of *Feijoa* increased linearly over time compared to height of *Ligustrum* (Table 1) and the final height of *Feijoa* was 40% taller than the final height of *Ligustrum* (Fig. 2a). The height of all Arizona-grown plants that were not treated with paclobutrazol increased quadratically over time compared to those treated with paclobutrazol (Table 1). For those plants treated with paclobutrazol, no additional growth inhibition was found to occur for plants treated with 500 or 750 ppm compared to those treated at 250 ppm (Fig. 2b). Height differences between the mean of all paclobutrazol-treated plants and the untreated control plants became apparent in early summer and by the end of summer, the untreated control plants were 45% taller than those treated with paclobutrazol.

Height of all Georgia-grown plants increased linearly over time (Table 1). For height growth, there was a species by paclobutrazol interaction (Table 1). Height of untreated *Feijoa* increased quadratically over time compared to those treated with paclobutrazol (Table 1). There was no further inhibition of height growth for *Feijoa* treated with 500 or 750 ppm compared to those treated at 250 ppm (Fig. 2c). Height of treated *Feijoa* increased linearly over time ($P = 0.001$). For Georgia-grown *Ligustrum,* height of plants that were not treated with paclobutrazol increased cubically over time compared to those treated with paclobutrazol (Table 1). Height of treated *Ligustrum* increased linearly over time ($P = 0.001$). The untreated control for *Ligustrum* increased in height primarily during May and June and again during September (Fig. 2d). *Ligustrum* treated with 250 ppm paclobutrazol appeared to begin to overcome paclobutrazol-induced growth suppression after five months.

A common response of many plants to the application of triazole growth regulators is reduced stem elongation and plant height growth; however, the regulation of plant growth is affected by growth regulator rate of application (5). In both Arizona and Georgia, plant height was not significantly different between plants treated with paclobutrazol while all treated plants were shorter than the untreated controls. These results suggest that for the application rate used in this study, use of paclobutrazol at concentrations higher than 250 ppm for additional height control of *Feijoa* and

Ligustrum is unnecessary. Rates lower than 250 ppm may also produce commercially acceptable plants.

Canopy transpiration of all plants in Arizona increased quadratically over time (Table 1). However, canopy transpiration of Arizona plants was also affected by an interaction of species and paclobutrazol treatment. For *Feijoa* grown in Arizona, there was no difference in the transpiration of paclobutrazol treated or untreated plants during the growing season (Fig. 3a). For Arizona-grown *Ligustrum,* canopy transpiration of the untreated control plants increased linearly over time when compared to plants treated with paclobutrazol (Fig. 3b). In addition, *Ligustrum* canopy transpiration increased linearly over time for treated plants (P = 0.001).

Canopy transpiration of all plants grown in Georgia increased cubically over time (Table 1) and there was no interaction between species and paclobutrazol. The highest canopy transpiration of *Feijoa* and *Ligustrum* occurred in August and July, respectively (Fig. 3c). At the end of August, *Feijoa* plants transpired 55% more water than *Ligustrum.* Both species showed a decrease in canopy transpiration during September which accounted for the significant cubic effect. Less canopy transpiration in September was associated with a decline in mean daily maximum and minimum air temperatures, shorter day lengths, and reduced solar radiation intensity (Fig. 1). Canopy transpiration of all Georgia plants treated with 250, 500, or 750 ppm paclobutrazol were less than for untreated control plants (Fig. 3d). Water use of untreated plants increased quadratically over time compared to plants treated with paclobutrazol. Water use of treated plants was cubic (P = 0.0097) over time. Peak canopy transpiration for the untreated control occurred in July compared to August for the plants treated with paclobutrazol. The largest differences in canopy transpiration between the untreated control and the plants treated with paclobutrazol occurred during the months of June and July in Georgia. All plants treated with paclobutrazol showed a trend for decreased transpiration during September.

