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Chemical Growth Retardants Increase Seed Yield in Apple Trees[1]

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Abstract

In two experiments the effects of trunk drenches with two gibberellin biosynthesis inhibitors on vegetative growth, seed yield and quality of 'Delicious' and 'Golden Delicious' apple trees were studied. In the first experiment trunk drenches of either paclobutrazol or uniconizole were applied to 'Golden Delicious' apple trees in spring 1984. Both chemicals significantly reduced shoot length in 1985 and 1986. In 1986, fruit number tended to be higher in treated trees, but was less than untreated trees in 1985 and 1984. The estimated number of sound seeds produced in 1986 on treated trees was increased. Neither chemical significantly affected seed quality or seedling growth. In a second similar experiment paclobutrazol, applied as a trunk drench in spring 1984 at rates of 2, 4 or 8 g active ingredient (ai)/tree, significantly reduced shoot growth in 1985 and 1986. The number of sound seed/tree was significantly increased in 1986 at all paclobutrazol levels due to an increase in the number of fruit/tree. Paclobutrazol application had no effect on seed quality, rate of germination, final percent germination, or on seedling growth. Potentially, both compounds could be used to control vegetative growth without affecting seed yield or quality in deciduous seed orchards.

Index words: Seed orchards, seed quality, seed yield, growth regulator, uniconizole, paclobutrazol

Growth Regulators Used in this study: paclobutrazol, ((2RS,3RS)-1-4(4-chlorophenyl)-4,4-dimethyl-2-1,2,4-triazol-1-yl) pentan-3-ol); uniconizole, ((E)-1-(p-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl)-1-penten-3-ol).

Introduction

Seed orchards are used to package and mass produce superior genotypes (17). To date most seed orchards are of coniferous species. Some nursery managers have established seed orchards for selected angiosperm shrub species (Sheffield, personal communication). High fertility, supplemental irrigation and pest control are used to promote early seed production and maintain high seed yields. Vegetative growth under these conditions is vigorous. In seed orchards of small tree or shrub species vigorous growth is not a problem, however, with trees, vigorous growth makes orchard operations challenging.

[1]Received for publication October 6, 1988; in revised form February 22, 1989. Salaries and research support provided by State and Federal Funds appropriated to the Ohio Agricultural Research and Development Center, The Ohio State University. Journal Article No. *245-87*.

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Angiosperm fecundity tends to be greater than that of conifers; it has been estimated that 10 to 15 sycamore trees (on 30 by 30 ft spacing) would produce one million plantable seedlings yearly, while 100 loblolly pine trees would be required to produce a similar number of seedlings (J. B. Jett, North Carolina State University, Raleigh, N.C., personal comunication). Thus, a few angiosperm trees could produce the entire seed supply for the U.S. nursery industry. Caution should be raised at the potentially low genetic base. However, to plant enough trees to insure a broad genetic base (a minimum of 30 to 40 is suggested) would require at least one acre. A means of controlling tree size without decreasing seed yield (per unit land area) or seed quality would simplify orchard operations and allow many genotypes to be planted in a small space.

Chemical growth regulators are one means of controlling vegetative growth. Recently an inhibitor of gibberellin biosynthesis, paclobutrazol, has proven effective in controlling vegetative growth of fruit trees (2, 4, 5, 6, 8, 12, 13) and also of pecan (16) and black walnut (9). Trunk drench applications dramatically shortened internodes (8, 15, 16). Typically greater reductions in shoot length occurred the

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season after application than in the year of application (5, 11). Less affected by paclobutrazol applications were leaf size, leaf number, flower number and fruit quality (4, 5, 8, 14, 15). Photosynthesis, on a unit leaf area basis, was not affected by paclobutrazol application (14) but total tree photosynthesis may be decreased due to reduced leaf number and size (3). Seedlings treated with paclobutrazol tended to have decreased shoot/root ratios (10, 15, 16).

Foliar application of paclobutrazol reduced apple fruit size and seed number the year of application (4). The following year flowering was not affected and fruit size was increased. No information was available on seed number the year following application.

