J Plant Growth Regul (1989) 8:167–174

Journal of
Plant
Growth
Regulation

Transitory Growth Control of Apple Seedlings with Less Persistent Triazole Derivatives

Eric A. Curry and A. Nathan Reed

USDA, Agricultural Research Service, Tree Fruit Research Laboratory, Wenatchee, Washington 98801, USA

Received July 30, 1988; accepted October 11, 1988

Abstract. Paclobutrazol, triapenthenol (RSW0411), and BAS111 were applied to 4-week-old Delicious apple seedlings (*Malus domestica* Borkh.) as a root drench at 0.1, 1.0, and 10.0 mg per plant. Paclobutrazol eliminated shoot extension growth for 8 weeks at all three rates. RSW0411 controlled shoot elongation only at the highest rate. BAS111 produced the widest response, with shoot growth ranging from 38% to 93% of controls for the highest and lowest rates, respectively. Generally, leaf area decreased and leaf density increased with increasing rates of all chemicals. Root weight of plants treated with paclobutrazol nearly doubled but increased only slightly with RSW0411 and BAS111. Chemical analysis of the leaf tissue 8 weeks after treatment showed paclobutrazol levels highest, followed by RSW0411 and BAS111.

In deciduous tree fruit production, control of excessive vegetative growth is necessary to maximize production efficiency (Cain 1970, Elfving 1988). Although some shoot growth is essential to maintain overall vigor of the tree and ensure adequate yield, excessive growth may reduce both yield and fruit quality (Cain 1971, Forshey 1970). Cultural methods used to control growth have included the use of dwarfing and semidwarfing rootstocks, dormant and summer pruning, root pruning, trunk girdling, scoring and ringing, limb bending, deficit irrigation and growth-regulating chemicals (Ferree, 1988).

Paclobutrazol is one of several triazole derivatives that block gibberellin (Graebe 1982, Heden and Graebe 1985) and sterol biosynthesis (Dalziel and

Mention of a trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products that may also be suitable.

Lawrence 1984, Henry and Sisler 1981) and reduce internode elongation. This chemical was first applied foliarly to mature apple trees in 1979 at 2,000 mg L^{-1} and resulted in a reduction in terminal shoot growth for several years as well as reduced leaf area and fruit size (Williams 1984). The long-term effects were largely due to residual chemical washing off the leaves and wood by rain and irrigation and being taken up through the root system (Williams 1984, Williams et al. 1986). Because of the chemical's high systemic activity and its long-lasting effects, the degree of growth reduction became very difficult to regulate consistently. Therefore other chemicals of a less persistent nature were considered. The efficacy and relative biological activity on different crops of several triazole derivatives have been reviewed (Curry et al. 1987, Radamacher and Jung 1981, 1986).

Preliminary experiments with sunflower *Helianthus annus* indicated certain triazoles had different effects on growth and development (Curry and Reed 1987). In this study, three triazole derivatives with varying degrees of efficacy were selected to determine if they would induce transitory control of vegetative growth of apple trees and if the degree of vegetative growth control was related to the triazole level in the tissue.

Materials and Methods

Seeds from fruit of open pollinated Delicious apples were surface sterilized with 2% NaOCl for 5 min, mixed with moist sterile sand, and stratified in the dark for 1400 h at 5°C. The sprouted seeds were planted in a 1:1 mixture of sand and vermiculite in 10 × 20 cm pots when the radicle length was about 3 mm. The plants were placed in a controlled environment with a temperature of 25°C, relative humidity of approximately 30%, and a photoperiod of 16 h provided by cool white fluorescent light at an average light intensity (PAR) of 240 $\mu mol\ m^{-2}s^{-1}$. Forty-five seedlings of uniform appearance, approximately 10 cm tall, received 0.1, 1.0, or 10.0 mg of either (1) paclobutrazol (ICI Americas), (2) RSW0411 (triapenthenol, Mobay Chemical Corp.), or (3) BAS111 (BASF Corporation) (Fig. 1) administered as a soil drench in 50 ml of water. There were five replications per treatment in a randomized complete block design. One treatment (five plants) consisted of 0 dosage and served as the control for all other treatments. Thereafter, each seedling was watered as needed with a nutrient medium containing (in mg/L) 590 $Ca(NO_3)2 \cdot 4H_2O$, 210 KNO_3, 56 K_2HPO_4, 308 $MgSO_4 \cdot 7H_2O$, 6 FeEDTA $\cdot$ $5H_2O$; (in μl/L) 438 $MnSO_4 \cdot 5H_2O$, 442 $ZnSO_4 \cdot 7H_2O$, and 563 H_3Bo_3 (Mori 1966). The field capacity of the rooting medium was never exceeded.

