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Paclobutrazol Soil Drenches Provide Partial Reductions in Symptoms of Apple Scab of Ornamental Trees and *Guignardia* Leaf Blotch of Horse Chestnut¹

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Abstract

A three year field trial was conducted using established apple (*Malus* cv. Crown Gold) and horse chestnut (*Aesculus hippocastanum* L.) to assess the efficacy of paclobutrazol (PBZ) root drenches against the foliar pathogens apple scab (*Venturia inaequalis* (Cooke) G. Wint.), and *Guignardia* leaf blotch (*Guignardia aesculi* (Peck) VB Stewart). In the case of horse chestnut, pathogen severity of *Guignardia* leaf blotch was less (23–79%) in each of the three-year experimental periods in PBZ-treated trees compared to non-treated controls. Pathogen severity of apple scab was not affected during the first year after PBZ application; however, less (25–73%) disease severity was recorded in years 2 and 3 compared to non-PBZ treated controls. An increased PBZ concentration was associated with lower pathogen severity of both fungal pathogens. Irrespective of species, less pathogen severity in PBZ-treated trees was accompanied with greater leaf chlorophyll fluorescence (16–49%) values as measures of leaf photosynthetic efficiency. Marked differences in growth regulation between apple cv. Crown Gold (tolerant) and horse chestnut (sensitive) were recorded. PBZ applications resulted in less mean stem extension in both tree species but only reduced mean leaf size of horse chestnut. Based on the results of this investigation it is suggested that PBZ root drenches potentially offer a means of reducing the severity of apple scab and *Guignardia* leaf blotch for professionals involved with the nursery industry. However, where a zero pathogen control policy is required supplementary fungicide sprays would be needed. Similarly, the potential loss of aesthetics due to excessive growth regulation needs to be weighed against the benefits of pathogen protection and failure of PBZ to achieve total pathogen control may result in strong selection pressure for PBZ resistance in surviving populations.

Index words: leaf pathogen, disease suppression, growth inhibitor, tree vitality, container production, orchard management.

Species used in this study: apple (*Malus* cv. Crown Gold); horse chestnut (*Aesculus hippocastanum* L.).

Chemicals used in this study: Cultar (paclobutrazol).

Significance to the Nursery Industry

Foliar pathogens such as scab and leaf blotch can be important constraint to the commercial production of ornamental and fruiting trees. Control of these pathogens relies heavily on repeat fungicide sprays (6). Paclobutrazol (PBZ) is a widely used growth inhibitor that possesses fungicidal activity (16, 19). The potential for PBZ to act as a systemic fungicide against woody plant foliar pathogens has received limited study (6). As PBZ is applied as a single soil drench treatment this potentially represents a saving on labor and pesticide application costs compared to conventional repeat spray pathogen control systems. Results of this investigation show that a PBZ soil drench can result in less pathogen severity of apple scab (*Venturia inaequalis* (Cooke) G. Wint.), and *Guignardia* leaf blotch (*Guignardia aesculi* (Peck) VB Stewart) in each of the three-year experimental period compared to non-treated controls. Total (100%) control was, however, not achieved that in turn may result in strong selection pressure for PBZ resistance in surviving populations. In addition, excessive growth regulation was, on occasion, recorded that would have to be weighed against the benefits of pathogen protection particularly if used as a long term practice.

Introduction

Scab (*Venturia inaequalis* (Cooke) G. Wint.) is one of the most common diseases of ornamental and fruiting apples in the UK (11). Symptoms first appear in the spring as small, ol-

ive green lesions on the lower leaf surface. As leaves age, the lesions become darker and more distinct in outline. If heavily infected, the leaf becomes distorted and drops early in the summer. Trees of highly susceptible apple varieties may be severely defoliated by mid to late summer. Fruit symptoms are similar to those found on leaves. The margins of the spots, however, are more distinct on the fruit. The lesions darken with age and become black and scabby. Scabs are unsightly, but only skin deep. Badly scabbed fruit becomes deformed and may fall before reaching a marketable size (1, 22, 27). Pathogens such as *Guignardia* leaf blotch caused by *Guignardia aesculi* (Peck) VB Stewart are a serious aesthetic problem on most horse chestnut species and consequently can be an important constraint to the commercial production of ornamental trees (22, 23). Symptoms include large irregular reddish-brown lesions with surrounding yellowed tissue on leaves, often badly disfiguring foliage by early to mid summer. Leaves curl and brown and, by August, the tree often appears to be suffering from severe leaf scorch. Premature leaf drop also occurs (1).