Ideally a woody angiosperm clonal seed orchard should be used to study the effects of growth retardants on seed yield and seed quality; mother tree significantly affects both seed yield and quality. Unfortunately, replicated clonal seed orchards do not exist for commercially important landscape trees. However, clonal apple orchards exist at the Ohio Agriculture and Research Development Center, Wooster and could be used for seed yield and quality studies. Further, 3 year data on the effects of paclobutrazol and uniconizole on vegetative growth and fruit yield of two apple clones were available (Ferree, unpublished data). Results from experiments with apple trees may be used to predict effects of these compounds on vegetative growth, seed yield and quality in commercially important nursery species.

Therefore the following two studies were conducted. In the first study paclobutrazol and uniconizole were applied as trunk drenches to 'Golden Delicious' apple trees and the effects on vegetative growth, seed yield and seed quality three years after application were studied. In the second study the effects of paclobutrazol trunk drenches on vegetative growth, seed yield and seed quality of 'Delicious' apples three seasons after application were studied.

Materials and Methods

Procedures common to both experiments are as follows: All trees were located at the Unit 2 Horticulture Farm, Wooster, OH. Trees were spaced 3.7 m (12 ft) within row and 6.1 m (20 ft) between rows. A 3 m (10 ft) wide clean cultivated strip was maintained under the trees with sod between rows. During the study period all trees received corrective fertilizer applications to maintain sufficient nutrient levels in the foliage. A commercially recommended pesticide schedule was followed. All trees were pruned according to recommended practices. No supplemental irrigation was applied. The soil type was a fine mixed mesic Typic Fragiudalf.

Experiments 1 and 2 were performed in separate orchard blocks. Treatments within experiments were arranged in a completely random design with 6 single tree replications.

Experiment 1. On April 19, 1984 either uniconizole or paclobutrazol were applied as trunk drenches on 16 year old 'Golden Delicious' apples grown on M.26 rootstocks. For each chemical, 4 g ai/tree in 1500 ml (approximately 1.5 quarts) of solution was poured around the trunk of each tree. Control trees were left untreated. Each fall trunk diameters and the lengths of 25 randomly selected terminal shoots per tree were measured.

Fruit were harvested, counted and weighed on an individual tree basis. In 1986, 20 randomly selected apples per tree were cut open and the number of filled and aborted seed in each fruit determined.

In 1986, seeds from additional randomly selected apples were extracted to obtain at least 400 filled seed/tree. From this sample, 50 seed were placed on moist KimPac germination paper in each of 4 $12 \times 17 \times 10$ cm ($4.5 \times 7 \times 4$ in) plastic germination boxes. Seed were then stratified at 3°C (35°F) for 90 days.

On February 24, 1987 seed were placed in one of two Conviron growth chambers under the following conditions: 25°C −1°C (76 + 1.5°F), 16 hour light period of 800–1000 klux from cool white fluorescent lamps with at least 85% relative humidity. At approximately two day intervals for the next 22 days the number of normal germinated seeds were counted. A seed was considered normal and germinated when the radicle was greater than 0.5 cm (0.2 in) long and white, cotyledons green and displayed parallel to the germination medium.

The remaining extracted filled seed were stratified under similar conditions. On February 13, 1987 two replicates of 13 seed were sown on Metro Mix 350, a pine bark:peat:vermiculite growing medium, in Super Cell plastic containers. The seeds were covered with 0.5 cm (0.2 in) sand and placed in a heated greenhouse to germinate under the following conditions: natural photoperiod and 25/15°C (76/60°F) day/night temperature. Seedlings were watered as needed and fertilized weekly with 200 ppm N from 20N–8.7P–16.6K (20–20–20) water soluble fertilizer.

Date of seedling emergence (cotyledons green, separated and displayed parallel to the medium surface) was recorded daily. Seedling height was measured 26, 38 and 49 days after sowing. On day 49 after sowing, the medium was washed from the seedling root systems, root collar diameter measured, seedlings oven dried at 70°C (158°F) for one week, and individual dry weights recorded.

