Naphthaleneacetic Acid Reduces Leader Growth of Fraser Fir Christmas Trees

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Additional index words. *Abies fraseri*, consumer preference, shearing, Easy Roller, Sprühsystem

Abstract. Two methods of application, the Danish Easy Roller and the German Sprühsystem, were tested to evaluate the effectiveness of naphthaleneacetic acid (NAA) at reducing leader growth (tips of primary axes) of fraser fir [*Abies fraseri* (Pursh) Poir.] Christmas trees. A commercial product, Sucker-Stopper RTU (1.15% ethyl 1-NAA), was applied to leaders at concentrations of 0 to 500 mL·L⁻¹ when leaders were 8 to 15 cm long. As the concentration increased, leader elongation decreased. The Easy Roller reduced leader growth the most, but leader mortality was unacceptable at concentrations 20 mL·L⁻¹ or greater. Although less effective than the Easy Roller, the Sprühsystem caused negligible mortality of leaders. Applying 40 mL·L⁻¹ with the Easy Roller yielded ≈50% of leaders with target lengths of 20 to 36 cm with little mortality. The Sprühsystem gave similar results at 250 mL·L⁻¹. NAA might be useful for producing dense trees with minimal shearing or for producing more natural, open trees during shorter rotations.

Fraser fir (*Abies fraseri*) is an important Christmas tree species both locally and nationally [North Carolina Christmas Tree Association, 2004; North Carolina Department of Agriculture and Consumer Services (NCDA&CS), 2005]. It is sheared once annually beginning at a height of 1 to 1.3 m. Shearing in July and August is optimal (Hinesley and Derby, 2004a, 2004b) to produce dense trees for American consumers. Traditional shearing removes the apical bud cluster from the leader (distal end of the primary axis) and most lateral branches. Leaders are usually shortened to 20 to 50 cm, often half the original length, depending

on the tree's potential for growth, its age, and consumer preferences (Hinesley et al., 1998).

The Christmas tree industry is driven by consumer preference. Tree shape is an important factor to consumers (NCDA&CS, 2002); ≈53% of American consumers favor a full tree, and 43% favor a more open tree (Helmsing, 2003). In Europe, most consumers prefer open trees with more uniform whorls and large gaps between the whorls for decorative purposes (Chastagner and Benson, 2000). European growers use little or no shearing, whereas American growers shear trees annually to produce the dense trees that most consumers prefer (Frampton and McKinley, 1999).

Sucker-Stopper RTU (SS-RTU) [1.15% ethyl 1-naphthalene acetic acid (NAA); Lawn and Garden Products, Inc., Fresno, CA] is used to reduce or prevent the growth of sprouts and suckers on various woody plants. Naturally occurring auxins such as indoleacetic acid are involved in shoot elongation, cell division, flower formation, and inhibition of root growth (Bandurksi and Nonhebel, 1984). Applying synthetic NAA during the growing period can reduce leader growth and the number of shoots (Bir and Ranney, 1992; Boswell et al., 1976; Domir and Wuertz, 1982; Wilson, 1983). When under stress because of high levels of auxins, ethylene production may be stimulated (Kefeli and Kalevitch, 2003). Ethylene is a hormone that may be produced after mechanical wounding or other stress-related events (Hellgren, 2003). Ethylene is a naturally

produced hormone that causes inactivation of auxins, leaf abscission, and growth inhibition (Kefeli and Kalevitch, 2003). At high levels, NAA can reduce growth and cause injury or death to plants (Boswell et al., 1976; Domir and Wuertz, 1982; Hare, 1982; Kramer and Kozlowski, 1979; Wilson, 1983). Therefore, objectives of this research were to 1) determine the effect of SS-RTU on leader growth of fraser fir; and 2) compare two methods of application.