Control of scab and leaf blotch pathogens under conventional orchard and ornamental tree management systems relies heavily on fungicide sprays applied at 10–14 day intervals throughout the growing season (5). While routine fungicide sprays are generally effective in reducing the severity of these pathogens a number of disadvantages are associated with excess spray applications. These include spray drift and/or ground water contamination potentially resulting in detrimental effects on fish and beneficial insects, higher labor and pesticide costs and under such heavy selection pressure increased build up of pathogen tolerance to fungicides (5, 11).

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Paclobutrazol (PBZ) is a widely used growth inhibitor that has been shown to possess fungicidal properties against *Chondrostereum purpureum* ([Pers.: ex Fr.] Pouzar), which causes silver leaf in plum (*P. domestica* L.), pear (*Pyrus communis* L.) and apple (*Malus sylvestica* L.) (10). Similarly, foliar applications of PBZ have been shown to have fungicidal activity against *Venturia inaequalis* (Cooke) G. Wint., (22) and powdery mildew (*Phyllactinia* sp) (3). Hotchkiss (18) investigating the influence of PBZ as a growth inhibitor on a range of urban trees recorded 60–80% reductions in the pathogen severity of *Rhytisma acerinum* (Pers.) Fr., the casual agent of tar spot of *Acer pseudoplatanus* L. Burpee et al. (7) and Mercer et al. (21) found that PBZ controlled dollar spot of turf grass with a 75–97% reduction in pathogen severity. Work *in vitro* demonstrated PBZ reduced mycelial growth of several pathogenic fungi (16). In addition frequency of spore germination was less in the presence of PBZ, and rhizomorph production in *Armillaria gallica* (Marxmüller and Romagnesi) was virtually eliminated (19). The potential for PBZ to act as a systemic fungicide, along with its persistence in plants (2–5 years) would make it a unique tool in controlling a wide variety of woody plant diseases (6). In addition, a single soil drench PBZ treatment potentially represents an economic saving on labor and pesticide costs compared to repeat spray applications. Objectives of this study are to: 1) Investigate the potential of PBZ for the control of apple scab and *Guignardia* leaf blotch, two common foliar pathogens of fruit and ornamental trees. 2) Determine the most effective concentration to achieve pathogen control and document growth regulatory effects that may influence the aesthetic appearance of the tree.

Materials and Methods

Trials commenced in April 2003 and were monitored over three growing seasons. The apple trial site consisted of a 1.5 ha (3.7 A) block of apple (*Malus* cv. Crown Gold) interspersed with individual trees of *Malus* 'Red Delicious' and 'Gala' as pollinators. Planting distances were based on a 1 × 1 m (3.3 × 3.3 ft) spacing. The trees were planted in 1979 and trained under the central-leader system to an average height of 2 ± 0.2 m (6.6 ± 0.6 ft) with mean trunk diameters of 33 ± 5 cm (13.2 ± 2.0 in) at 1 m (3.3 ft) above ground level. The horse chestnut trial site consisted of a 2.0 ha (5 A) block of horse chestnut (*Aesculus hippocastanum* L.) located adjacent to the apple trial site. Planting distances were based on a 2 × 1 m (6.6 × 3.3 ft) spacing. The trees were planted as large standards in 1999 and trained to produce a central-leader system to an average height of 3.5 ± 0.35 m (11.6 ± 1.2 ft) with mean trunk diameters of 50 ± 10 cm (20 ± 4 in) at 1 m (3.3 ft) above ground level. Both apple cv. Crown Gold and horse chestnut trial sites were located at the University of Reading Shinfield Experimental Site, Reading, Berkshire (51°43' N, -1°08' W). At both trial sites the soil was a sandy loam containing 4–6% organic matter, pH of 6.2, and available P, K, Mg, Na and Ca of 55.0, 678.1, 183.0, 45.1 and 2200 mg/liter (55, 678.1, 183.0, 45.1, 2200 ppm), respectively. Weeds were controlled chemically using glyphosate (Roundup; Green-Tech, Sweethills Park, Nun Monkton, York, UK) throughout the three year study. No watering or fertilization was applied during the three year trial. Historically both apple and horse chestnut suffered heavily from apple scab and *Guignardia* leaf blotch infection, respectively, on an annual basis. Consequently prior to the trial commencing in 2003 trees were inspected in September 2002 and only those trees

