Post-Emergent Control of Nuisance Cones in Fraser Fir Christmas Tree Plantations

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Abstract: Heavy cone production by Fraser fir Christmas trees requires significant labor inputs to remove nuisance cones. We conducted two field trials in collaboration with operational Christmas tree farms to evaluate the effectiveness of post-emergent herbicides to stop the development of newly emergent cone buds. In the first trial (2016), we applied six products (two conventional herbicides and four herbicides labeled for organic production) to trees using back-pack sprayers in operational plantations at four farms in Michigan. Three products; Scythe, Axxe, and Avenger, provided better cone kill than the other products but resulted in phytotoxicity at two locations. In 2017, we applied the three most effective products from the earlier trial at three farms either as single applications or as two applications approximately one week apart. We also evaluated a hand-held mechanical de-coning device at two farms. For all the products and the mechanical device, cone control in the 2017 trial was high (>80%). Phytotoxicity to foliage was low (mean rating, <0.3; 0 = none, 2 = severe) for single applications of the herbicides. Repeated applications increased cone control slightly but also increased risk for phytotoxicity. The mechanical device caused significant damage to shoots and foliage. We attribute the increased product effectiveness and reduced phytotoxicity between the 2016 and 2017 studies to improved coverage and earlier spray timing. Based on the current retail product cost, chemical cone control can be cost-effective compared to handpicking cones if trees have high numbers of cones that can take several minutes to remove. The effect of using surfactants and reducing product rates should be investigated along with mechanized application.

Keywords: coning; herbicides; cone picking; phytotoxicity; pelargonic acid

1. Introduction

Precocious cone production is a major production issue for Fraser fir (Abies fraseri (Pursh) Poir.) Christmas tree plantations. In North America, Fraser fir trees begin to produce female cones (strobili) within four or five years after planting (Figure 1). Fraser fir trees in native forests, in contrast, typically do not produce female cones until the age of 15 [1]. Cone production increases rapidly during the Christmas tree production cycle and trees that are 3 m tall can produce more than 1000 cones. Cones are a liability in Christmas trees because they disintegrate after maturing in the fall, leaving unsightly stalks that can render trees unsalable. Moreover, cones are a strong sink for photo-assimilates and reduce the amount of carbohydrates available for shoot and needle growth [2]. Because of the impacts of cones on Christmas tree quality and growth, growers pick female cones from trees shortly after cone buds emerge in the spring. Cone picking is labor intensive and results in one of the largest labor costs for Fraser fir Christmas tree producers in North America.
Research on reducing or eliminating cone production in Fraser fir has focused on (1) pre-emergent (or pro-active) strategies to prevent trees from forming cone buds and (2) post-emergent (or re-active) techniques to eliminate cones once they have formed. Pre-emergent approaches to reducing coning include influencing environmental factors that control coning and the application of plant growth regulators to reducing coning [3]. For example, the application of paclobutrazol, a gibberellic acid (GA) inhibitor, reduced cone production in Fraser fir trees in Christmas tree plantations in Michigan by up to 54% [4]. However, there are drawbacks to the pre-emergent approach to cone reduction. First, trees must be treated as buds are formed along new shoots. All trees in plantations must be treated because it is impossible for growers to identify which buds will be reproductive and which will be vegetative. Therefore, growers will likely treat many trees that would not cone even without treatment. Second, paclobutrazol treatments can be expensive as conifers require relatively high doses in order to induce a response, and rates increase as trees grow larger.

