ABSTRACT

ASPINWALL, MARTHA ELIZABETH. Chemical and Mechanical Methods to Reduce Leader Growth in Fraser fir. (Under the direction of Drs. John Frampton and Gary Blank)

The purpose of this research was to provide American Christmas tree growers with alternative methods of reducing leader growth compared to the traditional cultural practice of shearing. Separate experiments involving the use of a mechanical tool, the Top-Stop Nipper (TSN), and the application of naphthaleneacetic acid (NAA) were conducted in Avery County, North Carolina on Fraser fir [*Abies fraseri* (Pursh) Poir.] during the spring and summer of 2005 and 2006.

The Top-Stop Nipper, a four-bladed hand-held tool, placed incisions (nips) on the previous year's leader to reduce the amount of photosynthate being transported to the developing leader. The treatments for the 2005 experiment consisted of a control (0 nips, nonsheared), one, two, three, or four nips at each of three stages of leader elongation [pre-budbreak, 2-3 cm, and 6-9 cm]. For the 2006 experiment, a regression model, based on an apical bud volume index from the 2005 experiment, was used to predict the number of nips to apply to each leader to yield a target length of 25 to 36 cm. The treatments included control trees (0 nips, nonsheared) and one to seven nips per leader. Treatments were applied in early May as buds began to swell and elongate.

In 2005, a chemical experiment was conducted to evaluate the effectiveness of the potassium salt form of 1-naphthalene acetic acid (NAA) at reducing leader growth in Fraser fir. NAA was dissolved in water and applied using the Danish-

made Easy Roller. Treatments were applied to leaders at concentrations of 0 to 70 ppm in 10 ppm increments at three stages of leader elongation (6-9 cm, 12-18 cm, and 24-36 cm). In 2006, two methods of application, the Danish Easy Roller and the German Sprühsystem, were tested to evaluate the effectiveness of ethyl 1-naphthaleneacetic acid (NAA) at reducing leader growth of Fraser fir Christmas trees. A commercial product, Sucker-Stopper RTU (SS-RTU), which contains 1.15% ethyl 1-naphthaleneacetic acid was applied to leaders at concentrations of 0 to 500 ml/L commencing when leaders were 8 to 15 cm long.

Results for the 2005 TSN experiment included a significant reduction in leader elongation; the percentage of leaders that were within the target range of 20 to 36 cm increased from 18% for the control (no nips) to 46% with four nips. In 2006, when the number of nips increased with increasing bud volume, leader growth was about the same among all TSN treatments. Bud density on the 2006 leader increased with the number of nips applied to the 2005 leader. The TSN might be a useful alternative to standard shearing for growers who intend to produce dense trees with minimal shearing or for growers who leave longer leaders to produce a more open “European-style” tree during a shorter rotation time.

In 2005, the application of the potassium salt form of NAA had no effect on leader elongation, which may be due to the form of NAA used in the experiment. In 2006, as the concentration increased, leader elongation decreased. The Easy Roller more effectively reduced leader growth, but leader mortality was unacceptable at concentrations ≥120 ml/L. Although less effective than the Easy Roller in reducing leader growth, the Sprühsystem caused negligible mortality of leaders.

Applying 40 ml/L with the Easy Roller yielded about 50% of leaders with target lengths of 20 to 36 cm, with little mortality. The Sprühsystem gave similar results at 250 ml/L. NAA might be useful for producing dense trees with minimal shearing, or for producing more natural, open trees with shorter rotations.

Chemical and Mechanical Methods to Reduce Leader Growth in Fraser Fir

by
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Biography

Martha Elizabeth Aspinwall was born August 26, 1982 in High Point, North Carolina to, at the time, Martha Jo Beasley and Stephen Emmett Rutledge. She spent most of her childhood in Banner Elk, North Carolina, where she graduated from Avery County High School in May 2000. During high school, she began to work at Grandfather Mountain where her interest in biology, natural resources, and environmental conservation developed.

Miss Rutledge enrolled at Wingate University during August of 2000. During her four years at Wingate, she studied abroad for a semester in London, England, and spent a few weeks touring Switzerland learning about the Protestant Reformation. She completed her Bachelor of Science in Biology in May of 2004. After graduation, she accepted an internship with the USGS to work with an endangered honey creeper, the palila, in Hawaii Volcanoes National Park. After completing her internship in Hawaii, Elizabeth enrolled at North Carolina State University to pursue a Masters of Science in Natural Resources. Miss Rutledge wed Michael Aspinwall of Cincinnati, Ohio on December 16, 2006.

Following graduation, Elizabeth will pursue a PhD at North Carolina State University in the Fisheries and Wildlife program.

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Introduction

In recent years, Fraser fir [*Abies fraseri* (Pursh) Poir.] has gained popularity as a Christmas tree within the U.S. due to its conical shape, dark green foliage, pleasant aroma, and its excellent needle retention (Hinesley et al., 1995). Currently, there are more than 21,000 U.S. growers and national employment within the Christmas industry exceeds 100,000 individuals (Wolford, 2007). U.S. production area consists of ≈ 202,300 hectares (NCTA, 2005) with trees produced in all 50 states (Wolford, 2007). In the United States, 30 to 35 million Christmas trees are sold annually (Wolford, 2007) with as many as three seedlings planted to replace each harvested tree (NCTA, 2005). The average retail tree height is 1.8 to 2.1 m (6 to 7 ft.), which may take anywhere from 4 to 15 years in the field (NCTA, 2005).

North Carolina has an estimated 50 million planted Fraser fir with 1,600 growers and 10,100 hectares invested in Christmas tree production (NCCTA, 2004). Fraser fir constitutes about 96% of the Christmas tree industry in North Carolina, where annual sales exceed $100 million (NCDA&CS, 2005). The state ranks second behind Oregon in national production with an annual cut of 6 million Christmas trees, ≈ 19% of the nation's production (NCCTA, 2004).

Fraser fir is endemic to the high elevations of the southern Appalachian Mountains. These natural stands range from southwestern Virginia, through western North Carolina, and into eastern Tennessee (Burns, 1990). It most commonly occurs between 1,680 and 2,040 m and receives an average annual rainfall of 190 to 254 cm (Burns, 1990). Trees typically range from 15 to 18 m in height and have a diameter at breast height of ≈ 30 cm (Burns, 1990).

Fraser fir Christmas trees require annual shearing of the terminal leader and lateral branches to control excessive growth. This is done to produce Christmas trees with the higher crown density that most American consumers prefer. Many consumers believe that shape is the most important factor affecting Christmas tree selection, followed by needle retention, species, and price (NCDA&CS, 2002). In 2002, the National Christmas Tree Association found appearance to be the number one determinant of tree selection; 53% of consumers favored a full tree and 43% liked a more open tree (Helmsing, 2003).

Traditional shearing typically removes the distal portion of most large branches from the leader as well as the apical bud cluster. Although *Abies* species can be sheared throughout the year, July to August is optimum (Brown and Heiligmann, 2002; Douglass, 1983; Hinesley and Derby, 2004a, 2004b). Leaders of Fraser fir Christmas trees are typically cut to 20 to 50 cm, usually less than half the full length. The final length varies according to tree age, its growth potential, and the preferences of the grower's customers (Hinesley et al., 1998).

American and European consumers alike have different preferences when choosing a Christmas tree, thus requiring different cultural practices. Most American consumers prefer a conical dense tree, which requires annual shearing. European growers do not shear trees since their consumers prefer a natural tree that is more open with layered internodal branching and more uniform whorls (Chastagner and Benson, 2000). European consumers prefer more open trees since this style accommodates traditional decorations such as candles. Both American and European consumers prefer an adequate number of internodal branches on which to hang ornaments. Finally, many Europeans prefer slower growing, low to medium density Christmas trees with smaller crown diameters that fit into smaller rooms (Frampton and McKinley, 1999).

In my research, two different methods were used to reduce leader growth in Fraser fir. Reducing leader growth while maintaining the apical bud cluster will help to produce trees that have more uniformly dense, branch whorls. The overall goal is to produce naturally dense trees without shearing. The Top-Stop Nipper (TSN) [Top-Stop, Lars Geil, Langebakke 2, DK-8680 Ry, Denmark] was used to mechanically reduce leader growth in Fraser fir. In another experiment, Sucker-Stopper RTU (SS-RTU) [1.15% Ethyl 1-naphthaleneacetic acid (NAA)] was used to reduce leader growth in Fraser fir.

The TSN is a plier-like tool with two unevenly spaced (≈ 2 cm apart) blades on either side of the crimping end, each with a half circle cut out. The tool was developed in Denmark where it is used to mechanically reduce terminal leader growth by strategically placing incisions on the previous year's leader. The incisions sever the phloem and possibly part of the cambium, but when used properly they stop at the xylem. When the incisions are placed on the previous year's leader, they impede the flow of photosynthate to the developing leader, which reduces growth. The TSN has shown promising results in experiments with other fir species. In Europe, the TSN reduced leader growth by 25% in Nordmann fir (*Abies nordmanniana* Spach) (Owen et al., 2004). The TSN has several advantages: regulation of the top, the absence of chemical applications, only one annual application, low cost, ease of use, and little required time per tree (Geil, 2004). In addition, leaving the terminal and subterminal buds intact maintains the mechanism of correlative inhibition among leaders and lower-order shoots (Kozlowski et al., 1973; Little, 1970), thus enabling lateral branches to form more naturally as in a nonsheared tree. This produces a full, uniform tree without having to shear the tops annually.

The second method for reducing leader growth in Fraser fir implemented the use of Sucker-Stopper RTU [1.15% Ethyl 1-naphthaleneacetic acid (NAA)]. The active ingredient in SS-RTU, NAA (a synthetic auxin), is used to reduce the growth of sprouts and suckers on various woody plant species. Indoleacetic acid (IAA) is a naturally occurring auxin that is involved in shoot elongation, cell division, flower stimulation, and root inhibition (Bandurski and Nonhebel, 1984). During the growing period, the application of NAA can reduce leader growth and the number of shoots (Wilson, 1983; Domir and Wuertz, 1982; Bir and Ranney, 1992; Boswell et al., 1976). High levels of auxins may cause stress which can stimulate the production of ethylene (Kefeli and Kalevitch, 2003). Ethylene 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). High levels of NAA can reduce growth and cause injury or death to plants (Wilson, 1983; Domir and Wuertz, 1982; Boswell et al., 1976; Kramer and Kozlowski, 1979; Hare, 1982).

Both chemical and mechanical methods for reducing leader growth in Fraser fir could be useful to Christmas tree growers who are interested in implementing new cultural tools that reduce management inputs. The objectives of this research were to determine: (1) the effectiveness of the TSN at reducing leader growth of Fraser fir Christmas trees (2) the effect of 1-naphthaleneacetic acid, potassium salt on leader growth (3) develop and verify a model, based on a bud volume index, and to determine the number of nips to apply with a TSN to achieve a specified target leader length, and (4) the effect of NAA concentration on leader growth and to compare two methods of application.

