Attachment C

Christmas Tree Promotion Board

CTPB Project Number: 22-06-MSU

Project Title: Managing cone formation in *Abies* Christmas tree species

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Progress Report

Introduction

Early cone production remains one of the most significant issues for growers that produce Fraser fir Christmas trees. If cones are allowed to mature, the cones disintegrate in the fall and unsightly cone stalks remain, reducing tree value. In addition, developing cones divert the tree's resources from shoots and needle growth. To reduce the negative impacts of cone formation, growers routinely pick cones that emerge each spring. Cone picking is labor-intensive and expensive and can also present safety concerns as pickers use ladders when picking cones from tall trees.

During the current reporting period, our research on managing cone formation has focused on four objectives: 1) Evaluating post-emergent cone-control with tractor-mounted spray equipment, 2) Evaluating coning response to plant growth regulators (PGRs), 3) Selecting genotypes for delayed coning, and 4) Developing protocols for accelerated screening for coning.

Objective 1) Evaluating post-emergent cone-control with tractor-mounted spray equipment

Research at Michigan State University and North Carolina State University has demonstrated that properly-timed applications of burn-down herbicides that contain pelargonic acid or related compounds, such as Scythe® and Axxe®, can stop development of newly emergent cones (Owen, 2022; Cregg et al., 2018) and reduce the need to pick cones. To date, our trials on post-emergent control of coning have been conducted with back-pack sprayers. This may limit adoption of this technique as many growers would prefer to use tractor-mounted sprayers. In May 2023, we conducted an operational trial in collaboration with Badger Evergreen Nursery, Allegan, MI.

On May 10, 2023 over 1,000 trees were treated using Badger's Jutek two-row tractor-mounted sprayer (Photo 1). Approximately 210 trees (2 rows of 105 trees) were assigned to one of five treatments:

1) Control (water only)
2) 2.5% Scythe - one pass only
3) 2.5% Scythe - two passes, one in each direction along the row

4) 5.0% Scythe - one pass only
5) 5.0% Scythe - two passes, one in each direction along the row

The trees were approximately 2 m tall and 77% of trees had cones, with a mean cone density of 23.4 cones per tree. Tractor speed and spray nozzles were adjusted to provide even wetting of the upper 1/3rd of the tree crowns during the application of water to the Control trees. At 1 mph tractor speed, each pass down the tree rows used 70 L of mixed product (divided by 210 trees per pass = 0.35 L per tree). Weather on the treatment day was clear and sunny with a high temperature = 77.1 deg. F and mean RH = 59.5%.

We assessed responses to treatments on May 16, 2023. For each tree we counted the number of cones that were alive, damaged (Photo 2), or dead (Photo 3). Based on our previous experience, cones that were rated as 'damaged' will continue to grow where they have green tissue. Cones rated as dead will remain brown but will not senesce from the trees. We also noted any evidence of phytotoxicity, mainly needle browning (Photo 4). Weather during the period between treatment and assessment was mostly clear and sunny with mean high temperature = 75.2 deg. F, mean RH = 55.3%, with total of 0.02" of rainfall.

Cone control increased with Scythe concentration and number of passes (Chart 1). Two passes up and down the tree rows with 5% Scythe provided over 80% cone kill and left less than 5% of cones undamaged. This level of control would likely be satisfactory for most growers, and the remaining live or damaged cones could be picked, if desired. The undamaged cones in this treatment were mainly cones at the tops of tall trees that were above the spray zone. One pass with 5% Scythe killed approximately 35% of cones, but coverage was not adequate to provide satisfactory control. The 2.5% rate of Scythe resulted in consistent cone damage but provided little cone kill with either one or two passes. Treatment with the 5% rate of Scythe resulted in some needle browning, especially with two passes down the tree row (Table 1). For most trees, needle browning was minor and would likely be concealed by subsequent growth.

Table 1. Proportion of Fraser fir trees with phytotoxicity following application of Scythe herbicide to control cones.