with 50–80% of leaves affected, severe foliar discoloration, and subsequent scab/leaf blotch infection were used in the trial. Five liter root drenches of PBZ at 0.0 (control) 0.25 (250 ppm), 0.5 (500 ppm), 1.0 (1000 ppm), 2.0 g (2000 ppm)/liter active ingredient per 2.5 cm (1 in) girth were applied to trees (six trees per PBZ treatment) on April 2 2003. Root drenches were applied over an area 3× the diameter of the trunk at 1 m (3.3 ft) above ground. The treatments (4 PBZ and a water control) were applied in 6 randomized complete blocks with a single tree as the experimental unit, giving a total of 30 observations per response variable. A minimal insecticide program based on the residual pyrethroid insecticide deltamethrin (Product name Bandu, Headland Agrochemicals Ltd, Saffron Walden, Essex, UK) was applied every two months during each growing season commencing in May 2003 (25), a standard practice followed at the University of Reading experimental site for insect control. All sprays were applied using a Tom Wanner Spray Rig sprayer at 40 ml (1.2 fl oz) deltamethrin per 100 liter (2.6 gal) water. Trees were sprayed until runoff, generally 3.5 liter (0.9 gal)/tree.

Pathogen severity was assessed visually in September 2003, 2004 and 2005. Each tree was rated on a 0–5 rating scale, using a visual indexing technique and ratings on the scale: 0 = no scab or leaf blotch observed; 1 = less than 5% of leaves affected and no aesthetic impact; 2 = 5–20% of leaves affected with some yellowing but little or no defoliation; 3 = 21–50% of leaves affected, significant defoliation (30–50%) and/or leaf yellowing; 4 = 51–80% of leaves affected, severe foliar discoloration and defoliation (51–90%); 5 = 81–100% of foliage affected with 91–100% defoliation. The individual ratings for each tree in each treatment were used as a pathogen severity index for statistical analysis.

Ten leaves per tree selected throughout the crown were adapted to darkness for 30 min by attaching light exclusion clips to the leaf surface and chlorophyll fluorescence was measured using a HandyPEA portable fluorescence spectrometer (Hansatech Instruments Ltd, King's Lynn, UK). Measurements were recorded up to 1 second with a data acquisition rate of 10 µs for the first 2 ms and of 1 ms thereafter. The fluorescence responses were induced by a red (peak at 650 nm) light of 1500 µmol/m²/s photosynthetically active radiation (PAR) intensity provided by an array of six light emitting diodes. A photosynthetic index (PI) was used to quantify effects on leaf tissue (9). The photosynthetic index has been shown to be a highly sensitive measure of leaf photosynthetic activities and an indirect measure of plant vitality (26). Photosynthetic index values were automatically calculated by the HandyPEA. Ten leaf values per tree were pooled to provide a mean for each tree for statistical purposes. Chlorophyll fluorescence values were recorded each September over three growing seasons.