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Chapter 1

Top-Stop Nipper Reduces Leader Growth in Fraser Fir Christmas Trees

(In the format appropriate for submission to HortScience)

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Top-Stop Nipper Reduces Leader Growth in Fraser Fir Christmas Trees

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Top-Stop Nipper Reduces Leader Growth in Fraser Fir Christmas Trees

Additional index words: Abies fraseri, shearing, consumer preference, crown density

Abstract. The Top-Stop Nipper (TSN), a four-bladed, hand-held tool used to reduce leader growth in Christmas trees was evaluated on Fraser fir [*Abies fraseri* (Pursh) Poir.]. The TSN placed incisions (nips) on the previous year's leader to reduce the amount of photosynthate transported to the developing leader. Treatments consisted of a control (0 nips), one, two, three, or four nips at each of three stages of leader elongation [pre-budbreak, 2-3 cm, and 6-9 cm]. The TSN significantly reduced leader elongation. The percentage of leaders that were within the target range of 20 to 36 cm increased from 18% for the control (no nips) to 46% with four nips. The TSN might be a useful alternative to standard shearing for growers who intend to produce dense trees with minimal shearing or for growers who want to leave longer leaders to produce a more open "European-style" tree during a shorter rotation time.

In recent years, Fraser fir (*Abies fraseri*) has gained popularity as a Christmas tree within the United States due to its conical shape, dark green foliage, pleasant aroma, and excellent needle retention (Hinesley et al., 1995). It constitutes about 96% of the Christmas tree industry in North Carolina, where annual sales exceed $100 million (NCDA&CS, 2005). The annual harvest of 6 million Christmas trees in North Carolina accounts for about 19% of national production, and ranks second behind Oregon (NCCTA, 2004).

To remain competitive, Christmas tree growers must minimize production costs while accounting for consumer preferences. In response to preference for higher density trees, the practice of shearing began during the 1940s and 50s (Chastagner and Benson, 2000). Shape is the most important factor affecting Christmas tree selection, followed by needle retention, species, and price (NCDA&CS, 2002). A survey in 2002 by the National Christmas Tree Association found appearance to be the number one determinant of tree selection; 53% of consumers favored a full tree and 43% liked a more open tree (Helmsing, 2003).

Fraser fir is sheared once annually to produce Christmas trees with dense crowns. Traditional shearing removes the apical bud cluster from the leader and from most large branches while also removing many lateral buds on the distal end of the shoots. *Abies* species (fir) can be sheared almost anytime during the year, but July to August is optimum (Brown and Heiligmann, 2002; Douglass, 1983; Hinesley and Derby, 2004a, 2004b). Typically, leaders of Fraser fir are shortened to 20 to 50 cm, often less than half the full length. The final length varies according to tree age, its potential for growth, and customer preferences (Hinesley et al., 1998).

American consumers prefer dense trees, which require annual shearing, whereas Europeans like a more natural appearance, which requires little to no shearing (Frampton and McKinley, 1999). The European style is more open with layered internodal branching and more uniform whorls (Chastagner and Benson, 2000). European trees tend to have gaps between the whorls to accommodate more traditional decorations such as candles. American and European consumers both prefer an adequate number of internodal branches on which to hang ornaments. To accommodate smaller rooms, many Europeans also prefer slower grown Christmas trees with smaller crown diameters and low to medium density (Frampton and McKinley, 1999).

The Top-Stop Nipper (TSN) (Top-Stop, Lars Geil, Langebakke 2, DK-8680 Ry, Denmark) is a plier-like tool with two unevenly spaced (≈ 2 cm apart) blades on either side of the crimping end, each with a half circle cut out (Fig. 1A). It was developed in Denmark to reduce terminal leader growth by placing transverse incisions (perpendicular to the long axis) on the previous year's leader. The incisions sever the phloem and possibly part of the cambium, but when used properly they stop at the xylem. The incisions reduce leader growth by disrupting the flow of photosynthate to the developing leader. Some photosynthate is used for wound repair at the incisions. In Europe, the TSN reduced leader growth by 25% in Nordmann fir (*Abies nordmanniana* Spach) (Owen et al., 2004).

Advantages of the TSN include regulation of the top, no chemical applications, used once annually, low cost, ease of use, and requires little time per tree (Geil, 2004). In addition, leaving the terminal and subterminal buds intact maintains the mechanism of correlative inhibition among leaders and lower-order shoots (Kozlowski et al., 1973; Little, 1970), thus enabling lateral branches to form more naturally as in a nonsheared tree. This produces a full, uniform tree without having to shear the tops annually. Therefore, the objective of this research was to determine the effectiveness of the TSN at reducing leader growth of Fraser fir Christmas trees.

Materials and Methods

The experiment was conducted in three commercial Christmas tree plantations (1,040 to 1,220 m above sea level) in Avery County in western North Carolina during 2005. Stands were typical of Christmas tree plantations in that region. A total of 900 sheared trees (height ≈ 1.2 to 1.5 m) were used. Most trees had been in the field for 5 years and were likely 5 years from seed when planted. Trees were excluded that were too short, too tall, or had disease or insect damage.

Prior to treatment, total height through 2003 and total height through 2004 were measured on each tree. Sheared leader length for 2004 was calculated by difference. On the uppermost bud on the 2004 leader, two cross-sectional diameters (top to bottom and side to side) were measured with a digital caliper. The two numbers were averaged and multiplied by bud length to calculate total bud volume. Prior to bud swelling, leader diameter for 2005 was measured 4 cm above its insert on the stem.

The randomized complete block design consisted of three sites with 20 blocks per site. Within each block, single-tree plots were randomly assigned to the 13 treatments. The treatments included a control (0 nips, three trees per block) and the application of one, two, three, or four nips at three stages of leader elongation: pre-budbreak, 2-3 cm, and 6-9 cm (one tree per block for each combination of nipping x time of application). Each nip consisted of the insertion of four blades into the bark, stopping at the xylem (Fig. 1B). When using multiple nips, the tool was rotated 90 degrees before applying each additional nip. Nips were positioned to reduce damage to developing lateral buds. Pre-budbreak treatments were applied on 30

April; the remaining treatments were applied as the new leaders reached the appropriate stage of elongation.

On site 2, weekly measurements were recorded for every tree over 7 weeks, beginning 26 June. Final measurements were taken at all sites after 9 weeks. Means were plotted for site 2 after 1, 2, 3, 4, 5, 6, 7, and 9 weeks, but only for week 9 on the other two sites. Data were analyzed using GLM and REG procedures (SAS Institute, Inc., 2003). Regressions were developed to describe the relationship between leader length and time for the control trees and trees treated with three nips at site 2. A combined analysis of variance for leader length was carried out to test sources of variation for sites, times, number of nips, and interactions. Components of the experimental error had similar mean squares, so a pooled error term was used for testing treatment effects. A separate analysis was carried out for each of the three sites. One of the 12 degrees of freedom for treatments in each analysis was used in a comparison of 'control vs. nipped'. In addition, an analysis of covariance was conducted to test the relationship between each covariable (bud volume, leader diameter, leader length in 2004, tree height) and final leader length in 2005.

Data were interpreted for two shearing regimes (traditional and accelerated), based on final leader length. These regimes refer to the leader length which is set during shearing. With a traditional regime, leader length would be reduced to 20 to 36 cm, while the accelerated regime would leave leaders 30 to 46 cm in length. For each regime, percentages were calculated for the number of leaders that were too short, optimum, or too long relative to the ideal target length.

Results

Leader elongation decreased as the severity of wounding increased up to three nips (Fig. 2A). Applying a fourth nip caused little additional reduction in leader length (data not shown). The pattern of leader elongation was similar for all nip treatments (Fig. 2A) and average leader growth was greatest at site 1 (51 cm) and least at site 3 (31 cm) (Fig. 2B).

In the combined analysis for 9-week data, the following sources were significant: site, time of application, number of nips, and the interaction of site x time of application (Table 1). The number of nips was significant in the separate analyses for individual sites, whereas timing of treatment was significant only at site 1 (Table 2, Fig. 2B). In the analysis of covariance, leader diameter in 2004 (r = -0.29, $P \leq 0.05$) and bud volume in 2004 (r = 0.47, $P \leq 0.05$) were more strongly related to leader length in 2005 compared to tree height in 2004 (r = 0.14, $P \leq 0.05$) and leader length in 2004 (r = 0.10, $P \leq 0.05$).

When all levels of nips over the three sites were averaged, 35% of the leaders were in the target range (20 to 36 cm) for the traditional shearing regime, while 39% were in the target range (30 to 46 cm) for the "accelerated" regime (Fig. 3). For the traditional regime, the percentage of leaders that were within the target range increased from 18% for the control (no nips) to 46% with four nips (Fig. 3A). Even though almost half of the leaders were within the target range for three or four nips, 38% to 45% of the leaders were still too long (Fig. 3A). For the accelerated regime, three to four nips yielded 40% to 42% of leaders in the target range, and only 15% to 20% were too long (Fig. 3B).

Discussion

The TSN effectively reduced leader growth in Fraser fir Christmas trees. In a similar experiment in the Pacific Northwest, the TSN reduced leader growth of Noble (*Abies procera* Rehd.) and Nordmann fir by 25% to 50% depending on the species and individual tree (Fletcher et al., 2005). For nontreated Noble fir, about 22% of trees produced leaders in the target range while nipping increased the yield to 46% (Landgren and Fletcher, 2006). A study with the TSN in western North Carolina in 2004 showed that four nips reduced leader growth of Fraser fir by 32% without reducing bud counts on the leaders (Owen et al., 2004).

In conifers, formation of the terminal leader is a 2-year process (Powell, 1982). The first year consists of formation of bud primordia, which determines the amount of leader elongation during the second year. Favorable environmental conditions during this period produce more shoot growth during the second year (Kozlowski, 1962). Bud size is a good indicator of subsequent shoot growth (Kozlowski et al., 1973; Little, 1970). Fraser fir is excurrent, so the new leader displays dominance (apical control) over the laterals, which allows for greater allocation of photosynthate to the developing leader. For a time after budbreak, the leader is a carbohydrate sink within the tree. This period of growth is determined by climate, species, and genotype (Luxmoore et al., 1995). Later, the leader becomes self-sufficient with regard to carbohydrate production and finally becomes a carbohydrate source and storage site for the rest of the tree (Luxmoore et al., 1995).

Incisions placed on the previous year's leader by the TSN sever the phloem and most likely damage the vascular cambium as well. This reduces the amount of photosynthate reaching the developing leader during the second year of growth, and a portion of the transported nutrients is also devoted to wound repair. In the present investigation, the degree of reduction in leader length increased with the number of nips (Fig. 1C and D). Depending on site characteristics and tree-to-tree variation, three nips were normally sufficient to reduce leader growth to the desired length.

