CYCLANILIDE PROMOTES BRANCHING OF

WOODY ORNAMENTALS

Except where reference is made to the work of others, the work described in this thesis is my own or was done in collaboration with my advisory committee. This thesis does not include proprietary or classified information.

____
Amanda Suzanne Holland

Certificate of Approval:

____
J. Raymond Kessler, Jr.
Associate Professor
Horticulture

____
Gary J. Keever, Chair
Professor
Horticulture

____
Fenny K. Dane
Associate Professor
Horticulture

____
George T. Flowers
Interim Dean
Graduate School

CYCLANILIDE PROMOTES BRANCHING OF

WOODY ORNAMENTALS

Amanda Suzanne Holland

A Thesis

Submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfillment of the

Requirements for the

Degree of

Master of Science

Auburn, Alabama
May 10, 2007

CYCLANILIDE PROMOTES BRANCHING OF

WOODY ORNAMENTALS

Amanda Suzanne Holland

____

Signature of Author

____

Date of Graduation

VITA

Amanda Suzanne Holland, daughter of Michael Paul Holland and Suzanne Theresa (Puckett) Holland, was born on May 16, 1980 in Fairburn, GA. She found her passion for plants at a young age, and fondly remembers helping her mother in the garden throughout her early childhood. She began working in retail garden centers while attending Creekside High School in Fairburn, GA, from which she graduated in 1998. She entered the Landscape Horticulture program at Auburn University in 1999 and received her Bachelor of Science in 2003. She designed, installed and maintained seasonal flower beds throughout the Southeast before returning to Auburn University in 2005 to earn her Master of Science in Horticulture in 2007. She has one brother, John Anthony Holland.

THESIS ABSTRACT

CYCLANILIDE PROMOTES BRANCHING OF

WOODY ORNAMENTALS

Amanda Suzanne Holland

Master of Science, May 10, 2007
(B.S., Horticulture, Auburn University, 2003)

92 Typed Pages

Directed by Gary J. Keever

Woody ornamental shrub production often requires multiple prunings to promote branching and compaction. Pruning, a labor-intensive practice that results in a loss of plant biomass, often lengthens production time but is considered essential to develop attractive, marketable shrubs.

The effects of cyclanilide (CYC), a relatively new bioregulator recently made available for testing, were evaluated as a means of lessening or eliminating the mechanical pruning of select woody ornamental shrubs. Single foliar sprays of 25 to 200 ppm CYC increased branching and enhanced overall quality of 12 of 19 tested species of

woody landscape shrubs, however CYC-induced effects tended to be short-lived and treated plants often appeared similar to untreated plants by 120 days after treatment.

Multiple foliar sprays of 100 to 300 ppm CYC, applied either weekly or biweekly, promoted branching and quality of 5 of 9 woody ornamental shrubs, and CYC effects generally persisted longer than those from single CYC applications. However, increased longevity of plant response was often associated with foliar injury, symptoms of which generally increased in severity with increasing CYC concentrations. Although injury was transient and no longer evident by approximately 120 days after treatment, symptoms were severe enough to discourage multiple foliar applications of CYC concentrations above 100 ppm to ensure plant marketability during the growing season of application.

The interaction between pruning and CYC application was evaluated on several woody ornamental shrubs. CYC concentrations of 100 to 200 ppm applied to overwintered nursery crops increased shoot formation, however quality was usually not enhanced, suggesting woody shrubs that have become leggy and misshapen will probably require pruning before CYC application to fully enhance plant form and marketability. Results of another study in which 200 ppm CYC was applied to plants immediately after pruning or when new foliage elongated to either 1.3 – 2.5 cm (0.5 to 1.0 in) or 2.5 – 5.1 cm (1.0 – 2.0 in) suggested that shoot formation is most effectively enhanced when plant foliage is allowed to elongate 1.3 – 5.1 cm (0.5 – 2.0 in).

ACKNOWLEDGMENTS

The author humbly expresses gratitude for the knowledge and time contributed by the outstanding people who guided her in the completion of an otherwise unobtainable Master's degree. She specifically appreciates her advisor, Dr. Gary J. Keever, for his expertise in research and in manuscript preparation, and for his patience and understanding throughout her learning process. The author also sincerely thanks her committee members, Dr. J. Raymond Kessler, Jr., and Dr. Fenny Dane, for their advice during the research process, and their willingness to assist with the preparation of her thesis, even during the holiday season. Thanks are also due Rasima Bakhtiyarova for her time spent assisting the author with data collection and statistical analyses. Above all, the author acknowledges the friendship and love she shares with her family, and she thanks her parents, Michael and Suzanne Holland, and her best friend, "Bonner" Holland, for keeping her laughing, for directing her focus on what matters, and for their wisdom, love and support during this part of her life's journey.

Style manual used or journal used: Journal of Environmental Horticulture

Computer software used: Microsoft Word 2000, Microsoft Excel 2000, SAS 9.1

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

Introduction and Literature Review

Horticulture has long played a role in the wellbeing of both humans and the environment (Leszczynska-Borys and Borys, 2000). Over the past decade, the role of ornamental horticulture has expanded to one of economic importance (Lawson, 1996). In the United States, recent trends suggest an increased demand for ornamental shrubs (Kidd and Davis, 1993; Lawson 1996). This demand centers on aesthetic value and consumers use height, branching and/or flowering to visually assess quality before purchase (Grzesik, 1989). Relative to ornamental shrubs, plant shape dominates in quality perception and consumers prefer a compact, well-branched plant (Heuvelink et al., 2004).

Unfortunately, the natural shape of ornamental shrubs is often loose, leggy, and thus highly unmarketable (Keever and Foster, 1990) due to apical dominance. Apical dominance refers to the control that the terminal buds of a plant stem exert over the lateral buds; the terminal bud produces a hormone called auxin that diffuses downward and inhibits development of lateral buds (Cline, 1991; Tamas, 1987). Therefore, in order to produce a well-branched, highly marketable plant, apical dominance must be interrupted (Cline, 1991; Keever and Foster, 1990; Tamas, 1987). Most growers accomplish this through removal of terminal meristems, e.g. pruning. Manual pruning alleviates apical dominance and thus lateral buds develop into lateral shoots, resulting in well-branched, highly marketable plants. Unfortunately, most shrubs require multiple prunings to overcome excessive stem elongation and promote branching (Keever and Foster, 1990; Oates et al., 2004). This incurs substantial production time/costs and yields variable results, therefore chemicals are being explored as alternative branching agents (Grzesik, 1989). In many woody species, chemical growth regulation has indeed promoted as many or more lateral shoots as mechanical pruning (Grzesik, 1989; Keever and Foster, 1990; Oates et al., 2004).

Plant growth regulators (PGRs) are chemical compounds or plant hormones that alter growth and development (McAvoy, 1989). PGRs can increase or retard plant height, prolong or break bud dormancy, promote rooting, and increase branching and/or flowering (Larson, 1985; McAvoy, 1989; Steffens, 1979). Currently, the five main PGRs used in ornamental horticulture are daminozide, paclobutrazol, uniconazole, chlormequat and ancymidol (Gent and McAvoy, 2000), and although these have been, and are, used in the greenhouse, none has become widely used in ornamental shrub production.

Cyclanilide (CYC), a relatively new bioregulator recently made available for testing by Bayer Environmental Science, Montvale, N.J., could potentially benefit the ornamental industry by promoting branching of woody ornamental shrubs during nursery production. Current use labels CYC a cotton defoliant. Cotton usually requires defoliation before harvest to prevent debris or coloration in the finished product (Burmester et al., 2001). Also, single, rather than multiple, harvests are possible if cotton bolls open at about the same time (Burmester et al., 2001; Pedersen et al., 1997). While several products, such as Dropp/FreeFall (thidiazuron), Ginstar (thidiazuron + diuron), and Def 6/Folex 6 (phosphoro-trithioate) defoliate cotton plants and open cotton bolls, many lose efficacy at temperatures below 60 degrees F (Burmester et al., 2001). Because cotton harvest takes place in late summer to early fall, when temperatures can be cool, the objective was to find a defoliant that would remain active at low temperatures. Research indicated that ethephon in combination with CYC defoliated cotton, caused bolls to ripen at about the same time, and prevented terminal regrowth, even at cool temperatures (Pedersen et al., 1997).

This led Bayer Environmental Science to market FINISH, a combination of ethephon and CYC, as a cotton defoliant . During a study comparing the effects of CYC, ethephon and auxin transport inhibitors on leaf abscission in bean plants, it was discovered that CYC inhibited apical meristem growth and stimulated lateral growth (Pedersen et al., 2003). Dr. Don Elfving, Washington State University, then tested CYC effects on apple trees (Elfving and Visser, 2005).

Apple growers prefer to purchase well-branched trees, yet this is hard to achieve without interrupting apical dominance using mechanical pruning and/or application of PGRs that alter auxin metabolism, including 6-benzyladenine (BA) or gibberellic acid isomers GA_4 and GA_7 (GA_{4+7}) (Miller, 1988). However, these chemicals are not effective on all apple cultivars and may damage shoot tips of responsive cultivars, therefore none have become commercially significant (Elfving, 1985). Initial information provided by Bayer suggested that cyclanilide might have growth-inhibitory effects similar to prohexadione-calcium (P-Ca, BASF Corp., Research Triangle Park, NC) so early experiments compared the effects of CYC, BA plus GA_{4+7} (Promalin (PR), Valent BioSciences, Walnut Creek, Calif.), and/or pro-hexadione-calcium (Apogee, P-Ca, BASF Corp., Research Triangle Park, N.C.) on select apple varieties.

Elfving initially tested concentrations of 25, 50 or 100 mg active ingredient (a.i.) CYC•L^{-1} and 125 mg a.i. P-Ca•L^{-1} for inhibition of shoot elongation of 'Cameo'/'Gala'/M.26 apple trees. P-Ca decreased overall shoot length, as expected, but did not increase the number of lateral shoots (feathers). However, CYC at concentrations of 50 or 100 mg•L^{-1} increased the number of lateral shoots without affecting shoot length.

A second experiment eliminated the lowest CYC concentrations (25 and 50 mg a.i.•L^{-1}) and tested the effects of two applications of 100 or 250 mg•L^{-1} CYC applied to 'TAC114Fuji'/M.26 apple trees. Untreated trees were included for comparison to treatment effects. Once again, the overall number of lateral shoots increased, but unlike single CYC applications, two CYC applications reduced terminal shoot length. Length reduction persisted for approximately 11 weeks after the last CYC application. Terminal shoots elongated slowly into the fall and shoots of trees treated with the lowest CYC concentration were eventually of comparable size to terminal shoots of untreated trees. However, shoots of trees treated with the highest CYC concentration remained shorter than shoots of untreated controls after growth stopped in the fall, suggesting that two applications of 250 mg•L^{-1} exceeds the optimal range for this apple cultivar.

Elfving also compared the effects of 100 mg•L^{-1} a.i. CYC, 250 mg•L^{-1} a.i. PR or a tank mix of both on 'Scarletspur Delicious'/B/118 trees. Untreated trees were included for comparison. This cultivar of 'Delicious' is known for its difficulty in lateral shoot induction, and while CYC induced a substantial increase in lateral bud formation, few buds elongated into shoots. PR stimulated bud activity similar to that of CYC. Tank mixes of both chemicals reduced formation of buds in comparison to either product applied alone. Another experiment on a different 'Delicious' cultivar, 'Scarletspur

Delicious'/M.7, tested CYC rates of 50 or 100 mg•L^{-1} a.i. with or without 250 mg•L^{-1} a.i. PR. Trees treated with CYC showed linear increases in lateral shoot production with increasing CYC concentration. Shoot length, although reduced by CYC, was acceptable.

Overall, CYC promoted a well-branched canopy, and more importantly, contrary to current products used for the feathering of apple trees (6-benzyladenine (BA) and gibberellic acid isomers GA_4 and GA_7 (GA_{4+7}), CYC promoted branching without deformity or long-term carry over effects (Elfving and Visser, 2005). Because research suggested that CYC could be a useful product for nursery production of well-feathered apple trees, the possibility of CYC as a branching agent for sweet cherry was considered. Cherry trees naturally grow vigorously upright, exhibit strong apical dominance and thus, sparse lateral branching. Pruning alleviates apical dominance and promotes lateral branching, but stimulates excessive foliage growth that delays fruit-set and reduces ultimate economic returns (Elfving and Visser, 2006).

Limited research on the induction of lateral shoot (feather) formation in cherries suggested that BA, with or without bioregulators, to be effective in feathering apple trees, but often ineffective when applied to sweet cherry. Elfving conducted five experiments between 2002 and 2003 using proprietary formulations of CYC and BA plus GA_{4+7} on several varieties of sweet cherry. Concentrations of 50, 100 or 200 mg•L^{-1} CYC alone or mixed with 500 mg•L^{-1} PR were applied to 'Bing'/Mazzard sweet cherry which were vigorously producing shoots. Trees treated with CYC, regardless of specific CYC concentration, formed approximately six times more lateral shoots than untreated trees. Lateral shoots were initially shorter than those formed on untreated trees, however all were of acceptable length by the end of the growing season. CYC did not affect the length of new terminal shoots. Some injury to foliage was observed at 200 mg•L^{-1} CYC. PR, either alone or tank-mixed with CYC, had minimal effect on feather induction.

CYC effects on cherry variety 'Ranier'/Mazzard were also tested. Upright shoots developed in 2002 were pruned in Spring 2003 and 50 or 100 mg•L^{-1} CYC alone, 250 mg•L^{-1} a.i PR alone, or a tank mix of each CYC concentration with 250 mg•L^{-1} a.i PR was applied. After shoots formed, newly induced terminal shoots were selected and lateral shoots arising from these terminals were counted and measured. Similar to 'Bing'/Mazzard, PR did not increase lateral shoot production, whether applied alone or in combination with CYC. However, CYC substantially increased lateral shoot number. CYC-induced shoots were shorter than shoots of untreated trees but were of acceptable length by the end of the growing season.

Elfving applied the same treatments to 'Bing' and 'Lapins'/Mazzard cherry trees. Feathering of 'Bing' increased linearly with increasing CYC concentration and feathers were induced at a lower point of origin than untreated trees or those in treatments that included PR. PR alone increased feather development but not when combined with CYC. Similar to 'Bing', CYC increased feather production of 'Lapins' linearly with respect to increased CYC concentration without effecting feather length. PR did not improve feathering or affect feather length of 'Lapins'.

Elfving increased PR concentration to 500 mg•L^{-1} a.i. and applied PR alone or in combination with 100 mg•L^{-1} CYC to 'Bing' and 'Skeena'/Mazzard cherry trees. All treatments showed increased feather development in both cultivars. CYC reduced height to first feather and feather length in both cultivars and reduced total leader length slightly in 'Bing', yet trunk caliper and branch crotch angle were unaffected by treatment.

Finally, 50 or 100 mg•L^{-1} CYC, with or without 500 mg•L^{-1} a.i. PR, and 500 mg•L^{-1} a.i. PR were applied to 'Lapins'/Mazzard trees. CYC increased feathering of 'Lapins', with or without the addition of PR, with minimal effect on trunk caliper, leader length, height to feather, feather length and crotch angle. PR alone only slightly increased feather development. Few bioregulators have produced comparable results in sweet cherry, and those chemical pinching agents that induce branching in apples have had little effect on sweet cherries. CYC appears promising for feather formation in cherry trees during nursery production due to its ability to strongly and consistently stimulate well-developed lateral shoots with uniform distribution around the leader circumference. These studies suggested CYC as a potential alternative to pruning or PR for lateral branching in sweet cherry trees. Additionally, CYC did not cause long-term height reduction or damage to the terminal meristem (Elfving and Visser, 2006).

CYC-induction of lateral branching in apple as well as sweet cherry trees suggests that the PGR has potential as a lateral branching agent for woody ornamentals commonly hand-pruned to improve shape or promote early flowering (Olsen, 2003). In 2004 at Auburn University, under the direction of Dr. Gary J. Keever, Dr. Teresa A. Morrison screened 13 woody ornamental shrubs commonly used in the landscape for their response to CYC. A single foliar application of 0, 25, 50, 100 or 200 ppm cyclanilide was made, new shoots counted 30 days after treatment (DAT) and plants rated for quality 120 DAT. Results varied among species, but 10 species exhibited higher shoot counts and quality ratings in response to CYC (unpublished data, 2004).

When compared to untreated controls, shoot formation of small anisetree increased up to 279% in treated plants, the number of shoots of treated Florida anise increased up to 60%, and quality of treated plants of both species was superior to untreated plants. When compared to untreated controls, treated Japanese camellia formed 116% to 366% more shoots, treated sasanqua camellia 50% to 149% more shoots, and plant quality was higher. Azalea cultivars 'Chinsan', 'Red Slippers' and 'Watchet', formed up to 100%, 72% and 275% more lateral shoots, respectively, than untreated plants. Although treated oakleaf hydrangea plants suffered interveinal chlorosis, the number of shoots increased 33% to 233% in treated plants as compared to untreated controls. Treated inkberry hollies showed increased number of shoots, 55% to 116%, and higher quality than untreated. Treated 'Eleanor Taber' Indian hawthorn showed dramatic increases in new shoots, from 212% to 307%, and had a higher quality rating than control plants (unpublished data, 2004).