Detailed measurements of plant growth were taken periodically throughout the duration of the experiment. Shoot length was measured from the cotyledonary node to the youngest visible node. Plants were removed 55 days after treatment, the shoots weighed, the roots washed and weighed, and the leaves removed, weighed, and lyophilized. Values presented in the figures are based on fresh weight. Leaf area was determined on the 10 most distal leaves by a model LI 3100 Area Meter (LI-COR, Inc.). Leaf density was calculated by dividing the individual leaf fresh weight by the area. The lyophilized leaf tissue

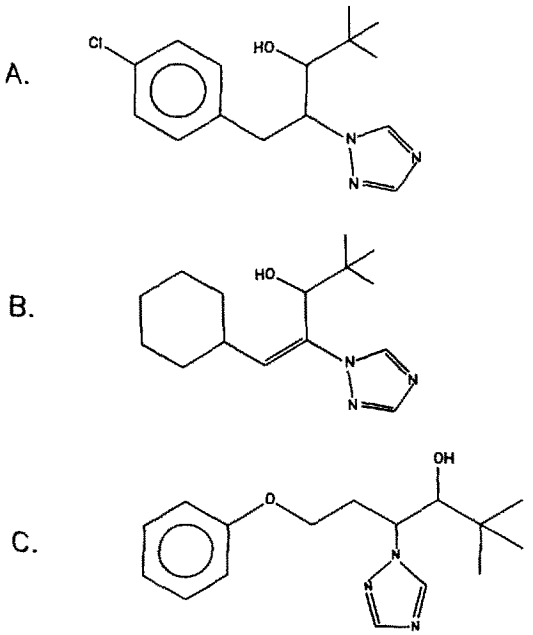

Fig. 1. Molecular structures of (A) paclobutrazol[(2RS,3RS)-1-(4-chlorophenyl)-4,4-dimethyl-2-(1,2,4-triazol-1-yl)-pentan-3-ol], MW 293.8; (B) triapenthenol [(E)-(RS)-1-cyclohexyl-4,4-dimethyl-2-(1H-1,2,4-triazol-l-yl) -pent-1-en-3-ol], MW 263.4; and (C) BAS111 [1-phenoxy-5,5-dimethyl-3-(1,2,4-triazol-l-yl)-hexan-5-ol], MW 289.4.

was analyzed for parent triazole using a capillary GC equipped with an NP detector according to a previously published method (Reed 1988).

Results

Generally, trees treated with paclobutrazol showed a similar degree of growth inhibition regardless of dosage. Those treated with RSW0411 showed a slight dosage response. The greatest response to dosage was on BAS111-treated trees, where shoot length ranged from 38% to 93% of the controls (Fig. 2).

The average number of leaves was reduced from 18 on control trees to 16 and 13, respectively, for trees treated with paclobutrazol and RSW0411 at 10.0 mg per tree. At lower doses of paclobutrazol and RSW0411 or with BAS111, there was no difference (data not shown). Generally, as dosage increased, the average area per leaf decreased (Fig. 3A). Even though increasing the dosage of paclobutrazol did not further reduce shoot elongation, leaf area continued to decrease (Fig. 3A). At 0.1 mg per tree, RSW0411 reduced shoot growth to 45% of controls without reducing leaf area. Leaf area was reduced with RSW0411 at 1.0 and 10.0 mg per tree and with BAS111 at 10 mg per tree. Generally, leaf density increased as leaf size decreased (Fig. 2B).