The TSN might be useful to growers who retain longer leaders to produce taller trees during shorter rotations. For an accelerated shearing regime, when the number of nips increased, a higher proportion of trees measured within the short range as opposed to the long range. Many of these leaders would still be acceptable depending on grower preference. Also, means for the accelerated regime were more equally divided among the three categories than the traditional regime, increasing the percentage of acceptable trees. Unless the technique can produce a greater percentage of trees with target leader lengths, growers are unlikely to adopt this practice. With current shearing practices, virtually 100% of trees have leader lengths within the target range. A third alternative might be a hybrid regime where treated trees with excessive leader length could be mechanically sheared while trees with acceptable leader length could be left untouched to preserve the natural appearance.

The success of the TSN might be influenced by consumer preference. For a particular species and height class, about half of consumers view full and open trees as similar in value, while 13% are willing to pay a premium price for a more open tree (Helmsing, 2003). Most consumers who prefer a more open tree are women, who are responsible for about 80% of Christmas tree purchases (Helmsing, 2003).

In general, women decorate with more ornaments, which require more space for perfect placement. An open, more natural tree can hold up to two-thirds more ornaments than a heavily sheared tree (Dishneau, 2004). For trees of a given height, an open tree weighs less than a dense tree, providing several advantages: 1) easier harvesting, 2) lower transportation costs, and 3) ease of handling, especially for women and children.

In summary, the TSN reduced leader growth of Fraser fir Christmas trees and is an alternative to traditional shearing. It has the potential to form a more open, "European style" tree with a layered, natural appearance. However, there is so much variation in response among trees and sites that a single treatment is not appropriate for all situations. More nips are required on vigorous trees to achieve the desired target range of leader length. Currently, the effect of the TSN on long-term appearance, quality, and marketability of Fraser fir trees is unknown.

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Table 1. Combined analysis of leader length for Fraser fir Christmas trees treated with a Top-Stop Nipper.

Source of variation[Z]	df	Leader length
Site = S	2	**
Block (Site)	57	--
Control = C	1	**
Time = T	2	**
Nips = N	3	**
T x N	6	NS
S x T	4	**
S x N	6	NS
S x T x N	12	NS
S x C	2	**
error	793	--
R^2 = 0.51		

[Z]Three sites, 20 blocks per site, three times of application, and four nipping treatments.

NS, ** Nonsignificant or significant at P = 0.01.

Table 2. Analysis of leader length for Fraser fir Christmas trees treated with a Top-Stop Nipper.

Source of variation[Z]	df	Site 1	Site 2	Site 3
Block	19	--	--	--
Treatments	12			
Time = T	2	**	NS	NS
Nips = N	3	**	**	**
T x N	6	NS	NS	NS
Control vs. nipped	1	**	**	**
Error		258	268	267
R^2	--	0.36	0.27	0.28

[Z]There were 20 blocks per site, three application dates, and four nipping treatments.

NS, ** Nonsignificant or significant at P = 0.01, respectively.

Fig. 1. (A) Jaws and cutter blades on the Top-Stop Nipper (TSN), **(B)** application of cuts to a leader of Fraser fir using the TSN, **(C)** leader elongation of a nontreated control tree, and **(D)** leader elongation of a tree that received four nips with the TSN.

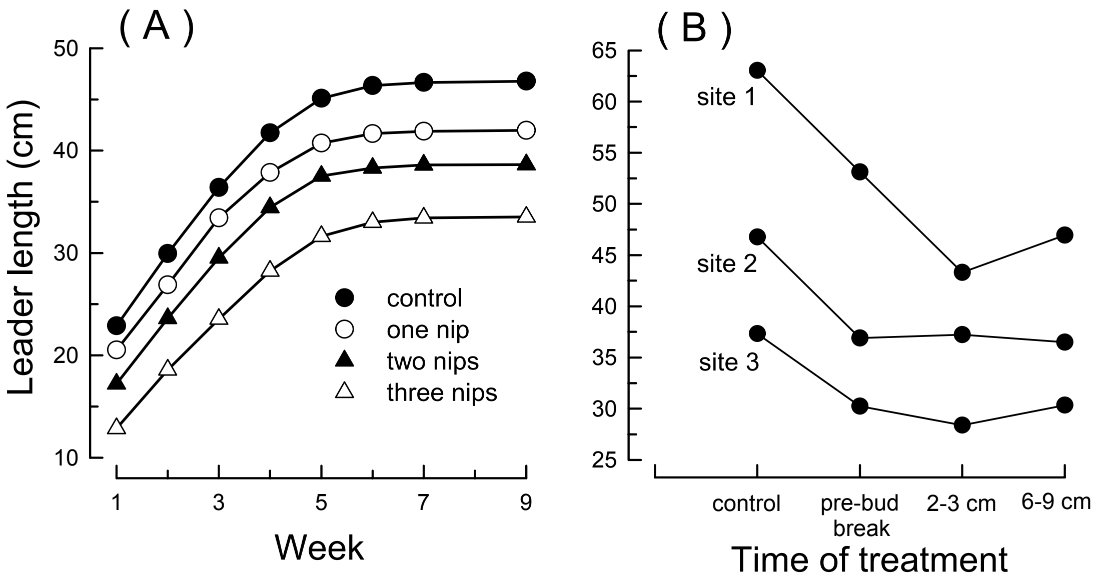

Fig. 2. (A) Average weekly leader length (LL, in centimeters) for TSN treatments at site 2. Measurements were taken at weeks 1, 2, 3, 4, 5, 6, 7, and 9. Data points: n = 60. The curves for three and four nips were similar, so only the curve for three nips is shown. Model for three nips: $LL_{(3\ nips)} = 11.8 + 11.75 \times \ln(\text{week})$, $R^2 = 0.98$. Model for control treatment: $LL_{(cont)} = 21.9 + 13.82 \times \ln(\text{week})$, $R^2 = 0.99$, **(B)** interaction between site and application time for final LL. Values are shown for individual sites. Data points: n = 80 for nip treatments; for controls n = 60. The SE for nip treatments = 1.24.

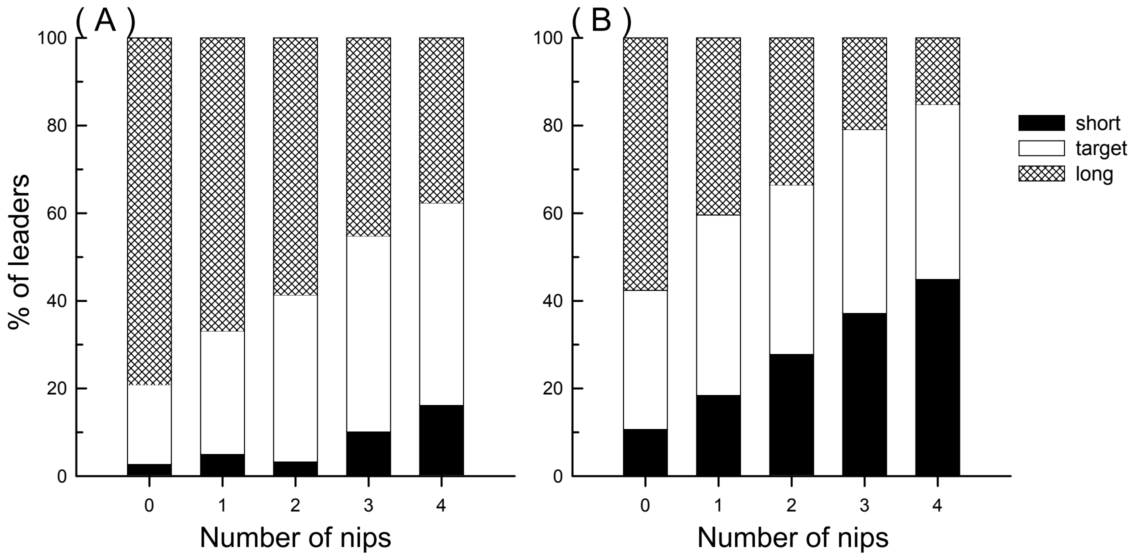

Fig. 3. Percent of trees with final leader length (LL) classified as short, target, or long for four TSN treatments and a nontreated control. **(A)** Traditional shearing regime: target LL = 20 to 36 cm, and **(B)** accelerated shearing regime: target LL = 30 to 46 cm. Results are averaged across three sites.

Chapter 2

Evaluation of Naphthaleneacetic Acid to Reduce Leader Growth in Fraser fir

Evaluation of Naphthaleneacetic Acid to Reduce Leader Growth in Fraser fir

Abstract

The research was conducted in Avery County, North Carolina during the spring and summer of 2005 to evaluate the effectiveness of the potassium salt form of 1-naphthaleneacetic acid (NAA) at reducing leader growth in Fraser fir. NAA was dissolved in distilled water and applied using the Danish made Easy Roller. Treatments included a control and 10, 20, 30, 40, 50, 60, and 70 ppm at three stages of leader elongation (6-9 cm, 12-18 cm, and 24-36 cm). There were significant differences in final leader length between sites and blocks within sites; however, results showed no significant differences among naphthaleneacetic acid, potassium salt treatment concentrations for leader elongation.

Introduction

Fraser fir [*Abies fraseri* (Pursh) Poir.] is the basis for the Christmas tree industry of western North Carolina. Sales exceeded $100 million in 2004, and more than 96% of the trees were Fraser fir (NCDA&CS, 2005). North Carolina ranks second in the nation to Oregon in Christmas tree production (NCCTA, 2004). Fraser fir is one of the most popular Christmas trees in North America due to its appealing fragrance, superior ability to retain needles, dark green foliage, conical shape, and high decorative value (Hinesley et al., 1995).

Currently, Fraser fir is sheared once annually, usually in July or August, beginning at a height of about 1 m to produce dense trees for American consumers. Traditional shearing removes the apical bud cluster from the leader and many lateral buds on the distal end of the shoots. Leaders are usually shortened to 20 to 50 cm, often half the original length. Sheared length depends upon the tree's potential for growth, its age, and consumer preferences (Hinesley et al., 1998).

Naturally occurring auxins such as indoleacetic acid (IAA) are involved in shoot elongation, cell division, flower stimulation, and root inhibition (Bandurski and Nonhebel, 1984). High levels of auxins may stimulate the production of ethylene, which causes inactivation of auxins, leaf abscission, and growth inhibition (Kefeli and Kalevitch, 2003). At high levels, NAA can reduce growth and even cause injury to plants (Wilson, 1983; Domir and Wuertz, 1982; Boswell et al., 1976; Kramer and Kozlowski, 1979; Hare, 1982).

The objectives of this research were to determine the effect of 1-naphthaleneacetic acid, potassium salt: (1) on leader growth of Fraser fir Christmas trees, and (2) on the timing of treatments.