Cyclanilide has the potential to lessen or even eliminate mechanical pruning of fruit trees and woody ornamental shrubs as well as increase quality and thus economic value. Although optimal rates (ppm) must be determined and adverse effects, such as phytotoxicity, stunting or persistence in the landscape, must be explored, cyclanilide may become a beneficial PGR for the ornamental horticultural industry.

Literature Cited

Burmester, C., M.G. Patterson and C.D. Monks. 2001. Cotton defoliation. AL Cooperative Extension System.

Cline, M.G. 1991. Apical dominance. The Bot. Rev. 57: 318-358.

Elfving, D.C. 1985. Comparison of cytokinin and apical-dominance-inhibiting growth regulators for lateral-branch induction in nursery and orchard apple trees. J. HortScience 60:447-454.

Elfving, D.C. and D.B. Visser. 2005. Cyclanilide induces lateral branching in apple trees. HortScience 40:119-122.

Elfving, D.C. and D.B. Visser. 2006. Cyclanilide induces lateral branching in sweet cherry trees. HortScience 41:149-153.

Gent, M.P., and R.J. McAvoy. 2000. Plant Growth Retardants in Ornamental Horticulture. Food Products Press, New York. 265 pages.

Grzesik, M. 1989. Factors influencing the effectiveness of growth regulators in nursery production. Acta Hortic. 251:371-375.

Heuvelink, E., P. Tijskens and M.Z. Kang. 2004. Modeling product quality in horticulture: a product overview. Acta Hortic. 654:19-30.

Keever, G.J. and W.J. Foster. 1990. Chemically induced branching of woody landscape plants. J. Environ. Hort. 8:78-82.

Kidd, G., and M. Davis. 1993. Analyzing the U.S. Horticultural industry. Bio/Technology 11:1510-1511.

Larson, R.A. 1985. Growth regulators in floriculture. Hort. Rev. 7:399-480.

Lawson, R.H. 1996. Economic importance and trends in ornamental horticulture. Acta Hortic. 432:226-237.

Leszczynska-Borys, H. and M.W. Borys. 2000. Ornamental plants-an integral part of environmental horticulture. Proc. Interamerican Soc. Tropical Hort. 42:27-45.

McAvoy, R.J. 1989. Considerations for the grower when using plant growth regulators. Conn. Greenhouse Newsletter 152:16-19.

Miller, S.S. 1988. Use of plant bioregulators in apple and pear culture. Hort. Rev. 10:309-401.

Oates, J.M., G.J. Keever and J.R. Kessler, Jr. 2004. BA-induced shoot formation in Indian hawthorn. J. Environ. Hort. 22:71-74.

Olsen, C. 2003. USA03470 Study Summary. Bayer Environmental Science.

Pedersen, M.K., J.D. Burton, H.D. Coble, J.R. Collins, and D. Fritz. 1997. Efficacy of Finish and its mechanism of action. Proc. Beltwide Cotton Conf. 2:1363-1365.

Pedersen, M.K., J.D. Burton and H.D. Coble. 2003. Effect of cyclanilide, ethephon, auxin transport inhibitors and temperature on whole plant defoliation. Bayer Crop Science. Unpublished article.

Steffens, G.L. 1979. Applied uses of growth substances. Plant Growth Substances. 12:398-408.

Tamas, I.A. 1987. Plant hormones and their role in growth and development. Plant Biology 20:393-410.

CHAPTER II

Single Cyclanilide Applications Promote Branching of Woody Ornamentals

Abstract

In 2004 and 2005, single applications of 0 to 200 ppm cyclanilide (CYC), an experimental bioregulator effective in stimulating lateral branching in fruit trees, were applied foliarly to 19 species or cultivars of woody landscape shrubs, 12 of which exhibited increased branching in response to treatment. Shoot number increases were concentration and species dependent, and compared to untreated controls at 30 days after treatment (DAT) in 2004, ranged from 26% to 48% in Florida anise, 117% to 317% in 'Elizabeth Ann' Japanese camellia, 36% to 117% in 'Nigra' inkberry holly, 57% to 100% in 'Chinsan' azalea, 14% to 72% in 'Red Slippers' azalea, 135% to 274% in 'Watchet' azalea, 39% to 72% in 'Ellen Huff' oakleaf hydrangea, 50% to 149% in 'Brandy's Temper' sasanqua camellia, and 212% to 306% in 'Eleanor Taber' Indian hawthorn.
In 2005, increases in branching at 60 DAT ranged from 119% to 240% in 'Ellen Huff' oakleaf hydrangea, 32% to 68% in 'Brandy's Temper' sasanqua camellia, 70% to 187% in 'Eleanor Taber' Indian hawthorn, 46% to 108% in 'Olivia' Indian hawthorn, 48% to 63% in 'Sky Pencil' holly, and up to 24% in 'Foster' holly. Plant size often decreased linearly with increasing CYC concentration, but not in all species or cultivars. Foliage of 'Ellen Huff' oakleaf hydrangea in 2004 and both 'Eleanor Taber' and 'Olivia' Indian

hawthorn in 2005 was injured by CYC application, however symptoms were no longer evident by the end of the growing season. Quality of treated responsive plants was usually higher than untreated plants and generally increased linearly with increasing CYC concentration at the end of the growing season in 2004, but not in 2005.

Index words: auxin transport inhibitor, plant growth regulator, nursery production.

Species used in this study: ‘Elizabeth Ann’ Japanese camellia (*Camellia japonica* L. ‘Elizabeth Ann’), ‘Brandy’s Temper’ sasanqua camellia (*Camellia sasanqua* L. ‘Brandy’s Temper’), spreading yew (*Cephalotaxus harringtonia* C. Koch. ‘Prostrata’), leyland cypress (× *Cypressocyparis leylandii* (Dallim. & A.B. Jackson) Dallim.), fragrant daphne (*Daphne odora* Thunb.), ‘Ellen Huff’ oakleaf hydrangea (*Hydrangea quercifolia* Bartr. ‘Ellen Huff’), ‘Foster’ holly (*Ilex* ×*attenuata* Ashe. ‘Fosteri’), ‘Sky Pencil’ holly (*Ilex crenata* Thunb. ‘Sky Pencil’), ‘Nigra’ inkberry holly (*Ilex glabra* (L.) A. Gray ‘Nigra’), Florida anise (*Illicium anisatum* L. ‘Semmes’), leatherleaf mahonia (*Mahonia bealei* (Fort.) Carr.), ‘Harbour Dwarf’ nandina (*Nandina domestica* Thunb. ‘Harbour Dwarf’), ‘Conia’ (Olivia™) and ‘Conor’ (Eleanor Taber™) Indian hawthorn (*Rhaphiolepis indica* (L.) Lindl.), ‘Elegans’ rhododendron (*Rhododendron* L. ‘Elegans’), ‘Chinsan’ azalea (*Rhododendron* L. ‘Chinsan’), ‘Red Slippers’ azalea (*Rhododendron* L. ‘Red Slippers’), ‘Watchet’ azalea (*Rhododendron* L. ‘Watchet’) and ternstroemia (*Ternstroemia gymnanthera* Thunb.).

Chemical used in this study: cyclanilide [1-(2,4-dichlorophenylaminocarbonyl)-cyclopropane carboxylic acid].

Significance to the Industry

Woody ornamental shrubs often require multiple pruning during nursery production to develop compact, well-branched plants. However, significant labor costs and loss of plant biomass can lengthen production time and may diminish the benefits of mechanical pruning. Cyclanilide, an experimental plant growth regulator, has the potential to induce branching without mechanical pruning. Single foliar sprays of 25 to 200 ppm CYC increased lateral branching of 'Elizabeth Ann' Japanese camellia (*Camellia japonica* 'Elizabeth Ann'), 'Brandy's Temper' sasanqua camellia (*Camellia sasanqua* 'Brandy's Temper), 'Ellen Huff' oakleaf hydrangea (*Hydrangea quercifolia* 'Ellen Huff'), 'Foster' holly (*Ilex ×attenuata* 'Fosteri'), 'Sky Pencil' holly (*Ilex crenata* 'Sky Pencil'), 'Nigra' inkberry holly (*Ilex glabra* 'Nigra'), Florida anise (*Illicium anisatum* 'Semmes'), 'Eleanor Taber' Indian hawthorn (*Rhaphiolepis indica* 'Eleanor Taber'), 'Olivia' Indian hawthorn (*Rhaphiolepis indica* 'Olivia'), 'Chinsan' azalea (*Rhododendron* 'Chinsan'), 'Red Slippers' azalea (*Rhododendron* 'Red Slippers') and 'Watchet' azalea (*Rhododendron* 'Watchet'). In general, when a species developed new shoots after treatment with CYC, height and often growth index [GI = (height + widest width + width 90^{o} to widest width) ÷ 3] were reduced, resulting in a denser canopy. These results suggest cyclanilide may substitute or complement mechanical pruning in these species.

Introduction

The nursery industry contributes over 300 million dollars per year to the annual total of 1.9 billion dollars in revenue generated by Alabama's Ornamental Horticulture Industry, or "Green Industry" (1). A significant cost associated with the production of most nursery crops, especially woody landscape crops, is the costly, time-consuming manual pruning necessary to develop well-branched, marketable plants. Typically, plants sold in 3.8 liter (#1) containers have been pruned at least once during the 18 to 20 month production time, and plants in 11.4 liter (#3) containers have been pruned at least three times during the 27 to 32 month production time (Tom Dodd Nurseries, Semmes, AL, pers. comm.). Plant growth regulators have been evaluated as a substitute or supplement to mechanical pruning of woody ornamentals with mixed results (7, 8, 9, 10, 11, 12, 13, 14).

Benzyladenine (BA), a synthetic cytokinin, is believed to release apical dominance by reducing auxin to cytokinin ratios in shoot tips (4). Foliar sprays or media drenches of BA have been shown to promote axillary bud growth in several woody landscape crops (9, 10, 12, 13, 14), although response varied with species and cultivar (9, 10, 12, 13, 14), plant developmental stage (14), or application rate (9, 10, 12, 13, 14), application number (9, 12, 13) and application interval (12). In addition to branching response, foliar injury ranging from mild to moderate discoloration, cupping, twisting, and/or stunting of new growth occurred in some species, including 'Olivia' Indian hawthorn (12, 13, 14), 'Harbour Dwarf'(9, 14), 'Moyer's Red' and 'Firepower' nandina (9) and 'Nigra' inkberry holly (14). However, injury to all species was transient, and symptoms were no longer evident by the end of the growing season.

Thidiazuron (TDZ), a phenylurea cytokinin registered as a cotton defoliant (Dropp 50WP, Aventis CropScience, Research Triangle Park, NC), promoted branching in *Nandina domestica* cultivars with minimal effect on plant size and produced visibly fuller plants than untreated controls (8). However, mild chlorosis of immature foliage occurred following TDZ applications in *Nandina* and several other species (unpublished data).

Despite the potential of BA and TDZ as branching agents for select woody species, neither is EPA registered, thus they are unavailable for commercial use. Currently, dikegulac sodium (Atrimmec, PBI/Gordon, Kansas City, MO) is the only registered chemical branching agent for use on woody ornamentals. However, it also has growth retarding activity (3, 7), making it more useful in landscape settings than in nurseries (2). Recently, cyclanilide (CYC, Bayer Environmental Science, Research Triangle Park, NC) became available for experimental evaluation as a bioregulator of apple trees. Initial information from Bayer suggested CYC may act as a growth retardant (unpublished data). In subsequent work at Washington State University, Dr. Don Elfving tested directed sprays of 25 to 250 ppm CYC for its inhibitory effects on shoot elongation of apple. While small reductions in shoot length occurred, the primary effect was stimulation of lateral shoots on current growth and from spurs on older wood (5). A later study using 50 to 200 ppm CYC on sweet cherry trees yielded similar branching results and slight foliar injury to one tree variety, ‘Bing’/Mazzard, due to application of 200 ppm CYC (6). Lateral branch induction in both studies occurred after a temporary interruption of apical dominance without long-term growth reduction or damage to the terminal meristem (5,6). Based on positive results from Elfving’s studies, CYC was evaluated as a branching agent for several shrub species or cultivars commonly grown by the southeastern U.S. nursery industry.

Materials and Methods

Two experiments were conducted, one in 2004 and one in 2005 using similar methodology unless otherwise noted. Growth medium was a 7:1 pinebark:sand substrate amended per m^3 (yd^3) with kg (16 lb) 16.5N-2.6P-10K (PolyOn 17-6-12, Pursell Industries, Sylacauga, AL), 0.9 kg (1.5 lb) Micromax (The Scotts Company, Marysville, OH) and 3 kg (5 lb) dolomitic limestone. Plants were spaced outdoors in full sun unless otherwise noted and under twice-daily irrigations of approximately 1.3 cm (0.5 in) each. Plants were re-spaced as needed. Treatments were applied using a CO_2 sprayer with a flat spray nozzle (XR TeeJet 8003VK, Bellspray, Inc., Opelousas, LA) at 138 kPa (20 psi). A nonionic surfactant, Buffer-X (Kalo Agr. Chemicals, Overland, KS), was included at a 0.2% rate. Dry- and wet-bulb temperatures were recorded at treatment time and relative humidity was determined. Plants were treated under tree shade to minimize possible foliar burn by sun-drying of solutions and to prolong absorption. Plants were returned to irrigated growing areas after a minimum of 6 hours.

Data collection included: shoot height and width, from which growth index (GI) was calculated [GI = (height + widest width + width 90^o to widest width) ÷ 3], counts of new terminal and/or lateral shoots ≥ 1 cm (0.4 in) in length, and ratings of overall plant quality. Quality rating (QR) on a 1 to 5 scale (1 = poorly branched and unmarketable to 5 = compact, well-branched and highly marketable) was determined by the same person within each experiment. Data were subjected to an analysis of variance, using the SAS

General Linear Model procedure (SAS Institute, Cary, NC) and orthogonal contrasts were used to test linear and quadratic responses to CYC rate at $P = 0.05$.

2004. Liners of fragrant daphne, 'Eleanor Taber' Indian hawthorn, 'Nigra' inkberry holly, Florida anise, 'Brandy's Temper' sasanqua camellia, 'Chinsan', 'Red Slippers' and 'Watchet' azalea, 'Ellen Huff' oakleaf hydrangea, 'Harbour Dwarf' nandina and 'Elegans' rhododendron and quarts of 'Elizabeth Ann' Japanese camellia were obtained on February 04, 2003. With the exception of 'Brandy's Temper' and 'Elizabeth Ann' camellia, which were repotted into 7.6 liter (#2) containers on April 1, 2004, all plants were repotted into 3.7 liter (#1) containers: 'Chinsan', 'Red Slippers' and 'Watchet' azalea on March 11, 2004, fragrant daphne and 'Elegans rhododendron on March 30, 2004, Florida anise, 'Harbour Dwarf' nandina and 'Nigra' inkberry holly on March 31, 2004, 'Eleanor Taber' Indian hawthorn and 'Ellen Huff' oakleaf hydrangea on April 14, 2004.

Single foliar applications of 0, 25, 50, 100 or 200 ppm were applied to 'Red Slippers' azalea, 'Nigra' inkberry holly, 'Elizabeth Ann' Japanese camellia, fragrant daphne, 'Ellen Huff' oakleaf hydrangea, 'Harbour Dwarf' nandina, 'Elegans' rhododendron and 'Eleanor Taber' Indian hawthorn during the first flush of spring growth on April 23, 2004. Treatments were arranged in a completely randomized design within species and replicated with 5 to 8 plants per treatment. Dry bulb temperature and relative humidity at application ranged from 26 to 29C (79-85F) and from 47% to 57%, respectively. Single foliar applications of the same CYC concentrations were applied to 'Chinsan' azalea, Watchet' azalea, Florida anise and 'Brandy's Temper' sasanqua camellia on June 22, 2004 at which time spring growth had matured and plants had little, if any, immature foliage. Treatments were arranged in a completely randomized design within species and replicated with 6 to 10 plants per treatment. Dry bulb temperature and relative humidity at application ranged from 27 to 30C (81-86F) and from 67% to 76%, respectively.

New shoots were counted 30 DAT, shoot height and widths from which GI was calculated were measured 60 DAT, and overall plant quality was rated 100 or 120 DAT. Treated 'Ellen Huff' oakleaf hydrangea displayed symptoms of foliar injury due to CYC application, therefore the extent of injury was rated at 30 DAT using a 1-5 scale (1 = no injury; 2 = mild foliar discoloration; 3 = mild to moderate foliar discoloration and mild stunting and/or distortion; 4 = moderate to severe foliar discoloration and moderate to severe stunting and/or distortion; and 5 = dead).