Shoot architecture and leaf morphology of both species were affected differently at each location. In Arizona, there was a species by paclobutrazol interaction for branching where the branching of *Ligustrum* was inhibited by paclobutrazol but the branching of *Feijoa* was not (Table 2). At the highest rate of application (750 ppm), the number of branches per plant on *Ligustrum* was decreased by 60%. This is in direct contrast to previous work in Alabama which showed an increase in branching for *Ligustrum japonicum* 'Aureo-marginatum' with increased rates of paclobutrazol

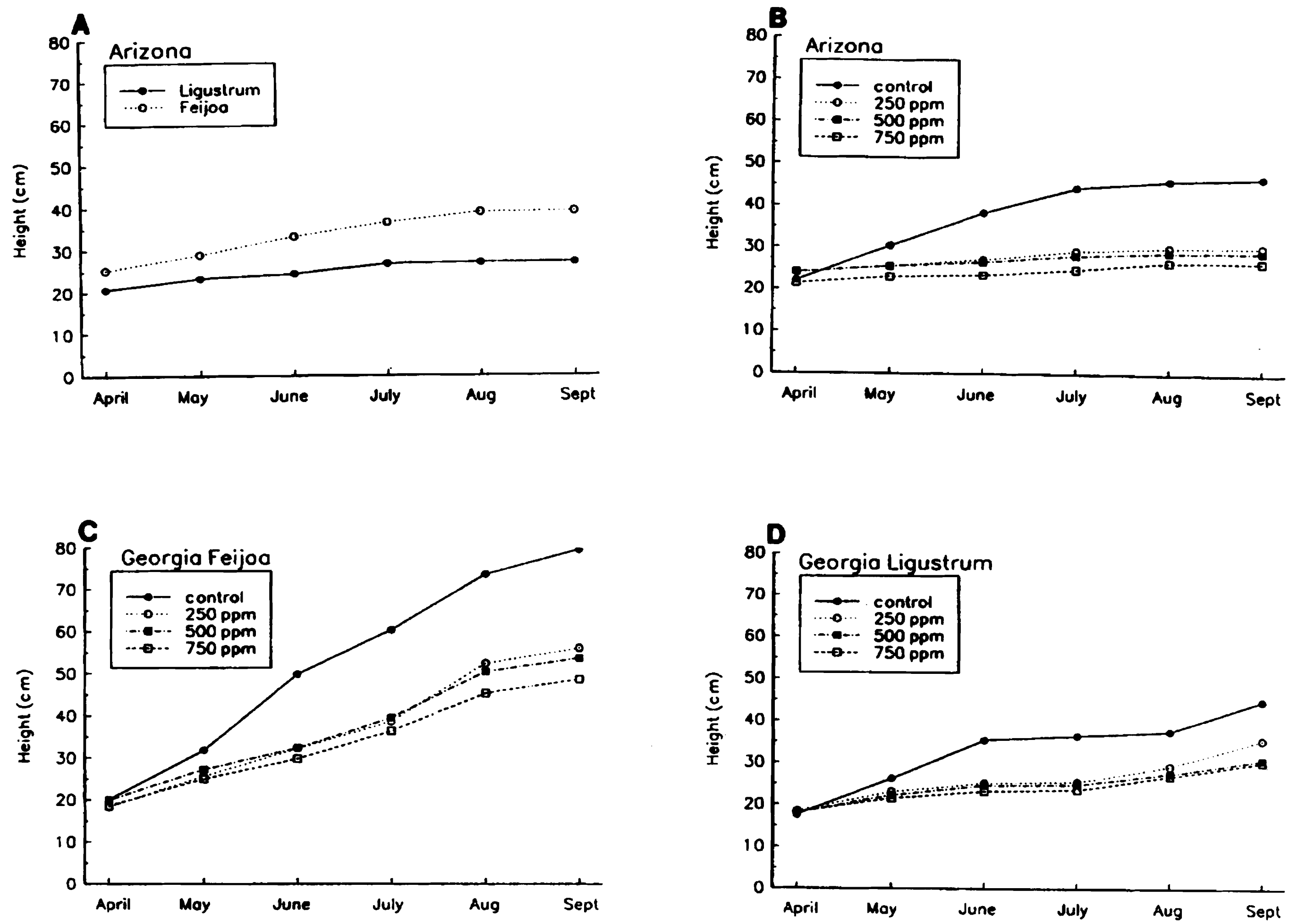

Fig. 2. (A-D). Height growth of landscape plants grown in Arizona and Georgia during the Spring and Summer 1992 using repeated measures analysis: (A) by species across paclobutrazol treatments and control, B) by paclobutrazol treatments and control across species, C) *Feijoa* by paclobutrazol interaction, and D) *Ligustrum* by paclobutrazol interaction).

(7) . Canopy leaf number and area of *Feijoa* were 37% and 41% more, respectively, than for *Ligustrum* (Table 2). Paclobutrazol reduced canopy leaf area of *Ligustrum,* but had no affect on canopy leaf area of *Feijoa* (Table 2). In addition, paclobutrazol-treated *Ligustrum* in Arizona had shortened internodes and leaves that were generally yellowed with recurvate leaf margins.

Paclobutrazol had no effect on the branching or canopy leaf number of plants grown in Georgia (data not shown). Canopy leaf area in Georgia was influenced by species and paclobutrazol application concentration (Table 3). *Ligustrum* had 34% less leaf area than *Feijoa.* Canopy leaf area decreased quadratically in response to increased paclobutrazol application concentration of paclobutrazol. Canopy leaf area was reduced by 26% at the highest rate of application compared to the control.