Materials and Methods

The NAA treatments were applied at three sites, each site containing 10 blocks with 24 trees per block for a total of 720 trees. There were 24 treatment combinations within each block. A control and 7 concentrations (10, 20, 30, 40, 50, 60, and 70 ppm) of NAA were applied at three stages of leader elongation (6-9 cm, 12-18 cm, and 24-36 cm). Weekly measurements for leader elongation were recorded at site 2 over a 7 week time period and a final measurement was recorded at all three sites after 9 weeks.

The Easy Roller (Easy Roller, Lars B. Madsen, Langmosevej 6, 8620 Kjellerup, Denmark) has two rollers mounted parallel to one another on the end of two metal extensions. The apparatus with rollers is connected to a push-pump container by plastic tubing. The two rollers are placed on either side of the base of the leader and are gently rolled upwards as a chemical is pumped through the rollers and dispersed onto the leader.

Data were analyzed using the GLM procedure (SAS Institute Inc., 2003). The model tested for significant differences between sites, blocks within sites, NAA concentrations, and stages of leader elongation. The model also tested for significant interactions between sites, blocks within sites, NAA concentrations, and stages of leader elongation. At site 2, an analysis of variance was also conducted to test for significant concentration and stage of leader elongation effects on each weekly leader length measurement.

Results and Discussion

Leader elongation did not significantly differ by application of NAA (Table 1). Significant differences in final leader length existed between sites (40 cm, 46 cm, and 43 cm, respectively) and among blocks within sites. However, there were no significant interactions between any combination of site, concentration, and stage of leader elongation (Table 1). In addition, there were no differences in leader length at the time of each weekly measurement at site 2. No further analysis was attempted. Future tests should include using another form of NAA or higher concentrations of the same form.

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Tables and Figures

Table 1. Analysis of variance for leader length when applying concentrations of NAA using the Easy Roller.

Sources of variation[z]	df	Leader length (cm)
Site	2	**
Block (Site)	27	**
Time	2	NS
Concentration	7	NS
Site × Time	4	NS
Site × Concentration	14	NS
Time × Concentration	14	NS
Site × Time × Concentration	28	NS
Total	713	$R^2 = 0.19$

[z]There were 3 sites with 240 trees per site.

NS, ** Nonsignificant or significant at P ≤ 0.01, respectively.

Chapter 3

Using a Bud Volume Index with the Top-Stop Nipper to Control Leader Growth of Fraser fir Christmas Trees

(In the format appropriate for submission to HortScience)

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Using a Bud Volume Index with the Top-Stop Nipper to Control Leader Growth of Fraser Fir Christmas Trees

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Subject Category: Crop Production

Using a Bud Volume Index with the Top-Stop Nipper to Control Leader Growth of Fraser Fir Christmas Trees

Additional index words: Abies fraseri, shearing, bud density, consumer preference, correlative inhibition

Abstract. The Top-Stop Nipper, a four-bladed hand-held tool developed for reducing leader growth in Christmas trees, was used as a wounding technique to reduce leader growth of Fraser fir [*Abies fraseri* (Pursh) Poir.]. A regression model, based on an apical bud volume index, was used to predict the number of nips to apply to each leader to yield a target length of 25 to 36 cm. Treatments included control trees (0 nips, nonsheared) and one to seven nips per leader, and were applied in May as buds began to swell and elongate. In a previous study, increasing the number of nips decreased leader elongation when randomly applied to trees without regard to the size of the apical bud. When the number of nips increased with increasing bud volume, leader growth was about the same among all TSN treatments. Bud density on the 2006 leader increased with the number of nips applied to the 2005 leader. These results may be useful for growers who intend to produce dense trees with minimal shearing or for growers who choose to leave a longer leader to produce a more open, “European-style” tree during a shorter rotation time.

Fraser fir [*Abies fraseri* (Pursh) Poir.] with its dark green foliage, pleasant fragrance, conical shape, and outstanding needle retention, has increased in popularity as a Christmas tree in the United States (Hinesley et al., 1995). North Carolina ranks second in the country for Christmas tree production, accounting for about 19% of the total (NCCTA, 2004), and Fraser fir constitutes about 96% of the $100 million annual sales (NCDA&CS, 2005).

A large demand for high quality trees ensures that growers must stay competitive by minimizing production costs while accounting for consumer preferences. In response to preference for higher density trees, the practice of shearing began during the 1940's and 50's (Chastagner and Benson, 2000). Shape is the number one factor affecting Christmas tree selection, followed by needle retention, species, and price (NCDA&CS, 2002). About 53% of American consumers favor trees with dense crowns, 43% favor a more open tree (Helmsing, 2003).

Fraser fir is sheared once annually beginning at 1 to 1.3 m in height. Traditional shearing removes the apical bud cluster from the leader and from most large branches. Depending on its severity, shearing also removes many lateral buds on the distal end of the shoots. Although *Abies* species can be sheared almost anytime during the year, July to August is optimum (Brown and Heiligmann, 2002; Douglass, 1983; Hinesley and Derby, 2004a, 2004b). When Fraser fir is sheared, the leaders are typically reduced to a length of 20 to 50 cm. The chosen length greatly reflects the age of the tree, its potential for growth, and customer preference (Hinesley et al., 1998).

American growers favor dense trees, which require annual shearing, compared to European growers who incorporate little to no shearing (Frampton and McKinley, 1999). Europeans prefer more open trees with layered internodal branching and more uniform whorls (Chastagner and Benson, 2000). These trees have gaps between the whorls to accommodate decorations such as candles while both American and European consumers prefer an adequate number of internodal branches on which to hang ornaments. To accommodate smaller living spaces, many Europeans also prefer a slower growing Christmas tree that has a smaller crown diameter with a low to medium density (Frampton and McKinley, 1999).

Originally developed in Denmark, the plier-like Top-Stop Nipper (TSN) (Top-Stop, Lars Geil, Langebakke 2, DK-8680 Ry, Denmark) is used to place incisions on the previous year's leader. The crimping tool has two unequally spaced (≈ 2 cm apart) blades on either side, each with a half circle cut out (Fig. 1A). The insertion of the blades severs the phloem while stopping at the xylem (Fig. 1B). Disrupting the flow of photosynthate to the developing leader and the allocation of photosynthate to wound repair causes reduced leader growth. In Europe, the TSN has reduced leader growth in Nordmann fir (*Abies nordmanniana* Spach) by 25% (Owen et al., 2004). Advantages of the TSN include regulation of the top, no chemical applications, used once annually, low cost, ease of use, and requires little time per tree (Geil, 2004). In addition, leaving the terminal and subterminal buds intact maintains the mechanism of correlative inhibition among leaders and lower -order shoots (Kozlowski et al., 1973; Little, 1970), thus, enabling lateral branches to form more naturally as in a nonsheared tree. The objectives of this research using

Fraser fir Christmas trees was to develop and verify a model, based on a bud volume index and to determine the number of nips to apply with a TSN to achieve a specified target leader length.

Materials and Methods

Experiment 1 (Derivation of model). The objective of this research was to develop a regression model to predict the number of nips needed from a TSN to control leader growth of Fraser fir based on a bud volume index. During 2005, measurements were carried out in three representative Fraser fir Christmas tree plantations in Avery County in western North Carolina. A total of 900 sheared trees were used (height ≈ 1.2 to 1.5 m, with no symptoms of disease or noticeable insect damage). Trees had been in the field 5 yr and were likely 5 yr from seed when planted. On each site the experimental design was a randomized complete block with 20 blocks and 15 trees per block. Each tree in each block was randomly assigned to one of the 13 treatments (there were three control trees per block).

Prior to treatment, two height measurements were taken on each tree: total height through 2003 and total height through 2004. Sheared leader length for 2004 was calculated by difference. On the uppermost bud on the 2004 leader, two cross-sectional diameters (top to bottom and side to side) were measured with a digital caliper. The average of the two numbers was squared and multiplied by bud length to calculate a bud volume index.

Treatments included a control (0 nips) and the application of 1, 2, 3, or 4 nips at three stages of leader elongation: pre-budbreak, 2-3 cm, and 6-9 cm. The tool was rotated 90 degrees before applying each additional nip. Damage to lateral buds was minimized by carefully positioning the nips (Fig. 1D). Weekly measurements were recorded for every tree at site 2 over 7 weeks, beginning June 26. Final measurements were taken at all sites 9 weeks later.

An analysis of covariance was conducted to test the relationship between each covariable (bud volume, leader diameter, leader length in 2004, tree height) and final leader length in 2005. Bud volume was most strongly correlated with final leader length. A regression model using bud volume index and the number of nips was used to predict the number of nips required to yield a target leader length of 25 to 36 cm (Table 1). This model was used to apply nip treatments in a second experiment in 2006.

Experiment 2 (Validation of model). This experiment was conducted in the same Christmas tree plantations in 2006. A total of 120 trees were used in each plantation. Nip treatments were based on the model using bud volume index (Expt. 1) were applied to 100 trees, and 20 trees were used as controls at each site. Apical bud width and length were measured for each tree using a digital caliper. A bud volume index was then calculated by squaring the width and multiplying it by the bud length. Total tree height was recorded after the 2005 growing season along with the sheared height through 2004. Leader length (2005) was calculated by difference. In 2006, measurements included the length of the first lateral branch below the 2006 leader, and the length of the lowest lateral branch on the 2005 leader.

Treatments (1 to 7 nips applied at budbreak) were determined from Equation 1 (Fig. 1C). Measurements were taken at site 2 for weeks 1, 2, 3, 4, 5, 6, and 7; beginning on 26 June. Final measurements for all three sites were taken at week 9.

Data were analyzed using GLM, REG, and CORR procedures (SAS Institute, Inc., 2003). A GLM analysis, using combined data from the three sites, was conducted to test main effects and the site x nip interaction for the dependent variables: leader length, bud count, upper lateral branch growth, lower lateral branch growth, and bud density (buds/cm). Proc CORR in SAS was used to determine the relationships between bud volume and leader length, bud count, and bud density for the controls and treated trees. A linear regression model was used to predict bud density (buds/cm) for each of the seven levels of nipping, and predicted values were compared to actual values for each treatment.

Data were interpreted for two shearing regimes (traditional and accelerated), based on final leader length. These regimes refer to the leader length which is set during shearing. With a traditional regime, leader length would be reduced to 20 to 36 cm, while the accelerated regime would leave leaders 30 to 46 cm in length. For each regime, percentages were calculated for the number of leaders that were too short, optimum, or too long relative to the ideal target length.

