REGULATION OF TREE GROWTH AND DEVELOPMENT WITH TRIAZOLE COMPOUNDS

by Tim D. Davis

During the past ten years, much research has been conducted on the response of plants to triazole-type plant growth regulators. This research has included work with a variety of shade and fruit trees. The objective of this brief article is to summarize results of triazole growth regulator research conducted with trees during the past several years. Rather than presenting a detailed catalogue of past research, major findings are highlighted.

Much of what is known about the response of trees to triazoles is based on research with fruit trees. There are at least two reasons for this. First, fruit crops have a clearly demonstrable dollar value that provides considerable economic incentive to agrichemical companies for development of growth regulators. Second, fruit trees for research purposes are available in uniform orchard blocks which facilitates experimental design and reduces variability. Unfortunately, it is more difficult to find uniform blocks of shade trees for experimental purposes. For these reasons, some extrapolation of fruit tree data to shade trees is needed.

Before discussing tree responses to triazoles, a brief description of the general properties of these compounds is in order. Triazoles such as paclobutrazol (trade name = Clipper) and uniconazole (proposed trade name = Prunit) work primarily by inhibiting gibberellin biosynthesis and are among the most active and persistent of all plant growth retardants. Only relatively small dosages are needed to control growth for an extended period of time. These compounds are xylem-mobile; little transport seems to occur in the phloem. Once inside a tree, triazoles are broken down quite slowly. Although the carriers that are used to deliver triazoles to trees (e.g. alcohol) may cause some phytotoxicity, the triazoles themselves seldom cause damage. In many cases, leaves on treated plants are darker green than controls. For these reasons, triazoles have considerable potential as tree growth regulators.

Shoot Growth Inhibition

There is ample evidence to show that triazoles are potent inhibitors of shoot growth in a wide range of plant species (5). The challenge with trees is to deliver the growth retardant to the site of active growth (i.e. the meristems) in a timely, uniform manner. Because trees are large in stature and have a relatively complex vascular system, delivery is not as simple as with other plants. If applied too late in the growing season, the growth retardant effects may not be evident until the following growing season. The exact time that is "too late" has not been critically determined for any species and will probably depend somewhat upon tree size, method of application, location, and weather.

Once the triazoles begin inhibiting tree growth, their effect may persist anywhere from one to several years (Table 1). This depends upon the dosage administered. Unfortunately there is not much information available regarding the long-term effects of a wide range of triazole dosages on shoot growth. Few of the many published studies on the effects of triazoles on tree growth have been carried out long enough to determine when growth inhibition subsided. This type of information is needed in formulating dosage recommendations.

A less well-known triazole-induced phenomenon in trees is that of increased shoot growth following subsidence of growth inhibition. This has been observed in paclobutrazol-treated peach (1, 2) and apple (21) trees. Although the basis for this accelerated growth is unclear, it may be related to the accumulation of carbohydrates and minerals during the period of shoot growth inhibition which thereafter fuels rapid growth when the retardant dissipates. The consequences of this type of escape growth to the long-term health and value of the tree is not yet clear. Nevertheless, if this phenomenon is widespread, arborists will need to carefully observe treated trees and re-apply the growth retardant before such a growth flush occurs.

Several delivery methods have been devised for trees. At present, trunk injection is generally the most favored method. Hole angle, depth, and distribution are important variables in determining the efficacy of trunk injection (15). A hole angle of 30-45° is generally recommended; greater angles increase the chance of missing the xylem and lower angles may result in high pressure which can damage the tree. Judging the optimum hole depth and distribution is challenging. The holes should be deep enough to penetrate the xylem tissue and distributed so that the growth regulator can be evenly delivered to the canopy. The recommended hole spacing depends upon the species but is generally between 4 and 8 inches (7, 24).

A disadvantage of injection is that it requires that a hole be drilled in the trunk. Although the extent to which this damages the tree is a point of controversy, public perception of the hole is generally negative. One solution to this problem is to seal the hole with a vinyl plug (24). Bark splitting may also be reduced by avoiding injection during the dormant season. Another drawback to injection is that the time required to inject the growth regulator solution varies dramatically among species and time of year. For example, Watson (24) reported that only about 4 minutes were required to inject a black cherry tree but about 28 minutes were needed for white ash. Furthermore, injection times for a vairety of trees ranged from an average of 4 minutes in August and September to 45 minutes in February.

Soil injection and root collar drenches have been used to effectively apply growth retardants to trees (20) but consequent soil residues may be an ecological concern. In theory, bark paints may be useful for applying growth retardants, but thus far success has been limited. Solvents tried have either not been effective in evenly distributing the growth retardant or have caused considerable damage to the bark. Foliar sprays are inefficient and environmentally unacceptable for shade trees, particularly in populated areas.