In September 2003, 2004 and 2005, ten leaves per tree were selected throughout the crown and leaf areas were quantified using a Delta-T area meter. Mean leaf size was determined using the equation total leaf area / 10. Stem extension was recorded by measuring the distance from the tip of the leading apical shoot to the nodal area separating the previous years extension growth. The ten leaf size values per tree were pooled to provide a mean for each tree for statistical purposes. Twigs were tagged to ensure only the same stems were measured during the experimental period.

Statistical methods were as follows: Mean pathogen severity values for all treatments were transformed using

the Arcsin (\sin^{-1}) transformation. All data were analyzed using ANOVA and the differences between means were determined using Tukey *w* procedure ($P = 0.05$). Back transformed disease incidence values are presented here to ease interpretation of these data.

Results and Discussion

In all three years, damaging outbreaks of apple scab and *Guignardia* leaf blotch were recorded on the non-PBZ treated control trees as indicated by pathogen severity ratings of 4.5–4.8 and 4.3–4.7 on leaves of apple cv. Crown Gold and horse chestnut respectively. Greater pathogen severity on controls was mirrored by lower leaf chlorophyll fluorescence PI values as a measure of leaf photosynthetic efficiency compared to PBZ-treated trees. During the three-year study, none of the PBZ-treated or control trees died as a result of pathogen attack and none of the PBZ treatments evaluated were phytotoxic to apple or horse chestnut as measured by leaf chlorophyll fluorescence PI values.

Apple cv. Crown Gold. Applications of PBZ as a soil drench at 0.25–1.0 g (250–1000 ppm) per 2.5 cm (1 in) of girth had little effects on pathogen severity, mean leaf size or stem extension in 2003, i.e., the first growing season (Tables 1, 2, 3). Application of PBZ at 2.0 g (2000 ppm) per 2.5 cm (1 in) of girth however, resulted in less pathogen severity and mean leaf size during the first growing season growing season but did not influence stem extension (Tables 1, 2, 3). During the 2003 growing season applications of PBZ ≥ 0.5 g (500 ppm) per 2.5 cm (1 in) of girth resulted in greater leaf chlorophyll fluorescence PI values than untreated controls (Table 4). Paclobutrazol applied at 0.25 g (250 ppm) per 2.5 cm of girth had no effect on leaf chlorophyll fluorescence PI values (Table 4). Irrespective of concentration of PBZ applied, pathogen severity on leaves was 44 to 62% and 25 to 73% less than that of the control value, respectively, over the 2004 and 2005 growing seasons (Table 1). Likewise greater leaf chlorophyll fluorescence PI of 16 to 49% over controls was recorded in PBZ treated trees during the 2004 and 2005 growing seasons respectively (Table 4). Differences in the magnitude of protection conferred were recorded. Generally the higher the concentration of PBZ the greater the degree of apple scab control as manifest by lower pathogen severity on leaves and higher leaf PI values as measures of photosynthetic efficiency (Tables 1, 4). Irrespective of PBZ concentration applied few effects on mean leaf size were recorded during the 2004 and 2005 growing season with one exception, applications of PBZ at 2.0 g (2000 ppm) per 2.5 cm (1 in) of girth where mean leaf size during the 2004 growing season was smaller than that of controls (Table 2). Irrespective of concentration, PBZ application resulted in less mean stem in most cases over the 2004 and 2005 growing season compared to non PBZ treated controls (Table 3).

Horse chestnut. Applications of PBZ at 0.25 g (250 ppm) per 2.5 cm (1 in) of girth conferred no protection against *Guignardia* over the three year experimental period as determined by pathogen severity and leaf chlorophyll fluorescence PI values (Tables 5, 8). Likewise few effects on mean leaf size and stem extension was recorded with one exception; smaller mean stem extension during the 2005 growing season (Tables 6, 7). Soil drenches of PBZ ≥ 0.5 g (500 ppm) per 2.5 cm (1 in) of girth resulted in less pathogen

Table 1. Influence of PBZ soil drenches for the control of apple scab on leaves of apple cv. Crown Gold as measured by observed pathogen severity.