Experiment 2. 'Delicious' apple trees, Red Prince strain, 16 years old on M.26 rootstocks, were treated with trunk drenches of 0, 2, 4, or 8 g (ai) of paclobutrazol/tree. For all treatments, 1500 ml (approximately 1.5 qts) of solution was poured around the trunk base on April 25, 1984. Procedures for obtaining trunk diameter, shoot length, number and weight of fruit, seed count, germination test and seedling growth were as described for the 'Golden Delicious' apple trees, fruits, seeds and seedlings.

Data from the two experiments were analyzed separately using the Oneway or ANOVA procedures contained in SPSS/PC+ (7). Means were separated using Scheffe's test contained in SPSS/PC+. For non-significant effects in seed and seedling quality tests the probability of obtaining a larger F-value under the null hypothesis was reported. No statistical test was performed for the estimated number of filled seed/tree; the product of the number of filled seed/fruit and the number of fruit/tree.

Results and Discussion

Experiment 1. Shoot length of 'Golden Delicious' apple trees was not affected by trunk drench applications in the year of application (Table 1). Shoot growth was significantly less in treated trees than in untreated tree during the second and third years after application. Differences in shoot growth were most pronounced in 1985; shoot lengths for paclobutrazol and uniconizole treated trees were 37% and

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Table 1. Average shoot length and number of fruit per tree of 'Golden Delicious' apple trees treated with paclobutrazol or uniconizole 4 g ai/tree as a trunk drench in 1984.

Parameter	Year	Growth regulator		
		Control	Uniconizole	Paclobutrazol
Shoot length (cm)	1984	26.8a[z,y]	29.4a	25.7a
	1985	30.7b	17.2a	11.4a
	1986	31.3b	21.8a	24.3a
	Average	29.6b	22.8ab	20.4a
Fruit number	1984	126a	106a	113a
	1985	1169b	965ab	897a
	1986	129a	147a	138a
	Average	474b	406ab	383a

[z]Shoot length is the mean of 25 terminal shoots in each of six trees.

[y]Means within a row followed by the same letter or letters are not significantly different from each other, Scheffe's test, 0.05 level.

56%, respectively, of the control shoot length. The three year total trunk diameter increase was decreased by uniconizole applications, where application of paclobutrazol did not affect trunk diameter increase compared to untreated control trees (23, 18 and 22 cm^2 for control, uniconizole and paclobutrazol, respectively).

Paclobutrazol applications decreased fruit number in 1985 and tended to increase fruit number 1986 (Table 1). Fruit number averaged over the three year period was greater in untreated trees than in treated trees. Applications of paclobutrazol or uniconizole did not affect average fruit weight (data not presented).

There was no difference in total seed/fruit between treated and untreated 'Golden Delicious' trees (Table 2). The number of filled seed/fruit tended to be greater in fruit from treated trees than in fruit from untreated trees. The number of aborted seed/fruit was significantly less in fruit from paclobutrazol treated trees than in fruit from untreated trees. Estimates of filled seed/tree were 124% (uniconizole) and 118% (paclobutrazol) greater in treated trees than in untreated trees, again due to greater numbers of fruit per tree. It is not known what the estimated number of filled seed per tree was in 1984 and 1985 when the number of fruit per tree was greater in untreated trees than treated trees.

There was no difference between seed collected from treated 'Golden Delicious' trees and seed collected from untreated trees in cumulative germination or final germination (data not presented).

There were no differences among treatments in days to emergence ($p = 0.76$), seedling heights at 26, 38 or 49 days from seeding ($p = 0.06$, 0.18 and 0.08, respectively), root collar diameter ($p = 0.13$) and final dry weight of seedlings ($p = 0.91$).

Experiment 2. Paclobutrazol applications to 'Delicious' apple trees did not affect shoot length the year of application except at the 8 g AI/tree rate (Table 3). Shoot length was significantly reduced the following two years at all rates. The highest rate reduced shoot growth to 3.4% and 32% of the control in the second and third years, respectively. Trunk diameter increase was decreased at the 4 and 8 g ai/tree rates (15 vs 22 for the 4 and 8 vs 0 and 2 ai/tree rates).