Results

Experiment 1. Leader elongation decreased as the number of nips increased (Fig. 2), and the pattern of elongation was similar for all nip treatments. In the analysis of covariance, leader diameter in 2004 (r = -0.29, P<0.05) and bud volume in 2004 (r = 0.47, P<0.05) were more strongly related to leader length in 2005 compared to tree height in 2004 (r = 0.14, P<0.05) and leader length in 2004 (r = 0.10, P<0.05). The regression model to predict the number of nips to realize a target leader length of 25 to 36 cm was as follows:

[1] $LL = 28.8 – 4.0a + 62.8b – 1204.8b^2$, $R^2 = 0.38$

Where: LL= Leader length (cm), a = no. of nips, and b = bud volume index

Experiment 2. Although the TSN reduced leader elongation of Fraser fir in 2005 and in 2006, the shape of the relationship was different for the 2 years (Fig. 2). In 2005, leader elongation decreased linearly with the number of nips; in 2006, leader length was similar for all TSN treatments involving 1 to 7 nips (Table 2, Fig. 2). In contrast, bud density in 2006 increased with the number of nips (Table 2). Leader length for nonsheared controls was much greater ($P \leq 0.01$) than in all the TSN treatments (Fig. 2). Excluding controls, the site × nips interaction was negligible for all variables (Table 2). Upper lateral branch growth was significantly greater for sites 1 and 2, compared to site 3, while lower lateral branch growth was significantly lower for sites 1and 2, compared to site 3 (Table 2).

Control trees displayed a strong positive correlation between bud volume and final leader length (Fig. 3A). In contrast, trees that received 1 to 7 nips showed no significant relationship between bud volume and final leader length (Fig. 3A). There was a significant positive correlation between 2005 bud volume and 2006 bud count, particularly for control trees (Fig. 3B). Nipped trees exhibited a significant positive correlation between 2005 bud volume and bud density on the 2006 leader, whereas the correlation was negative for control trees (Fig. 3C). The prediction model for bud density showed a linear trend among the predicted values and a quadratic model described the trend for the actual values (Fig. 4). For the TSN treatments, bud density increased as the number of nips increased. For both shearing regimes (traditional and accelerated), there was a fairly uniform distribution of leaders within the target range for the treated trees (Fig. 5). With the traditional regime, about 95% of the control leaders were too long while five nips yielded 65% of leaders within the target range (Fig. 5). For the accelerated regime, four nips yielded 51% of leaders within the target range. A high percentage of leaders were classified as too short (Fig. 5), but might still be an acceptable length to many growers.

Discussion

The TSN effectively reduced leader growth in Fraser fir Christmas trees (Figs. 2 and 3) -- similar to results for other *Abies* species (Fletcher et al. 2005, Landgren and Fletcher 2006). In our research, bud density on the 2006 leader also increased more or less in proportion to the number of nips (Fig. 3C).

In conifers, formation of the terminal leader is a 2-year process (Powell, 1982). The first year consists of the formation of bud primordia, which in part determines the amount of height growth during year 2. Favorable environmental conditions during year 1 produce more shoot growth during year 2 (Kozlowski, 1962), perhaps explaining the similar positive correlations between bud count and bud volume for the treated trees as well as the controls (Fig. 3B). The number of buds present on a leader should not be affected by the nipping treatments which occur after primordial formation; therefore, the controls and nipped trees should have a similar relationship.

There was a good relationship between bud volume and shoot elongation – in agreement with earlier research (Kozlowski et al., 1973; Little, 1970). The TSN cuts through the phloem and most likely damages the vascular cambium as well.

Wounding reduces the amount of nutrients reaching the developing leader and a portion of the transported nutrients also goes to wound repair. In 2005, leader growth decreased as the number of nips increased (Fig. 2). Nip treatments were randomly applied to trees irrespective of bud volume; resulting in a negative slope for the relationship between leader length and the number of nips. On the other hand, in 2006 the number of nips increased as bud volume increased, resulting in no relationship between leader length and the number of nips (slope ≈ zero) (Fig. 2). Therefore, bud volume was an effective predictor of the number of nips needed to produce leaders with a specified target length. Reducing leader growth, while maintaining the same number of buds, increases bud density, which increases crown density. Because the TSN increases bud density on the leader, it might allow growers to retain longer leaders, compared to traditional shearing, to produce taller trees during shorter rotations.

The utility of the TSN might be influenced by consumer preference. About half of consumers view full and open trees as similar in value, while 13% are willing to pay more for an open tree (Helmsing, 2003). Women, who purchase about 80% of Christmas trees, tend to prefer a more open tree (Helmsing, 2003). Women often use more ornaments, which require more space for perfect placement. An open, more natural tree can hold more ornaments than a heavily sheared tree (Dishneau, 2004). Open trees weigh less than dense trees, providing several advantages: 1) easier harvesting, 2) lower costs, and 3) ease of handling, especially for women and children.

TSN treatments, based on bud volume, uniformly reduced leader growth. The TSN has the potential to form a more open “European style” tree with a layered, natural appearance, and might be an alternative to traditional shearing. Currently, the effect of the TSN on long-term appearance, quality, and marketability of Fraser fir trees is unknown.

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Table 1. Allocation of TSN treatments to 360 Fraser fir Christmas trees in 2006, based on a bud volume index.

Nips	Bud vol. index	Site 1	Site 2	Site 3	*Total*
control	--	18	20	19	57
1	0.005 – 0.007	2	3	17	22
2	0.008 – 0.011	15	5	14	34
3	0.012 – 0.016	29	9	10	48
4	0.017 – 0.022	29	18	20	67
5	0.023 – 0.028	13	10	14	37
6	0.029 – 0.036	5	14	8	27
7	0.037 – 0.051	4	38	4	46

Table 2. Analysis of leader length, bud count, bud density, and growth of lateral branches for Fraser fir Christmas trees treated with a Top-Stop Nipper.

Source of variation [Z]		df	Leader length	Bud count	Bud density	Upper lateral Branch	Lower lateral branch
Site		2	NS	NS	NS	**	**
Nips		6	NS	NS	**	NS	NS
Site × Nips		12	NS	NS	NS	NS	NS
Error		260	--	--	--	--	--
	R^2	--	0.05	0.13	0.12	0.18	0.24

[Z]There were three sites with 120 trees per site. Control trees (20 per site) were not used in the analysis. NS, ** Nonsignificant (P<0.05) or significant at (P<0.01), respectively.

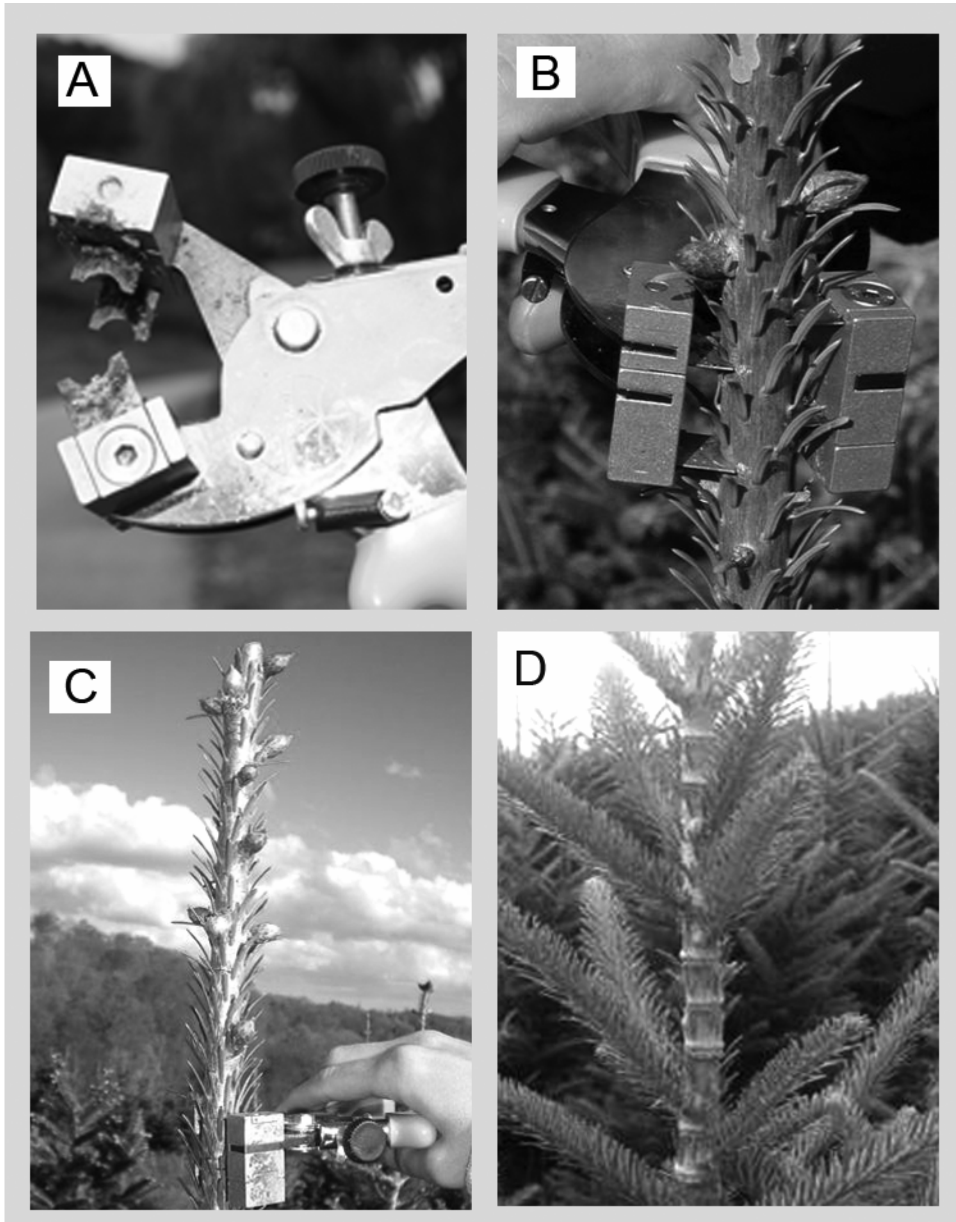


Fig. 1. (A) Jaws and cutter blades on the Top-Stop Nipper (TSN), **(B)** application of cuts to the leader of Fraser fir using the TSN, **(C)** application of cuts to the leader while buds were swelling, and **(D)** scars from TSN treatments after lateral branch elongation.