In contrast to pre-emergent cone treatments, post-emergent treatments are intended as a substitute for manually picking cones. An advantage to post-emergent control is that growers only need to treat trees that produce cones, rather than treating all trees as in a pre-emergent strategy. Chemical post-emergent control of Fraser fir cones might be possible because cone buds emerge two to three weeks prior to vegetative bud-break. The asynchrony between cone bud emergence and vegetative bud break provides a window during which cones are susceptible to herbicides, but existing foliage can be relatively tolerant. Owen [5] conducted trials and found that up to 90% of emerging cones could be killed with properly timed herbicide sprays. Owen tested products that included conventional herbicides, as well as herbicides listed for use in organic production systems. Organic-registered herbicides might be well suited for this application because they have a relatively low overall toxicity. Many are natural products such as citrus oils or short-chain fatty acids that work as desiccants [6–9]. This suggests they could potentially cause “burn-down” of newly emerged cones with minimal damage to existing needles with thick cuticles.
The objective of the current project is to develop protocols for post-emergent control of cones in Fraser fir Christmas tree plantations. Specific objectives of the current studies are to: (1) determine the effectiveness of treatments on stopping cone development and (2) evaluate the severity of phytotoxicity on needles and shoots.

2. Materials and Methods

2.1. 2016 Trial

2.1.1. Study Locations

This trial included four locations and plots were installed throughout the state of Michigan. Three experiments were located at grower-cooperator farms and one was located at the Michigan State University Forestry Tree Research Center in East Lansing (Figure 2). The treatment plots had tree heights that ranged from 1.9 to 3.5 m.

At each location, we selected 140 trees with at least 10 cones per tree. Cone sizes ranged from 2.6 to 3.6 cm at the time of treatment. The study was installed as a completely randomized design. At each farm, treatments were assigned to individual trees at random by selecting color-coded ribbons (one color per treatment) from a bucket. Herbicide treatments were applied in the third week of May.

Temperature and wind speed data were compiled from the Michigan State University Enviroweather stations located closest to each experiment plot (Table 1).

2.1.2. Study Design and One Treatments

At each location, we selected 140 trees with at least 10 cones per tree. Cone sizes ranged from 2.6 to 3.6 cm at the time of treatment. The study was installed as a completely randomized design. At each farm, treatments were assigned to individual trees at random by selecting color-coded ribbons (one color per treatment) from a bucket. Herbicide treatments were applied in the third week of May. Temperature and wind speed data were compiled from the Michigan State University Enviroweather stations located closest to each experiment plot (Table 1).

Table 1. Locations, dates, daily maximum temperatures, and wind speeds at time of post-emergent cone herbicide application at four sites in Michigan in 2016.

<table>
<thead>
<tr>
<th>Location</th>
<th>Application Date</th>
<th>Max Air Temp C</th>
<th>Wind m/s</th>
<th>Station 1</th>
<th>GPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Allegan, MI</td>
<td>May 19</td>
<td>22.6</td>
<td>2.1</td>
<td>Allegan</td>
<td>42.5292° N, 85.8553° W</td>
</tr>
<tr>
<td>Horton, MI</td>
<td>May 18</td>
<td>19.1</td>
<td>2.1</td>
<td>Leslie</td>
<td>42.4514° N, 84.4325° W</td>
</tr>
<tr>
<td>Sidney, MI</td>
<td>May 17</td>
<td>18.5</td>
<td>2.3</td>
<td>Entrican</td>
<td>43.2925° N, 85.0814° W</td>
</tr>
<tr>
<td>East Lansing, MI</td>
<td>May 13</td>
<td>17.1</td>
<td>4.7</td>
<td>MSU-HTRC</td>
<td>42.6406° N, 84.5153° W</td>
</tr>
</tbody>
</table>

1 Michigan State University Enviroweather Network Station.
Twenty trees were assigned at random to one of seven treatments: Avenger, Axxe, Goal, Reflex, Scythe, WeedZap, and control (Table 2). Herbicides were sprayed to run-off with a backpack sprayer on the upper one-third of the tree where cones typically grow.

Table 2. Description of herbicide products and rates applied.