Materials and Methods

Two methods of application were used. The Easy Roller (Easy Roller; Lars B. Madssen, Langmosevej 6, 8620 Kjellerup, Denmark) has two rollers mounted parallel on the end of two metal extensions (Fig. 1A). The roller apparatus connects to a push-pump container by plastic tubing. The two rollers are placed on either side of the base of the leader and gently rolled upward as a chemical is pumped through the rollers and dispensed onto the leader (Fig. 1B). The chemical is applied until foliage is wet, which takes only a few seconds. The Sprühsystem (Michael Scherer, Donauwörth, Germany), which uses a backpack sprayer, has two nozzles that are contained in a cage-like box along with three small rollers that are used for application (Fig. 1C). The cage, acting as a shield, slides from the base of the leader to the terminal while a fine chemical spray is dispensed by a trigger (applied according to the manufacturer's instructions) on the handle of the applicator (Fig. 1D). At 0.2 to 0.4 MPa, the Sprühsystem dispenses ≈24 mL of solution in 30 s and requires ≈3 s to cover a 45-cm leader.

The research was conducted in the mountains of western North Carolina during Spring and Summer 2006. The three test sites—typical of fraser fir Christmas tree plantations—were 920 to 1200 m above sea level. A total of 1500 sheared trees was used (height, 1.2 to 1.5 m). Most trees had been in the field for 5 to 6 years and were likely 5 years from seed when planted. Trees shorter than 1.2 m or taller than 1.5 m as well as trees with noticeable disease or insect damage were not used.

The completely randomized block design consisted of three sites with 50 blocks per site and 10 trees per block. Each tree was randomly assigned one of the 10 treatment combinations.

Before the experiment, total tree height (growth through 2005) and the sheared height up to the previous year's whorl (growth through 2004) were recorded. Leader length for the 2005 growing season was calculated by difference. The length and the width of each tree's apical bud were measured using digital calipers. The two bud widths were averaged and multiplied by the apical bud length to derive a bud volume index. These measurements were taken to determine if there were significant relationships between the pretreatment measurements and final leader length.

Received for publication 10 July 2007. Accepted for publication 29 Oct. 2007.

This research was funded by the North Carolina Agricultural Research Service (NCARS), Raleigh, NC, through the Christmas Tree Genetics Program. We thank Avery County Extension Director Jerry Moody and Avery County IPM Technician Doug Hundley for guidance and support. We also thank Avery County Christmas tree growers Waightstill Avery, Robert Reece, and Jack Wiseman for allowing us to use their Christmas trees.

Use of trade names in this publication does not imply endorsement by the NCARS of products named nor criticism of similar ones not mentioned. This paper is from M.E. Rutledge's MS thesis.

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Fig. 1. Applicator components and application of Sucker-Stopper. (A) Easy Roller, (B) Easy Roller application, (C) Sprühsystem, and (D) Sprühsystem application.

Seven treatments were applied with the Easy Roller: control (leaders treated with water), 40, 80, 120, 160, 250, or 500 mL·L⁻¹. Concentrations of 40, 120, and 250 mL·L⁻¹ were applied with the Sprühsystem. Treatments were applied only during warm, dry periods of the day to allow for adequate drying. Solutions were mixed with distilled water and also contained 10 mL·L⁻¹ of WA-100 Plus (Ag Spray, Inc., Salem, OR), a surfactant. Trees were checked regularly, and treatments were applied as the new leaders reached a length of 8 to 15 cm.

In Fall 2006, the number of lateral buds was counted on each leader. The length of the lowest lateral branch on the south side of the 2005 leader was measured to determine if SS-RTU affected lateral branch growth. Finally, leaders were rated for foliage injury (percent) using a scale of 1 to 5: 1 = alive and healthy and 5 = dead. Categories 2, 3, and 4 represented foliage injury levels of 1% to 33%, 34% to 67%, and 68% to 99%, respectively.