Paclobutrazol had no effect on shoot dry weight of *Feijoa* grown in Arizona (Table 4). This is in contrast to previously reported research on ornamental species (7, 14). Shoot dry weight of *Ligustrum* decreased linearly in response to rate of paclobutrazol application. Root dry weight of *Ligustrum* decreased quadratically and was affected by paclobutrazol more so than that of *Feijoa* (Table 4). Since shoot growth is inhibited to a greater degree by paclobutrazol than root growth, treated plants often have decreased S:R ratios compared to untreated plants (5). While paclobutrazol had no effect on the S:R of *Feijoa* grown in Arizona, the S:R ratio of *Ligustrum* decreased quadratically (Table 4).

Treatment with paclobutrazol resulted in decreased shoot dry weight compared to the control for *Ligustrum* in this study (Table 5). Paclobutrazol had no effect on the shoot or root dry weight of *Feijoa* grown in Georgia (Table 5). Root dry weight of *Ligustrum* decreased quadratically in response to increased rates of paclobutrazol application. The S:R ratio of both species was not influenced by rate of paclobutrazol application (Table 5).

Root growth of plants treated with paclobutrazol is generally less inhibited than shoot growth which results in a lower S:R ratio (5). *Feijoa* and *Ligustrum* grown in Arizona had 54 and 51% less shoot dry weight, respectively, and 71 and 78% less root dry weight, respectively, compared to plants grown in Georgia (Table 4 and 5). The S:R ratio of plants in Arizona was approximately 2 times higher than for those grown in Georgia. Plant growth at the different locations used in this study can be explained by environmental differences mediated by climatic dissimilarities (Fig. 1). Higher air temperatures in Arizona in conjunction with more intense solar radiation probably resulted in higher root-zone temperatures and plant respiration and less root growth for plants in Arizona compared to plants in Georgia.