Paclobutrazol at 0.1–1.0 mg per tree significantly increased the weight of roots over the controls (Fig. 4A). RSW0411 and BAS111 induced no significant increase in root weight, although trees treated with RSW0411 and paclobutrazol showed signs of root clubbing at the two higher dosages.

Root/shoot ratios (R/S) for all three chemicals were greatest at 10.0 mg per

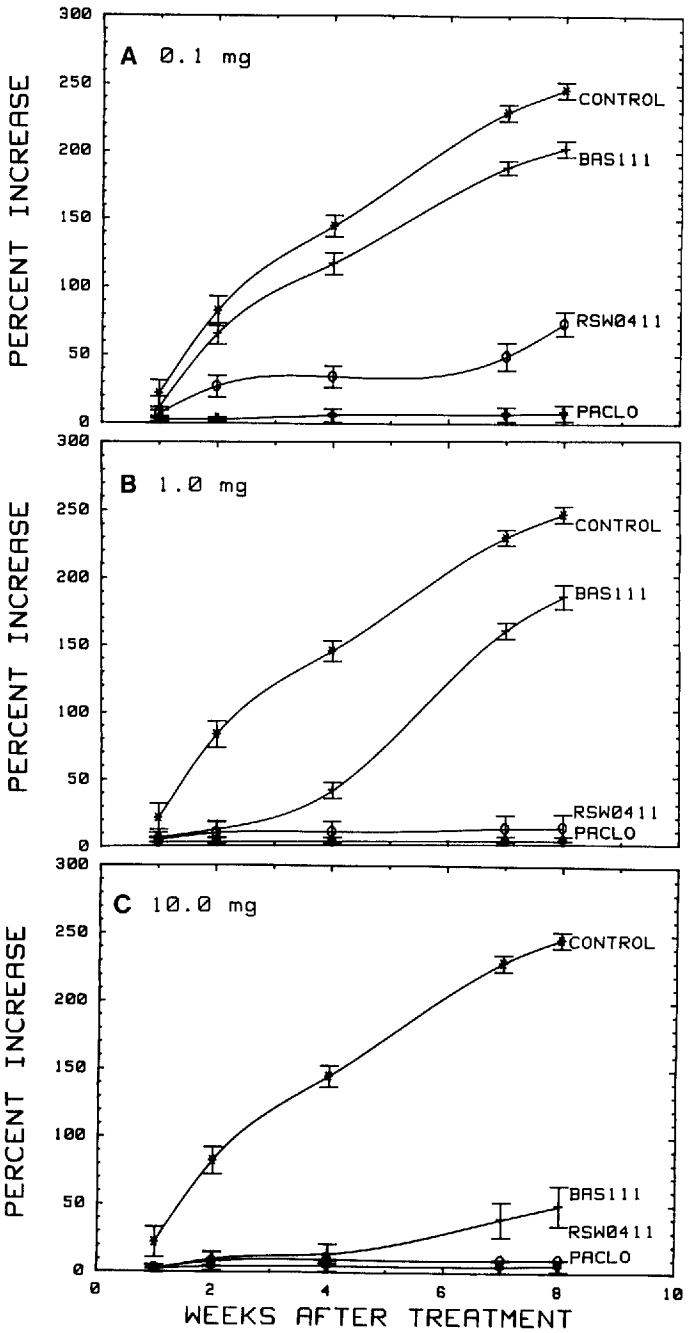

Fig. 2. Percent increase in shoot growth of Delicious seedlings receiving (A) 0.1 mg, (B) 1.0 mg, or (C) 10.0 mg per tree of either paclobutrazol, RSW0411, or BAS111. Bars represent ± SE.

tree. At this rate R/S for RSW0411 was more than three times that of the control (Fig. 4B).