<table>
<thead>
<tr>
<th>Product</th>
<th>Manufacturer</th>
<th>Description</th>
<th>Type</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avenger</td>
<td>BioSafe Formulations, Buford, GA</td>
<td>d-limonene (citrus oil)</td>
<td>Organic</td>
<td>250 mL/L</td>
</tr>
<tr>
<td>Axxe</td>
<td>BioSafe Systems, LLC, East Hartford, CT</td>
<td>ammonium nonanoate (ammonium salt of pelargonic acid)</td>
<td>Organic</td>
<td>100 mL/L</td>
</tr>
<tr>
<td>Goal</td>
<td>Dow AgroSciences LLC, Indianapolis, IN</td>
<td>oxynil (pre/post emergent herbicide)</td>
<td>Conventional</td>
<td>50 mL/L</td>
</tr>
<tr>
<td>Reflex</td>
<td>Syngenta Crop Protection, LLC, Greensboro, NC</td>
<td>sodium salt of fomesafen (pre/post emergent herbicide)</td>
<td>Conventional</td>
<td>20 mL/L</td>
</tr>
<tr>
<td>Scythe</td>
<td>Gowan Company, Yuma, AZ</td>
<td>pelargonic acid</td>
<td>Organic</td>
<td>50 mL/L</td>
</tr>
<tr>
<td>WeedZap</td>
<td>JH Biotech, Inc., Ventura, CA</td>
<td>Cinnamon oil + clove oil</td>
<td>Organic</td>
<td>50 mL/L</td>
</tr>
<tr>
<td>Control</td>
<td>na</td>
<td>untreated</td>
<td>untreated</td>
<td>na</td>
</tr>
</tbody>
</table>

2.1.3. Evaluations

Each tree was evaluated for cone kill and phytotoxicity (needle browning). The evaluations took place three to four weeks after the herbicide application. Cones were categorized as live (green and growing), damaged (brown or partially brown with evidence of growth), or dead (brown with no evidence of additional growth). Phytotoxicity to foliage for each was evaluated on a 0 to 3 scale: 0 = no damage, 1 = slight (minor tip browning of new growth), 2 = moderate (browning of new and old growth), and 3 = unacceptable (extreme browning of new and old shoot growth), and evaluated on needles in the top one-third of the tree where the herbicides were sprayed.

2.1.4. Statistical Analysis

The effects of Farm, Treatment, and Farm × Treatment interaction were tested by analysis variance using the PROC GLM procedure in SAS (SAS Institute Inc., Cary, NC, USA). Where Treatment main effects were significant (p < 0.05), means were separated using Tukey’s studentized range test.

2.2. 2017 Trial

2.2.1. Study Locations

The 2017 study had three locations installed on grower-cooperator farms throughout Michigan (Figure 3). The tree heights in the plot ranged from 2.0 to 4.0 m and there were ten or more cones per tree.

Figure 3. Locations of cone herbicide plots installed throughout Michigan’s Lower Peninsula in 2017.
2.2.2. Study Design and Cone Treatments

At each location, we selected 160 trees with at least ten cones per tree. The study was installed as a completely randomized design. At each farm, treatments were assigned to individual trees at random by selecting color-coded ribbons (one color per treatment) from a bucket. The three best performing products from the 2016 study (Avenger, Axxe, Scythe) were chosen for this study. Each product was initially applied to 40 trees at each farm (Table 3).

**Table 3.** Description of herbicide products and rates applied for the 2017 study.

| Treatment   | Manufacturer                                      | Product          | Description                                                                 | Rate  
|-------------|---------------------------------------------------|------------------|-----------------------------------------------------------------------------|-------
| Avenger     | Cutting Edge Formulations, Buford, GA             | Avenger          | d-limonene (citrus oil)                                                     | 250 mL/L |
| Axxe        | BioSafe Systems, LLC, East Hartford, CT           | Axxe             | ammonium nonanoate (ammonium salt of pelargonic acid)                        | 100 mL/L |
| Scythe      | Gowan Company, Yuma, AZ                           | Scythe           | pelargonic acid                                                             | 50 mL/L |
| Mechanical  | BlossomCinch, Manistee, MI                        | na               | Mechanical cone removal                                                      | na     |
| Control     | na                                                | na               | untreated                                                                   | na     |

* Treatments denoted as ×2 were applied a second time, one to two weeks after initial application.