For Site 2, beginning 26 June 2006, average leader length was recorded for Weeks 1, 2, 3, 4, 5, 6, 7, and 9; measurements on the other two sites were for Week 9 only. Data were analyzed using GLM and REG procedures (SAS Institute, Inc., Cary, NC). Analysis of variance was conducted to test for differences among main effects and interactions for site, concentration, and method of application. Correlation coefficients

were calculated using CORR procedures (SAS Institute, Inc.) to determine the strength of the relationships between the pretreatment measurements and final leader length.

Leader length was evaluated relative to two shearing regimes: traditional and accelerated. These regimes refer to the leader length, which is normally set during shearing. Traditional leaders are 20 to 36 cm, whereas the target range for accelerated leaders is 30 to 46 cm. For each shearing regime, leaders were grouped into three categories: short, within the target range, or long.

Results

For both application methods, as the concentration of NAA increased, average leader elongation decreased (Figs. 2, 3, and 4A). This was true for both applicators and all concentrations of SS-RTU except for the 120 mL·L⁻¹ and 160 mL·L⁻¹ response curves for the Easy Roller, which were inverted (Fig. 2). We have no explanation for this occurrence. The response to SS-RTU for leader length and bud count significantly differed between sites, concentrations, and methods of application (Table 1). With regard to leader length, there were also significant interactions for applicator × concentration and site × applicator. Across all sites and applicators, there was a significant positive correlation between final leader length in 2006 and tree height in

Fig. 2. Leader length of fraser fir Christmas trees on Site 2 as affected by concentration of Sucker-Stopper RTU. Applicator was the Easy Roller. Curves for 120 and 250 mL·L⁻¹ were similar. Data points: n = 50; bars = SE of the mean.

Fig. 3. Leader growth and mortality (averaged overall sites) for fraser fir Christmas trees treated with various concentrations of Sucker-Stopper RTU using the Easy Roller. Data points: n = 150; bars = SE of the mean.

2005 ($r = 0.24$, $P < 0.01$) as well as final leader length in 2006 and bud volume in 2005 ($r = 0.49$, $P < 0.01$). With the Easy Roller (all sites), there was a significant positive relationship between final leader length in 2006 and tree height in 2005 ($r = 0.21$, $P < 0.01$) as well as final leader length in 2006 and bud volume in 2005 ($r = 0.44$, $P < 0.01$). For treatments that were applied with the Sprühsystem, similar correlations occurred between final leader length in 2006 and tree height in 2005 ($r = 0.29$, $P < 0.01$) as well as final leader length in 2006 and bud volume in 2005 ($r = 0.52$, $P < 0.01$).

Of the two methods of application, the Easy Roller reduced leader elongation most effectively (Fig. 4A). A concentration of 40 mL·L⁻¹ reduced leader length by 16% with negligible mortality (Fig. 3). Increasing the concentration to 80 mL·L⁻¹ reduced leader length by 32% with leader mortality of 3%. Mortality increased from 5% for the 120 mL·L⁻¹ treatment to 57% for 250 mL·L⁻¹ and 86% for 500 mL·L⁻¹ (Fig. 3). The Sprühsystem was less effective at reducing leader elongation, but leader mortality never exceeded 4% even at 250 mL·L⁻¹ (Fig. 4B). The biggest difference was at 250 mL·L⁻¹ in which the Easy Roller reduced leader length

Fig. 4. Length (A), mortality (B), and bud count (C) of leaders of Fraser fir Christmas trees as affected by concentration of SS-RTU and method of application. Data points: $n = 150$; bars = SE of the mean.

Table 1. Analysis of variance for final leader length, bud count, and lateral branch length of Fraser fir Christmas trees treated with Sucker-Stopper RTU.

Source of variation ²	df	Leader length	Bud count	Lateral branch growth
Easy Roller				
Site (S)	2	NS	*	*
Concn. (C)	6	**	*	NS
S × C	12	NS	NS	NS
Sprühsystem				
S	2	**	NS	*
C	2	*	NS	NS
S × C	4	NS	NS	NS
Both applicators				
S	2	**	**	**
C	2	**	**	NS
Applicator = A	1	**	**	NS
S × C	2	NS	NS	NS
S × A	4	*	NS	NS
C × A	2	**	**	NS
S × C × A	4	NS	NS	NS

²There were three sites, 50 blocks per site, and 10 trees per block.