| Treatment | Apple scab severity on leaves | | |
|-----------------|-------------------------------|-------|------|
| | 2003 | 2004 | 2005 |
| Water (control) | 4.5a ^{z,y} | 4.8a | 4.7a |
| PBZ 0.25g | 4.0ab | 2.7b | 3.5b |
| PBZ 0.50g | 4.5a | 2.7b | 2.5c |
| PBZ 1.00g | 4.2ab | 2.2bc | 1.7d |
| PBZ 2.00g | 3.5b | 1.8c | 1.3d |

^zAll values mean of six trees.

^yLower case letters indicate significant differences between means for each evaluation date ($P = 0.05$).

Table 2. Influence of PBZ soil drenches on mean leaf size of apple cv. Crown Gold.

| Treatment | Mean leaf size (cm ²) | | |
|-----------------|-----------------------------------|-------|-------|
| | 2003 | 2004 | 2005 |
| Water (control) | 8.53a ^{z,y} | 8.82a | 8.70a |
| PBZ 0.25g | 8.75a | 8.83a | 8.27a |
| PBZ 0.50g | 8.66a | 8.80a | 7.70a |
| PBZ 1.00g | 8.62a | 8.60a | 8.38a |
| PBZ 2.00g | 8.18a | 7.75b | 7.85a |

^zAll values mean of six trees, ten leaves per tree.

^yLower case letters indicate significant differences between means for each evaluation date ($P = 0.05$).

Table 3. Influence of PBZ soil drenches on mean stem extension of apple cv. Crown Gold.

| Treatment | Mean stem extension (cm ²) | | |
|-----------------|--|--------|--------|
| | 2003 | 2004 | 2005 |
| Water (control) | 11.68a ^{z,y} | 13.15a | 11.20a |
| PBZ 0.25g | 10.78ab | 12.22a | 11.47a |
| PBZ 0.50g | 10.98ab | 10.60b | 11.50a |
| PBZ 1.00g | 10.12ab | 9.20bc | 8.15b |
| PBZ 2.00g | 9.62b | 8.70c | 8.28b |

^zAll values mean of six trees, ten stems per tree.

^yLower case letters indicate significant differences between means for each evaluation date ($P = 0.05$).

Table 4. Influence of PBZ soil drenches for the control of apple scab on apple cv. Crown Gold as measured by leaf chlorophyll fluorescence PI values.

| Treatment | PI | | |
|-----------------|----------------------|--------|-------|
| | 2003 | 2004 | 2005 |
| Water (control) | 7.13a ^{z,y} | 5.40a | 5.52a |
| PBZ 0.25g | 7.75ab | 6.27ab | 6.10a |
| PBZ 0.50g | 8.07ab | 7.47b | 7.35b |
| PBZ 1.00g | 8.12b | 6.77ab | 8.22b |
| PBZ 2.00g | 8.23b | 7.53b | 7.43b |

^zAll values mean of six trees, ten leaves per tree.

^yLower case letters indicate significant differences between means for each evaluation date ($P = 0.05$).

Table 5. Influence of PBZ soil drenches for the control of *Guignardia* leaf blotch on leaves of horse chestnut as measured by observed pathogen severity.

| Treatment | Apple scab severity on leaves | | |
|-----------------|-------------------------------|------|------|
| | 2003 | 2004 | 2005 |
| Water (control) | 4.3a ^{z,y} | 4.7a | 4.7a |
| PBZ 0.25g | 4.7a | 4.8a | 5.0a |
| PBZ 0.50g | 3.3b | 1.8b | 1.3c |
| PBZ 1.00g | 3.3b | 1.7b | 2.0b |
| PBZ 2.00g | 3.2b | 1.3b | 1.0c |