Half of the trees in each herbicide treatment were treated a second time (×2) approximately one week after the initial application. The rate of herbicide applied was the same for the single application and the repeated application. Herbicide treatments were sprayed in May 2017 and were dependent on weather forecasts to avoid rain within 24 h after treatment. Temperature and wind speed data were compiled from the Michigan State University Enviroweather stations located closest to experiment plot (Table 4). All herbicides were sprayed to run off with a backpack sprayer to the top one-third of the tree where the cones commonly grow.

**Table 4.** Locations, dates, daily maximum temperatures, and wind speeds at time of application of post-emergent cone herbicide application at three sites in Michigan in 2017.

<table>
<thead>
<tr>
<th>Location</th>
<th>Application Date</th>
<th>Max Air Temp C</th>
<th>Wind m/s</th>
<th>Station 1</th>
<th>GPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Horton, MI</td>
<td>May 3</td>
<td>15.8</td>
<td>2.3</td>
<td>Leslie</td>
<td>42.4514° N, 84.4325° W</td>
</tr>
<tr>
<td>Horton, MI</td>
<td>May 10</td>
<td>20.7</td>
<td>2.3</td>
<td>Leslie</td>
<td>43.2925° N, 85.0814° W</td>
</tr>
<tr>
<td>Sidney, MI</td>
<td>May 3</td>
<td>15.6</td>
<td>1.6</td>
<td>Entrican</td>
<td>44.3900° N, 85.2867° W</td>
</tr>
<tr>
<td>Sidney, MI</td>
<td>May 16</td>
<td>29.5</td>
<td>3.0</td>
<td>Entrican</td>
<td>44.3900° N, 85.2867° W</td>
</tr>
<tr>
<td>Manton, MI</td>
<td>May 15</td>
<td>24.5</td>
<td>1.1</td>
<td>Arlene</td>
<td>44.3900° N, 85.2867° W</td>
</tr>
<tr>
<td>Manton, MI</td>
<td>May 22</td>
<td>17.6</td>
<td>4.7</td>
<td>Arlene</td>
<td>44.3900° N, 85.2867° W</td>
</tr>
</tbody>
</table>

1 Michigan State University Enviroweather Network Station.

At each farm, we tested a mechanical de-coning device powered by a cordless drill on 20 trees at each farm to remove cones (Figure 4). The device uses spinning “fingers” to dislodge cones. We attempted to dislodge as many cones as possible while minimizing obvious damage to needles and shoots.
2.2.3. Evaluations

Each tree was evaluated for cone kill and phytotoxicity (needle browning). The evaluations were conducted three to four weeks after the final herbicide application. Cones were scored as live or dead (Figure 5). We observed in the 2016 trial that cones rated as “damaged” often continued to grow, so they were counted as “live” for the 2017 evaluation. Some evidence of frost damage was observed on cones in the control treatment and they were scored as “dead” for the cone kill evaluation. Phytotoxicity evaluations were narrowed in 2017 and separated into three categories: 0 = no damage, 1 = slight (moderate browning to new or old shoots), and 2 = unacceptable (extreme browning to new and old shoots), and evaluated on needles in the top one-third of the tree where the herbicides were sprayed.
2.2.4. Statistical Analysis

The effects of Farm, Treatment, and Farm × Treatment interaction were tested by analysis variance using the PROC GLM procedure in SAS (SAS Institute Inc., Cary, NC, USA). Where Treatment main effects were significant ($p < 0.05$), means were separated using Tukey’s studentized range test. In addition, the effect of applying the chemical treatments a second time was tested using an a priori contrast comparing the means of all three products applied once versus all three products applied twice.

3. Results

3.1. 2016 Trial

Farm, Treatment, and Farm × Treatment interaction affected cone kill and extent of damage to needles and shoots. Applications of Avenger and Axxe resulted in the fewest live, undamaged cones (Figure 6). All products resulted in a high proportion (50 to 80%) of cones that were slightly browned but not killed. Avenger, Axxe, and Scythe produced the highest cone kill (35 to 50%), whereas Goal, Reflex, and Weedzap killed less than 20% of cones on treated trees.