Treatment	Trees with needle damage (%)
Control	0%
2.5% - 1x	0%
2.5% - 2x	0%
5% - 1x	1.25%
5% - 2x	26.40%

Two passes of 5% Scythe applied with a tractor-sprayer provided over 80% cone control, which is comparable to the level of control achieved with backpack sprayers in earlier trials (Cregg et al., 2018). In the current trial, the tractor-mounted spray system delivered about 0.35 L of product per tree per pass. At the 5% rate this equates to 0.033 L of Scythe concentrate. Based on current on-line price of $20 per liter, the product cost is about $0.66 per tree, excluding operator time and equipment use. The principal disadvantage of the tractor-sprayer system relative to backpack application is that all trees are treated regardless of whether they have cones or not. Moreover, backpack sprayers can target cones and will use less product per tree. A compromise approach that has been suggested by a grower is the use of tractors set up for spraying colorant on trees, which provide individual spray wands and relieve workers from carrying backpack sprayers for extended intervals. We will investigate the utility of this approach during the 2024 coning season.

Photo 1. Fraser fir cones treated with a two-row Jutek sprayer.

Photo 2. Example of Fraser fir tree with live and damaged cones following Scythe application.

Photo 3. Example of Fraser fir tree with 100% cone kill following Scythe application.

Photo 4. Example of Fraser fir tree with needle phytotoxicity following Scythe application.

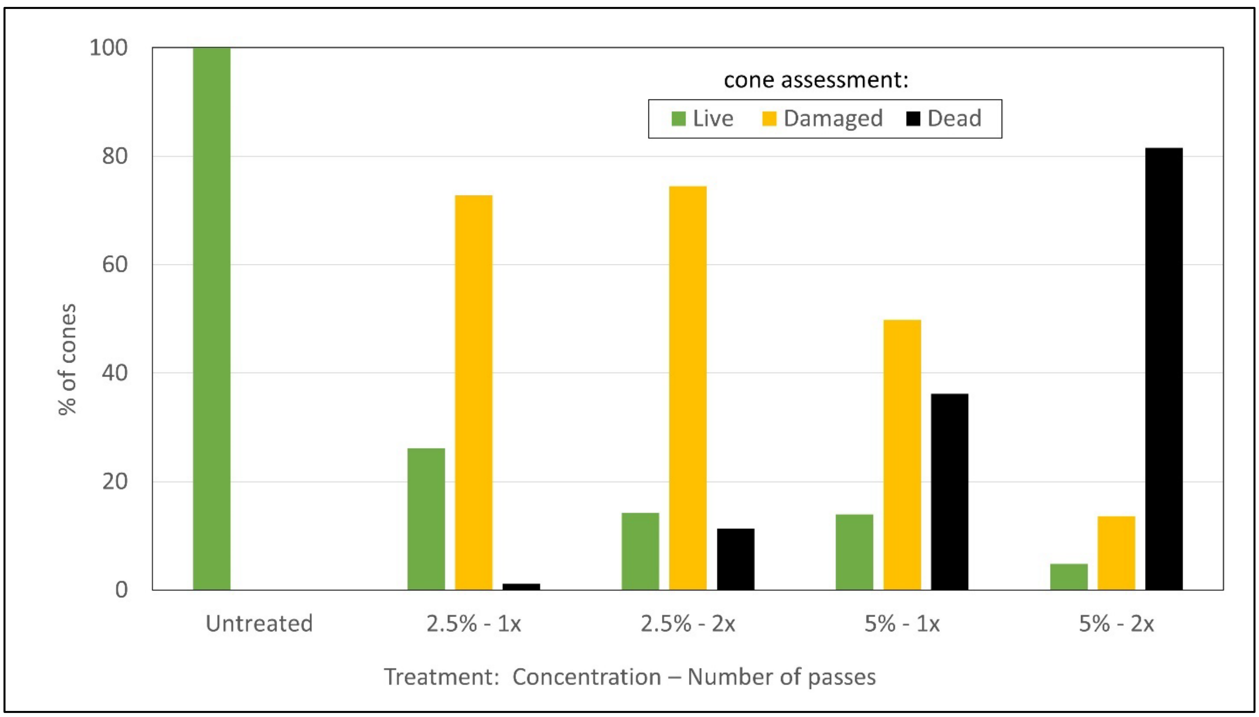

Chart 1. Proportion of Fraser fir cones damaged or killed by Scythe herbicide applied with a tractor-mounted spray system. Treatment indicates Scythe concentration and number of passes through the tree-row.

Objective 2) Evaluating coning response to plant growth regulators (PGRs)

Research under this objective is focused on understanding the potential of reducing or eliminating cone formation through the application of plant growth regulators (PGRs), particularly gibberellic acid (GA) inhibitors. Gibberellic acid increases cone production in conifers (Crain and Cregg, 2018; Pharis and Kuo, 1977); therefore, we hypothesized that GA-inhibitors would reduce cone formation in Fraser fir.