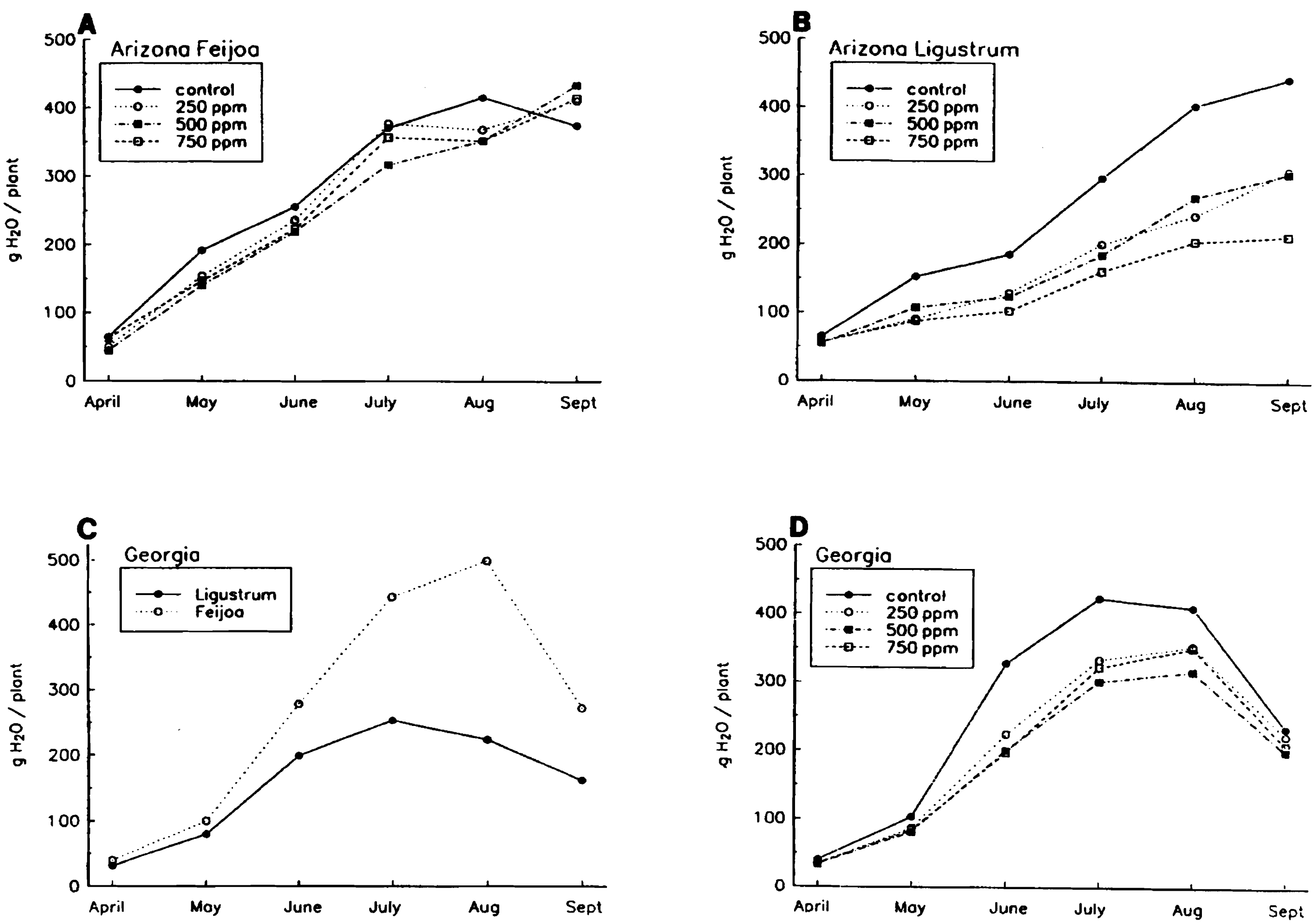

Fig. 3. (A-D). Diurnal canopy transpiration of landscape plants grown in Arizona and Georgia during Spring and Summer 1992 using repeated measures analysis: (A) *Feijoa* by paclobutrazol interaction, B) *Ligustrum* by paclobutrazol interaction, C) by species across paclobutrazol treatments and control, and D) by paclobutrazol treatments and control across species.