2005. Plants of 'Brandy's Temper' sasanqua camellia, 'Foster' holly, 'Sky Pencil' holly, 'Harbour Dwarf' nandina, 'Eleanor Taber' Indian hawthorn, 'Olivia' Indian hawthorn, spreading yew, leyland cypress and ternstroemia in 3.8 liter (#1) containers were blocked by plant size and placed outdoors in full sun under overhead irrigation. Plants of 'Ellen Huff' oakleaf hydrangea and leatherleaf mahonia in 3.8 liter containers (#1) were blocked by plant size and placed outdoors under 47% shade. Between April 15, 2005 and May 17, 2005 single foliar sprays of 0, 50, 100 or 200 ppm CYC were applied to plants arranged in a randomized complete block design within each species or cultivar and replicated with 10 plants per treatment. Treatments were applied during the first flush of spring foliage while plants were actively growing. Dry bulb temperature and relative humidity during application ranged from 25 to 31C (77-88F) and from 78% to 96%, respectively. Treated spreading yew, leyland cypress, leatherleaf mahonia, 'Harbour Dwarf' nandina and ternstroemia lacked visual treatment effects at 60 DAT and thus received an additional CYC application at the same concentrations on July 6, 2005. Some plants were repotted once, into 11.4 liter (#3) containers, during the study: leyland cypress on July, 8 2005, 'Sky Pencil' and 'Foster' holly on July, 13 2005, 'Olivia' and 'Eleanor Taber' Indian hawthorn on July14, 2005 and ternstroemia on July 18, 2005. Data collection included measurement of shoot height and widths, from which GI was calculated, a count of new lateral and/or terminal shoots 60 DAT and a rating of plant quality 120 DAT.

Results and Discussion

CYC was applied to 11 species or cultivars of woody ornamental shrubs in 2004, nine of which exhibited increased branching in response to treatment. In 2005, six of ten species or cultivars exhibited increased branching in response to CYC application. Branching of fragrant daphne and 'Elegans' rhododendron was unaffected by a single foliar CYC application in 2004 (data not shown). There was no branching response from spreading yew, leyland cypress, leatherleaf mahonia or ternstroemia in 2005 due to CYC application, despite a second application on July 6, 2005 (data not shown). Branching of 'Harbour Dwarf' nandina was unaffected by CYC treatment in both 2004 and 2005 (data not shown). These results concur with fruit tree research in that plant branching response due to CYC application varies with species and cultivar while some plants do not respond to CYC (5, 6).

Florida anise. In 2004, shoot numbers of Florida anise at 30 DAT showed quadratic increase in response to increasing CYC concentration (Table 1). The number of shoots on treated plants compared to untreated plants increased by 26%, 48%, 47%, and 44% with 25, 50, 100 and 200 ppm CYC, respectively. Plant height was unaffected by CYC, however GI at 60 DAT increased linearly with increasing CYC concentration. Generally, internodes of CYC-treated plants appeared shorter than internodes of untreated plants, giving CYC-treated plants a more compact appearance. Plant quality was not affected by treatment.

'Elizabeth Ann' Japanese camellia. New shoot formation of 'Elizabeth Ann' Japanese camellia at 30 DAT in 2004 showed linear increases with increasing CYC concentration, ranging from 117% in plants treated with 25 ppm CYC to 367% in plants treated with 200 ppm CYC, compared to non-treated controls (Table 1). Shoot height at 60 DAT decreased linearly and GI at 60 DAT increased linearly as CYC concentration increased. The combination of abundant lateral growth on shorter plants gave treated plants a fuller, more compact appearance than untreated plants, resulting in an increase in quality rating at 120 DAT as CYC concentration increased.

'Nigra' inkberry holly. Shoot number of 'Nigra' inkberry holly increased linearly with increasing CYC concentration; treated plants formed 36% to 117% more shoots than untreated plants 30 days after application of 25 to 200 ppm CYC in 2004, respectively (Table 1). Shoot height and GI were not affected by treatment at 60 DAT. Plant quality at 120 DAT showed a linear increase from 50% to 125% as CYC concentration increased from 25 to 200 ppm, reflecting the dense, full appearance of treated plants due to the proliferation of CYC-induced lateral growth.

'Chinsan' azalea. Shoots of treated 'Chinsan' azalea showed a linear increase in number, by 57%, 65%, 84% and 100% in response to 25, 50, 100 and 200 ppm CYC at

30 DAT in 2004 (Table 2). Shoot height and GI at 60 DAT decreased linearly with increasing CYC concentration by up to 33% and 34%, respectively, and treated plants were shorter and more compact than controls. Quality of treated plants at 100 DAT increased linearly with increasing CYC concentration and, when compared to untreated plants, was 19% to 58% higher in plants treated with 25 to 200 ppm, respectively.

'Red Slippers' azalea. In 2004, treated 'Red Slippers' azaleas showed a linear increase in number of shoots, ranging from 14% to 72% at 30 days after application of 25 to 200 ppm CYC (Table 2). Shoot height and GI decreased linearly with increasing CYC concentration at 60 DAT. Treated plants appeared fuller and more compact than untreated plants and the quality of treated plants increased linearly with increasing CYC concentration at 120 DAT.

'Watchet' azalea. Number of new shoots of 'Watchet' azalea showed a linear increase in response to increasing CYC concentration at 30 DAT in 2004, ranging from an increase of 135% with 25 ppm to 274% with 100 and 200 ppm (Table 2). Treatment effects were short-lived for this cultivar in that shoot height and GI were not affected at 60 DAT. Treated plants were similar in appearance to untreated plants at 100 DAT and thus 'Watchet' was not rated for quality.

'Ellen Huff' oakleaf hydrangea. In 2004, shoot numbers of 'Ellen Huff' oakleaf hydrangea at 30 DAT showed a linear increase from 39% and 72% as CYC concentration increased from 25 ppm to 200 ppm, respectively (Table 3). Increased shoot production at 60 DAT in 2005 was also linear, increasing by 119% to 240% as concentration increased from 50 to 200 ppm (Table 4). GI decreased linearly in response to increasing CYC concentration at 60 DAT in 2004 but was not affected at 60 DAT in 2005. Injury rating at 30 DAT ranged from slight reddening of new foliage to stunting and distortion of new foliage in 2004; injury increased linearly as CYC concentration increased. Plants treated with 25, 50 and 100 ppm CYC displayed mild foliar discoloration as compared to untreated plants, while plants treated with 200 ppm CYC displayed moderate foliar discoloration and mild stunting/distortion of new growth (data not shown). Symptoms were still present, but less severe, at 60 DAT, and were no longer evident by 120 DAT. There was no injury to oakleaf hydrangea in 2005. Quality of treated plants was similar to untreated plants at 120 DAT in both 2004 and 2005.

'Brandy's Temper' sasanqua camellia. Similar to 'Elizabeth Ann' Japanese camellia, CYC increased shoot production of 'Brandy's Temper' sasanqua camellia. In 2004, shoot number at 30 DAT showed a linear increase from 50% in plants treated with 25 ppm CYC to 125% in plants treated with 200 ppm CYC (Table 3). Plant response was similar at 60 DAT in 2005. Plants a showed linear increase in shoot number as CYC rates increased, from 32% in 50 ppm plants to 68% in 200 ppm plants, compared to untreated plants (Table 4). Lower percentage increases for 'Brandy's Temper' camellia in 2005 may be due to use of older, more well-branched plants compared to the younger, more sparsely branched plants treated in 2004. Shoot height at 60 DAT in 2004 decreased linearly with increasing CYC concentrations. In 2005, height of treated plants compared to untreated plants at 60 DAT increased in response to 50 and 100 ppm CYC before decreasing at 200 ppm CYC. In both years, treated plants generally appeared fuller and more compact than untreated controls. Treated plants were of higher quality than untreated at 100 DAT in 2004; quality increased in response to 25, 50 and 100 ppm CYC before decreasing with 200 ppm CYC. In 2005, quality of plants treated with 50, 100 and 200 ppm CYC increased linearly by 14%, 17% and 35%, respectively, when compared to untreated plants at 120 DAT.

'Eleanor Taber' Indian hawthorn. In 2004, shoot numbers of 'Eleanor Taber' Indian hawthorn increased linearly by 212% and 306% at 30 DAT with CYC concentrations of 50 and 200 ppm, respectively (Table 3). A similar linear trend occurred at 60 DAT in 2005; new shoot production ranged from 70% to 187% in treated 50 and 200 ppm plants compared to untreated plants (Table 4). Shoot increases combined with minimal differences in both height and GI at 60 DAT in both 2004 and 2005 resulted in dense plants with a compact appearance. Although not present in 2004, mild to moderate foliar injury, ranging from slight discoloration to stunting and/or cupping of new growth, was evident in treated plants by 45 DAT in 2005. Injury was not rated, but symptoms appeared to increase in severity as CYC concentration increased. Symptoms were no longer evident by the end of the growing season, ~220 DAT. Plant quality increased linearly with increasing CYC concentration at 120 DAT in 2004, but, due to foliar injury, was insignificant in 2005.

'Olivia' Indian hawthorn. This cultivar of Indian hawthorn was included in 2005, and similar to 'Eleanor Taber', 'Olivia' showed a higher number of shoots following CYC application. Yet contrary to 'Eleanor Taber', shoot formation was quadratic in response to increasing CYC concentrations at 60 DAT. Treated plants formed 86% more shoots than untreated plants at 50 ppm CYC, increasing to 108% at 100 ppm, and decreasing to 46% at 200 ppm, suggesting that an optimal CYC range for this cultivar was exceeded at 200 ppm (Table 5). Shoot height response at 60 DAT was quadratic; untreated plants and plants treated with 50 and 100 ppm were of similar height but plants treated with 200 ppm CYC were taller than all other plants, treated or untreated. Shoot GI was not affected by treatments. Similar to 'Eleanor Taber', plant quality was not significant in 'Olivia' due to foliar injury that was evident by 45 DAT. Symptoms were not quantified, but appeared to increase in severity as CYC concentration increased, ranging from slight yellowing of new foliage in plants treated with lower CYC concentrations to more severe yellowing and/or stunting/cupping of new foliage with higher CYC concentrations. Injury was transient and no longer evident by 220 DAT.

'Sky Pencil' holly. Shoot formation of 'Sky Pencil' holly at 60 DAT in 2005 showed a linear increase as ppm CYC increased, from 48% in plants treated with 50 ppm CYC to 63% in plants treated with 200 ppm CYC, compared to untreated controls (Table 5). Height and GI of treated plants at 60 DAT was lower than that of untreated plants. The combination of abundant lateral shoot growth on shorter plants gave treated plants a dense, compact appearance. Quality of treated plants at 120 DAT increased up to 100 ppm before decreasing slightly at 200 ppm.

'Foster' holly. Increasing CYC concentrations caused a linear increase in shoot production of Foster holly in 2005 (Table 5). Treated plants formed as many as 24% more shoots than untreated plants at 60 DAT. Shoot height was not affected, however GI decreased linearly with increasing CYC concentration at 60 DAT, and the canopy of treated plants was densely compact with new foliage. Treatment effects had dissipated when plants were rated for quality at 120 DAT and all plants, untreated and CYC-treated, were similar in appearance.

Results from these studies indicate that CYC can promote branching of Florida anise, ‘Elizabeth Ann’ Japanese camellia, ‘Nigra’ inkberry holly, ‘Chinsan’, ‘Red Slippers’ and ‘Watchet’ azaleas, ‘Ellen Huff’ oakleaf hydrangea, ‘Brandy’s Temper’ sasanqua camellia, ‘Eleanor Taber’ and ‘Olivia’ Indian hawthorn and ‘Sky Pencil’ and ‘Foster’ holly. However, similar to previous studies that found branching effects of TDZ and BA on woody ornamental shrubs and branching effects of CYC on fruit trees, CYC-induced branching response varied with species, cultivar and application rate, and there is a potential for plant injury.

Generally, shoot number of ‘Elizabeth Ann’ and ‘Brandy’s Temper’ camellia, ‘Nigra’ inkberry holly, ‘Sky Pencil’ holly and ‘Eleanor Taber’ Indian hawthorn, showed linear increases as CYC concentration increased while height, GI or both decreased linearly with increasing CYC concentration. As a result, treated plants appeared full, densely compact and more attractive than untreated controls. However, shoot production in azalea cultivars showed linear increases in response to increasing CYC concentration while effects on height and GI were often minimal. Foliar injury was noted in three species: slight discoloration to moderate stunting of new foliage of ‘Ellen Huff’ oakleaf hydrangea in 2004 and mild to moderate yellowing and/or stunting of new growth of ‘Eleanor Taber’ and ‘Olivia’ Indian hawthorn in 2005, but plants outgrew injury symptoms by the end of the growing season.

Plant quality of responsive species was generally higher in treated plants when compared to untreated plants at 100 or 120 DAT in 2004, but quality was generally insignificant at 120 DAT in 2005 due to either injury (Indian hawthorn sp.) or the maturation of CYC-induced shoot formation that caused most treated plants to appear similar to untreated plants when data were collected at 120 DAT. Plants used in the 2005 tests were more mature and often fairly well-branched before treatment while the majority of plants used in 2004 were younger and more sparsely branched. Perhaps duration of plant response to CYC effects is longer-lived if plants are initially younger, smaller in size and/or less branched.

Regardless, plants outgrew the effects of single CYC applications in both 2004 and 2005 by the end of the growing season, approximately 220 DAT, and treated plants were similar in appearance to untreated controls. Future research should explore methods that will increase the duration of plant response to CYC, while minimizing the potential for foliar injury.

Literature Cited

1. Alabama Agricultural Experiment Station. 2005. State's green industry grows to $1.9 billion. http://www.ag.auburn.edu/aaes/webpress/2005/green.htm. (Last accessed October 2006).

2. Banko, T.J. and M.A. Stefani. 1996. Growth response of large, established shrubs to Cutless, Atrimmec and Trim-Cut. J. Environ. Hort. 14:177-180.

3. Bruner, L. L., G.J. Keever, J.R. Kessler, Jr., and C.H. Gilliam. 2002. Atrimmec suppresses shoot length and promotes branching of Lonicera ×heckrottii 'Goldflame' (Goldflame honeysuckle). J. Environ. Hort. 20:73-76.

4. Cline, M.G. 1998. Apical dominance. Bot. Rev. 57:318-358.

5. Elfving, D.C. and D.B. Visser. 2005. Cyclanilide induces lateral branching in apple trees. HortScience 40:119-122.

6. Elfving, D.C. and D.B. Visser. 2006. Cyclanilide induces lateral branching in sweet cherry trees. HortScience 41:149-153.

7. Fain, G.B., C.H. Gilliam, and G.J. Keever. 2001. Response of *Lagerstroemia* × 'Tuscarora' to Pistill and Atrimmec. J. Environ. Hort. 19:149-152.

8. Keever, G.J. and D.A. Findley. 2001. Thidiazuron increases shoot formation in nandina. J. Environ. Hort. 20:24-28.

9. Keever, G.J. and T.A. Morrison. 2003. Multiple benzyladenine applications increase new shoot formation in nandina. J. Environ. Hort. 21:144-147.

10. Keever, G.J. and W.J. Foster. 1990. Chemically induced branching of woody landscape plants. J. Environ. Hort. 8:78-82.

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

12. Oates, J.M., G.J. Keever, and J.R. Kessler, Jr. 2005. BA application frequency and concentration effects on two Indian hawthorn cultivars. J. Environ. Hort. 23:37-41.

13. Oates, J.M., G.J. Keever, and J.R. Kessler, Jr. 2004. BA-induced shoot formation in Indian hawthorn. J. Environ. Hort. 22:71-74.

14. Oates, J.M., G.J. Keever, and J.R. Kessler, Jr. 2005. Developmental stage influences plant response to benzyladenine. J. Environ. Hort. 23:149-152.

Table 1. Effects of single foliar applications of cyclanilide on the growth of three species of woody nursery crops in 2004.

CYC conc. (ppm)		Shoot number[z]	Height (cm)	Growth index[y]	Quality rating[x]
		Florida anise			
		30 DAT	60 DAT	60 DAT	120 DAT
0		11.7	51.3	52.6	2.8
25		14.7	50.0	53.8	3.1
50		17.3	54.0	60.7	3.3
100		17.2	51.5	57.9	3.3
200		16.8	54.0	61.7	3.3
	Sign.[w]	Q*	NS	L*	NS
		'Elizabeth Ann' Japanese camellia			
		30 DAT	60 DAT	60 DAT	120 DAT
0		8.7	70.2	54.6	2.0
25		18.8	70.2	57.3	2.5
50		24.5	82.3	66.2	2.7
100		27.5	62.3	59.3	3.7
200		40.5	65.7	65.6	3.8
	Sign.	L***	L*	L**	L***
		'Nigra' Inkberry holly			
		30 DAT	60 DAT	60 DAT	120 DAT
0		26.7	49.3	43.6	2.0
25		41.5	48.3	44.9	3.0
50		54.7	51.0	47.5	3.7
100		55.7	45.0	44.4	3.7
200		57.8	46.0	45.3	4.5
	Sign.	L***	NS	NS	L***

[z]Total number of terminal and lateral shoots, quantified 30 days after treatment (DAT).

[y]Growth index (GI = [(height + widest width + width 90^{o} to widest width) ÷ 3]), in cm.

[x]Quality rating: 1 = minimal branching, open and leggy to 5 = prolific branching, dense and compact, evaluated 100 or 120 DAT.

[w]Nonsignificant (NS) or significant linear (L) or quadratic (Q) trends at $P = 0.05$ (*), $P = 0.01$ (**), or $P = 0.001$ (***).