In previous research trials initiated in 2016 and 2017 at four farms in Michigan, we found that the GA-inhibitor paclobutrazol applied via soil-injection reduced cumulative coning of Fraser fir trees by approximately 40% in the three years following application. In a separate trial initiated in 2018, we found that foliar-applied GA-inhibitors could also reduce cumulative coning by 40% over two years and that paclobutrazol was the most effective treatment among the compounds tested (Cregg et al., 2023).

In 2020 we initiated trials in collaboration with Christmas tree farms at three locations in Michigan: Sidney, MI (Korson's Tree Farm), Allegan, MI (Badger Evergreen Nursery), and Horton, MI (Gwinn's Tree Farm). The goal of the current trials is to determine if there is a synergistic response of combining soil-applied and foliar-applied treatments that will reduce coning more than either approach alone. At each location, the plots included 450 trees, and we installed each trial as a 3 x 3 factorial of soil and foliar PGR application (Table 2). At each farm we treated 50 trees with each combination of soil x foliar treatments. Mean tree heights at the beginning of the trial were 0.89 m, 1.29 m, and 1.43 m for Allegan, Horton, and Sidney sites, respectively. We applied the soil-applied paclobutrazol (Cambistat®, Rainbow EcoScience) as a soil drench of 0, 200, or 400 ml of dilute product (11:1, water: concentrate) in May 2020. Foliar treatments were applied in early summer each year using back-pack sprayers. We sprayed the upper one-third to one-half of each tree to run-off using an 8% solution of paclobutrazol formulated for foliar application (Trimtect®, Rainbow EcoScience). Foliar applications were applied once (1x) or repeated approximately 10 days later (2x). We evaluated all trees for coning by counting cones in 2021, 2022, and 2023 (Photo 5). We measured terminal shoot growth with a meter stick and counted vegetative buds on each terminal shoot in fall 2021 and 2022. Bud density (buds per cm leader length) of the terminal shoots was calculated as bud count ÷ leader length. We will evaluate shoot length and bud density for 2023 once shoot growth is completed for the current year.

Table 2. Study design for 2020 MSU PGR Coning Trials.

Soil application[1]	Foliar application[2] 0x	1x	2x
0 ml	**0 ml: 0x**	**0 ml: 1x**	**0 ml: 2x**
200 ml	**200 ml: 0x**	**200 ml: 1x**	**200 ml: 2x**
400 ml	**400 ml: 0x**	**400 ml: 1x**	**400 ml: 2x**

1. Applied once as soil drench in May 2020
2. Applied June/early July in 2020, 2021, and 2022.

Photo 5. Michigan State University Research Assistants Noah Dressander (left) and Claire Komarzec evaluate coning response of Fraser fir trees at a cooperating farm in June 2023.

Averaged across all sites, soil- and foliar-applied paclobutrazol treatments were more effective at reducing cumulative coning of Fraser fir when they were combined (Chart 2). Combining the high rate of soil application with 2x foliar application reduced total cone production by approximately 40% compared to the untreated control. Soil application of paclobutrazol was effective on trees in Allegan, which had the smallest trees at the start of the study. Conversely, paclobutrazol was less effective at controlling cone production at Sidney, which had the largest trees when treatments began. Paclobutrazol was also effective at controlling leader growth. In 2021 and 2022, soil-applied and foliar applied paclobutrazol significantly reduced shoot growth compared to untreated control trees (Chart 3). In both years, application of paclobutrazol resulted in a 15 cm reduction in shoot extension compared to untreated control. We did not observe any phytotoxicity in response to paclobutrazol treatments, though we did observe some loss of apical dominance and leaders deviating from vertical at the Sidney, MI site.