Table 1. **Analysis of variance of significant polynomial time trends and treatment contrasts for height and diurnal canopy transpiration of *Feijoa Sellowiana* and *Ligustrum japonicum* grown in Arizona or Georgia, respectively, during Spring and Summer, 1992.**

Source of variation	df	MS	F	P > F values[z]
Height				
Arizona				
Time	1	542.1	10.6	0.002 Q
Species × Time	1	390.4	5.9	0.024 L
Paclobutrazol × Time[yx]				
1 vs 2, 3, and 4	1	378.2	8.1	0.007 Q
Georgia				
Time	1	78092.1	117.1	0.001 L
Feijoa				
Paclobutrazol × Time				
1 vs. 2, 3, and 4	1	421.3	17.5	0.001 Q
Ligustrum				
Paclobutrazol × Time				
1 vs. 2, 3, and 4	1	68.9	8.3	0.005 C
Diurnal canopy transpiration				
Arizona				
Time	1	26831.9	13.6	0.001 Q
Ligustrum				
Paclobutrazol × Time				
1 vs. 2, 3, and 4	1	72716.8	17.0	0.001 L
Georgia				
Time	1	446526.1	162.4	0.001 C
Species × Time	1	159715.5	51.0	0.001 C
Paclobutrazol × Time				
1 vs. 2. 3. and 4	1	60080.9	11.6	0.001 Q

[z]Linear (L), quadratic (Q), or cubic (C) fitted line responses across time, respectively.

[y]All plants were foliarly-drenched with paclobutrazol at 0 (water control), 250, 500, or 750 ppm.

[x]Treatment contrasts for paclobutrazol are 1 (water control), 2 (250 ppm), 3 (500 ppm), or 4 (750 ppm).

Table 2. **Branching, canopy leaf number, and canopy area of *Feijoa Sellowiana* and *Ligustrum japonicum* grown in Arizona during Spring and Summer 1992.**

Species × Paclobutrazol[xyz]	Branching (#/plant)
Feijoa Sellowiana	
control	9
250 ppm	10
500 ppm	9
750 ppm	9
Significance[x]	NS
Ligustrum japonicum	
control	14
250 ppm	10
500 ppm	9
750 ppm	6
Significance	* L
Species[wv]	**Canopy leaf number (lvs/plant)**
Feijoa Sellowiana	189a
Ligustrum japonicum	110b
Species[wv]	**Canopy leaf area (cm^2/plant)**
Feijoa Sellowiana	1389a
Ligustrum japonicum	822b
Paclobutrazol	
control	1219
250 ppm	1690
500 ppm	1622
750 ppm	1414
Significance	NS
Ligustrum japonicum	
control	1036
250 ppm	938
500 ppm	752
750 ppm	360
Significance	* L

[z]All plants were foliar-drenched with paclobutrazol at 0 (water control), 250, 500, or 750 ppm.

[y]For branching, n = 72.

[x]Nonsignificant (NS), significant 5% (*), or 1% (**); linear (L) or quadratic (Q) response, respectively.

[w]Mean separation in columns (within species across paclobutrazol) by Fisher's LSD test, P = 0.05, n = 20.

[v]For change in canopy leaf number and canopy leaf area, n = 20.

Supraoptimal root zone temperatures can have profound effects on growth, assimilate partitioning, and respiratory mechanisms in plants (3, 9, 10, 12, 13). Dark and maintenance respiration have been shown to have a Q_{10} of 2 or more in a variety of plants (11). Higher night temperatures in Arizona might further increase plant respiration and decrease growth which could result in net carbon balances that are negative (6).

Lower transpiration rates by paclobutrazol-treated plants has been reported for numerous species (1, 2, 5, 17, 19). Steinberg *et al.* (16), working with *Ligustrum* and a triazole growth regulator (uniconazole) similar to paclobutrazol found that application of uniconazole decreased leaf area and reduced water use compared to untreated control plants. Paclobutrazol was shown to influence diurnal transpiration of container-grown peaches *(Prunus persica)* under different environmental conditions (2). In this study, lower diurnal canopy transpiration of treated plants was related to reduced canopy leaf area, except for Arizona *Feijoa*. Results from our study provide further evidence that any affect which paclobutrazol has on plant water use stems primarily from changes in leaf morphological characteristics.