Fruit number on treated 'Delicious' trees was higher than untreated trees in 1985 and 1986 and for the three year average (Table 3). There were no differences in fruit number in 1984. Fruit number was increased over the control by 113% in 1984 and by 167% and 152% in 1985 and 1986, respectively, for the 2 g ai/tree rate.

The number of filled ($p = 0.99$), aborted ($p = 0.33$) or total number of seed/fruit ($p = 0.33$) in 1986 was not affected by 1984 paclobutrazol applications. However, the estimated number of filled seed/tree in treated trees was increased 153% to 157% compared to untreated trees. The increase can be attributed to greater numbers of fruit/tree; the number of filled seed per fruit averaged 5.5 for all treatments.

Cumulative germination of seed collected from trees receiving 4 g ai/tree was less than that of seed collected from trees given 0, 2 or 8 g ai/tree (Table 4). Final percent germination was lowest for seed collected from trees receiving 4 g ai/tree.

Table 2. Fruit and seed yield in 1986 of 'Golden Delicious' apple trees treated with paclobutrazol or uniconizole at 4 g ai/tree as a trunk drench in April 1984.

Growth regulator	No. fruit/tree	No. Seed/fruit			Filled seed %	Estimated Filled seed per tree
		Filled	Aborted	Total		
Control	127 A[z]	6.8 A	2.6 A	9.4 A	72 A	864
Uniconizole	147 A	7.3 A	2.3 AB	9.6 A	76 A	1073
Paclobutrazol	138 A	7.4 A	1.9 B	9.3 A	80 B	1021
Prob. > F value	0.41	0.06	0.03	0.20	0.04	

[z]Means within a column followed by the same letter are not significantly different from each other, Scheffe's test, 0.05 level.

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Table 3. Average shoot length and number of fruit per tree for 'Delicious' apple trees treated with paclobutrazol as a trunk drench in 1984.

Parameter	Year	Paclobutrazol (g ai/tree) 0	2	4	8
Shoot length (cm)	1985	35.0b[z,y]	33.8b	36.2n	28.2a
	1985	37.3b	18.8a	6.5a	1.3a
	1986	36.1b	29.1b	26.5ab	11.7a
	Average	36.1b	27.7ab	23.1ab	13.7a
Fruit number	1984	400a	455a	450a	389a
	1985	797a	1332b	1258b	1370ab
	1986	88a	134b	135b	134b
	Average	428a	641b	614b	631b

[z]Shoot length is mean of 25 terminal shoots in each of six trees.

[y]Means within a row followed by the same letter or letters are not significantly different from each other, Scheffe's test, 0.05 level.

There were no significant differences among treatments in days to emergence ($p = 0.16$), height at 26, 38 or 49 days from seeding ($p = 0.89$, 0.44 and 0.20, respectively), final root collar diameter ($p = 0.34$) or final dry weight ($p = 0.40$) of the seedlings.

In both experiments paclobutrazol and uniconizole trunk drenches significantly reduced shoot elongation in 1985 and 1986. Application of paclobutrazol reduced 'Delicious' shoot length by 19% to 68% of the control, whereas 'Golden Delicious' shoot length was reduced by 22% and 30% for paclobutrazol and uniconizole, respectively, treated trees. In both experiments paclobutrazol and uniconizole increased the number of filled seed/tree compared with control trees by increasing the number of fruit per tree. With 'Delicious' apple trees paclobutrazol increased fruit number/tree in each of the three years. However, with 'Golden Delicious' increased numbers of fruit/tree occurred only in the third year of the study.

The increased numbers of filled seed per tree produced on paclobutrazol and uniconizole treated trees were of similar quality and seedlings of similar vigor compared with seed and seedlings from untreated trees. The effects of these two chemicals on vegetative growth, seed and seedling production and quality should be studied on commercially important nursery species.