Table 2. Effects of single foliar applications of cyclanilide on the growth of three azalea cultivars in 2004.

CYC conc. (ppm)		Shoot number[z]	Height (cm)	Growth index[y]	Quality rating[x]
		'Chinsan' azalea			
		30 DAT	60 DAT	60 DAT	100 DAT
0		17.7	16.8	22.9	2.6
25		27.8	15.5	19.6	3.1
50		29.2	15.5	19.6	3.5
100		32.5	11.3	15.2	2.8
200		35.4	13.0	18.6	4.1
	Sign.[w]	L**	L*	L**	L**
		'Red Slippers' azalea			
		30 DAT	60 DAT	60 DAT	120 DAT
0		8.6	23.8	22.1	2.0
25		11.8	23.4	21.3	2.6
50		9.8	21.2	20.1	2.8
100		12.4	21.0	20.0	3.2
200		14.8	16.8	19.9	4.3
	Sign.	L**	L***	NS	L***
		'Watchet' azalea			
		30 DAT	60 DAT	60 DAT	100 DAT
0		7.8	26.8	30.0	-
25		18.3	22.8	25.0	-
50		21.7	22.5	24.7	-
100		29.2	22.7	27.0	-
200		29.2	23.0	26.5	-
	Sign.	L***	NS	NS	Not rated

[z]Total number of terminal and lateral shoots, quantified 30 days after treatment (DAT).

[y]Growth index (GI = [(height + widest width + width 90^{o} to widest width) ÷ 3]), in cm.

[x]Quality rating: 1 = minimal branching, open and leggy to 5 = prolific branching, dense and compact, evaluated 100 or 120 DAT.

[w]Nonsignificant (NS) or significant linear (L) or quadratic (Q) trends at *P* = 0.05 (*), *P* = 0.01 (**), or *P* = 0.001 (***).

Table 3. Effects of single foliar applications of cyclanilide on the growth of three species of woody nursery crops in 2004.

CYC conc. (ppm)		Shoot number[z]	Height (cm)	Growth index[y]	Quality rating[x]
		'Ellen Huff' oakleaf hydrangea			
		30 DAT	60 DAT	60 DAT	120 DAT
0		1.8	50.9	55.5	2.2
25		2.5	50.9	53.7	2.1
50		2.4	38.9	51.2	2.1
100		2.8	35.6	42.2	2.0
200		3.1	39.6	47.0	2.1
	Sign.[w]	L*	NS	L*	NS
		'Brandy's Temper' sasanqua camellia			
		30 DAT	60 DAT	60 DAT	100 DAT
0		16.9	62.9	72.6	2.7
25		25.4	56.3	67.5	2.8
50		27.2	56.2	70.4	2.8
100		42.1	54.7	70.6	3.5
200		38.0	49.5	65.2	2.5
	Sign.	L***	L*	NS	Q*
		'Eleanor Taber' Indian hawthorn			
		30 DAT	60 DAT	60 DAT	120 DAT
0		13.5	25.8	39.4	3.1
25		42.1	24.6	38.5	3.9
50		43.4	23.1	36.7	3.8
100		46.7	25.3	36.3	3.6
200		54.9	25.0	36.7	4.6
	Sign.	L***	NS	L*	L*

[z]Total number of terminal and lateral shoots, quantified 30 days after treatment (DAT).

[y]Growth index (GI = [(height + widest width + width 90^{o} to widest width) ÷ 3]), in cm.

[x]Quality rating: 1 = minimal branching, open and leggy to 5 = prolific branching, dense and compact, evaluated 100 or 120 DAT.

[w]Nonsignificant (NS) or significant linear (L) or quadratic (Q) trends at $P = 0.05$ (*), $P = 0.01$ (**), or $P = 0.001$ (***).

Table 4. Effects of single foliar applications of cyclanilide on growth of three species of woody nursery crops in 2005, repeated from 2004.

CYC conc. (ppm)		Shoot number[z]	Height (cm)	Growth index[y]	Quality rating[x]
		'Ellen Huff' oakleaf hydrangea			
		60 DAT	60 DAT	60 DAT	120 DAT
0		4.7	58.2	55.5	1.6
50		10.3	42.8	49.8	2.2
100		15.5	42.8	47.7	2.5
200		16.0	42.2	45.6	2.9
	Sign.[w]	L***	NS	NS	NS
		'Brandy's Temper' camellia			
		60 DAT	60 DAT	60 DAT	120 DAT
0		41.7	78.0	71.9	3.7
50		55.0	87.5	74.5	4.2
100		68.2	78.5	73.4	4.3
200		70.2	65.3	70.3	5.0
	Sign.	L**	Q*	NS	L***
		'Eleanor Taber' Indian hawthorn			
		60 DAT	60 DAT	60 DAT	120 DAT
0		12.8	19.5	27.6	3.2
50		21.8	19.7	27.6	3.5
100		30.0	19.3	28.2	3.5
200		36.8	18.3	27.6	3.3
	Sign.	L***	NS	NS	NS

[z]Total number of terminal and lateral shoots, quantified 60 days after treatment (DAT).

[y]Growth index (GI = [(height + widest width + width 90^{o} to widest width) ÷ 3]), in cm.

[x]Quality rating: 1 = minimal branching, open and leggy to 5 = prolific branching, dense and compact, evaluated 120 DAT.

[w]Nonsignificant (NS) or significant linear (L) or quadratic (Q) trends at $P = 0.05$ (*), $P = 0.01$ (**), or $P = 0.001$ (***).

Table 5. Effects of single foliar applications of cyclanilide on growth of three species of woody nursery crops in 2005.

CYC conc. (ppm)		Shoot number[z]	Height (cm)	Growth index[y]	Quality rating[x]
		'Olivia' Indian hawthorn			
		60 DAT	60 DAT	60 DAT	120 DAT
0		17.7	23.3	32.6	3.2
50		32.8	22.3	33.4	3.8
100		36.8	23.8	31.7	4.0
200		25.8	25.8	31.3	4.2
	Sign.[w]	Q***	Q**	NS	NS
		'Sky Pencil' holly			
		60 DAT	60 DAT	60 DAT	120 DAT
0		34.3	34.3	19.7	2.0
50		50.8	29.8	18.8	2.8
100		54.3	31.8	18.5	3.7
200		55.8	31.2	18.3	3.0
	Sign.	L*	Q*	L*	Q*
		'Foster' holly			
		60 DAT	60 DAT	60 DAT	120 DAT
0		18	22.0	25.3	2.5
50		18.2	27.3	27.8	3.0
100		17.5	21.7	24.8	2.7
200		22.3	23.7	24.3	3.2
	Sign.	L**	NS	L*	NS

[z]Total number of terminal and lateral shoots, quantified 60 days after treatment (DAT).

[y]Growth index (GI = [(height + widest width + width 90^{o} to widest width) ÷ 3]), in cm.

[x]Quality rating: 1 = minimal branching, open and leggy to 5 = prolific branching, dense and compact, evaluated 120 DAT.

[w]Nonsignificant (NS) or significant linear (L) or quadratic (Q) trends at $P = 0.05$ (*), $P = 0.01$ (**), or $P = 0.001$ (***).

CHAPTER III

Multiple Cyclanilide Applications Promote Branching of Woody Ornamentals

Abstract

Multiple weekly or biweekly applications of 0, 100, 200 or 300 ppm cyclanilide (CYC), a bioregulator effective in stimulating branching of apple and cherry trees, and select woody ornamental shrubs, were applied foliarly to eight species or cultivars of woody landscape shrubs, five of which showed increased branching in response to treatment. Shoot number increases were concentration and species dependent, and compared to untreated controls, branching at 60 days after first treatment (DAFT) with three weekly applications of 100 to 300 ppm CYC in 2005 increased from 1400% to 1900% in ‘Brandy’s Temper’ sasanqua camellia, 114% to 175% in ‘Sky Pencil’ holly, 385% to 458% in ‘Foster’ holly 166%, 335% in ‘Eleanor Taber’ Indian hawthorn, and 1885% to 2230% in ‘Olivia’ Indian hawthorn. In 2006, branching 60 DAFT with three biweekly applications of 100 to 300 ppm CYC increased 34% to 73% in ‘Foster’ holly, 268% to 413% in ‘Eleanor Taber’ Indian hawthorn, and 2540% to 4440% in ‘Olivia’ Indian hawthorn. Plant size often decreased with increasing CYC concentration, but not in all species or cultivars. Injury to new foliage of ‘Brandy’s Temper’ camellia and ‘Sky Pencil’ and ‘Foster’ holly occurred in 2005, and to new foliage of ‘Eleanor Taber’ and ‘Olivia’ Indian hawthorn in both 2005 and 2006, however

symptoms were transient and no longer evident by 120 DAFT. Quality of treated responsive plants at 120 DAFT was usually higher than that of untreated plants, and CYC-induced treatment effects generally persisted until the end of the growing season.

Index words: auxin transport inhibitor, plant growth regulator, container nursery production.

Species used in this study: ‘Brandy’s Temper’ sasanqua camellia (*Camellia sasanqua* Thunb. ‘Brandy’s Temper), spreading yew (*Cephalotaxus harringtonia* C. Koch. ‘Prostrata’), ‘Foster’ holly (*Ilex ×attenuata* Ashe.‘Fosteri’), ‘Sky Pencil’ holly (*Ilex crenata* Thunb.‘Sky Pencil’), leatherleaf mahonia (*Mahonia bealei* (Fort.) Carr.), ‘Harbour Dwarf’ nandina (*Nandina domestica* Thunb. ‘Harbour Dwarf’), ‘Conia’ (Olivia™) and ‘Conor’ (Eleanor Taber™) Indian hawthorn (*Rhaphiolepis indica* (L.) Lindl.).

Chemical used in this study: cyclanilide [1-(2,4-dichlorophenylaminocarbonyl)-cyclopropane carboxylic acid].

Significance to the Nursery Industry

Woody ornamental shrubs often require multiple prunings during nursery production to develop compact, well-branched plants. However, significant labor costs and loss of plant biomass that can lengthen production time are incurred with mechanical pruning. Single foliar sprays of 25 to 200 ppm cyclanilide (CYC), an experimental plant growth regulator (Bayer Environmental Science, Research Triangle Park, NC) increased

shoot formation, promoted plant compaction and thus enhanced overall appearance and marketability of 12 species or cultivars of woody landscape shrubs in a previous study. However, these effects were transitory and treated plants appeared similar to untreated plants by the end of the growing season (~220 days after treatment). Three weekly foliar sprays of 100, 200 or 300 ppm CYC increased branching, promoted compaction and enhanced quality of ‘Brandy’s Temper’ sasanqua camellia (*Camellia sasanqua* ‘Brandy’s Temper’), ‘Foster’ (*Ilex* ×*attenuata* ‘Fosteri’) and ‘Sky Pencil’ holly (*Ilex crenata* ‘Sky Pencil’) and ‘Eleanor Taber’ (*Rhaphiolepis indica* ‘Eleanor Taber’) and ‘Olivia’ Indian hawthorn (*Rhaphiolepis indica* ‘Olivia’), and effects were more persistent than single foliar applications. However, foliar injury occurred in all species, although symptoms were transitory and plants outgrew injury by 120 days after first treatment (DAFT). Symptoms generally increased from slight discoloration of new foliage to moderate to severe discoloration and/or stunting of new foliage as CYC concentrations increased from 100 to 300 ppm. While all CYC concentrations promoted plant branching and compaction, injury was minimal with 100 ppm foliar sprays. These results suggest that multiple CYC applications increase plant branching, compaction and overall quality more effectively than single applications, however injury, although transitory, was severe enough to discourage weekly applications at concentrations above 100 ppm.

Introduction

Most woody shrubs utilized in southeastern U.S. landscapes require costly, time-consuming manual pruning during nursery production to be well-branched and marketable. Plant growth regulators that may offer a substitute to manual pruning, such as benzyladenine (BA) and thidiazuron (TDZ), have been tested for branching effects on select woody species with mixed results (5, 6, 7, 8, 9, 10) and neither is EPA registered for commercial nursery use. Dikegulac sodium (Atrimmec, PBI/Gordon, Kansas City, MO), the only registered chemical branching agent for use on woody ornamentals, has growth retarding activity (1, 4) and is widely used in commercial landscape maintenance, but not in nurseries.

Recently, the bioregulator cyclanilide (CYC, Bayer Environmental Science, Research Triangle Park, NC) has become available for testing as a growth retardant for apple trees. Concentrations of 25 to 250 ppm CYC generally promoted slight reductions in shoot length but mainly stimulated lateral shoot formation on both current and previous season's growth without injury (2). In a subsequent study with sweet cherry, 50 to 200 ppm CYC promoted branching, although 'Bing'/Mazzard sweet cherry tree was injured by 200 ppm CYC (3). Lateral branch induction in both apple and sweet cherry tree appeared to result from a temporary interruption of apical dominance without long-term growth reduction or damage to the terminal meristem (2, 3).

Because CYC induced lateral branching in fruit tree studies, the effectiveness of single foliar applications of 25 to 200 ppm CYC on branching of 19 commonly produced woody ornamental shrubs was evaluated. 12 shrubs showed increased branching in response to treatment (unpublished data). In general, shoot numbers of responsive species increased linearly with increasing CYC concentration and treated plants were full and densely compact. Foliar injury symptoms, which generally increased in severity as CYC concentration increased, occurred in three species: New foliage of treated 'Ellen Huff' oakleaf hydrangea (*Hydrangea quercifolia* 'Ellen Huff') displayed interveinal chlorosis and new foliage of ‘Eleanor Taber’ and ‘Olivia’ Indian hawthorn displayed mild to moderate yellowing and/or stunting. However, injury was transient and symptoms were no longer evident by the end of the growing season.

Unfortunately, enhancement of plant compaction and quality was also transient and by the end of the growing season maturation of the single flush of CYC-induced growth resulted in treated plants similar in appearance to untreated plants. In research with BA, multiple applications made to species responsive to single applications more effectively stimulated shoot formation. For example, shoot formation of ‘Harbour Dwarf’ nandina was minimally affected by a single application of up to 2500 ppm BA (7), but shoot numbers increased linearly as weekly application number of 1250 to 5000 ppm BA increased from two to five (6).

Additionally, multiple BA applications promoted shoot formation of species unresponsive to single BA applications. Indian hawthorn did not show increases in number of new shoots in response to single BA applications of up to 3750 ppm (7) however four applications of 2500 to 5000 ppm BA increased shoot numbers of ‘Olivia’ Indian hawthorn. In another study, three applications of up to 5000 ppm BA induced more new shoots in ‘Eleanor Taber’ and ‘Olivia’ Indian hawthorn than two applications (9). Our objective was to determine if multiple CYC applications would increase the duration of branching in five responsive species, as well as promote branching in three previously unresponsive species.

Materials and Methods

Two experiments were conducted, one in 2005 and one in 2006, using similar methodology unless otherwise noted. Growth medium was a 7:1 pinebark:sand substrate amended per m^3 (yd^3) with 7.3 kg (16 lb) 16.5N-2.6P-10K (PolyOn 17-6-12, Pursell Industries, Sylacauga, AL), 0.9 kg (1.5 lb) Micromax (The Scotts Company, Marysville, OH) and 3 kg (5 lb) dolomitic limestone. Depending on specific cultural requirements, plants were spaced outdoors in either full sun or under 47% shade and irrigated twice-daily with approximately 1.3 cm (0.5 in) water per irrigation cycle. Plants were re-spaced and/or re-potted as needed. Treatments were applied using a CO_2 sprayer with a flat spray nozzle (XR TeeJet 8003VK, Bellspray, Inc., Opelousas, LA) at 138 kPa (20 psi). A nonionic surfactant, Buffer-X (Kalo Agr. Chemicals, Overland, KS), was included at the rate of 0.2%. Dry and wet-bulb temperatures were recorded at treatment time and relative humidity was determined from these measurements. Plants were treated under tree shade to reduce possible foliar burn by sun-drying of solutions and to prolong absorption. After a minimum of 6 hours, plants were returned to irrigated growing areas.

Data collection included: shoot height and width, from which growth index (GI) was calculated [GI = (height + widest width + width 90^o to widest width) ÷ 3]; counts of new terminal and/or lateral shoots ≥ 1 cm (0.4 in) in length; plant injury rating, if applicable (1 = no injury; 2 = slight discoloration of new foliage; 3 = slight to moderate discoloration, slight to moderate stunting of new foliage; 4 = moderate to severe discoloration, moderate to severe stunting of new foliage; 5 = necrosis of new foliage) and a 1 to 5 rating of overall plant quality (1 = poorly branched and unmarketable to 5 = compact, well-branched and highly marketable). Quality and injury were rated by the same person at each collection date in each experiment. Data were subjected to an analysis of variance, using the SAS General Linear Model procedure (SAS Institute, Cary, NC), and orthogonal contrasts were used to test linear and quadratic response trends to CYC rate ($P = 0.05$).