Plant drought tolerance during episodes of water stress is generally believed to be inversely correlated with S:R ratio (18). The lower S:R ratio and canopy leaf area of Georgia plants treated with paclobutrazol may not only decrease water use, but may also improve plant water-status, particularly when container-grown plants are transplanted into the landscape and experience water stress. Additional research is needed to determine how paclobutrazol applied during the container-phase will affect ensuing plant establishment and performance in the landscape.

Literature Cited

1. Atkinson, D. and J.S. Chauhan. 1987. The effect of paclobutrazol on the water use of fruit plants at two temperatures. J. Hort. Sci. 62:421–426.

2. Biasi, R., G. Costa, F. Sexy, C. Nishijima and G.C. Martin. 1989. Paclobutrazol and root zone water content influence peach seedling behavior. J. Amer. Soc. Hort. Sci. 114:923–926.

3. Cooper, A.J. 1973. Root temperature and plant growth. Bur. Hortic. Plant. Crops Res. Rev. 4, p 1–73.

4. Dalziel, J. and D.K. Lawrence. 1984. Biochemical and biological effects of kaurene oxidase inhibitors such as paclobutrazol. Brit. Plant Growth Regulate. Group., Monogr. 11.

Table 3. **Branching, canopy leaf number, and canopy area of *Feijoa Sellowiana* and *Ligustrum japonicum* grown in Georgia during Spring and Summer 1992.**

Species[zy]	Branching (#/plant)
Feijoa Sellowiana	24a
Ligustrum japonicum	15b
Species[x]	Canopy leaf number (lvs/plant)
Feijoa Sellowiana	438a
Ligustrum japonicum	319b
Species	Canopy leaf area (cm²/plant)
Feijoa Sellowiana	7408a
Ligustrum japonicum	4909b
Paclobutrazol[w]	
control	7249
250 ppm	6172
500 ppm	5747
750 ppm	5342
Significance[v]	* L

[z]For branching, n = 72.

[y]Mean separation in columns (within species across paclobutrazol) by Fisher's LSD test, P = 0.05.

[x]For change in canopy leaf number and canopy leaf area, n = 20.

[w]All plants were foliarly-drenched with paclobutrazol at 0 (water control), 250, 500, or 750 ppm.

[v]Nonsignificant (NS), significant 5% (*), or 1% (**); linear (L) or quadratic (Q) response, respectively, n = 20.

Table 4. **Shoot dry weight (SDW), root dry weight (RDW), and shoot:root ratio (S:R) of *Feijoa Sellowiana* and *Ligustrum japonicum* grown in Arizona during Spring and Summer 1992.**

Species × Paclobutrazol[z]	SDW (g/plant)	RDW (g/plant)	S:R
Feijoa Sellowiana			
control	48.3	32.4	1.44
250 ppm	57.5	44.0	1.49
500 ppm	48.0	29.9	1.89
750 ppm	43.9	28.4	1.62
Significance[y]	NS	NS	NS
Ligustrum japonicum			
control	40.3	31.5	1.32
250 ppm	32.0	16.4	2.17
500 ppm	25.9	12.1	2.31
750 ppm	19.7	15.1	1.45
Significance	** L	** Q	* Q

[z]All plants were foliarly-drenched with paclobutrazol at 0 (water control), 250, 500, or 750 ppm.

[y]Nonsignificant (NS), significant 5% (*), or 1% (**); linear (L) or quadratic (Q) response, respectively, n = 20.