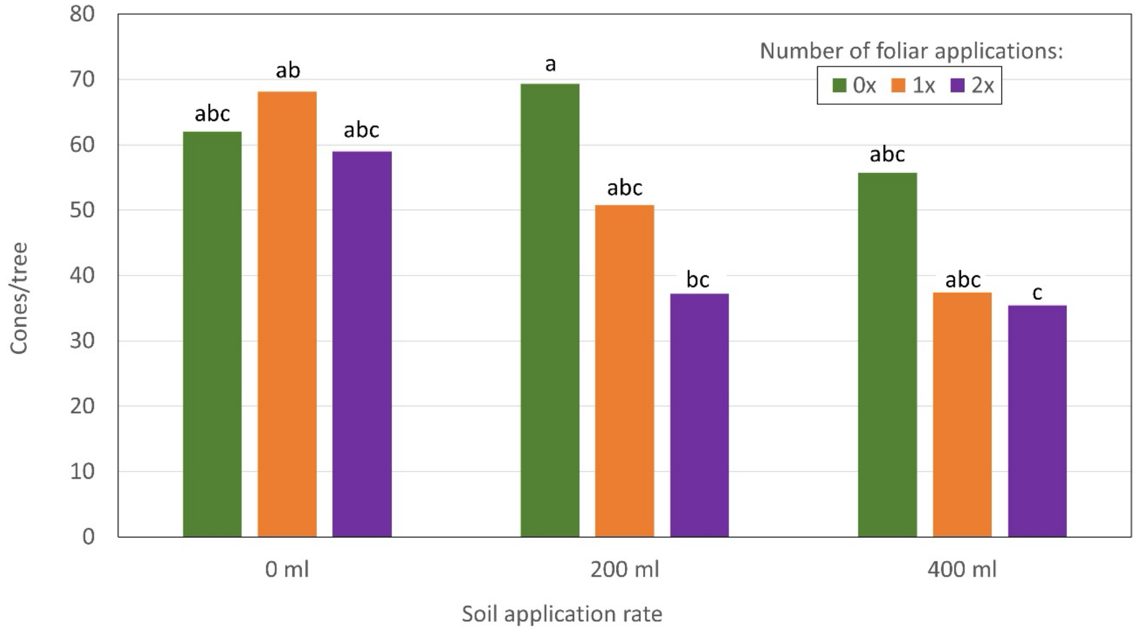

Chart 2. Mean cone density (cones/tree) of Fraser fir trees treated with soil and/or foliar applications of paclobutrazol. Note: Soil treatments were applied once in 2020; foliar treatments were applied annually in 2020, 2021, and 2022. Cone density was calculated as sum of cone counts for each tree in 2021, 2022, and 2023.

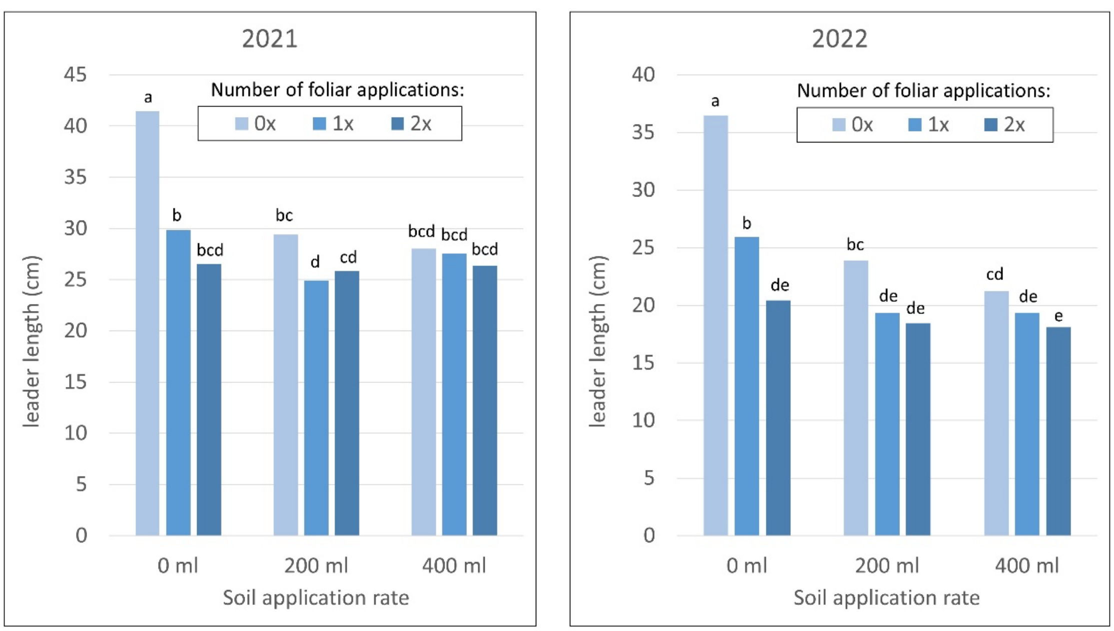

Chart 3. Mean leader lengths of Fraser fir trees treated with soil and/or foliar applications of paclobutrazol. Note: Soil treatments were applied once in 2020; foliar treatments were applied annually in 2020, 2021, and 2022.