2005. Beginning on June 10, 3 weekly applications of 0, 100, 200 or 300 ppm CYC were made to 5 species responsive to single CYC applications: plants of 'Brandy's Temper' camellia, 59.0 to 65.5 cm (23.2 to 25.8 in) in height, 'Foster' holly, 19.2 to 26.2 cm (7.6 to 10.3 in) in height, 'Sky Pencil' holly, 22.7 to 26.2 cm (8.9 to 10.3 in) in height, 'Olivia' Indian hawthorn, 23.0 to 23.6 cm (9.1 to 9.3 in) in height and 'Eleanor Taber' Indian hawthorn, 21.1 to 22.3 cm (8.3 to 8.8 in) in height. Also beginning on June 10, 5 weekly applications of the same CYC concentrations were made to three species unresponsive to single CYC applications: plants of 'Harbour Dwarf' nandina, 12.7 to 13.7 cm (5.0 to 5.4 in) in height, spreading yew, 9.3 to 13.5 cm (3.7 to 5.3 in) in height, and leatherleaf mahonia, 12.0 to 14.0 cm (4.7 to 5.5 in) in height. All plants were blocked by initial height, treated in 3.8 liter (#1) containers and replicated with 10 plants per treatment, except 'Brandy's Temper' camellia, which was in 11.4 (#3) containers and replicated with 6 plants per treatment. At first application, plants had completed their first growth flush of the season and most shoot tissue was mature (previous season's growth) or had recently matured (current season's growth), although some young foliage was present.

Dry bulb temperature and relative humidity at application ranged from 26 to 32C (79-90F) and from 62% to 83%, respectively. With the exception of leatherleaf mahonia and spreading yew, plants in 3.8 liter (# 1) containers were repotted into 11.4 (#3) containers using the previously described substrate: 'Olivia' and 'Eleanor Taber' Indian hawthorn on July 12, 'Foster' and 'Sky Pencil' holly on July 15 and 'Harbour Dwarf' nandina on July 21. Shoot height and widths, from which GI was calculated, were measured 60 and 120 days after first treatment (DAFT). New shoots ≥ 1 cm (0.4 in) in length were counted 60 DAFT and plant quality was rated 120 DAFT.

2006. 'Foster' holly, 'Eleanor Taber' and 'Olivia' Indian hawthorn in 3.8 liter (#1) containers were overwintered outdoors in full sun under overhead irrigation and covered with perforated white polyethylene sheets during periods of forecasted freezing temperatures. On March 20, 2006, plants were repotted into 11.4 liter (#3) containers using the previously described substrate. Beginning on June 5, 3 biweekly applications of 0, 100, 200 or 300 ppm CYC were made to plants of 'Foster' holly, 80.0 to 86.2 cm (31.5 to 33.9 in) in height, 'Eleanor Taber' Indian hawthorn, 29.5 to 33.5 cm (11.6 to 13.2 in) in height, and 'Olivia' Indian hawthorn, 29.5 to 35.5 cm (11.6 to 14.0 in) in height. Hollies were arranged in a randomized complete block design and replicated with 10 single plants per treatment. Hawthorns were placed in a factorial arrangement (CYC × cv.) and replicated with 5 single plants per cultivar; main effects and interactions were determined using analysis of variance (ANOVA). Dry bulb temperature and relative humidity during application ranged from 29 to 32C (84 to 90F) and from 59% to 92%, respectively. Data 60 DAFT included measurement of height and widths, from which GI was calculated, a count of new lateral and/or terminal shoots ≥ 1cm (0.4 in) in length and an injury rating, if applicable. Data 120 DAFT included an additional injury rating, if applicable, and a quality rating.

Results and Discussion

‘Harbour Dwarf’ nandina, spreading yew and leatherleaf mahonia, which were unresponsive to single CYC applications, did not respond to CYC, even after 5 weekly applications (data not shown). However, species responsive to single CYC applications, ‘Brandy’s Temper’ sasanqua camellia, ‘Sky Pencil’ and ‘Foster’ holly, and ‘Eleanor Taber’ and ‘Olivia’ Indian hawthorn also responded to three weekly and/or biweekly CYC applications.

‘Brandy’s Temper’ sasanqua camellia. In 2005, attractive reddening of new foliage of all treated ‘Brandy’s Temper’ camellia, regardless of specific CYC concentration, was noted 21 DAFT and persisted until approximately 90 DAFT. Dramatic differences in number of shoots were evident at 60 DAFT. Controls had fewer than three new shoots per plant, while plants treated with 100 ppm CYC had almost 17 times as many new shoots (Table 1). A further increase in shoot number occurred with 300 ppm CYC, but the increase was relatively minor. Shoot height was not affected at either 60 or 120 DAFT. However, GI of treated plants increased linearly with increasing CYC concentrations at 60 DAFT and plant form was noticeably wider and more pendulous in comparison to untreated plants, possibly due to CYC disruption of apical dominance that temporarily halted upright growth. A similar change in plant form occurred in fruit-trees: CYC application stimulated lateral branching while simultaneously inhibiting upright growth (2, 3). CYC-induced changes in plant form of ‘Brandy’s Temper’ camellia was still evident at 120 DAFT and GI of all treated plants remained higher than that of untreated plants.

Multiple CYC applications delayed flowering of treated ‘Brandy’s Temper’ camellia, which did not occur with single CYC applications. Flower buds of untreated plants began to open in mid-October, those of plants treated with 100 ppm CYC approximately one week later, followed by plants treated with 200 ppm CYC and finishing with plants treated with 300 ppm CYC in the middle of November, although no data was collected. Number of flowers per plant and flower morphology did not appear to be affected.

‘**Sky Pencil’ holly**. ‘Sky Pencil’ holly can be costly to produce because its slender growth habit often necessitates up to three liners per one gallon container to give the illusion of one marketable plant. Therefore, our primary objective was to increase plant width. In 2005, shoot number at 60 DAFT changed quadratically in response to 100, 200 and 300 ppm CYC, increasing 115%, 175% and 166%, respectively (Table 1). CYC-treated plants were up to 28% and 12% shorter at 60 and 120 DAFT, respectively, and GI was up to 17% and 6% lower at 60 and 120 DAFT, respectively, reflecting creation of more dense, compact plants. A change in shape of newly formed leaves was noted 21 DAFT; treated plants formed oval to linear new leaves while untreated plants formed rounded leaves, however these symptoms were no longer evident by 90 DAFT. Plant quality at 120 DAFT increased linearly with increasing CYC concentrations and treated plants were full and highly marketable.

‘Foster’ holly. Shoot number of ‘Foster’ holly increased in response to both weekly and biweekly CYC treatments, although specific response varied. In 2005, shoot formation in ‘Foster’ holly changed quadratically and plants treated with 100, 200 and 300 ppm CYC produced 384%, 446% and 458% more shoots, respectively, than untreated plants at 60 DAFT (Table 1). Shoot numbers increased linearly at 60 DAFT in 2006 and plants treated with 100 and 300 ppm CYC formed 34% and 74% more shoots than untreated controls (Table 2). A lower percent increase in 2006 could be because controls themselves formed a high number of shoots. When comparing initial plant stage of development and/or size between years: Younger 2005 plants in 3.8 liter (#1) containers averaged only 21.2 cm (8.3in) in height and had a mean GI of 23.9 cm (9.4 in), whereas older 2006 plants in 11.4 (#3) containers that were over-wintered from 2005, averaged 82.6 cm (32.5 in) in height and had a mean GI of 62.7 cm (24.7 in). Perhaps 'Foster' holly naturally produces fewer shoots when younger and more shoots as they grow older. Another possibility is that younger plants, regardless of species or cultivar, are more responsive to CYC application than are older plants. Regardless, treated plants formed more shoots than untreated plants in response to both weekly and biweekly CYC applications.

Shoot height and GI were lower in all CYC-treated plants at 60 DAFT and 120 DAFT in 2005, reflecting the altered growth habit of treated plants; untreated plants grew upright and were taller than they were wide, while treated plants were about as wide as they were tall. The change in form of treated plants persisted throughout the 2005 growing season and, although not quantified, into spring of 2006. Plant size was unaffected by CYC at both 60 and 120 DAFT in 2006. Mild discoloration of leaves and reddening of leaf margins developed on new growth of treated plants by 21 DAFT in 2005; symptoms were no longer evident by 90 DAFT. Plants were not injured in 2006. Plant quality in both 2005 and 2006 increased linearly with increasing CYC concentration and treated plants were fuller and more attractively shaped than untreated plants.

Indian hawthorn. Except for shoot counts, there were no interactions for any Indian hawthorn data in 2006, hence shoot height, GI, injury rating and quality rating data were pooled for the two cultivars.

In 2005, shoot number of ‘Eleanor Taber’ Indian hawthorn showed a linear increase with increasing CYC concentration at 60 DAFT (Table 1). Compared to controls, increases following three applications of 100, 200 and 300 ppm CYC were 165%, 257% and 335%, respectively. In 2006, ‘Eleanor Taber’ plants formed 19, 97.5, 86 and 70 shoots at 60 DAFT in response to 0, 100, 200 and 300 ppm CYC, respectively (data not shown). Branching response in ‘Olivia’ was more pronounced than in ‘Eleanor Taber’, primarily because fewer shoots formed on control plants. Under normal production conditions, ‘Olivia’ does not readily branch and therefore requires more frequent pruning to develop a marketable plant than does ‘Eleanor Taber’. In 2005, untreated ‘Olivia’ at 60 DAFT formed only 2 shoots whereas treated plants formed 40, 47 or 43 shoots in response to 100, 200 or 300 ppm CYC, respectively (Table 1). In 2006, shoot formation at 60 DAFT increased linearly as CYC concentration increased, from 2 shoots on untreated plants to 53, 65 and 91 shoots on plants treated with 100, 200 or 300 ppm CYC, respectively (data not shown).

In 2005, shoot height and GI of treated ‘Eleanor Taber’ plants decreased linearly with increasing CYC concentration at both 60 and 120 DAFT and plants were full and compact. No effect on plant size of treated ‘Olivia’ at 60 or 120 DAFT in 2005 combined with prolific shoot formation gave plants a densely compact appearance. Shoot height and GI of Indian hawthorn was unaffected in 2006 (Table 2).

Transient injury to new foliage occurred in treated Indian hawthorn in both 2005 and 2006. Symptoms were similar in both years and ranged from mild or moderate discoloration to stunting, cupping and twisting and generally increased with CYC concentration. Symptoms were evident approximately 21 DAFT in 2005 and approximately 60 DAFT in 2006, suggesting weekly applications injured plants more quickly than biweekly applications. Injury was not quantified in 2005, but in 2006 injury ratings at 60 DAFT increased linearly with increasing CYC concentration. Ratings at 120 DAFT were not significant (data not shown), indicating injury symptoms had dissipated.

In 2005, quality of ‘Eleanor Taber’ at 120 DAFT showed a linear increase as CYC concentration increased. Quality of ‘Olivia’ at 120 DAFT in 2005 was highest (3.7) in plants treated with 100 ppm, although all treated plants were full, compact and of higher quality than untreated plants. Plant quality in 2006 was insignificant due to usage of overwintered plants that were initially misshapen. Therefore, despite CYC-induced shoot formation, plant canopies were not well-shaped and marketable, suggesting that pruning may be necessary if plants are unattractive initially.

In research with the cytokinin BA, multiple applications promoted shoot formation in species unresponsive to single applications (7, 9) as well as greater shoot formation in previously responsive species (6, 7). Neither a single CYC application nor 5 weekly CYC applications affected branching in spreading yew, leatherleaf mahonia, or ‘Harbour Dwarf’ nandina. However, multiple weekly and/or biweekly CYC applications made to species responsive to single CYC applications: 'Brandy's Temper' sasanqua camellia, 'Sky Pencil' and 'Foster' holly and 'Eleanor Taber' and 'Olivia' Indian hawthorn, promoted shoot formation and a compact, well-branched canopy and therefore enhanced overall plant quality. However, plants treated with a single CYC application generally responded with a linear increase in shoot production as CYC concentration increased, while plants treated with multiple CYC applications generally responded with a quadratic change in shoot production. When compared to untreated controls, shoot number increased substantially in response to 100 ppm CYC. Shoot number increase in response to 200 ppm and 300 ppm was usually slightly higher than at 100 ppm, although in 'Sky Pencil' holly and 'Olivia' Indian hawthorn at 300 ppm stimulated fewer shoots than at 200 ppm CYC.

Overall, multiple CYC applications seem more effective in stimulating shoot production and increasing plant compaction and quality than single CYC applications. Plants in the single application study usually differed in height and/or GI at 60 DAT but by 120 DAT plants had often outgrown CYC-induced plant compaction and were thus of similar quality to untreated plants. Conversely, plants that received multiple applications of CYC were generally lower in height and GI and higher in quality at 60 DAFT. These treatment-related differences were still present at 120 DAFT, and even to the end of the growing season, although this was not quantified.

Unfortunately, increased longevity of plant response often came with the cost of initial foliar injury. In 2005, injury to all species was evident 21 DAFT with 3 weekly CYC applications. In 2006, injury to Indian hawthorn cultivars was evident 45 DAFT with three biweekly CYC applications. In 'Brandy's Temper' camellia, injury was limited to attractive reddening of new foliage, in 'Sky Pencil' holly the shape of new leaves was oval to linear instead of rounded and in 'Foster' holly leaves were mildly discolored coupled with attractive reddening of leaf margins. However, injury to Indian hawthorn cultivars initially detracted from plant quality. Injury at 100 ppm CYC was limited to mild discoloration of new foliage, 200 ppm CYC caused moderate discoloration of new foliage and 300 ppm caused moderate to severe discoloration and stunting, cupping and/or twisting of new foliage. Although plants outgrew injury symptoms by 120 DAFT, results of this study suggest little practical application in multiple CYC applications with concentrations above 100 ppm because shoot production, plant compaction and quality were enhanced with this concentration while injury was minimal. Regardless, future research with multiple CYC applications warrants the investigation of concentrations lower than 100 ppm so that branching, compaction and quality are promoted without plant injury.

Literature Cited

1. Bruner, L. L., G.J. Keever, J.R. Kessler, Jr., and C.H. Gilliam. 2002. Atrimmec suppresses shoot length and promotes branching of Lonicera ×heckrottii ‘Goldflame’ (Goldflame honeysuckle). J. Environ. Hort. 20:73-76.

2. Elfving, D.C. and D.B. Visser. 2005. Cyclanilide induces lateral branching in apple trees. HortScience 40:119-122.

3. Elfving, D.C. and D.B. Visser. 2006. Cyclanilide induces lateral branching in sweet cherry trees. HortScience 41:149-153.

4. Fain, G.B., C.H. Gilliam, and G.J. Keever. 2001. Response of *Lagerstroemia* × ‘Tuscarora’ to Pistill and Atrimmec. J. Environ. Hort. 19:149-152.

5. Keever, G.J. and D.A. Findley. 2001. Thidiazuron increases shoot formation in nandina. J. Environ. Hort. 20:24-28.

6. Keever, G.J. and T.A. Morrison. 2003. Multiple benzyladenine applications increase new shoot formation in nandina. J. Environ. Hort. 21:144-147.

7. Keever, G.J. and W.J. Foster. 1990. Chemically induced branching of woody landscape plants. J. Environ. Hort. 8:78-82.

8. Oates, J.M., G.J. Keever, and J.R. Kessler, Jr. 2005. BA application frequency and concentration effects on two Indian hawthorn cultivars. J. Environ. Hort. 23:37-41.

9. Oates, J.M., G.J. Keever, and J.R. Kessler, Jr. 2004. BA-induced shoot formation in Indian hawthorn. J. Environ. Hort. 22:71-74.

10. Oates, J.M., G.J. Keever, and J.R. Kessler, Jr. 2005. Developmental stage influences plant response to benzyladenine. J. Environ. Hort. 23:149-152.

Table 1. Effects of three weekly foliar applications of cyclanilide on the growth of five species of woody nursery crops in 2005.

CYC conc. (ppm)		Shoot #[z]	Height (cm)		Growth index[y]		Quality[x]
		'Brandy's Temper' camellia					
		60 DAFT[w]	60 DAFT	120 DAFT	60 DAFT	120 DAFT	120 DAFT
0		2.7	82.8	82.5	81.8	87.8	4.2
100		43.2	89.3	87.8	90.2	93.0	4.3
200		40.5	84.0	92.0	92.0	96.2	4.3
300		54.0	85.5	75.0	98.2	89.4	4.5
	Sign.[v]	Q*	NS	NS	L**	Q*	NS
		'Sky Pencil' holly					
		60 DAFT	60 DAFT	120 DAFT	60 DAFT	120 DAFT	120 DAFT
0		32.1	55.9	26.6	66.6	32.7	3.2
100		69.0	41.9	29.9	60.6	32.2	3.7
200		88.3	40.3	22.0	60.9	32.1	3.6
300		85.7	40.2	22.5	58.5	30.9	4.0
	Sign.	Q***	Q*	Q**	L*	L*	L**
		'Foster' holly					
		60 DAFT	60 DAFT	120 DAFT	60 DAFT	120 DAFT	120 DAFT
0		18.1	44.2	66.6	44.8	65.4	3.0
100		87.7	25.8	48.4	29.4	55.2	3.2
200		98.9	25.3	50.0	28.3	53.1	3.8
300		101.0	25.3	47.4	31.6	53.5	3.9
	Sign.	Q***	Q***	L*	Q***	Q*	L*
		'Eleanor Taber' Indian hawthorn					
		60 DAFT	60 DAFT	120 DAFT	60 DAFT	120 DAFT	120 DAFT
0		15.4	24.9	32.1	35.2	46.5	3.5
100		40.9	23.2	29.4	32.6	42.7	4.2
200		55.0	22.4	29.7	32.6	41.6	4.3
300		67.0	22.8	27.9	32.9	41.4	4.7
	Sign.	L***	L*	L**	Q*	L***	L***
		'Olivia' Indian hawthorn					
		60 DAFT	60 DAFT	120 DAFT	60 DAFT	120 DAFT	120 DAFT
0		2.0	24.5	27.6	34.2	42.6	2.1
100		39.7	20.9	27.9	31.5	39.3	3.7
200		46.6	21.4	26.3	31.1	39.2	3.1
300		43.0	21.6	28.7	31.3	39.7	3.5
	Sign.	Q***	NS	NS	NS	NS	Q**

[z]Total number of terminal and lateral shoots, quantified 60 days after first treatment (DAFT).