Table 5. **Shoot dry weight (SDW), root dry weight (RDW), and shoot:root ratio (S:R) of *Feijoa Sellowiana* and *Ligustrum japonicum* grown in Georgia during Spring and Summer 1992.**

Species × Paclobutrazol[z]	SDW (g/plant)	RDW (g/plant)	S:R
Feijoa Sellowiana			
control	116.9	122.6	0.98
250 ppm	106.0	124.0	0.85
500 ppm	92.0	124.7	0.75
750 ppm	88.2	117.2	0.76
Significance[y]	NS	NS	NS
Ligustrum japonicum			
control	101.2	116.5	0.89
250 ppm	54.1	76.0	0.71
500 ppm	54.6	73.2	0.72
750 ppm	46.7	75.3	0.62
Significance	* Q	* Q	NS

[z]All plants were foliarly-drenched with paclobutrazol at 0 (water control), 250, 500, or 750 ppm.

[x]Nonsignificant (NS), or significant 5% (*) or 1% (**), linear (L) or quadratic (Q) response, respectively, n = 20.

5. Davis, T.D., G.L. Steffens and N. Sankhla. 1988. Triazole plant growth regulators, p. 63–106. *In:* J. Janick (Editor) Hort. Reviews. AVI Publishing Co., Inc., Westport, CT.

6. Deal, D.L., J.C. Raulston and L.E. Hinesley. 1990. Leaf color retention, dark respiration, and growth of red-leafed Japanese maples under high night temperatures. J. Amer. Soc. Hort. Sci. 115:135–140.

7. Keever, G.J., W.J. Foster and J.C. Stephenson. 1990. Paclobutrazol inhibits growth of woody landscape plants. J. Environ. Hort. 8:41–47.

8. Martin, C.A. and D.L. Ingram. 1988. Paclobutrazol and irradiance level affect growth of *Magnolia grandiflora* 'Glen St. Mary'. Proc. Fla. State Hort. Soc. 101:316–319.

9. Martin, C.A. and D.L. Ingram. 1991. Growth and photosynthesis of *Magnolia grandiflora* 'St. Mary' in response to constant and increased container volume. J. Amer. Soc. Hort. Sci. 116:439–445.

10. Neilsen, K.F. 1974. Roots and root temperatures. p. 293–33. *In:* E.W. Carson (Editor). The plant root and its environment. Univ. of Virginia Press. Charlottesville, VA.

11. Penning de Vries, F.W.T. 1974. Substrate utilization and respiration to growth and maintenance in higher plants. Neth. J. Agr. Sci. 22:40–44.

12. Ruter, J.M. and D.L. Ingram. 1990. ^{14}Carbon-labelled photosynthate partitioning in *Ilex crenata* 'Rotundifolia' at supraoptimal root-zone temperatures. J. Amer. Soc. Hort. Sci. 115: 1008–1013.

13. Ruter, J.M. and D.L. Ingram. 1991. The effect of supraoptimal temperatures on root respiratory characteristics of 'Rotundifolia' holly. J. Amer. Soc. Hort. Sci. 116:560–564.

14. Ruter, J.M. 1992. Growth and flowering response of butterfly-bush to paclobutrazol formulation and rate of application. HortScience 27:929.

15. Smajstrla, A.G. and F.S. Zesty. 1987. Estimating irrigation requirements of sprinkler irrigated container nurseries. Proc. Fla. State Hort. Soc. 100:343–348.

16. Steinberg, S.L., J.M. Zajicek and M.J. McFarland. 1991. Short-term effect of uniconazole on the water relations and growth of *Ligustrum*. J. Amer. Soc. Hort. Sci. 116:460–464.

17. Swietlik, D. and S.S. Miller. 1983. The effect of paclobutrazol on growth and response to water stress of apple seedlings. J. Amer. Soc. Hort. Sci. 108:1076–1080.

18. Turner, N.C. and G.E. Begg. 1981. Plant-water relations and adaptation to stress. Plant and Soil 58:97–133.

19. Wample, R.L. and E.B. Culver. 1983. The influence of paclobutrazol, a new growth regulator, on sunflowers. J. Amer. Soc. Hort. Sci. 108:122–125.

20. Wilkinson, R.I. and D. Richards. 1991. Influence of paclobutrazol on growth and flowering of *Rhododendron* 'Sir Robert Peel'. HortScience 26:282–284.