Significance to the Nursery Industry

Seed orchards can be used to produce consistent crops of genetically superior seed. Growth retardant chemicals such as paclobutrazol and uniconizole can significantly reduce plant size without sacrificing seed yield or seed quality. Chemically dwarfed trees would simplify orchard operations and allow planting of many trees per acre. If care is practiced in the selection of seed orchard trees, then many genetically diverse trees can be planted in a limited space, ensuring a broad genetic base in the resulting seed.

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Table 4. Cumulative germination of 'Golden Delicious' apple seed collected from the 1986 fruit crop after treatment with Paclobutrazol applied as a trunk drench in 1984.

Paclobutrazol g AI/tree	Cumulative germination (days after placement at 30°C)[z] 3	5	8	10	12	15	17	19	22	% Germination
0	2.6	16.1	32.8[z]ab[y]	38.6	43.2ab	43.6ab	43.9ab	42.2ab	44.3ab	87ab
2	1.4	14.5	35.0b	41.7	45.6b	46.0b	46.1b	46.2b	46.2b	92b
4	1.4	9.0	26.4a	36.1	38.3a	38.7a	38.9a	39.1a	39.1a	78a
8	1.3	12.5	30.6ab	37.7	41.2ab	41.8ab	41.9ab	41.9ab	41.9ab	84ab
Prob >F	0.45	0.08	0.02	0.22	0.005	0.003	0.002	0.002	0.002	0.002

[z]Mean number of four seed replications.

[y]Means within a column followed by different letters are significantly different, Scheffe's test, 0.05 level.

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Influence of Root-zone Temperature on Growth of *Ailanthus altissima* (Mill.) Swingle[1]

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Abstract

Growth of tree-of-heaven (*Ailanthus altissima* (Mill.) Swingle) seedlings was evaluated during a 28-day exposure to constant root-zone temperatures of 18°, 24°, 30°, and 36°C (64°, 75°, 86°, and 97°F). Leaf area, stem length, root-to-shoot ratio, and shoot and root dry weights were greatest among plants with 24°C (75°F) root zones. Diminished growth among plants at high root-zone temperatures was associated with reduced leaf conductance. After 14 days of treatment, leaf diffusive resistance of plants in the 36°C (97°F) regime was eight times greater than that of plants with 24°C (75°F) root zones. Regulation of leaf gas exchange among plants with 36°C (97°F) root zones probably contributed to the maintenance of moderate leaf water potentials but limited the fixation of carbon necessary to sustain growth.

Index words: urban horticulture, root temperature stress

Introduction

Trees physically and aesthetically enhance the habitability of urban areas. Unfortunately, many city trees are plagued by symptoms of stress that decrease their visual quality and longevity. An increased heat load is characteristic of many urban mesoclimates and may contribute to the decline of urban trees. Commonly called the heat-island effect, mean annual air temperatures in metropolitan centers typically exceed those in surrounding areas by 1°C to 4°C (2°F to 7°F) (2, 10, 15). Within cities, diverse physical characteristics of different planting sites probably result in temperature regimes unique to the microclimate of each tree. For example, during the same 24-hr period in New York City, maximum air temperature near tree canopies in Central Park was 32°C (90°F), while canopy temperatures in Manhattan were as high as 41°C (106°F) (17).

Although urban atmospheric temperatures have been studied for many years, the relationship between urbanization and below-surface temperature has received little attention. Recently, root-zone temperatures 5 to 50 cm (2 to 20 in) beneath the surface at street tree planting sites in downtown Lafayette, Indiana, were reported to average 7°C (13°F) higher than those in a nearby wooded area (6). Temperatures exceeding 30°C (86°F) were common in urban Lafayette root zones where direct solar radiation was incident on soil surfaces covered with concrete and asphalt (4). Given the prevalence of these surface materials in most urban areas

[1]Received for publication November 11, 1988; in revised form February 22, 1989. Journal Paper No. 11811 of the Purdue Univ. Agr. Expt. Sta. Research supported by Horticultural Research Institute, Inc., 1250 I Street N.W., Suite 500, Washington, D.C. 20005.

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