[y]Growth index (GI = [(height + widest width + width 90^{o} to widest width) ÷ 3]), in cm.

[x]Quality rating: 1 = minimal branching, open and leggy to 5 = prolific branching, dense and compact, evaluated 120 DAFT.

[w]DAFT = days after first treatment

[v]Nonsignificant (NS) or significant linear (L) or quadratic (Q) trends at *P* = 0.05 (*), *P* = 0.01 (**) or *P* = 0.001 (***).

Table 2. Effects of three biweekly applications of cyclanilide on the growth of two species of woody nursery crops in 2006.

		'Foster' holly						
CYC		Shoot #[z]	Height (cm)		Growth index[y]		Injury[x]	Quality[w]
(ppm)		60 DAFT[v]	60 DAFT	120 DAFT	60 DAFT	120 DAFT	60 DAFT	120 DAFT
0		77.1	94.0	111.0	71.2	79.3	-	2.7
100		103.1	83.2	115.9	67.3	82.5	-	2.8
200		133.8	87.6	118.0	65.6	78.6	-	3.4
300		133.3	84.0	104.9	69.3	77.1	-	3.6
	Sign.[u]	L**	NS	NS	NS	NS	-	L*
		Indian hawthorn[t]						
		60 DAFT	60 DAFT	120 DAFT	60 DAFT	120 DAFT	60 DAFT	120 DAFT
0		-	36.6	49.2	39.6	55.5	1	3.0
100		-	36.8	51.2	39.0	55.8	2.3	3.0
200		-	34.3	47.1	38.5	53.4	3.1	3.5
300		-	36.4	49.2	42.6	56.4	3.6	3.1
	Sign.	-	NS	NS	NS	NS	L***	NS

[z]Total number of terminal and lateral shoots, quantified 60 days after first treatment (DAFT).

[y]Growth index (GI = [(height + widest width + width 90^{o} to widest width) ÷ 3]), in cm.

[x]Injury rating: 1 = no injury; 2 = slight discoloration of new foliage; 3 = moderate discoloration; 4 = moderate to severe discoloration, moderate to severe stunting; 5 = necrosis.

[w]Quality rating: 1 = minimal branching, open and leggy to 5 = prolific branching, dense and compact.

[v]DAFT = days after first treatment

[u]Nonsignificant (NS) or significant linear (L) trends at *P* = 0.05 (*), *P* = 0.01 (**) or *P* = 0.001 (***).

[t]CYC x cultivar nonsignificant for all attributes except shoot counts, hence data for the two cultivars were pooled. Shoot counts for each cultivar are presented in the body of the paper.

CHAPTER IV

Interactive Effects of Pruning and Cyclanilide Application on Growth of Woody Nursery Crops

Abstract

A study was conducted to determine the effects of pruning on plant response to cyclanilide (CYC), a bioregulator that promotes lateral branching of fruit trees and select woody nursery crops. In April 2003, a single foliar application of 0, 25, 50, 100 or 200 ppm CYC was made to non-pruned ‘Elizabeth Ann’ Japanese camellia and small anisetree, and 0, 50 or 100 ppm CYC was applied to ‘Elizabeth Ann’ camellia and small anisetree that had been uniformly pruned prior to treatment. In June 2006, a single foliar application of 0, 100 or 200 ppm CYC was made to plants of ternstroemia, ‘Sky Pencil’ holly and ‘Jennifer’ azalea that were either not pruned or uniformly pruned before CYC treatment. At 30 and 60 days after treatment (DAT), non-pruned, CYC-treated plants formed more shoots than pruned CYC-treated plants, however quality at 120 DAT was generally higher in pruned-CYC treated plants. Another experiment with ternstroemia, ‘Sky Pencil’ holly, ‘Jennifer’ azalea and ‘Snow White’ Indian hawthorn determined the effects of 200 ppm CYC on branching when applied at three different stages of lateral shoot development following pruning (DS 1 – 3). At 60 days after pruning (DAP), shoot formation of ternstroemia and ‘Sky Pencil’ holly was highest in DS 3 plants, shoot

formation of ‘Jennifer’ azalea was highest in DS 1 plants and shoot formation of ‘Snow White’ Indian hawthorn was highest in DS 2 plants. Injury occurred in all species except ‘Jennifer’ azalea, and when compared to pruned, non-CYC treated plants, injury at 60 and 120 DAP was more pronounced in DS 3 plants of ternstroemia and ‘Sky Pencil’ holly, and in DS 2 plants of ‘Snow White’ Indian hawthorn. Plant quality of all species at 120 DAP was similar in all treatments.

Index words: auxin transport inhibitor, plant growth regulator, container nursery production.

Species used in this study: ‘Elizabeth Ann’ Japanese camellia (*Camellia japonica* L. ‘Elizabeth Ann’), ‘Snow White’ Indian hawthorn (*Rhaphiolepis indica* (L.) Lindl. ‘Snow White’), small anisetree (*Illicium parviflorum* Michx. ex Vent.), ‘Sky Pencil’ holly (*Ilex crenata* Thunb. ‘Sky Pencil’), ‘Jennifer’ azalea (*Rhododendron* L. ‘Jennifer’), ternstroemia (*Ternstroemia gymnanthera* Thunb.).

Chemical used in this study: cyclanilide [1-(2,4-dichlorophenylaminocarbonyl)-cyclopropane carboxylic acid].

Significance to the Nursery Industry

Cyclanilide (CYC), a new bioregulator made available by Bayer Environmental Science (Research Triangle Park, NC) for experimental evaluation as a branching agent for nursery crops, can be highly effective in stimulating lateral shoot growth of fruit trees (2, 3) and several woody ornamental shrubs (unpublished data) without pruning and could therefore become a valuable resource for expediting the production of quality nursery crops. However, in a recent study that utilized overwintered plant material, quality and marketability was not enhanced, despite CYC-induced branching. In nursery production, pruning is often necessary to correct legginess and establish quality and marketability. Results of studies that evaluated the interaction of pruning and CYC application on the growth of ‘Elizabeth Ann’ Japanese camellia (*Camellia japonica* ‘Elizabeth Ann’), ‘Snow White’ Indian hawthorn (*Rhaphiolepis indica* ‘Snow White’), small anisetree (*Illicium parviflorum*), ‘Sky Pencil’ holly (*Ilex crenata* ‘Sky Pencil’), ‘Jennifer’ azalea (*Rhododendron* ‘Jennifer’) and ternstroemia (*Ternstroemia gymnanthera*) indicate that pruning before CYC application often enhanced plant quality more effectively than applying CYC to non-pruned plants. Additionally, this research suggests that allowing new shoots to elongate 1.7 – 5.1 cm (0.5 – 1.0 in) before applying CYC stimulates greater subsequent shoot formation than applying CYC immediately after pruning, but with the risk of greater foliar injury.

Introduction

Apical dominance refers to the control that the terminal buds of a plant stem exert over the lateral buds. Terminal buds produce auxin, which diffuses basipetally and inhibits the development of lateral buds, often resulting in loose, sparsely branched plants. Therefore, in order to develop compact, well-branched plants, apical dominance must be disrupted (1). Most nurserymen accomplish this through removal of terminal meristems, e.g. pruning, which alleviates apical dominance and stimulates the development of lateral buds into lateral shoots, resulting in well-branched plants.

Unfortunately, most woody landscape shrubs require multiple prunings during nursery production to stimulate branching and create full, compact and marketable plants. Although pruning is considered necessary for plant quality, the process removes viable tissue and reduces overall plant size. A minimum of three weeks of active plant growth is lost as a result of each pruning (10) and because plants sold in one gallon containers have been pruned at least once and plants sold in three gallon containers have been pruned at least twice (Tom Dodd Nurseries, Semmes, AL, pers. comm) substantial production time is often added before plants are marketable. The relatively new bioregulator, cyclanilide (CYC, Bayer Environmental Science, Research Triangle Park, NC), promotes branching of fruit trees (2, 3) and select woody ornamental shrubs (unpublished data) without pruning, possibly by inhibiting auxin transport and thus temporarily disrupting apical dominance (8).

However, while a single foliar spray of 25 to 200 ppm CYC and 3 weekly foliar sprays of 100 to 300 ppm CYC applied to young, actively growing shrubs stimulated branching and enhanced plant quality, three biweekly foliar sprays of 100 to 300 ppm applied to older, overwintered shrubs stimulated branching but did not improve plant shape and overall quality (unpublished data). A concept known as “apical control” refers to physiological factors, such as plant age or stage of development, that supercede apical dominance in the determination of plant branching patterns and therefore overall shape and form of the plant canopy (1). Apical control can influence the relative length and orientation of lateral shoots (1, 12) and although shoot length and orientation of plants in the biweekly CYC study were not quantified, this concept may explain why increased shoot formation did not enhance overall appearance and quality.

Another possibility is that plant response to CYC is greater if applied to immature, actively growing foliage instead of mature, hardened foliage. Research with the cytokinin, BA showed that branching response was generally optimal when BA was applied to actively growing plants, and response declined if applications were made prior to or after a growth flush (4, 5, 7, 11). In another study, 3 applications of 1750 to 3500 ppm BA were applied at 7-day intervals to 'Eleanor Taber' and 'Olivia' Indian hawthorn, inkberry holly and 'Harbour Dwarf' nandina at three stages of increasing shoot development: When bud break had recently occurred and shoots were just beginning to expand, developmental stage 1 (DS 1), when actively flushing shoots with immature pubescent foliage were present, DS 2, or when shoots were hardening with fully expanded glabrous green foliage, DS 3. Results of this study agreed with previous research: plants in DS 2 formed more shoots in response to BA than plants in DS 1 or DS 3 and new shoot counts increased with increasing BA concentration. Additionally, plants treated at DS 1 and DS 2 incurred foliar injury, but not those treated at DS 3.

Because nursery crops often require pruning to correct legginess and because optimal stage of plant development for applying CYC was not known, the overall objective of this research was to investigate the interactive effects of pruning and CYC application.

Materials and Methods

Three experiments were conducted, one in 2004 and two in 2006, using similar methodology unless otherwise noted. Growth medium was a 7:1 pinebark:sand substrate amended per m^3 (yd^3) with 7.3 kg (16 lb) 16.5N-2.6P-10K (PolyOn 17-6-12, Pursell

Industries, Sylacauga, AL), 0.9 kg (1.5 lb) Micromax (The Scotts Company, Marysville, OH) and 3 kg (5 lb) dolomitic limestone. Plants were spaced outdoors, in either full sun or 47% shade, under twice-daily irrigations of approximately 1.3 cm (0.5 in) each. Plants were re-spaced as needed. Treatments were applied using a CO_2 sprayer with a flat spray nozzle (XR TeeJet 8003VK, Bellspray, Inc., Opelousas, LA) at 138 kPa (20 psi). A nonionic surfactant, Buffer-X (Kalo Agr. Chemicals, Overland, KS), was included at a rate of 0.2%. Dry and wet-bulb temperatures were recorded at treatment time and relative humidity was determined from these measurements. Plants were treated under tree shade to reduce possible foliar burn by sun-drying of solutions and to prolong absorption. After a minimum of 6 hours, plants were returned to irrigated growing areas.

Data collection included: counts of new terminal and/or lateral shoots ≥ 1cm (0.4 in) in length; shoot height and width, from which growth index (GI) were calculated (GI = [(height + widest width + width 90^o to widest width) ÷ 3]); ratings of foliar injury, if applicable; and ratings of overall plant quality. Injury rating (1 = no injury to 5 = necrosis of new foliage) and subjective quality rating (QR) on a 1-5 scale (1 = poorly branched and unmarketable to 5 = compact, well-branched and highly marketable) were determined by the same person for each collection date within each experiment.

Experiment 1, 2004. This experiment was conducted to determine the effects of CYC, pruning and the combination of the two on the branching of 'Elizabeth Ann' Japanese camellia and small anisetree. On April 9, uniform, unbranched plants of 'Elizabeth Ann' Japanese camellia and small anisetree in 3.8 liter (#1) containers were obtained from Tom Dodd Nurseries in Semmes, AL. 'Elizabeth Ann' camellia and small anisetree were pruned on April 23 by uniformly removing about one-third and three-fourths, respectively, of existing foliage before plants were treated with 0, 50 or 100 ppm CYC. Anise were excessively tall and sparsely branched, if at all, at the beginning of the experiment and were heavily pruned to promote branching low on the main shoot, however pruning removed most of the foliage. Also on April 23, actively growing, non-pruned plants with immature soft shoots were treated with foliar sprays of 0, 25, 50, 100 or 200 ppm CYC. Plants were arranged in a completely randomized design within species and the eight treatments were replicated with 6 single plants each. Dry bulb temperature and relative humidity at the time of application were 20C (68F) and 50%, respectively. An additional CYC application was made to all ‘Elizabeth Ann’ camellia and to pruned small anisetree on June 23, 60 days after initial treatment, to determine if further stimulation of new shoots would occur. Dry bulb temperature and relative humidity at time of application were 32C (90F) and 67%, respectively. New shoots were counted 30 and 90 DAT; shoots counted 30 DAT had matured by 90 DAT and were not recounted. Plant height and width were measured 60 DAT, from which GI was calculated. Overall plant quality was rated 120 DAT. Statistical analysis tested linear and quadratic response to CYC in non-pruned and in pruned treatments and paired contrasts were used to compare pruned treatments to each of common non-pruned CYC treatments.

Experiment 2, 2006. This experiment was conducted to further elucidate interactive effects of pruning and CYC application. Plants of ternstroemia in 3.8 liter (#1) containers were obtained from Tom Dodd Nurseries on March 10 and plants of ‘Sky Pencil’ holly and ‘Jennifer’ azalea in 7.6 liter (#2) containers were obtained from the Alabama Experimental Substation in Mobile on March 16. All plants were placed outdoors in full sun under overhead irrigation. On April 5, ternstroemia and 'Jennifer' azalea were repotted into 11.4 liter (#3) containers using the previously described substrate. On June 9, a single foliar spray of 0, 100 or 200 ppm CYC was applied to non-pruned plants of: Ternstroemia averaging 53.1 cm (20.9 in) in height, 'Jennifer' azalea averaging 52.6 cm (20.7 in) in height and 'Sky Pencil' holly averaging 82.7 cm (32.6 in) in height. Also on June 9, a single foliar spray of 0, 100 or 200 ppm CYC was applied to plants of ternstroemia averaging 37.4 cm (14.7 in) in height, 'Jennifer' azalea averaging 35.3 cm (13.9 in) in height and 'Sky Pencil' holly averaging 33.1 cm (13.0 in) in height that had been uniformly pruned just prior to treatment. At time of treatment, spring growth had hardened and there were few immature shoots on any of the plants. Foliage of non-pruned ternstroemia and 'Jennifer' azalea formed a rosette at the terminals of long branches, and because of sparse foliage along the branch length, the wood of branches was often visible. Treatments in this 2 × 3 factorial experiment were completely randomized and replicated with 10 single plants. Dry bulb temperature and relative humidity at the time of application ranged from 27 to 28C (80 to 82F) and from 68% to 72%, respectively. New shoots were counted 60 DAT, shoot height and widths were measured and GI calculated 60 and 120 DAT, and plants were rated for quality 120 DAT. The significance of main effects and interactions was determined using analysis of variance (ANOVA) and the linear and quadratic trend analysis of CYC concentration and pruned vs. non-pruned treatments was determined with orthogonal contrasts.