Figure 5. Example of Fraser fir Christmas tree with 100% cone kill.
Phytotoxicity occurred with any product at Sidney or East Lansing.

At Horton, the application of Axxe, Scythe, and Avenger resulted in mean phytotoxicity scores of greater than 0.8 on the scale of 0-no damage to 2-unacceptable injury. Axxe and Reflex caused the greatest phytotoxicity (mean phytotoxicity rating >0.7) at the Allegan farm. Very little phytotoxicity occurred with any product at Sidney or East Lansing.

**Figure 6.** Mean percentage of cones unaffected (Live), damaged, or killed on Fraser fir trees treated with post-emergent herbicides at four locations in Michigan, 2016. Means within a group with the same letter are not different at $p < 0.05$. Means were separated using Tukey’s range test.

**Figure 7.** Mean phytotoxicity score of Fraser fir trees treated with post-emergent herbicides at four locations in Michigan, 2016. Means within a location with the same letter are not different at $p < 0.05$. Means were separated using Tukey’s range test. NOTE: Mean phytotoxicity was zero for Control trees at all locations.
3.2. 2017 Trial

Cone mortality was affected by \( p < 0.05 \) Treatment, Farm, and the interaction of Treatment × Farm (Figure 8). All chemical treatments provided excellent cone control, ranging from 80% cone mortality for single applications of Avenger and Axxe at Manton to 100% cone control for \( \times 2 \) applications of Scythe and Axxe at Horton. Overall, repeated applications of chemical treatment increased cone mortality by 7.8% compared to single applications (contrast of \( \times 1 \) vs. \( \times 2 \) for all chemical treatments was significant at \( p < 0.05 \)). The mechanical de-coning device removed 82% of cones averaged across the two farms where it was used. The device was effective at removing exposed cones but failed to dislodge cones on interior branches. The interaction of farm and cone treatment was largely due to cone mortality (17%) on control trees associated with a late frost at Sidney, whereas there was no cone mortality on control trees at the other two locations.

Figure 8. Mean mortality of Fraser fir cones following cone control treatments at three locations in Michigan, 2017. Means were separated using by Tukey’s range test. * Mechanical cone removal device was not used at Sidney farm.
Mean phytotoxicity score also varied among farms and cone control treatments, and there was an interaction effect of farm and treatment ($p < 0.05$) (Figure 9). The mechanical de-coning device resulted in the highest “phytotoxicity” scores at both farms where it was used. Damage from the device was associated with needle browning and shoot damage in the upper-third of tree crowns. Single applications of post-emergent herbicides resulted in very little phytotoxicity. The highest phytotoxicity score for a single chemical treatment was 0.27 at Sidney. Phytotoxicity increased with repeated applications of herbicide treatments. Averaged across all farms, the mean phytotoxicity score increased from 0.05 for single applications to 0.36 when treatments were repeated. Phytotoxicity on foliage was particularly high for repeated applications of Scythe and Avenger at Sidney.

![Figure 9](image_url)

**Figure 9.** Mean phytotoxicity score of Fraser fir trees following cone removal treatments at three locations in Michigan, 2017. Phytotoxicity was rated from 0 (no damage) to 2 (unacceptable browning). Means within a location with the same letter are not different at $p < 0.05$. Means were separated using Tukey’s range test. * Mechanical cone removal device was not used at Sidney farm.
4. Discussion