^zAll values mean of six trees.^yLower case letters indicate significant differences between means for each evaluation date ($P = 0.05$).**Table 6. Influence of PBZ soil drenches on mean leaf size of horse chestnut.**

| Treatment | Mean leaf size (cm ²) | | |
|-----------------|-----------------------------------|---------|---------|
| | 2003 | 2004 | 2005 |
| Water (control) | 351.5a ^{z,y} | 362.5a | 368.3a |
| PBZ 0.25g | 343.2a | 322.5ab | 329.2ab |
| PBZ 0.50g | 314.2ab | 298.2b | 288.7b |
| PBZ 1.00g | 299.7bc | 226.7c | 217.2c |
| PBZ 2.00g | 267.3c | 212.5c | 196.2c |

^zAll values mean of six trees, ten leaves per tree.^yLower case letters indicate significant differences between means for each evaluation date ($P = 0.05$).**Table 7. Influence of PBZ soil drenches on mean stem extension of horse chestnut.**

| Treatment | Mean stem extension (cm) | | |
|-----------------|--------------------------|--------|--------|
| | 2003 | 2004 | 2005 |
| Water (control) | 12.62a ^{z,y} | 10.15a | 12.10a |
| PBZ 0.25g | 12.20ab | 9.24ab | 10.88a |
| PBZ 0.50g | 11.07b | 8.97b | 9.07b |
| PBZ 1.00g | 7.60c | 4.35c | 2.08c |
| PBZ 2.00g | 4.30d | 2.88d | 0.88d |

^zAll values mean of six trees, ten stems per tree.^yLower case letters indicate significant differences between means for each evaluation date ($P = 0.05$).**Table 8. Influence of PBZ soil drenches for the control of *Guignardia* leaf blotch on leaves of horse chestnut as measured by leaf chlorophyll fluorescence PI values.**

| Treatment | PI | | |
|-----------------|----------------------|-------|-------|
| | 2003 | 2004 | 2005 |
| Water (control) | 5.93a ^{z,y} | 5.08a | 5.05a |
| PBZ 0.25g | 5.50a | 3.93a | 3.85a |
| PBZ 0.50g | 7.38b | 7.07b | 7.63b |
| PBZ 1.00g | 7.57b | 7.58b | 7.82b |
| PBZ 2.00g | 7.22b | 7.52b | 7.62b |

^zAll values mean of six trees, ten leaves per tree.^yLower case letters indicate significant differences between means for each evaluation date ($P = 0.05$).

severity and greater chlorophyll fluorescence PI values as a measure of leaf photosynthetic efficiency over the three year experimental period (Tables 5, 8). Likewise a smaller mean leaf size and stem extension was recorded in each of the three year experimental period (Tables 6, 7). Pathogen severity was 23–79% less with the greatest differences occurring in the second and third years following PBZ application. Greatest reductions in disease severity were recorded with 2.0 g (2000 ppm) PBZ per 2.5 cm (1 in) of girth (Table 5).

Results of this study show that soil drench applications of PBZ at concentrations >0.5–2.0 g (500–2000 ppm) per 2.5 cm (1 in) of girth reduced pathogen severity of apple scab and *Guignardia* leaf blotch in both apple cv. Crown Gold and horse chestnut. This indicates that PBZ basal drenches offer potential for the regulation of apple scab and *Guignardia* leaf blotch assuming partial control of the pathogen is acceptable to professionals involved in the nursery industry. In the case of *Guignardia* leaf blotch reduced pathogen severity was recorded over the three year experimental period. In the case of apple scab pathogen severity was only reduced in years two and three post PBZ application. These results are consistent with those obtained by Blaedow et al. (6) who showed that apple scab severity in PBZ-treated *Malus* genotypes was less in years 2–3 post application but marginal during the first year of treatment. Differences in the degree of control displayed in year one by apple cv. Crown Gold and horse chestnut may be related to differences in uptake and transport of PBZ to the leaf canopy (6). The efficacy of, for example, injected pesticides is related to uptake and translocation from injection site to target which in turn is dependent on pesticide solubility, health of transport tissues within the vascular system and tree species (14, 27, 31).