Experiment 3, 2006. The objective of this study was to determine how CYC affects branching when applied at various stages of lateral shoot development following pruning. Between March 10 and March 16, plants of 'Snow White' Indian hawthorn and ternstroemia in 3.8 liter (#1) containers and plants of ‘Sky Pencil’ holly and ‘Jennifer’ azalea in 7.6 liter (#2) containers were placed outdoors in full sun under overhead irrigation. All plants except ‘Sky Pencil’ holly were repotted into #3 containers using the previously described substrate: ‘Snow White’ hawthorn on March 23 and ternstroemia and ‘Jennifer’ azalea on April 5. On June 9, plants of ‘Snow White’ hawthorn averaging 22.4 cm (8.7 in) in height, plants of ternstroemia averaging 33.5 cm (13.1 in) in height, plants of ‘Jennifer’ azalea averaging 30.0 cm (11.7 in) in height and plants of ‘Sky Pencil’ holly averaging 33.1 cm (12.9 in) in height, were uniformly pruned: ‘Snow White’ hawthorn, ternstroemia and ‘Jennifer’ azalea by one-third, and ‘Sky Pencil’ holly by one-half. Then, plants were treated with 200 ppm CYC either: immediately after pruning, (developmental stage 1 (DS 1)), on June 28 when new shoots were 1.3 to 2.6 cm (0.5 to 1 in) in length (DS 2), or on July 7 when new shoots were 2.6 to 5.1 cm (1.0 to 2.0 in) in length (DS 3). This experiment included a pruned, non-CYC treated control and treatments were arranged in a completely randomized design within species and replicated with 10 single plants. Dry bulb temperature and relative humidity during each of the 3 treatment dates ranged from: 27 to 28C (80 to 82F) and 68% to 72% on June 09; 27 to 29C (81 to 85F) and 83% to 84% on June 28; and 28 to 29C (82 to 24F) and 84-88% on July 7, respectively.

Data, including shoot counts, measurement of height and widths and calculation of GI, was collected based on plant response to treatment; shoot development occurred at different times following treatment, therefore the specific date of data collection varied with each species. Shoots of ‘Snow White’ hawthorn plants in treatments 1 and 2 (pruned only and DS 1 plants) were counted and plants measured approximately 45 days after pruning (DAP) and shoots of DS 2 and DS 3 plants were counted and plants measured approximately 60 DAP. New shoots of all 'Jennifer' azalea, 'Sky Pencil' holly and ternstroemia were counted and plants measured approximately 60 DAP. Injury to new foliage of treated 'Snow White' hawthorn, 'Sky Pencil' holly and ternstroemia was rated 60 and 120 DAP using a 1 to 5 scale. Injury rating scale differed according to species. 'Snow White' Indian hawthorn rating scale was: 1 = no injury; 2 = slight discoloration of new foliage, slight reddening of leaf margins, no stunting or distortion; 3 = slight to moderate discoloration of new foliage, reddening of leaf margins, slight stunting, cupping and/or twisting; 4 = moderate to severe reddening of new foliage, moderate to severe stunting, twisting and/or folding; 5 = necrosis of new foliage. 'Sky Pencil' holly rating scale was: 1 = no injury; 2 = slight change in shape of new foliage; 3 = slight change in shape of new foliage and mild discoloration; 3 = change in shape of new foliage and mild to moderate discoloration; 4 = change in shape of new foliage and moderate to severe discoloration; 5 = necrosis of new foliage. Ternstroemia rating scale was: 1 = no injury; 2 = slight discoloration of new foliage; 3 = moderate discoloration of new foliage; 4 = moderate to severe discoloration of new foliage, stunting; 5 = necrosis of new leaves. Finally, height and widths of all plants were measured, GI calculated and plant quality rated 120 DAP.

Data were subjected to the SAS General Linear Model procedure (SAS Institute, Cary, NC) to test linear and quadratic trends to time after pruning and grouped orthogonal contrasts were used to provide a trend analysis of pruning and CYC application ($P = 0.05$).

Results and Discussion

Experiment 1, 2004. New shoot formation of non-pruned 'Elizabeth Ann' Japanese camellia plants was stimulated by all CYC concentrations. At 30 DAT shoot numbers of non-pruned plants showed a linear increase of 116%, 182%, 216% and 366% in response to 25, 50, 100 and 200 ppm CYC, respectively (Table 1). Although non-CYC treated pruned plants formed 113% more shoots than non-CYC treated non-pruned plants, shoot counts of pruned plants was not affected by CYC. Plants that were pruned before receiving an application of 50 ppm or 100 ppm CYC formed fewer shoots than plants of the corresponding non-pruned treatments (21% and 46% fewer, respectively). At 90 DAT, and 30 days after a second CYC application, new shoot counts of non-pruned plants increased linearly by 256%, 186%, 627% and 1232% as CYC concentration increased from 25, 50, 100 and 200 ppm, respectively. The generally higher increases in shoot number following the second CYC application reflects the low number of shoots formed on control plants. Shoot formation of pruned plants remained unaffected by CYC at 90 DAT. At 60 days after the first CYC application, height of non-pruned plants treated with 25 and 50 ppm was equal to or greater than that of non-pruned controls but height of non-pruned plants treated with 100 and 200 ppm was less than that of non-pruned controls. By 120 DAT, height of non-pruned plants was not affected by CYC. GI of all CYC-treated, non-pruned plants was greater than untreated non-pruned controls at both 60 and 120 DAT and CYC-treated plants appeared wider, possibly due to increased shoot formation. Height or GI of pruned plants was not affected by CYC at any of the collection dates. Although pruned plants treated with 0 or 50 ppm CYC were more attractive at 120 DAT than the corresponding non-pruned plants, quality was highest in plants that were not pruned and treated with 100 and 200 ppm CYC.

New shoot formation of non-pruned small anisetree at 30 DAT increased by 204%, 272%, 223% and 269% in response to 25, 50, 100 and 200 ppm CYC, respectively, compared to the control (Table 1). Pruned plants did not respond to CYC at 30 DAT, possibly because most of the foliage was removed by pruning. However, by 90 DAT (30 days after a second CYC application to the pruned plants) plants that received both pruning and CYC had extensive new shoot development, while plants in all other treatments, including pruning alone, had none. Shoot height and GI of non-pruned CYC-treated plants were lower than that of non-pruned controls at both 60 and 120 DAT. Other than a linear decrease in height of pruned plants in response to increasing CYC concentration at 120 DAT, height and GI of pruned plants was not affected by CYC. Quality of both pruned and non-pruned plants showed a linear increase in response to increasing CYC concentration at 120 DAT and treated plants were dense, compact and attractively shaped, especially those that received a pruning treatment and 2 applications of 100 ppm CYC.

Experiment 2, 2006. At 60 DAT an interaction between pruning and CYC application on new shoot production of ternstroemia was detected (Table 2). Compared to untreated plants, new shoots of non-pruned plants showed an increase of 76% and 97% in response to 100 and 200 ppm CYC, respectively, while shoots of pruned plants increased by 33% and 17% in response to 100 and 200 ppm CYC, respectively. However, increased branching did not enhance the appearance of non-pruned ternstroemia, as proliferation of shoots formed a rosette on long, spindly branches and plants drooped unattractively. This may have contributed to the linear decrease in height (60 and 120 DAT) and GI (120 DAT) in response to increasing CYC concentration since pendulous branches reduced overall plant height (Table 3). Shoot height and GI of pruned plants at 60 and 120 DAT was significantly lower on non-pruned plants Pruned plants were compact and attractively shaped (Table 4). At 120 DAT, quality of plants that were not pruned before receiving an application of 100 or 200 ppm CYC decreased with increased CYC concentration and was significantly lower than the corresponding pruned treatment (Table 2), further reflecting the unattractive appearance of the proliferation of shoots that formed an unattractive cluster toward the terminal of long branches. This differs from CYC-induced shoot formation in cherry trees in which shoots were uniformly distributed around the leader circumference (3). Quality was highest in plants that were pruned and treated with 100 ppm CYC, followed closely by plants that were pruned and treated with 200 ppm CYC (Table 2).

As with ternstroemia, there was an interaction between pruning and CYC application for new shoot formation in ‘Sky Pencil’ holly at 60 DAT (Table 2). While untreated pruned plants formed 52% more shoots than untreated non-pruned plants, all other pruned treatments resulted in fewer shoots than the corresponding non-pruned plants. New shoot formation of non-pruned plants increased by 163% and 293% in response to 100 and 200 ppm CYC, respectively, while shoot increases of pruned plants were only 0.2% and 29% in response to 100 and 200 ppm CYC, respectively. GI of non-pruned plants at 120 DAT showed a linear increase as CYC concentration increased and CYC-treated plants were wider and denser than non-CYC treated plants (Table 3). However, foliage density was concentrated in the bottom half of the plant; the top half was loose and open. Both height and GI at 60 and at 120 DAT were significantly lower in the pruned treatments as compared to the non-pruned treatments (Table 4), but the entire plant was full, dense with foliage and attractively shaped. Plant quality increased linearly with increasing CYC concentration at 120 DAT and was significantly higher in pruned 'Sky Pencil' than in non-pruned (Table 3).

There were no interactions between pruning and CYC in 'Jennifer' azalea for any of the measured attributes. New shoot formation at 60 DAT showed a linear increase of 9% and 29% as CYC concentration increased from 100 to 200 ppm, respectively (Table 3). However, new shoots were not evenly distributed along the length of the branches, but concentrated near branch terminals, forming a rosette of foliage. This added to the appearance of pruned plants, as the rosettes formed on short, upright stems and foliage coalesced into a full, compact canopy, but in the non-pruned plants, rosettes formed on long, diagonal stems and canopy was open and a large portion of the stem was exposed. The shoot formation of non-pruned CYC-treated 'Jennifer' azalea was different than shoot formation of cherry trees in which shoots were evenly distributed down the leader circumference (4). CYC decreased height and GI of all treated plants at both 60 and 120 DAT and all pruned plants had significantly lower height and GI at both 60 and 120 DAT (Table 4). Quality at 120 DAT was not affected by CYC but was significantly higher in pruned plants because increased shoot formation on short stems gave the canopy a full, dense and attractive shape.

Experiment 3, 2006. 'Sky Pencil' holly showed a linear increase in new shoot formation as the length of developing shoots increased when CYC was applied (Table 5). There was no benefit in shoot formation with applying CYC immediately after pruning

(DS 1), however allowing shoots to elongate 1.3 – 2.5 cm (0.5 – 1.0 in) or 2.5 cm – 5.1 cm (1.0 – 2.0 in), DS 2 and DS 3, respectively, stimulated 122% or 183% more shoots, respectively, compared to non-CYC treated controls. This does not agree with BA research on a species of the same genus, *Ilex glabra,* in which new shoot formation was highest when plants were treated at DS 2, not DS 3 (6). Shoot height at 60 DAT decreased as foliage length during CYC application increased, but height was not affected at 120 DAT. GI was not affected by treatment at either 60 or 120 DAT. A change in the shape of developing leaves occurred in CYC-treated plants and while new leaves of non-CYC treated plants were larger and rounded, new leaves of CYC-treated plants were smaller and linear to elliptical. This differs from injury to *Ilex glabra* resulting from BA application as injury symptoms were the most severe if plants were treated when foliage was immature and actively growing, and injury did not occur if BA was applied to mature foliage (6). Symptoms were rated 120 DAT and by this time, all leaves except those of DS 3 plants had enlarged and were round. All plants were full and compact, possibly due to pruning, but plants that were treated with CYC were wider than non-CYC treated plants. Plant quality at 120 DAT was not impacted by specific developmental stage at which CYC was applied, however DS 1 and DS 3 plants appeared fuller, wider and of higher quality than untreated plants.

Shoot counts of ‘Jennifer’ azalea changed quadratically at 60 DAT and DS 1 plants formed 18% more shoots than non-CYC treated plants and more shoots than plants in any other treatment (Table 5). DS 3 plants formed only 8% more shoots than non CYC-treated plants and DS 2 plants formed 13% fewer shoots than non-CYC treated plants. Shoot formation of ‘Jennifer’ azalea in response to CYC applied at different stages of plant development did not agree with any prior research of the influence of developmental stage on plant shoot response to BA as plants used in BA research formed the most shoots if treated at DS 2 (4, 5, 6, 7, 11). Shoot height and GI were not affected by time of CYC application at either 60 or 120 DAT, however height of DS 1 plants was significantly lower than height of untreated plants at 60 and 120 DAT. GI of DS 1 plants was significantly lower than GI of non-CYC treated plants at both 60 and 120 DAT and GI of all CYC-treated plants was significantly lower than GI of untreated controls at 120 DAT. All plants were full, compact and attractively shaped, possibly due to pruning and not CYC, and quality ratings at 120 DAT were similar among all plants.

All CYC-treated ternstroemia formed more shoots at 60 DAT than untreated plants (Table 5). Shoot numbers changed quadratically and were highest in DS 3 plants; these plants formed 102% more shoots than untreated plants. Plants treated in DS 1 increased shoot production by 38% when compared to untreated controls and plants treated in DS 2 formed only ~7 more shoots per plant than untreated plants. Shoot height was not affected by specific stage of CYC application at either 60 or 120 DAT, although DS 3 plants were significantly taller than pruned controls at 60 DAT, possibly because of a high number of shoots. GI at 60 DAT was highest in DS 1 plants but by 120 DAT GI was insignificant. Discoloration of developing foliage occurred and was rated 60 DAT. Symptoms in plants treated either in DS 1 or DS 2 were limited to mild discoloration and were similar to that of untreated plants, suggesting discoloration was not due to CYC. However, symptoms in DS 3 plants included moderate discoloration of new growth and were significantly different from symptoms of non-CYC treated plants. By 120 DAT, symptoms were less noticeable, although still highest in DS 3 plants. Plant shoot response and plant injury due to CYC, once again, did not agree with previous research of plant shoot and injury response to BA in which shoot response was greatest if BA was applied during DS 2 (4, 5, 6, 7, 11) and injury the least severe if applied during DS 3 (6). However, injury to ternstroemia in response to CYC application did not detract from plant appearance; all plants were full, compact and marketable at 120 DAT but quality was not affected by CYC.

Branching of ‘Snow White’ Indian hawthorn increased linearly in response to CYC and the number of new shoots of all CYC-treated plants was higher than non-CYC treated plants (Table 5). Plants treated at DS 1 formed 50% more shoots than untreated plants, and the highest number of new shoots formed on DS 2 plants (124% more than untreated plants), which concurs with research on developmental stage and BA application to ‘Olivia’ Indian hawthorn (6). Shoot numbers of DS 3 plants were 106% higher than in pruned, non-CYC treated plants. Shoot height and GI were not affected at 60 DAT, however at 120 DAT, height increased linearly as shoot length when CYC was applied increased, and DS 3 plants were taller than untreated plants. GI of CYC-treated plants was higher in DS 1 and DS 3 plants and lowest in DS 2 plants when compared to that of untreated plants. Shoot height and GI differences are probably due to plant injury. Symptoms were rated 60 DAT and at this time, new growth of DS 1 plants displayed slight discoloration of entire leaf and reddening of leaf margins; these symptoms could be considered aesthetically pleasing. However, injury to DS 3 plants included moderate discoloration of entire leaf, reddening of leaf margins and slight cupping. As with BA applied to ‘Olivia’ Indian hawthorn at DS 2, injury was highest in DS 2 plants of CYC-treated DS 2 plants (6) and included moderate to severe reddening of entire leaf, stunting and folding of new growth. Symptoms were generally less severe by 120 DAT. At this time, DS 1 plants appeared similar to uninjured controls, injury of DS 2 plants considerably less severe and while leaves were still discolored, they were not stunted or folded. Injury of DS 3 plants changed minimally from 60 DAT to 120 DAT. Although injury was still evident in many treated plants at 120 DAT, symptoms were not unattractive and plant canopies was dense, compact and well-shaped. Plant quality at 120 DAT was not affected by CYC.

Results of our evaluation of the interaction of pruning and CYC application on the growth of woody nursery crops indicate that non-pruned plants form more shoots than pruned plants as a result of CYC application, possibly due to the presence of more foliage that facilitates CYC absorption into the plant. However, CYC-induced shoot formation generally occurs near branch terminals, not evenly along the branch length, therefore if plants are initially leggy, CYC does not enhance plant quality and plants in this research were generally of higher quality when pruned before CYC application. Optimal time for CYC application following pruning varied according to species, but allowing new growth to elongate 1.3 – 5.1 cm (0.5 – 2.0 in) stimulated greater shoot formation than applying CYC immediately following pruning. However, foliage is more likely to be injured.

Literature Cited

1. Cline, M.G. 1998. Apical dominance. Bot. Rev. 57:318-358.

2. Elfving, D.C. and D.B. Visser. 2005. Cyclanilide induces lateral branching in apple trees. HortScience 40:119-122.

3. Elfving, D.C. and D.B. Visser. 2006. Cyclanilide induces lateral branching in sweet cherry trees. HortScience 41:149-153.

4. Little, C.A. 1985. Increasing lateral shoot production in balsam fir Christmas trees with cytokinin application. HortScience 20:713-714.

5. Nauer, E.M. and S.B. Boswell. 1981. Stimulating growth of quiescent citrus buds with 6-benzylaminopurine. HortScience 16:162-163.

6. Oates, J.M., G.J. Keever, and J.R. Kessler, Jr. 2005. Developmental stage influences plant response to benzyladenine. J. Environ. Hort. 23:149-152.

7. Ohkawa, K. 1979. Promotion of renewal canes in greenhouse roses by 6-benzylaminopurine without cutback. HortScience14:612-613.

8. Pedersen, M.K., J.D. Burton, H.D. Coble, J.R. Collins, and D. Fritz. 1997. Efficacy of Finish and its mechanism of action. Proc. Beltwide Cotton Conf. 2:1363-1365.