Objective 3) Selecting Fraser fir genotypes for delayed coning (i.e., trees that will not cone until after typical harvest age)

MSU established a delayed-coning seed orchard for Fraser fir in 2010. The seed orchard consists of 60 trees that were phenotypically selected from operational plantations based on the tree's lack of coning and overall form and appearance. The trees were dug with a tree spade and transplanted to the MSU Horticulture Teaching and Research Center near East Lansing, MI. Over the past five years, we have made three collections from the seed orchard (Table 3). Seed from each of the collections have been sown at a cooperating nursery (Peterson's Riverview Nursery, Allegan, MI). The oldest progeny from the seed orchard (2017 collection) were lifted as 2+2 seedlings in fall 2021 and are now growing in #3 containers at the MSU Horticulture Teaching and Research Center (Photo 6). Seedlings from the 2019 and 2021 collections are growing at Peterson's nursery (Photos 7 & 8). Progeny from the seed orchard will be evaluated for coning using techniques developed through Objective 4 below and eventually through on-farm trials with cooperating growers.

Photo 6. Trees from the initial (2017) seed collection from the MSU delayed coning seed orchard growing in #3 containers at the MSU Horticulture Teaching and Research Center, May 2022.

Table 3. Collections from MSU Delayed Coning Seed Orchard

Year	Families collected	Status	Notes
2017	10	Approximately 100 trees from 4 families growing in #3 containers at MSU Pot-in-Pot nursery	Trees will be evaluated for coning relative to similar-aged nursery-run stock from Peterson's.
2019	21	Approximately 800 2-0 seedlings planted in transplant beds at Peterson's Nursery in spring 2022 (Photo 6)	Trees will be grown on to produce 2 + 2 transplants that will be used for further evaluations.
2021	12	Seed sown at Peterson's Nursery in fall 2021	Subsample of families collected in 2019. Goal is to have more trees per family and distribute to cooperators for operational evaluation.

Photo 7. Transplants from the 2019 collection from the MSU delayed coning seed orchard in transplant beds at Peterson's Nursery, June 2023.

Photo 8. Seedlings from the 2021 collection from the MSU delayed coning seed orchard in seedling beds at Peterson's Nursery, June 2023.

Objective 4) Developing protocols to evaluate genotypic variation in coning in *Abies spp*.

In this objective we seek to identify factors controlling coning in firs. In particular, we are focusing on developing protocols to induce coning. The rationale for this objective is two-fold. First, developing protocols to induce coning will enable us to evaluate progeny from our delayed coning seed orchard at an earlier age than deploying them in a typical plantation. Second, developing cone-induction protocols can benefit tree selection programs in general by reducing the time needed for trees to mature to begin to make crosses from selected parents.

A key to managing cone formation in Fraser fir and other firs is to improve our understanding of environmental signals and other factors that control coning. Environmental stresses, such as water stress, typically induce coning (Crain and Cregg, 2017, Owen et al., 2001). Moreover, we have observed that many conifers, including firs, Douglas-fir, and white pine, produce cones at a relatively early age when grown in containers, presumably due to restricted root volumes and periodic water stress (Photo 9).

In spring 2022 we initiated trials on four species of firs (concolor fir, Fraser fir, Korean fir and Nordmann fir) in our Pot-in-Pot research nursery at the MSU Hort Farm. Two of the species, Fraser fir and Korean fir, were selected because they typically cone at an early age in plantations. The other two species, concolor fir and Nordmann fir, cone at a relatively late age or cone infrequently. The trees were planted as 2 + 2 transplants in #3 containers and grown for two years and then up-potted to #7 or #20 containers. For trees in each size container, we grew trees at high or low rates of irrigation in 2022. Trees at the high rate of irrigation were irrigated daily to maintain approximately 20% leaching fraction (i.e., 20% of applied irrigation leaches through the container). Trees in the low irrigation level were watered at 50% of the high irrigation rate.