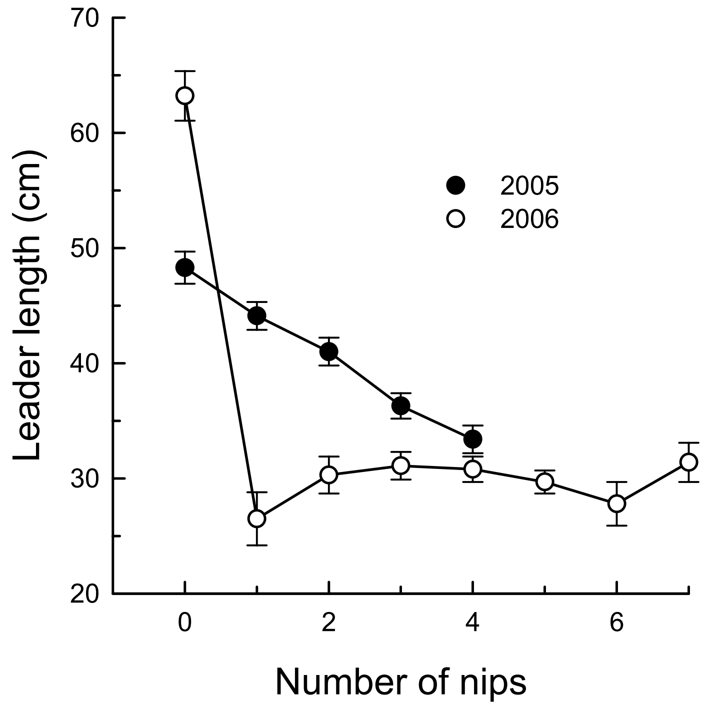
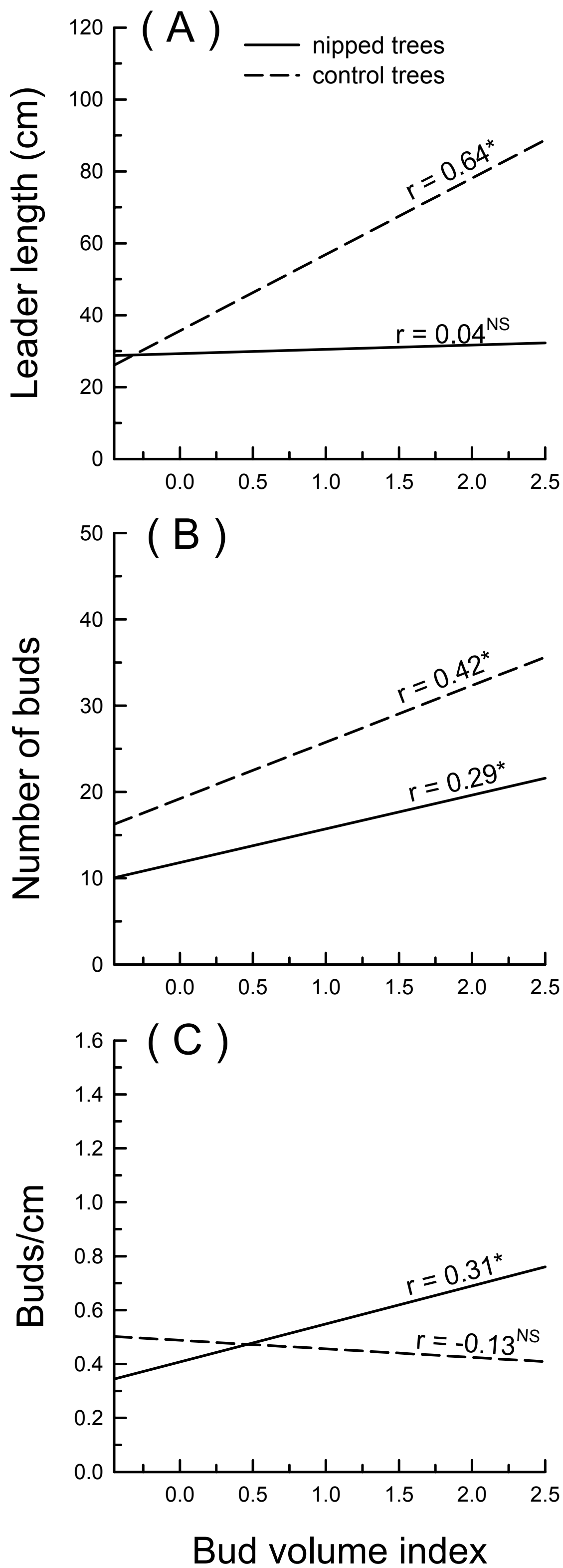


Fig. 2. Average leader length for Fraser fir Christmas trees that received 1 to 4 nips (2005) and 1 to 7 nips (2006) with a TSN. The means are averaged across all three sites for both the 2005 and 2006 experiments. Treatments in 2005 were applied randomly; in 2006 they were applied according to bud volume. Bars = SE of mean.

Fig. 3. Correlations and relationships between **(A)** leader length and bud volume index, **(B)** bud count and bud volume index, and **(C)** bud density and bud volume index for the control trees versus those that received the nipping treatments. Values represent all treated trees and control trees at all three sites. NS, *, ** Nonsignificant, significant at $P \leq 0.05$, or significant at $P \leq 0.01$, respectively.


(A)
nipped trees
control trees
Leader length (cm)
r = 0.64*
r = 0.04NS
(B)
Number of buds
r = 0.42*
r = 0.29*
(C)
Buds/cm
r = 0.31*
r = -0.13NS
Bud volume index

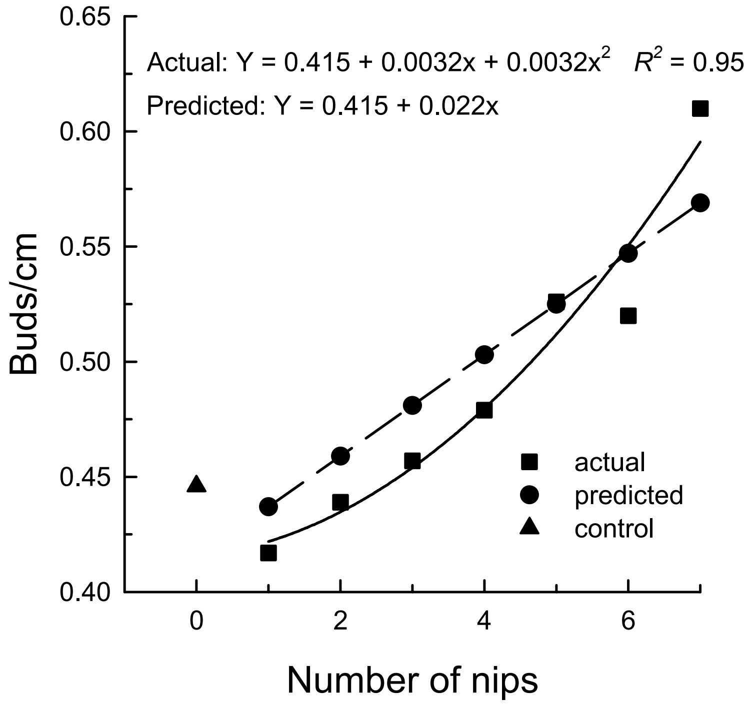


Fig. 4. Linear regression model predicting bud density (buds/cm) for control trees and treatments of 1 to 7 nips in comparison to the actual values for each mean across all three sites. The nip treatments were applied based on a bud volume index. The average bud density for the control trees is represented by a single value.

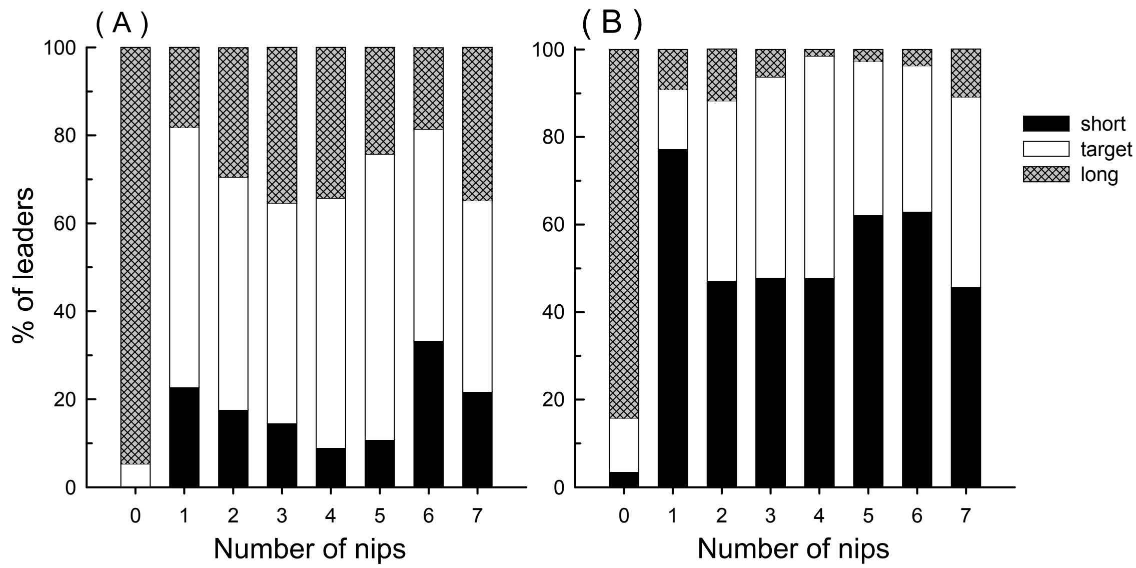


Fig. 5. Percent of trees with final leader length classified as short, target, or long for seven TSN treatments and a nontreated control, averaged across three sites. **(A)** traditional shearing regime: target leader length = 20 to 36 cm, and **(B)** accelerated shearing regime: target leader length = 30 to 46 cm.

Chapter 4

Naphthaleneacetic Acid Reduces Leader Growth of Fraser fir Christmas Trees

(In the format appropriate for submission to HortScience)

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Naphthaleneacetic Acid Reduces Leader Growth of Fraser fir Christmas Trees

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Subject Category: Crop Production

Naphthaleneacetic Acid Reduces Leader Growth of Fraser fir Christmas Trees

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 ethyl 1-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, which contains NAA, was applied to leaders at concentrations of 0 to 500 $mL \cdot L^{-1}$ commencing 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 ≥ 120 $mL \cdot L^{-1}$. Although less effective than the Easy Roller the Sprühsystem caused negligible mortality of leaders. Applying 40 $mL \cdot L^{-1}$ with the Easy Roller yielded about 50% of leaders with target lengths of 20 to 36 cm, with little mortality. The Sprühsystem gave similar results at 250 $mL \cdot L^{-1}$. NAA might be useful for producing dense trees with minimal shearing, or for producing more natural, open trees during shorter rotations. Chemical names used: Sucker-Stopper RTU (1.15% ethyl 1-naphthalene acetic acid, NAA, WA-100 Plus surfactant (Ag Spray, Inc., Salem, OR 97309), and Tipoff

(Universal Crop Protection Ltd, Park House, Maidenhead Road, Cookham, Maidenhead, Berkshire, SL6 9DS, UK).

Fraser fir (*Abies fraseri*) is the basis for the Christmas tree industry of North Carolina. During 2004, wholesale value exceed $100 million, and more than 96% of the trees were Fraser fir (NCDA&CS, 2005). North Carolina ranks second in the nation for Christmas tree production (NCCTA, 2004). Fraser fir is one of the most popular Christmas trees in North America due to its appealing fragrance, superior needle retention, dark green foliage, conical shape, and high decorative value (Hinesley et al., 1995).