9. Tamas, I.A. 1987. Plant hormones and their role in growth and development. Plant Biology 20:393-410.

10. Vander Woude, S. June 2002. Early Pruning Equals More Dollars. NM Pro 18(6):57-58.

11. Wang, Y.T. and C.A. Boogher. 1987. Effect of stock plant shading, developmental stage, and cytokinin on growth and lateral branching of *Syngonium podophyllum* 'White Butterfly'. Scientia Hortic. 33:137-145.

12. Wilson, B.F. 1990. The development of tree form. HortScience 25:52-54.

Table 1. Interaction of pruning and cyclanilide application on the growth of two species of woody nursery crops in 2004, expt. 1.

Treatment	Shoot counts[z]		Height (cm)		Growth index[y]		Quality[x]
'Elizabeth Ann' Japanese camellia	30 DAT	90 DAT	60 DAT	120 DAT	60 DAT	120 DAT	120 DAT
0 ppm	8.7*[w]	2.2	70.2	82.5	54.6*	57.1	2.0*
25 ppm	18.8	7.8	70.2	88.2	57.3	64.1	2.5
50 ppm	24.5*	6.3	82.3*	89.8*	66.2*	66.3	2.7*
100 ppm	27.5*	16	62.3*	74.5*	59.3*	89.9*	3.7*
200 ppm	40.5	29.3	65.7	78.7	65.6	69.0	3.8
Sign.[v]	L***	L***	L*	NS	L**	Q*	Q***
Pruned[u] control	18.5	0	41.3	55.0	34.9	44.3	3.0
Pruned + 50 ppm	20.2	0	40.5	58.8	36.7	47.2	3.0
Pruned + 100 ppm	18.8	0	39.3	59.0	33.6	49.7	3.0
Sign.	NS	NS	NS	NS	NS	NS	NS
Small anisetree	30 DAT	90 DAT	60 DAT	120 DAT	60 DAT	120 DAT	120 DAT
0 ppm	18.8*	0	93.8*	114.6	67.6*	91.1*	1.9
25 ppm	57.2	0	83.2	104.5	65.8	89.0	2.4
50 ppm	70.0*	0	82.5*	99.5	65.0*	80.4*	2.9
100 ppm	60.8*	0	68.2*	87.3	58.1*	78.0*	3.2
200 ppm	69.3	0	71.7	89.3	59.3	78.5	3.5
Sign.	Q***	NS	Q***	Q**	Q**	Q**	L***
Pruned control	10.3	0	32.5	86.2	27.1	58.2	2.5
Pruned + 50 ppm	10.8	22.3	30.3	72.7	27.5	51.5	3.0
Pruned + 100 ppm	10.8	34.2	31.7	66.7	29.4	53.3	4.5
Sign.	NS	L***	NS	L**	NS	NS	L***

[z]Total number of terminal and lateral shoots, quantified 30 days after treatment (DAT).

[y]Growth index = (height + widest width + width 90^{o} to widest width) ÷ 3), in cm.

[x]Quality rating: 1 = minimal branching, open and leggy to 5 = prolific branching, dense and compact.

[w]Means followed by an asterisk are significantly different from the corresponding means of the pruned treatment.

[v]Nonsignificant (NS) or significant linear (L) or quadratic (Q) trends at P = 0.05 (*), P = 0.01 (**) or P = 0.001 (***).

[u]Plants uniformly pruned to remove terminal shoots, 'Elizabeth Ann' camellia by one-third and small anisetree by three-fourths.

Table 2. Interaction of pruning and cyclanilide on the growth of two species of woody nursery crops in 2006, expt. 2.

CYC conc.		Ternstroemia			
		Shoot counts[z]		Quality Rating[y]	
		Non-pruned	Pruned	Non-pruned	Pruned
0 ppm		67.3	80.0	4.1	4.0
100 ppm		118.5	106.5	3.4*	4.8
200 ppm		132.5*[x]	93.6	3.1*	4.6
	Sign.[w]	L***	Q*	L**	NS

		'Sky Pencil' holly	
		Non-pruned	Pruned
0 ppm		73.4*	111.5
100 ppm		193.0*	111.7
200 ppm		288.1*	144.1
	Sign.	L***	L*

[z]Total number of terminal and lateral shoots, quantified 60 days after treatment (DAT).

[y]Quality rating: 1 = minimal branching, open and leggy to 5 = prolific branching, dense and compact, evaluated 120 DAT.

[x]Means followed by an asterisk are significantly different from the corresponding means of the pruned treatment.

[w]Nonsignificant (NS) or significant linear (L) or quadratic (Q) trends at $P = 0.05$ (*), $P = 0.01$ (**) or $P = 0.001$ (***).

Table 3. Effects of cyclanilide concentration on the growth of three species of woody nursery crops in 2006, expt. 2

Treatment		Shoot #[z]	Height (cm)		Growth index[y]		Quality[x]
		Ternstroemia					
		60 DAT	60 DAT	120 DAT	60 DAT	120 DAT	120 DAT
0 ppm		-	45.9	61.7	45.5	65.8	[w]
100 ppm		-	42.6	56.3	45.8	63.9	-
200 ppm		-	42.2	51.2	43.8	60.1	-
	Sign.[v]	-	L*	L**	NS	L*	-
		'Sky Pencil' holly					
		60 DAT	60 DAT	120 DAT	60 DAT	120 DAT	120 DAT
0 ppm		-	68.9	79.5	36.6	40.7	3.6
100 ppm		-	67.3	84.6	36.1	42.7	3.7
200 ppm		-	65.4	84.1	36.4	43.1	4.1
	Sign.	-	NS	NS	NS	L*	L**
		'Jennifer' azalea					
		60 DAT	60 DAT	120 DAT	60 DAT	120 DAT	120 DAT
0 ppm		361.7	47.4	53.8	50.8	68.0	3.8
100 ppm		395.5	43.1	47.3	47.4	62.3	4.0
200 ppm		465.4	44.1	49.8	48.3	64.0	3.9
	Sign.	L***	Q*	Q***	Q*	Q**	NS

[z]Total number of terminal and lateral shoots, quantified 30 days after treatment (DAT).

[y]Growth index (GI = [(height + widest width + width 90^{o} to widest width) ÷ 3]), in cm.

[x]Quality rating: 1 = minimal branching, open and leggy to 5 = prolific branching, dense and compact.

[w]Dashes indicate an interaction between pruning and cyclanilide concentration; where there were no interactions means represent concentration across pruned treatments.

[v]Nonsignificant (NS) or significant linear (L) or quadratic (Q) trends at *P* = 0.05 (*), *P* = 0.01 (**) or *P* = 0.001 (***).

Table 4. Effect of pruning on the growth of three species of woody nursery crops in 2006, expt. 2.

Species	Shoots[z] 60 DAT		Height 60 DAT		Height 120 DAT		Growth index[y] 60 DAT		Growth index[y] 120 DAT		Quality[x] 120 DAT	
	P	NP[w]	P	NP	P	NP	P	NP	P	NP	P	NP
Ternstroemia	[u]	-	37.1*[v]	50.0	53.2*	59.6	38.2*	51.8	57.5*	69.0	-	
'Sky Pencil' holly	-	-	44.5*	89.6	66.3*	99.1	28.2*	44.4	36.5*	47.7	4.5*	3.1
'Jennifer' azalea	400.1*	415.0*	35.3*	54.4	42.9*	57.6	44.9*	57.6	54.7*	74.7	4.7*	3.1

[z]Total number of terminal and lateral shoots, quantified 60 days after treatment (DAT).
[y]Growth index (GI = [(height + widest width + width 90^{o} to widest width) ÷ 3]), in cm.
[x]Quality rating: 1 = minimal branching, open and leggy to 5 = prolific branching, dense and compact.
[w] Pruned (P) or non-pruned (NP) treatment.
[v]Means followed by an asterisk are significantly different from the corresponding means of the non-pruned treatment.
[u]Dashes indicate an interaction between pruning and cyclanilide concentration; where there were no interactions means represent concentration across pruned treatments.

Table 5. Effects of the timing of cyclanilide application following pruning on the growth of two species of woody nursery crops in 2006, expt. 3.

Treatment		Shoot #[z]	Height (cm)		Growth index[y]		Injury rating[x]		Quality[w]
		'Sky Pencil' holly							
		60 DAT	60 DAT	120 DAT	60 DAT	120 DAT	60 DAT	120 DAT	120 DAT
P[v]		50.4	43.0	66.3	27.1	36.7	-	1.0	3.2
DS 1[u]		55.1	42.7	67.7	27.3	37.0	-	1.0	4.5*
DS 2		111.7*[t]	41.6	70.3	27.2	38.5	-	1.0	3.8
DS 3		142.4*	38.0	69.8	25.4*	38.8	-	1.4	4.2*
	Sign.[s]	L***	L**	NS	NS	NS	-	Q*	NS
		'Jennifer' azalea							
		60 DAT	60 DAT	120 DAT	60 DAT	120 DAT	60 DAT	120 DAT	120 DAT
P		305.3	43.5	50.1	49.9	60.7	-	-	4.7
DS 1		361.3	39.4*	45.3*	45.5*	55.5*	-	-	5.0
DS 2		265.2	40.5	45.9	47.2	57.0*	-	-	4.8
DS 3		329.7	40.1	42.0*	47.9	54.8*	-	-	5.0
	Sign.	Q*	NS	NS	NS	NS	-	-	NS

[z]Total number of terminal and lateral shoots.

[y]Growth index (GI = [(height + widest width + width 90^{o} to widest width) ÷ 3]), in cm.

[x]Injury rating: 1 = no injury; 5 = necrosis of new growth, evaluated 60 and 120 DAT.

[w]Quality rating: 1 = minimal branching, open and leggy to 5 = prolific branching, dense and compact.

[v]P = Pruned

[u]DS 1 = P + CYC @ 0 cm; DS 2 = P + CYC @ 1.3 - 2.5 cm; DS 3 = P + CYC @ 2.5 - 3.1 cm.

[t]Means followed by an asterisk are significantly different from the pruned control based on orthogonal contrasts at P = 0.05 (*), P = 0.01 (**) or P = 0.001 (***).

[s]Nonsignificant (NS) or significant linear (L) or quadratic (Q) trends at P = 0.05 (*), P = 0.01 (**) or P = 0.001 (***).

Table 6. Effects of the timing of cyclanilide application following pruning on the growth of two species of woody nursery crops in 2006, expt. 3.

Treatment		Shoot #[z]	Height (cm)		Growth index[y]		Injury rating[x]		Quality[w]
Ternstroemia									
		60 DAT	60 DAT	120 DAT	60 DAT	120 DAT	60 DAT	120 DAT	120 DAT
P[v]		67.8	34.6	57.9	48.4	60.6	1.6	1.1	3.8
DS 1[u]		93.7	35.8	60.0	58.0*[t]	60.2	2.0	1.6	4.0
DS 2		74.7	35.9	52.4	51.6	57.9	1.8	1.3	3.9
DS 3		136.8	39.2*	56.6	43.4	59.8	2.9*	1.9*	4.3
	Sign.[s]	Q***	NS	NS	L**	NS	Q*	NS	NS
'Snow White' Indian hawthorn									
		60 DAT[r]	60 DAT	120 DAT	60 DAT	120 DAT	60 DAT	120 DAT	120 DAT
P		32.0	24.6	29.4	33.9	46.5	1.0	1.0	4.5
DS 1		47.9*	22.9	28.3	33.8	47.8	2.2*	1.2	4.9
DS 2		71.7*	23.1	31.2	34.7	45.3	3.4*	2.1*	4.4
DS 3		66.0*	22.7	33.3*	35.7	51.0*	3.0*	2.7*	4.7
	Sign.	L**	NS	L**	NS	Q*	Q***	L***	NS

[z]Total number of terminal and lateral shoots.

[y]Growth index (GI = [(height + widest width + width 90° to widest width) ÷ 3]), in cm.

[x]Injury rating: 1 = no injury; 5 = necrosis of new growth, evaluated 60 and 120 DAT.

[w]Quality rating: 1 = minimal branching, open and leggy to 5 = prolific branching, dense and compact.

[v]P = Pruned

[u]DS 1 = P + CYC @ 0 cm; DS 2 = P + CYC @ 1.3 - 2.5 cm; DS 3 = P + CYC @ 2.5 - 5.1 cm.

[t]Means followed by an asterisk are significantly different from the pruned control based on orthogonal contrasts at *P* =0.05 (*), *P* =0.01 (**) or *P* = 0.001 (***).

[s]Nonsignificant (NS) or significant linear (L) or quadratic (Q) trends at P = 0.05 (*), P = 0.01 (**) or P = 0.001 (***).

[r]Shoot counts and first set of shoot height and GI measurements collected based on plant response to treatment; data collected 45 DAT for plants in P and DS 1 and 60 DAT for the remaining treatments.

CHAPTER V

Final Discussion

The significant contribution of over 300 million dollars per year made by the nursery industry adds to the total 1.9 billion dollars per year of revenue generated by Alabama's Ornamental Horticulture Industry warrants exploration of methods to help nurserymen produce crops more efficiently. Currently, most woody nursery crops are pruned multiple times during production to ensure well-branched, marketable plants. Pruning, in addition to being labor-intensive, removes a significant amount of plant tissue, thus lengthening production time. Chemicals such as benzyladenine (BA) and thidiazuron (TDZ) have promoted branching in select woody species, however neither is EPA registered for nursery use. The only registered chemical branching agent available for commercial use, dikegulac sodium (Atrimmec), has growth retarding activity, making it more useful in landscape settings than in nurseries.

Recently, cyclanilide (CYC) became available for experimental evaluation and researchers at Auburn University began screening several common woody ornamental shrubs for response to CYC. In an initial study that tested the effects of CYC on the growth of 19 species of woody nursery crops, single foliar sprays of 25 to 200 ppm CYC increased branching of 12 species of actively growing shrubs. Plants that did not respond were generally evergreen shrubs with waxy cuticles and CYC probably did not penetrate the leaves, suggesting that foliar absorption must occur for CYC to induce branching. Generally, when plants responded to CYC, branching increased and height and/or growth index decreased, resulting in dense, compact plants. However, plants generally outgrew treatment effects within the growing season (by ~120 days after treatment) and were similar in appearance to untreated controls, possibly eliminating the practicality of CYC as a pruning substitute.

Three weekly foliar applications of 100 to 300 ppm CYC promoted branching, compaction and quality of 6 previously responsive species. However, even 5 applications of 100 to 300 ppm did not promote branching of previously unresponsive species, indicating that CYC must penetrate leaf cuticle and be absorbed foliarly for efficacy. Treatment effects of responsive species persisted beyond 120 days after first CYC application, even into and/or beyond the end of the growing season. Unfortunately, injury to developing foliage occurred within 45 days after the first CYC application and generally increased in severity as CYC concentration increased, ranging from mild discoloration in plants treated with 100 ppm CYC to more severe discoloration coupled with stunting, cupping and/or twisting in plants treated with 300 ppm CYC. Injury symptoms, although transient and no longer evident by the end of the growing season, were often severe enough to impact marketability for at least three months after the first CYC application.

Three biweekly foliar applications of 100 to 300 ppm were made to 3 of the species utilized in the multiple weekly experiment to determine if the interval between CYC application impacted the likelihood for injury. Although injury symptoms took longer to manifest (usually 60 days after first application) severity due to biweekly CYC applications was comparable to that of weekly CYC applications, suggesting injury is related to application number and/or concentration instead of interval. Additionally, the number of new shoots on plants that received multiple CYC applications was similar to the number of new shoots on plants that received single foliar applications, leading to the question, if single applications of CYC concentrations higher than 200 ppm would promote longevity of plant branching response while minimizing injury? However, if multiple applications are indeed the key to longevity of the plant branching response, results of this research indicate little practical use for multiple CYC applications exceeding either 3 in number or 100 ppm in concentration.

Results of research evaluating the interaction of pruning and CYC indicate that if plants that are initially leggy and sparsely branched CYC, although effective in branch-induction, is not enough to correct legginess, therefore some form of pruning would probably be necessary for acceptable quality if CYC is applied to overwintered plants. Optimal time for CYC application following pruning varied according to species, however allowing foliage to elongate at least 1.3 cm (0.5 in) elicited greater branching response than applying CYC immediately after pruning. Specifically, ‘Sky Pencil’ holly formed more shoots when CYC was applied to 2.5 – 5.1 cm (1.0 – 2.0 in) shoot, but ‘Snow White’ Indian hawthorn formed more shoots when CYC was applied to 1.3 – 2.5 cm (0.5 – 1.0 in) shoots. Interestingly, plants were injured by a single application of 200 ppm CYC, suggesting injury might be related to the age of developing shoots. For example, injury to ‘Snow White’ hawthorn was greater when treated foliage was younger and softer than when treated foliage had somewhat hardened.

According to this research, CYC promotes branching of select woody ornamental shrubs and has the potential to become a useful tool for nurserymen who wish to reduce and/or eliminate manual pruning as part of their regime for creating full, compact and marketable plants. However, optimal concentration and/or application number will vary with species and must be further researched so that plant branching occurs without plant injury.