In spring 2023 we evaluated coning on all trees. The proportion of trees with cones and number of cones per trees was higher for trees in the #7 containers than trees in the #20 containers (Table 4). As expected, Korean and Fraser firs had the highest incidence of coning, though one Nordmann fir in the #20 containers produced cones. For the 2023 growing season we will re-impose the irrigation treatments and re-evaluate coning in spring 2024. We will also apply GA 4+7 (fresco®, Fine Americas, Inc.) to a subset of trees at each irrigation level in the #20 containers to determine the effect of GA application on coning in these species.

Table 4. Mean coning frequency (proportion of trees with cones) and cone density (cones per tree) of four fir species grown in two container sizes under high and low irrigation.

	Container size: #7			
	% trees with cones		cones per tree	
Species	Irr: Low	Irr: High	Irr: Low	Irr: High
Concolor	0.0	0.0	0.00	0.00
Fraser	15.4	0.0	0.54	0.00
Korean	53.8	44.4	14.54	5.00
Nordmann	0.0	0.0	0.00	0.00
Overall	17.3	11.1	3.80	1.30

	Container size: #20			
	% trees with cones		cones per tree	
Species	Irr: Low	Irr: High	Irr: Low	Irr: High
Concolor	0.0	0.0	0.00	0.00
Fraser	16.7	5.6	0.72	0.22
Korean	0.0	5.6	0.00	0.11
Nordmann	5.3	0.0	0.16	0.00
Overall	5.5	2.8	0.20	0.10

Photo 9. Restricted root volumes and periodic water stress can accelerate coning in container-grown conifers.

References

Crain, B. A., & Cregg, B. M. (2017). Gibberellic acid inhibitors control height growth and cone production in *Abies fraseri*. *Scandinavian Journal of Forest Research, 32(5), 391-396.*

Crain, B. A., & Cregg, B. M. (2018). Regulation and management of cone induction in temperate conifers. *Forest Science, 64(1), 82-101.*

Cregg, B., Ellison, D., & O'Donnell, J. (2018). Post-emergent control of nuisance cones in Fraser fir Christmas tree plantations. *Forests, 9(5), 233.*

Owen, J. 2022. Conclusion of spring cone control research in North Carolina. IN: Proceedings of the 15th International Christmas Tree Research and Extension Conference, Hidden Leaf Lake, CA, p. 31.

Owens, J. N., Chandler, L. M., Bennett, J. S., & Crowder, T. J. (2001). Cone enhancement in *Abies amabilis* using GA4/7, fertilizer, girdling and tenting. *Forest Ecology and Management, 154(1-2), 227-236.*

Pharis, R. P., & Kuo, C. G. (1977). Physiology of gibberellins in conifers. *Canadian Journal of Forest Research, 7(2), 299-325.*

1. Summary of Research Report for Public Release by CTPB- Summary should be suitable for non-scientific audience and should not exceed one page.

   Early cone production of Fraser fir trees results in significant labor costs for cone removal. In this project we are investigating several options for managing cones in Fraser fir including application of herbicides to kill emerging cones, application of plant growth regulators to reduce cone formation, and selection of tree genotypes for delayed and reduced coning. Based on research during the current reporting period we found that pelargonic acid (Scythe®) applied using tractor-mounted spray equipment could provide up to 80% cone kill. However, backpacks or other directed applications that target only trees with cones will likely be more efficient in terms of product use. In our plant growth regulator trials, we found that the effects of soil-applied and foliar-applied paclobutrazol were additive and that PGR applications could provide up to 40% reduction in cone production in the three years following initial application. We also saw evidence that starting treatments before trees began to cone resulted in greater inhibition of subsequent cone formation. We have completed the third cycle on cone collection from the MSU Delayed Coning Seed orchard. Trees from half-sib families from the initial (2017) collection are growing in #3 containers at the MSU Horticulture Teaching and Research Center. We are currently developing protocols to evaluate coning of the seed orchard progeny relative to nursery-run Fraser firs.

2. List of all Publications related to this Research Grant

Cregg, B., Ellison-Smith, D., & Rouse, R. (2023). Managing cone formation and leader growth in Fraser fir Christmas tree plantations with plant growth regulators. *Forests, 14(1), 25.*

Cregg, B. & Rouse, R. 2022. Managing cone formation in Fraser fir Christmas tree plantations: Highlights from the Michigan experience. 15th International Christmas Tree Research and Extension Conference, June 5-9, 2022, Fallen Leaf Lake, CA.