The Christmas tree industry is driven by consumer preference. Shape is the most important factor to consumers when selecting a Christmas tree (NCDA&CS, 2002). About 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 while American growers shear trees annually to produce the dense trees that most consumers prefer (Frampton and McKinley, 1999).

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

Sucker-Stopper RTU (SS-RTU) [1.15% ethyl 1-naphthaleneacetic acid (NAA)], is used to reduce or prevent the growth of sprouts and suckers on various woody plants. Naturally occurring auxins such as indoleacetic acid (IAA) are involved in shoot elongation, cell division, flower formation, and inhibition of root growth (Bandurski and Nonhebel, 1984). Applying synthetic NAA during the growing period can reduce leader growth and the number of shoots (Wilson, 1983; Domir and Wuertz, 1982; Bir and Ranney, 1992; Boswell et al., 1976). When under stress due to high levels of auxins, ethylene production may be stimulated (Kefeli and Kalevitch, 2003). Ethylene is a hormone, which 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 (Wilson, 1983; Domir and Wuertz, 1982; Boswell et al., 1976; Kramer and Kozlowski, 1979; Hare, 1982). Therefore, objectives of this research were to determine (1) 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. Madsen, Langmosevej 6, 8620 Kjellerup, Denmark) has two rollers mounted parallel to one another on the end of two metal extensions (Fig. 1A). The apparatus with rollers is connected 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 upwards as a chemical is pumped through the rollers and dispersed onto the leader (Fig. 1B). The Sprühsystem (Michael Scherer, Donauwörth, Germany) differs from the Easy Roller in that the chemical is placed in a backpack sprayer instead of a pumping container. It 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 instruction) on the handle of the applicator (Fig. 1D). Application to the leader using either the Easy Roller or Sprühsystem takes only a few seconds.

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 1,200 m above sea level. A total of 1,500 sheared trees were used (height = 1.2 to 1.5 m). Most trees had been in the field for ≈ 5 to 6 years, and were 3-2 transplants 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.

Total tree height (growth through 2005) and the sheared height up to the previous year's whorl (growth through 2004) were measured. Leader length for the 2005 growing season was calculated by difference. The length and the widths of each tree's apical bud were measured using a digital caliper. 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.

Seven treatments were applied with the Easy Roller: control (leaders treated with water), 40, 80, 120, 160, 250, or 500 $mL \cdot L^{-1}$. Concentrations of 40, 120, and 250 $mL \cdot L^{-1}$ 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 $mL \cdot L^{-1}$ of WA-100 Plus (Ag Spray, Inc., P.O. Box 12129, Salem, OR 97309), a surfactant. Trees were checked regularly, and treatments were applied as the new leaders reached a length of 8 to 15 cm. Leader lengths were recorded weekly for each tree at site 2 over a period of 7 weeks beginning 26 June 2005, and final measurements were taken on all sites after 9 weeks.

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, 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. Data were analyzed using GLM and REG procedures (SAS Inst., Inc., 2003). An analysis of variance

(ANOVA) was conducted to test for differences among main effects and interactions for site, concentration, and method of application. Correlation coefficients were calculated using Proc CORR (SAS Inst., Inc., 2003) 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 while 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). 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 was 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 2005 ($r = 0.24$, $P<0.01$) as well as final leader length in 2006 and bud volume in 2005 ($r = 0.49$, $P<0.01$). Furthermore, correlations for the Easy Roller across all three sites showed 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 ($r = 0.44$, $P<0.01$). Similar correlations were also found 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 ($r = 0.52$, $P<0.01$) when treatments were applied with the Sprühsystem.

Of the two methods of application, the Easy Roller reduced leader elongation most effectively (Fig. 4A). A concentration of 40 $mL \cdot L^{-1}$ reduced leader length by 16%, with negligible mortality (Fig. 3). Increasing the concentration to 80 $mL \cdot L^{-1}$ reduced leader length by 32%, with leader mortality of 3%. Mortality increased from 5% for the 120 $mL \cdot L^{-1}$ treatment to 86% for 500 $mL \cdot L^{-1}$ (Fig. 3). The Sprühsystem was less effective at reducing leader elongation, but leader mortality never exceeded 4% even at 250 $mL \cdot L^{-1}$ (Fig. 4B). The biggest difference was at 250 $mL \cdot L^{-1}$ where the Easy Roller reduced leader length by 50% compared to 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 not affected 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 vs. accelerated). 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 to 2% of leaders treated with 500 $mL \cdot L^{-1}$ from the Easy Roller (Fig. 5A). When applied with the Easy Roller, concentrations ≥ 120 $mL \cdot L^{-1}$ 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 $mL \cdot L^{-1}$ 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 about 50% with a concentration of 40 $mL \cdot L^{-1}$ of SS-RTU (Fig. 5B). When applied with the Sprühsystem, 250 $mL \cdot L^{-1}$ yielded 55% of leaders in the target range for the 'traditional' shearing regime, compared to 45% for the 120 $mL \cdot L^{-1}$ concentration in the 'accelerated' shearing regime (Fig. 5C and 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 TSN treatments shortened leader growth in Noble fir (*Abies procera* Rehd.) and Nordmann fir (*Abies nordmanniana* Spach) by 25% to 50%, although the response varied by species, treatment, and individual tree (Fletcher et al., 2005). In another experiment in the United Kingdom, Tipoff (Universal Crop Protection Ltd, Park House, Maidenhead Road, Cookham, Maidenhead, Berkshire, SL6 9DS, UK.), a growth regulator containing 0.289% NAA was applied to Fraser fir with the Easy Roller at 0 to 150 $mL \cdot L^{-1}$, and leader length decreased with increasing concentration. Only 20% of the control trees had leader lengths in the target range, compared to 44% with 150 $mL \cdot L^{-1}$ (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 87%) at concentrations > 160 $mL \cdot L^{-1}$. With the Sprühsystem, mortality was negligible even at the highest concentration of 250 $mL \cdot L^{-1}$. The difference might be related to how the solution contacts the leader. With the Easy Roller, the solution is rolled directly onto the leader, whereas it is sprayed onto the leader with the Sprühsystem.

In our research, there was a linear relationship (Fig. 4C) and a positive correlation between bud production and final leader length following treatment with NAA. Although concentration affected leader length as well as bud counts, it had negligible effect on lateral branch growth, and there was little correlation between lateral branch growth and leader length.

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 following growing season (Kozlowski, 1962). In determinant species, bud size is a good predictor of subsequent shoot length (Hinesley and Derby, 2004, Kozlowski et al., 1973, Little, 1970, Rasmussen et al., 2005). Application of a plant growth regulator such as NAA may complicate the relationship between bud size and final leader length by altering hormonal balances.

Application of SS-RTU using 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 $mL \cdot L^{-1}$, about 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. The Sprühsystem reduced leader growth with little risk of mortality, whereas, the Easy Roller suppressed leader growth more effectively, but with greater mortality. Mechanical shearing can place virtually all leaders within the preferred target range, compared to 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 where treated trees with excessive leader length could be mechanically sheared while trees with acceptable leader length could be left untouched to preserve the natural appearance.

Consumer preferences may influence the utility 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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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[z]	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
A × C	2	**	**	NS
S × A × C	4	NS	NS	NS

[z]There were three sites, 50 blocks per site, and 10 trees per block. Degrees of freedom for lateral branch growth for site = 1; n = 531 for both applicators.

NS, *, ** Nonsignificant or significant at $P \leq 0.05$ or 0.01, respectively.

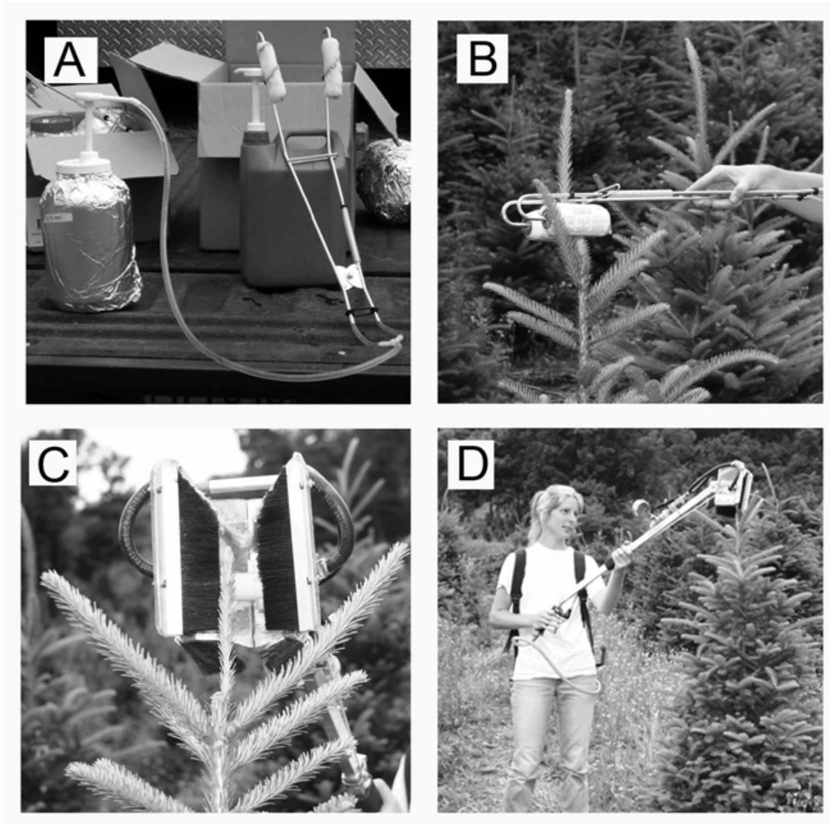

Fig. 1. Applicator components and application of Sucker-Stopper. **(A)** Easy Roller, **(B)** Easy Roller application, **(C)** Sprühsystem, and **(D)** Sprühsystem application.