NS, *, **Nonsignificant or significant at $P \leq 0.05$.

by 50% compared with 24% for the Sprühsystem (Fig. 4A).

There were significant differences in bud count for sites, concentrations, and methods of application for both applicators (Table 1). In addition, there was a significant interaction for concentration × applicator for bud count (Fig. 4C). Lateral branch growth differed only among sites and was unaffected by concentration or method of application (Table 1). There was no clear relationship between lateral branch growth and leader length.

When final leader lengths were categorized (short, target, or long), the percentage of trees in each category varied by concentration of SS-RTU and by shearing regime (traditional versus accelerated). Short leaders are more desirable than excessively long leaders. Lower concentrations yielded a higher percentage of “long” leaders. In the control treatment (no NAA), 73% of the leaders were longer than 36 cm (upper limit for “traditional” shearing regime) compared with 2% of leaders treated with 500 mL·L⁻¹ from the Easy Roller (Fig. 5A). When applied with the Easy Roller, concentrations 120 mL·L⁻¹ or greater yielded the most leaders 20 to 36 cm long, the target length for “traditional” shearing (Fig. 5A), but leader mortality was 20% for the 160 mL·L⁻¹ concentration and increased sharply at higher concentrations (Fig. 3). Using the Easy Roller, the highest percentage of leaders 30 to 46 cm in

length (target range for “accelerated” shearing) was ~50% with a concentration of 40 mL·L⁻¹ of SS-RTU (Fig. 5B). When applied with the Sprühsystem, 250 mL·L⁻¹ yielded 55% of leaders in the target range for the “traditional” shearing regime compared with 45% for the 120 mL·L⁻¹ concentration in the “accelerated” shearing regime (Fig. 5C–D).

Discussion

The Easy Roller and the Sprühsystem both reduced leader growth of Fraser fir Christmas trees (Table 1; Figs. 2, 3, and 4A). In a similar experiment in the Pacific Northwest, NAA in combination with the Top-Stop Nipper (a tool used for making cuts into the bark of the leader; Top-Stop; Lars Geil, Ry, Denmark) reduced leader length in Noble fir (*Abies procera* Rehd.) and Nordmann fir (*Abies nordmanniana* Spach) by 25% to 50%, respectively, although the response varied by species, treatment, and individual tree (Fletcher et al., 2005). In another experiment in the United Kingdom, Tipoff XT (Universal Crop Protection Ltd., Cookham, Maidenhead, Berkshire, UK), a growth regulator containing 0.29% NAA, was applied to Fraser fir with the Easy Roller at 0 to 150 mL·L⁻¹, and leader length decreased with increasing concentration. Only 20% of the nonsheared control trees had leader lengths in the target range

compared with 44% with 150 mL·L⁻¹ (L. Madsen, personal communication).

With the Easy Roller, leader damage and mortality increased with increasing concentration of SS-RTU (Fig. 3). Mortality was unacceptable (20% to 86%) at concentrations 160 mL·L⁻¹ or greater, whereas the Sprühsystem caused negligible mortality even at the highest concentration of 250 mL·L⁻¹. We do not have an explanation for this difference. The Sprühsystem sprays a constant concentration of solution onto the leaders. The Easy Roller applies solution directly to the leader, and the application rate might vary depending on the texture and surface features of the foliage, e.g., smooth, rough, short nap, coarse nap. Also, the concentration of SS-RTU as well as the surfactant might increase on the roller surfaces as water evaporates, similar to latex paint drying on the surface of a brush or roller. The output of the Easy Roller was not determined when treatments were applied. Even if the output were known, additional research might be required to determine the reason for the high leader mortality at concentrations 160 mL·L⁻¹ or greater.