At all three dosages, trees treated with paclobutrazol contained the highest residual triazole level (Table 1). At 0.1 mg per tree residual triazole levels from

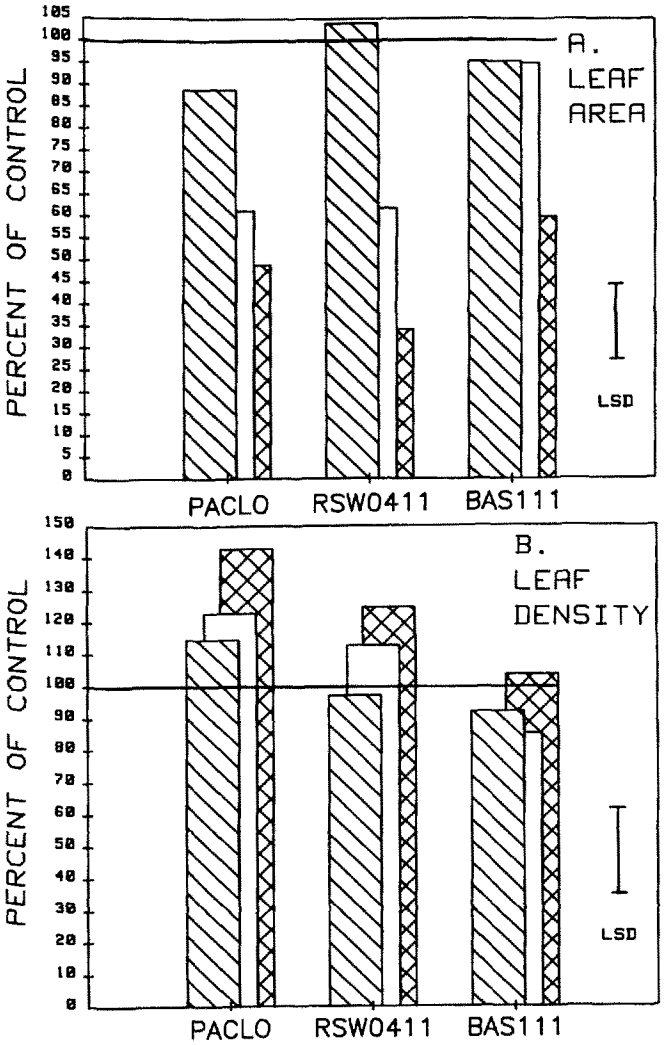

Fig. 3. (A) Leaf area and (B) leaf density (expressed at percent of control) of Delicious apple seedlings treated with paclobutrazol, RSW0411, or BAS111 at 0.1 (▨), 1.0 (□), or 10.0 (▩) mg per plant. Bars represent LSD at 5% level.

treatment with paclobutrazol and RSW0411 were similar, whereas the level from BAS111 treatment was considerably less. At the highest dosage, residual levels of paclobutrazol and RSW0411 were more than 50 times that of BAS111.

Discussion

Paclobutrazol applied as a drench to the rooting medium eliminated extension growth of apple seedlings for the 8-week duration of the experiment. Growth control was transitory with both RSW0411 and BAS111 treatment, with BAS111 being the less effective chemical. These data suggest that (1) the environmental half-life of RSW0411 and BAS111 is less than that of paclobutrazol, (2) these compounds are metabolized more quickly in the tissues, or (3) they