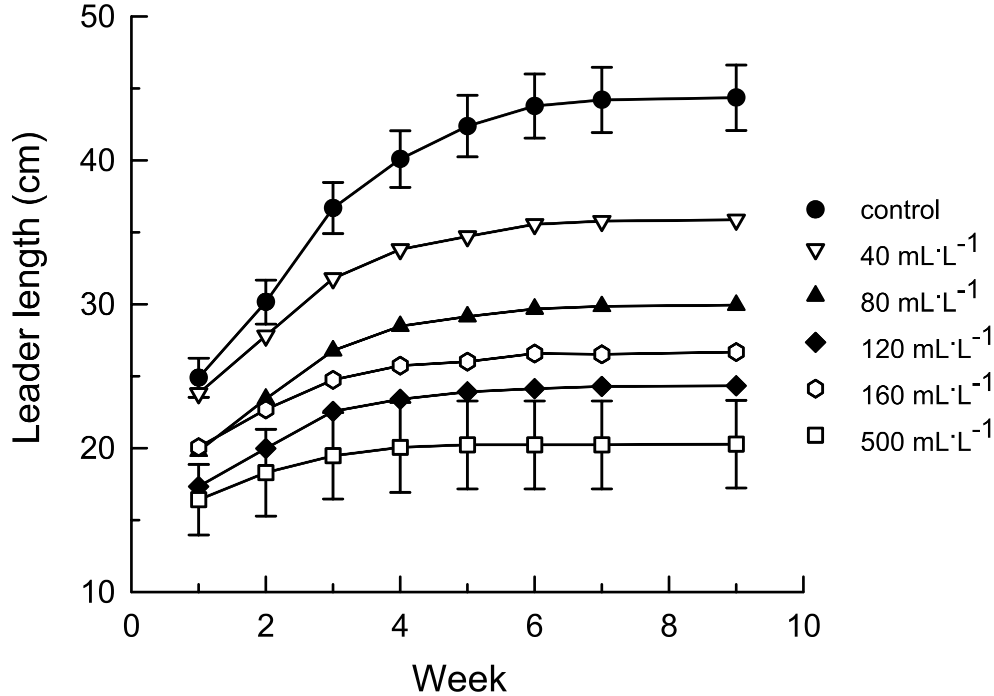

Fig. 2. Leader length of Fraser fir Christmas trees on Site 2 as affected by concentration of Sucker-Stopper RTU. Applicator was the Easy Roller. Curves for 120 and 250- $mL{\cdot}L^{-1}$ were similar. Data points: n = 50; bars = SE of the mean.

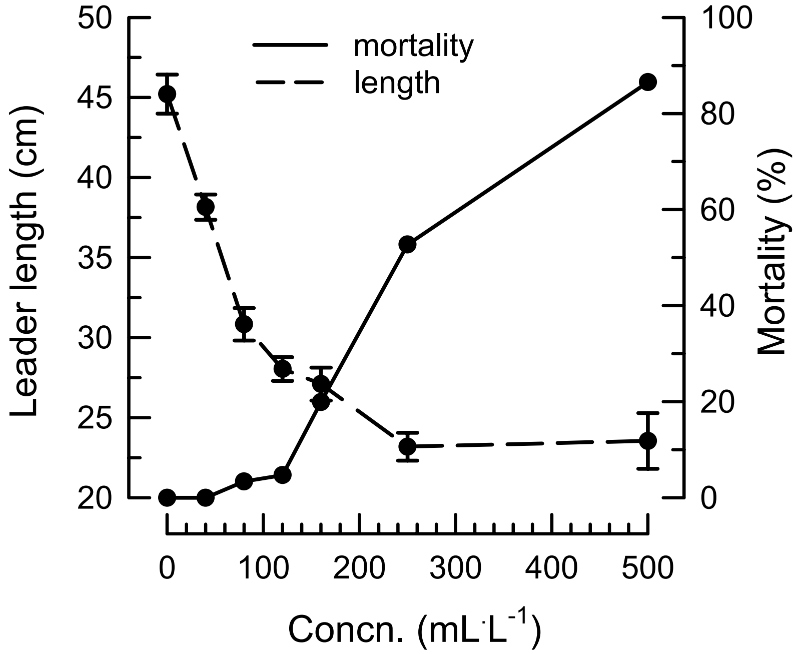

Fig. 3. Leader growth and mortality (averaged over all sites) for Fraser fir Christmas trees treated with various concentrations of Sucker-Stopper RTU using the Easy Roller. Data points: n = 150; bars = SE of the mean.

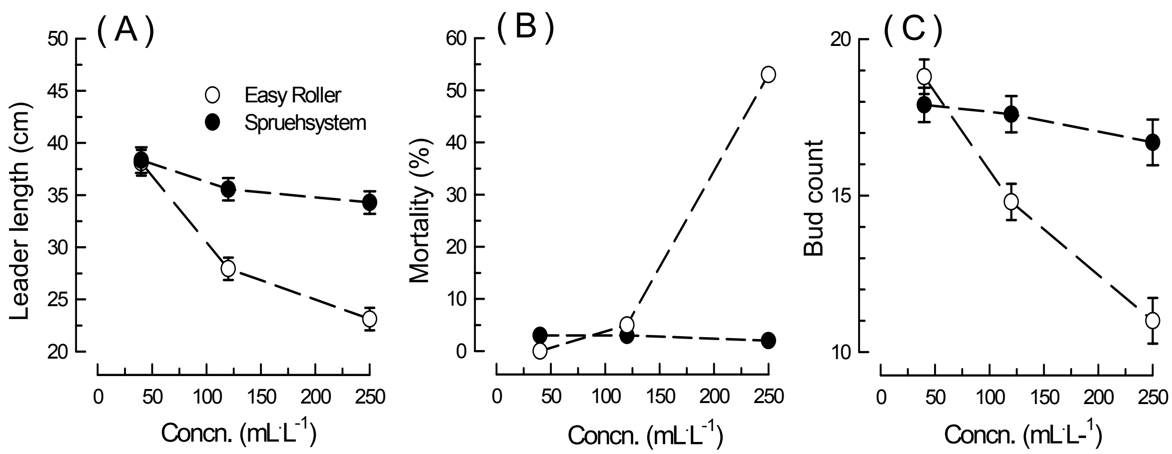

Fig. 4. Length **(A)**, mortality **(B),** and bud count **(C)** of leaders of Fraser fir Christmas trees as affected by concentration of SS-RTU and method of application. Data points: n = 150; bars = SE of the mean.

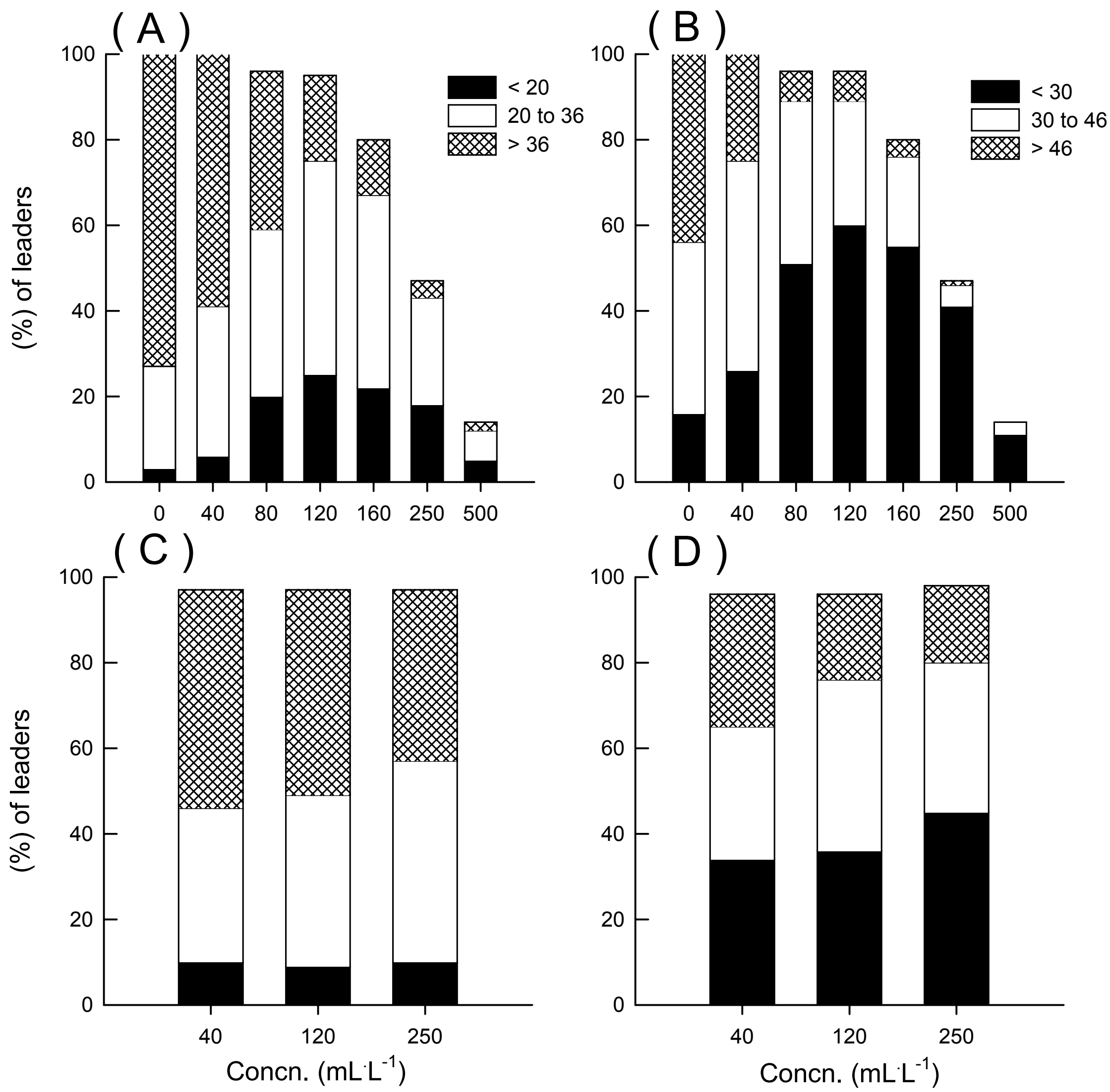

Fig. 5. Percentages of trees that measured within each range for final leader length; short, target, and long. Bars only include living leaders. The traditional target range for leader length is 20 to 36 cm; the accelerated is 30 to 46 cm. **(A)** traditional regime for the Easy Roller, **(B)** accelerated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

Conclusion

The Top-Stop Nipper (TSN) and Sucker-Stopper RTU (SS-RTU) (1.15% NAA) effectively reduced leader growth in Fraser fir. Currently, these methods may not produce a large enough percentage of leaders within the target range to incorporate into current Christmas tree operations but they offer some advantages and incentives for future research. Also, the effect of the TSN and application of NAA on long-term appearance, quality, and marketability of Fraser fir trees is unknown. Success of these methods will depend upon consumer preferences and the resources of Christmas tree growers.

The TSN and NAA provide some potential advantages over traditional mechanical shearing. First, they yield trees with a more open, natural appearance, thus providing consumers with a more diverse selection. Trees of a given height tend to weigh less than trees sheared with traditional methods. In addition, they are easier to bale, have lower transportation costs (more trees per truck), and are easier for women and children to handle. Finally, the TSN increases tree density by preserving a full complement of buds on the terminal leader while reducing leader elongation.

Future research should address several issues: 1) evaluate the effectiveness and feasibility of applying TSN treatments or growth regulators such as NAA on large scale Christmas tree operations, 2) spraying the entire tree with an NAA solution rather than only the leader, 3) combined TSN and NAA treatments throughout an entire rotation, 4) potential to combine traditional shearing and

TSN/NAA experiments in a hybrid system, 5) training of workers to properly apply or implement these methods, and 6) cost/benefits of treatments.