A number of studies have shown differences in the degree of pathogen sensitivity towards PBZ (7, 21). Differences in pathogen sensitivity may account for the fact that applications of PBZ at a concentration of 0.25 g (250 ppm) per 2.5 cm (1 in) of girth did not provide any degree of control against *Guignardia* leaf blotch of horse chestnut. Applications of PBZ at this concentration, however, reduced pathogen severity of apple scab by 25 and 43% during years 2 and 3 post application, respectively. Reductions in pathogen severity recorded in this study may be due to the direct fungicidal properties of PBZ whose mode of action is via inhibition of the C4-demethylase reactions in sterol biosynthesis of fungi (2). In addition, PBZ treatments have been shown to induce a suite of morphological adaptations that have been shown to be important in reducing pathogen severity in plants. For example increased leaf thickness and epicuticular wax layer induced by PBZ contribute to resistance to enzymatic degradation and increase impenetrability of the leaf surface to fungal pathogens (15). It has also been suggested that PBZ subtly alters the topography of the leaf surface interfering with fungal recognition of host penetration sites (32). A number of authors suggest that PBZ induced protection from environmental stress is an important factor in improving tree vitality that in turn allows the tree's own natural defence mechanisms to respond to pathogen invasion (4, 17, 33).

Chlorophyll fluorescence PI values provide a measure of leaf photosynthetic efficiency and provide an indirect measure of tree vitality (9). The application of PBZ to both tree species in the field produced no phytotoxic effects on leaf tissue and increased PI values indicating less damage to the leaf photosynthetic system caused by both fungal pathogens.

Thus, the plants treated with PBZ were found to be from 60 to 100% more efficient photosynthetically. The maintenance of high fluorescence values in PBZ-treated plants under stress has been observed in previous studies (28). Greater photosynthetic efficiency permits metabolic activity within the plant such as synthesis of defensive secondary metabolites. If the photosynthetic system is impaired then the carbohydrates required for secondary metabolite synthesis cannot be produced. Higher PI values in PBZ treated plants indicate less damage to the leaf photosynthetic system in turn manifest by a greater potential ability to protect undamaged tissue and repair tissue damaged following fungal attack.

The effect of growth inhibitors such as PBZ on plant height reductions is well documented (2, 18, 29). With respect to growth reductions, marked differences between apple cv. Golden Crown and horse chestnut were recorded in this investigation. Irrespective of PBZ concentration applied, few effects on mean leaf size and stem extension were recorded on apple cv. Golden Crown during the experimental period. Horse chestnut, however, was identified as far more sensitive to PBZ with reduced mean leaf size and stem extension during the three year study in response to most PBZ concentrations applied. Species specific growth responses to PBZ application have been shown elsewhere (18, 20). Long term (2–3 years) over-regulation of growth has been associated with PBZ applications that may be undesirable for tree production purposes and landscape planting where aesthetics are a major factor regarding tree selection (12, 13, 17). These growth regulatory effects have to be weighed against the benefits of enhanced pathogen control especially in the case of PBZ sensitive species such as horse chestnut.

In conclusion, results of this study provide evidence that soil drenches of PBZ could potentially play a useful role as an alternative or supplementary method of apple scab and *Guignardia* leaf blotch control compared to conventional spray systems. Basal soil drenches may be especially useful to the landscape industry and in amenity situations where spray applications of pesticides may result in drift contact with pedestrians and traffic. However, from a commercial aspect, growers and vendors of ornamental woody plants generally adopt a zero tolerance policy towards foliar diseases. Although PBZ reduced pathogen severity of both apple scab and *Guignardia* leaf blotch, total control was not achieved. To reduce pathogen levels to commercially accepted standards follow up fungicide sprays would need to be applied (8). Failure of PBZ to achieve total pathogen control may result in strong selection pressure for PBZ insensitivity in surviving populations (5, 11). In addition the potential loss of aesthetics due to growth regulation should be weighed against the benefits of pathogen protection.

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