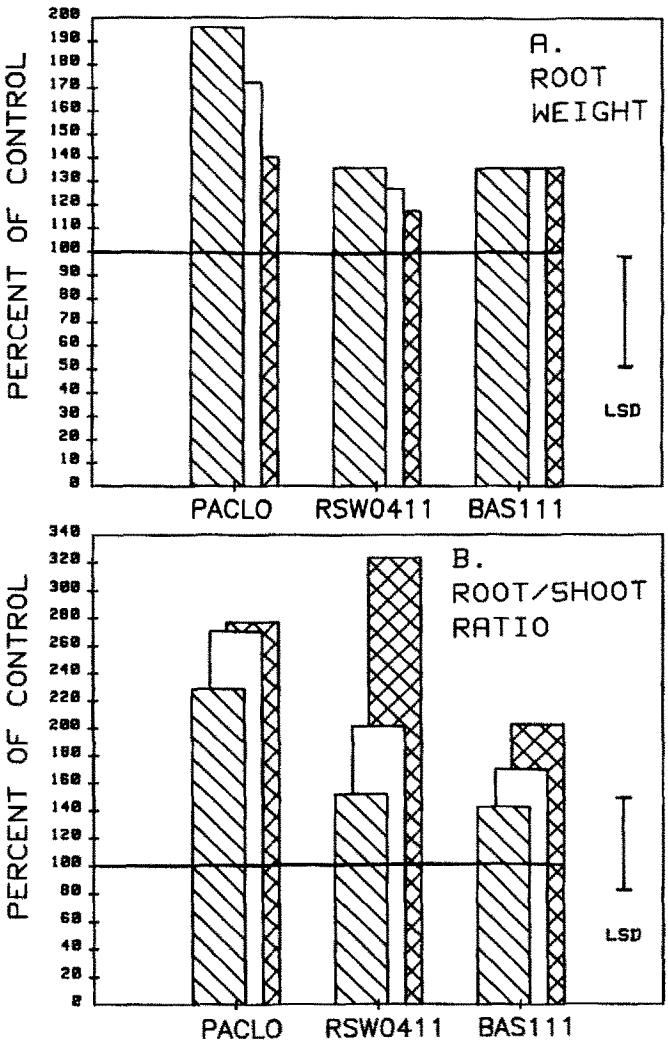

Fig. 4. (A) Root weight and (B) root-to-shoot ratio (expressed as percent of control) of Delicious apple seedlings treated with paclobutrazol, RSW0411, or BAS111 at 0.1 (▨), 1.0 (□), or 10.0 (▩) mg per plant. Bars represent LSD at 5% level.

are taken up or transported to the meristematic tissue more slowly by either the root or xylar tissues. The amount of chemical remaining in the rooting medium after 8 weeks was not analyzed. The duration of the experiment, however, may have been long enough to exceed the environmental half-life of the less persistent triazoles (Lever 1986), thereby reducing the chemical available for uptake. It is likely that the metabolism of these chemicals within the tissue also varies greatly, resulting in the wide range in leaf triazole concentrations. The high triazole concentrations in leaves of trees treated with the high dosage of both RSW0411 and paclobutrazol may be due to changes in root morphology that facilitate chemical permeability and uptake. Further work is necessary to determine how metabolism is affected and whether root uptake is more selective for one triazole over another.

Table 1. Triazole residues from lyophilized leaf tissue taken from Delicious apple seedlings 8 weeks after treatment.

Rate	μg/g DW		
	Paclobutrazol	RSW0411	BAS111
0.1 mg/tree	1.54 B	1.23 B	0.04 B
1.0 mg/tree	31.32 B	8.61 B	0.18 B
10.0 mg/tree	582.47 A	229.78 A	4.59 A

Values within columns followed by the same letter are not significantly different by LSD, 5% level.

Recently, it was shown the isomers of such triazoles as paclobutrazol and RSW0411 exhibit different levels of both growth-regulating and fungicidal activity (Köller 1987a,b). These reports also suggest that sterol biosynthesis inhibition may be responsible for both inhibition of fungal growth and plant growth reduction. It is not known whether uptake or metabolism is selective for specific isomers. Further work with individual isomers is needed to determine which specific metabolic pathways are most closely linked with certain physiological changes.