Handpicking cones in Fraser fir plantations is one of the single largest labor expenditures for Christmas tree producers in the upper Midwest and other regions of the country where Fraser fir is grown. In Michigan, growers report that picking cones can add over $2.00 in labor costs per tree for 3–4 m tall trees. Growers also report extensive issues with coning in North Carolina. Coning in that region could potentially impact decisions to deploy grafted seedlings, which can be more physiologically mature than seedling and therefore potentially more prone to coning (Eric Hinesley, personal communication). Results of our current trials indicate that the properly timed application of herbicides can stop the development of up to 95% of cones without phytotoxicity under the best-case scenario (single application of Scythe). Repeating applications of chemical control treatments can improve cone control slightly, but at the expense of increased phytotoxicity and labor and product cost. Treatments applied at or immediately after vegetative budbreak caused damage to new needles, as was the case in 2016; trees at Allegan and Horton had higher phytotoxicity than Sidney and East Lansing. This might be because the application dates were earlier at Sidney and East Lansing, and they are located at a higher latitude than Allegan and Horton, resulting in delayed vegetative bud break. Therefore, proper timing is essential to optimize cone kill while minimizing damage to foliage. Applicators must time treatments carefully in order to target cones soon after they emerge but before vegetative budbreak occurs [10,11]. This means that treatments must be applied in an approximately two-week long window in the spring.

We observed that cone control was better overall in the 2017 trial than in the 2016 trial. In particular, we found fewer instances of cones that were damaged but not killed in 2017 than in 2016. We attribute the increased efficacy of the second trial to greater experience with the products, particularly the need to thoroughly wet each cone and applying the products as soon after cone emergence as weather conditions will allow.

Mechanical cone removal in the 2017 trial caused a high level of needle and shoot browning at the two trial locations in which it was used. These results point out the difficulty of applying sufficient force to dislodge cones without damaging needles, shoots, and vegetative buds. Investigators should continue to explore options for physical cone removal without hand labor with an emphasis on techniques that reduce unintended damage, e.g., high-pressure water jets.

Economically, chemical cone control can compare favorably with hand picking when trees have more than 100 cones. Treating cones in a 2-m tree with post-emergent herbicides with a backpack sprayer requires approximately 45 s per tree. Based on our current application rates, the chemical cost per tree for each application ranges from $0.50 USD per tree for Scythe to $2.00 USD per tree for Avenger. Assuming $15 USD per hour for labor, cone-picking costs on large trees with heavy cone loads range between $0.50 USD to $2.00 USD per tree (2 to 8 min per tree). These product costs are based on retail prices. Growers might be able to reduce material costs by buying in bulk.

Two key outstanding questions remain for the use of herbicides for post-emergent cone control. First, do remnant, immature dead cones remaining on trees impact the marketability of the trees? For a given growing season, vegetative growth occurs after cones have emerged, so remnant cones killed by herbicide treatments could be largely hidden by new growth. If current-year growth of new shoots is not sufficient to hide remnant cones, growers may still need to pick cones in the year of harvest. Chemical control could nonetheless be of value in lieu of handpicking in years prior to harvest. A second remaining issue for chemical control of nuisance cones is the development of operational systems. Our experiments and earlier trials [5] have relied on backpack sprayers to treat individual trees. Mechanized spray systems could further reduce labor time and application costs. Owen [12] used a mist-blower to apply post-emergent cone control in North Carolina but found that control was only effective on exterior rows of trees nearest the sprayer. Owen used several rates of Off-Shoot-T (Chemtura Corporation, Middlebury, CT, USA), Off-Shoot-O (Cochran Corporation, Memphis, TN, USA), Axxe (BioSafe Systems, LLC, East Hartford, CT, USA), and Scythe (Gowan Company, Yuma,
Other spray equipment, e.g., an air curtain sprayer, could potentially offer better coverage and control.

5. Conclusions

Effective control of nuisance cones in Fraser fir Christmas tree plantations is possible with post-emergent herbicides. Proper timing of treatments, however, is essential in order to optimize cone control and reduce possible phytotoxicity. Cones must be treated shortly after they emerge and before vegetative budbreak. Thorough cone coverage is essential for good control. The application of post emergent herbicides can provide considerable savings over handpicking cones but consumer acceptance of trees with remnant, immature cones is not known.

Author Contributions: B.C., D.E., and J.O. conceived, designed, and performed the experiments; B.C. analyzed the data; D.E. developed presentation graphics; B.C. and D.E. wrote the paper.

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Conflicts of Interest: The authors declare no conflict of interest.

References


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