Even after several years of research, it is still difficult to accurately predict an appropriate triazole dosage for any given tree. Dosage formulas based upon trunk diameter are generally considered the most useful but considerable species and environmental variability still occur. Hence the development of better methods for estimating optimal dosages is needed. A better knowledge of the underlying factors that contribute to variability in tree response to triazole treatment would also be helpful.

In addition to reducing shoot elongation on trees, triazoles sometimes alter shoot orientation (4, 9). In particular, pear shoots have exhibited a horizontal or even downward direction of growth. Although this has not been widely observed in other species, it may result in a "weeping" appearance. Triazoles have not been found to influence leaf coloration or retention in the fall.

Other Effects

In addition to their well-known effects on shoot growth, triazoles have been found to promote flowering in a variety of woody species including some fruit crops (10, 13, 21, 22, 25) and ornamentals (11, 12, 23, 26) (Table 2). This response does no always occur (6, 14) and is probably strongly influenced by dosage and timing of application. In addition to increasing the number of flowers, triazoles have sometimes advanced flowering by several days. This could increase the chances for spring frost damage and suggests that triazoles may influence tree dormancy.

An example, research with cherry indeed has demonstrated altered dormancy characteristics in

Table 1. Duration of growth retardation in various paclobutrazol-treated trees.

Species	*Paclobutrazol treatment*	*Duration of effect*	*Reference*
Fiscus nitida	various trunk paints	1 year	8
Malus domestica (apple)	2 grams•m^{-2} soil surface (drench)	4 years	27
Malus domestica (apple)	1000 mg•liter^{-1} foliar spray	1 growing season	21
Prunus cerasus (tart cherry)	0.5-0.75 g tree soil drench	3 years	22
Prunus persica (peach)	2000 mg•liter^{-1} foliar spray	1 growing season	1
Prunus persica (peach)	2 g tree soil drench	1 growing season	2

paclobutrazol-treated trees (22). The number of growing degree (°C) hours (18) required to reach full bloom was reduced by 700-900 in paclobutrazol-treated trees. Rest intensity (based upon the amount of gibberellic acid needed to induce vegetative budbreak under favorable environmental conditions) was decreased by paclobutrazol. This suggests that paclobutrazol-treated trees were in a less-dormant state than the non-treated controls. It is not clear if this is a widespread phenomenon in triazole-treated trees and work with shade trees is needed. Nevertheless, this work demonstrates that triazoles may do more than simply reduce shoot elongation in trees.

In the previously-mentioned study with cherry trees (22), the altered dormancy characteristics in the paclobutrazol-treated trees were accompanied by reduced mid-winter cold hardiness of the flower buds. The treated trees had mid-winter T_{50} (temperature required to kill 50% of the buds) values that were about 2°C (ca. 4°F) higher than non-treated controls. A similar observation has been made with several other *Prunus* species that were treated with paclobutrazol (16). These findings are in sharp contrast to research with a variety of herbaceous species where paclobutrazol increased cold hardiness (reviewed in 5). Clearly more research is needed to fully understand the basis of triazole-induced alterations in cold hardiness. If reduced cold hardiness is a common tree response to triazoles, damage to flower buds could occur on treated trees that have marginal hardiness for a given locale. There seems to be little evidence that triazoles alter cold hardiness of vegetative buds.

Table 2. Woody species in which flowering has been promoted by paclobutrazol treatment.

Species	*Paclobutrazol dosage*	*Reference*
Camellia x *Williamsii* (camellia)	2 foliar sprays at 500 ppm	26
Fortunella crassifolia (kumquat)	1000 ppm foliar spray	10
Hebe x *franciscana* (hebe)	10 ppm foliar spray	12
Hibiscus rosa-sinensis (hibiscus)	0.1-0.2 mg soil-applied	23
Malus domestica (apple)	1000 ppm foliar spray	21
Prunus avium (sweet cherry)	1.6 g soil-applied	25
Prunus cerasus (tart cherry)	0.5-0.75 g soil-applied	22
Rhododendron indicum (azalea)	25-100 mg soil-applied	11

Preliminary observations by two independent research groups suggest that triazole-treated pear trees have lower insect population densities than their untreated counterparts (3, 17).

To my knowledge no such observations have yet been made with shade trees and it is unclear why triazole compounds should reduce insect populations. It is interesting to note, however, that triazoles have been found to increase hydrocyanic acid potential in sorghum seedlings (19). Hydrocyanic acid potential has been linked to plant defense against predators. Thus triazoles may influence insect resistance by altering host plant defense mechanisms. Much more work is needed to substantiate this possibility, however.

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