Annual foliar applications of high rates of paclobutrazol to apple trees in several parts of the world have resulted in excessive reductions in shoot length, leaf area, and fruit size in years following treatment due in part to material dripping onto the soil and being taken up by the roots. However, with chemicals that are more labile or that have higher degradation rates within the plant tissue, growth control via the secondary mode of entry, namely the root system, would be a minor factor. Thus, foliar application would become much more attractive. The likelihood of foliar application might also increase if the isomer(s) specific to GA biosynthesis inhibition were used exclusively, thereby enabling growth control with reduced rates.

As deciduous tree fruit orchards continue to increase in density, the problems of controlling tree growth will become more acute. Growth-controlling rootstocks or scions, although offering a good measure of vegetative growth control, are in themselves insufficient. Thus, there remains the need for other methods to consistently regulate vegetative growth.

References

Cain JC (1970) Optimum tree density for apple orchards. HortScience 5:232–234

Cain JC (1971) Effects of mechanical pruning of apple hedgerows with a slotting saw on light penetration and fruiting. J Am Soc Hort Sci 96:664–667

Curry EA, Reed AN (1987) Partial reversion with GA_3 of physiological changes induced by paclobutrazol and RSW0411 on plants with strong apical dominance. Proc Plant Growth Regul Soc Am 14:160–165

Curry EA, Williams MW, Reed AN (1987) Triazole bioregulators to control growth of fruit trees: An update. Bull Plant Growth Soc Am 15:4–7

Dalziel J, Lawrence DK (1984) Biochemical and biological effect of kaurine oxidase inhibitors such as paclobutrazol. Br Plant Growth Regul Group Monogr 11:43–47

Elfving DC (1988) Economic effects of excessive vegetative growth in deciduous fruit trees. HortScience 23:461–463

Ferree DC (1988) Role of rootstocks and spur-type scions for controlling vegetative growth of apple and peach tree growth. HortScience 23:464–467

Forshey CG (1970) The use of Alar on vigorous 'McIntosh' apple trees. J Am Soc Hort Sci 95:64–67

Graebe JE (1982) Gibberellin biosynthesis in cell-free systems from higher plants. In: Waring PF (ed) Plant growth substances 1982. Academic Press, London, pp 71–80

Heden P, Graebe JE (1985) Inhibition of gibberellin biosynthesis in cell-free homogenates of *Curcubita maxima* endosperm and *Malus pumila* embryos. J Plant Growth Regul 4:111–122

Henry MJ, Sisler HD (1981) Inhibition of ergosterol biosynthesis in *Ustilago maydis* by the fungicide 1-[2-(a2,4-dichlorophenyl)-4-ethyl,1,3-dioxolan-2-ylmethyl] 1H-1,2-4-triazole. Pestic Sci 12:98

Köller W (1987a) Isomers of sterol inhibitors: Fungicidal effects and plant growth regulator activities. Pestic Sci 18:129–147

Köller W (1987b) Plant growth regulator activities of stereochemical isomers of triadimenol. Physiol Plant 71:309–315

Lever BG (1986) 'Cultar'—a technical overview. Acta Hort 179:459–466

Mori H (1966) Technique for growing deciduous fruit trees in water culture. J Am Soc Hort Sci 88:253–261

Radamacher W, Jung J (1981) Comparative potency of various synthetic plant growth retardants on the elongation of rice seedlings. J Agron Crop Sci 150:363–371

Radamacher W, Jung J (1986) GA biosynthesis inhibitors—an update. Proc Plant Growth Regul Soc Am 13:102–114

Reed AN (1988) Quantitation of triazole and pyrimidine plant growth retardants. J Chromatogr 438:393–400

Williams MW (1984) Use of bioregulators to control vegetative growth of fruit trees and improve fruiting efficiency. Acta Hort 146:97–104

Williams MW, Curry EA, Greene GM (1986) Chemical control of vegetative growth of pome and stone fruit trees with GA biosynthesis inhibitors. Acta Hort 179:453–458