In the separate analyses for the Easy Roller and Sprühsystem, there were significant main effects for site and concentration but no significant interactions (Table 1). We do not know the basis for the site variation (soil, temperature, rainfall, other), but significant variation in tree growth is common among sites. In the combined analysis, the significant interaction for applicator × concentration (A × C) indicates there was a clear response to changing concentrations of NAA, but it varied from site to site depending on the method of application. Thus, results are presented and interpreted separately for each method of application.

In Fraser fir, a close relative of balsam fir (*Abies balsamea* L.), terminal leader formation is a 2-year process beginning with the formation of bud primordia (Powell, 1982). Optimum environmental conditions during that phase can yield more shoot growth the next growing season (Kozłowski, 1962). In determinant species, bud size is a good predictor of subsequent shoot length (Kozłowski et al., 1973; Little, 1970). Application of a plant growth regulator such as NAA may complicate the relationship between bud size and final leader length by altering hormonal balances.

Compared with the Sprühsystem, the Easy Roller would be more useful to growers who manage their trees for leaders longer than the traditional 20 to 36 cm, i.e., accelerated shearing regime. When SS-RTU was applied at 40 mL·L⁻¹, ~50% of the leaders were within the accelerated target range with no mortality. Furthermore, for both methods of application, as the concentration of SS-RTU increased, more trees fell into the short range than the long range—a preferred outcome. The Sprühsystem reduced leader growth with little mortality at concentrations 250 mL·L⁻¹ or less, whereas the Easy Roller suppressed leader growth more effectively but with unacceptable mortality at concentrations 80 mL·L⁻¹ or greater. Mechanical shearing

Fig. 5. Percentages of trees that measured within each range for final leader length; short, target, and long. Bars only include living leaders. The traditional target range for leader length is 20 to 36 cm; the accelerated is 30 to 46 cm. (A) Traditional regime for the Easy Roller, (B) accelerated regime for the Easy Roller, (C) traditional regime for the Sprühsystem, and (D) accelerated regime for the Sprühsystem.

puts virtually all leaders within the preferred target range compared with 50% for chemical treatment with SS-RTU. Thus, mechanically sheared trees would be more uniform in height with less variation among individual trees. A third alternative might be a hybrid regime in which trees with excessive leader length after treatment with SS-RTU could be conventionally sheared, whereas trees with leaders in the target range could remain untouched to preserve the natural appearance.

Nonsheared trees produce more biomass (stems and foliage) than sheared trees (Hinesley and Derby, 2004b); therefore, reducing branch growth and elongation while leaving a higher number of buds intact will produce a dense, more natural whorled tree. It appears that chemical applications alone are not sufficient; combining the chemical treatment with other methods (conventional shearing and/or Top-Stop Nipper) would increase the percentage of leaders in the target range, but at increased cost compared with a single conventional shearing each year.

The cost of SS-RTU is ≈\$32.00 per bottle (0.66 L = 0.17 gal = 22 oz). For a concentration of 160 mL·L⁻¹, at least 6000 leaders (length, 8 to 15 cm) could be treated with one bottle of concentrate (less than 1 cent per tree for the chemical). The application time per tree is only 2 to 3 s, so the additional labor associated with application would be small. The advantage of

chemical treatments, compared with conventional shearing, is that perhaps 50% of the trees would have a natural appearance with more distinctive branch whorls. The usefulness of SS-RTU would likely improve if applied to genetic selections that produce heavier bud set and less shoot elongation compared with average trees.

Consumer preferences might influence the use of SS-RTU in Christmas tree production. SS-RTU could be used to produce a more open “European-style” tree. Many consumers would pay the same price for a full or open tree, and some would pay more for an open tree (Helmsing, 2003). In general, women prefer a more open “European-style” tree (Helmsing, 2003), but preferences are influenced by culture and demographics (Dishneau, 2004). Ultimately, the marketplace will determine Christmas tree production practices, and these findings may influence the practicality of using growth regulating chemicals for leader growth reduction.

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