Attachment C

Christmas Tree Promotion Board

Final Research Report

CTPB Project Number: 21-19-03-MSU

Project Title: Managing cone formation in Abies Christmas tree species

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Institution: Michigan State University

Final Report

1. Technical report

Introduction

Cone production of Fraser fir (*Abies fraseri* (Pursh) Poir.) trees is a major concern for Christmas tree growers in the eastern United States. Individual plantation-grown Fraser fir trees can produce hundreds of cones, and growers have reported over 1,000 cones on large trees. Fir cones disintegrate in the fall leaving unsightly cone stalks that reduce the salability of trees. Moreover, developing cones compete for photosynthate reserves and reduce shoot and needle growth if they are not removed (Powell, 1977). Presently, growers remove cones using picking crews, which has become a major labor expense. In plantations with large trees, pickers use ladders, which creates potential worker safety concerns (Photo 1).

Reproductive development in conifers is controlled by a series of factors including environmental conditions, particularly temperature and tree water stress, and genetic predisposition (Crain and Cregg, 2018; Owens and Molder,1977; Owens and Singh). Both environmental and genetic control of cone formation are mediated through hormonal signaling within trees. In particular, gibberellic acid (GA) levels are a primary driver of coning in conifers and seed orchard managers often apply GA to induce coning. For example, trunk-injection of GA4/7 combined with fertilizer, girdling, and tenting resulted in a 30-fold increase in cone production in Pacific silver fir (*Abies amabilis* [Douglas ex Loudon] Douglas ex Forbes) (Owens et al., 2001). Likewise, endogenous GAs accumulate at the meristem from neighboring tissues immediately prior to strobilus initiation and regulate development of reproductive structures (Pharis and Kuo, 1977). Based on the stimulatory effect of GA on coning, we hypothesized that application of GA inhibitors to Fraser fir trees may reduce coning. GA inhibitors are used as plant growth regulators (PGRs) to control shoot growth in a range of horticultural applications (Rademacher 2015). In

previous research sponsored by the RTPB, we found that application of a GA-inhibitor, paclobutrazol, by either soil injection or foliar spray, could effectively reduce cone formation in Fraser fir Christmas tree plantations (Cregg et al. 2022). Paclobutrazol applications had an additional benefit of reducing shoot growth and reducing the need for pruning. In the current study, we expanded on this work and investigated if combining soil and foliar applications could provide additive effects and further reduce cone production.

Objectives:
1) Determine if soil and foliar applied paclobutrazol can reduce coning of Fraser fir
2) Determine if soil and foliar applied paclobutrazol can reduce terminal growth and increase bud density of Fraser fir
3) Document any negative consequences of paclobutrazol application in Fraser fir

Methods

Study sites and treatments

We established trials in June 2020 at three cooperating farms in Michigan (Badger Evergreen Nursery, Allegan, MI; Korson's Tree Farm, Sidney, MI; and Gwinn's Tree Farm, Horton, MI). All cooperating farms are commercial Christmas tree farms that produce trees for wholesale and/or retail markets. Trees at all farms were grown on approximately 1.6 m x 1.6 m spacing. All plots were located in operational blocks and growers maintained their standard cultural practices (i.e., weed control, fertilization, shearing), which are typical for Christmas tree farms in the region. Mean tree heights at the start of the trial were 1.29m, 1.60m, and 1.40m for the Allegan, Sidney, and Horton locations, respectively.

At each farm we applied paclobutrazol as combinations of soil and foliar treatments. Treatments were applied a 3 x 3 factorial of soil and foliar applications resulting in 9 treatment combinations (Table 1). For soil applications we applied paclobutrazol (tradename: Cambistat®) as a one-time soil drench at three rates (0, 200, or 400 ml of ready-to-use product per tree) (Photo 2). Ready-to-use product was prepared from concentrated product using an 11:1 dilution (v:v; water:concentrate) as directed by the product label. We applied paclobutrazol as a foliar spray (tradename: Trimtect®) using 4:1 dilution (v:v; water:concentrate) . Treatments were applied to five 10-tree row plots (i.e., n = 50 for each treatment combination at each farm) in a completely randomized design. Soil treatments were applied once in June 2020. Foliar spray treatments were applied once (1x), twice (2x) or trees were not sprayed (0x). The 1x Foliar spray treatment was applied each spring when current year's terminal shoots had reached approximately 50% of their total growth based on the MSU Fraser fir

shoot growth phenology model. For the 2x treatment a second application was made approximately two weeks after the first treatments. Foliar treatments were applied using a standard handpump backpack sprayer annually each spring. For each tree we sprayed the upper half of each tree crown. When spraying trees, we made a complete 360° pass around each tree and then reversed direction to minimize spray 'shadows'. All foliar applications were made when the crowns of the trees were dry, wind speeds were less than 2.5 m s^{-1} to minimize drift, and no rain was forecast for the next 24 h.

Table 1. Soil and foliar paclobutrazol treatment combinations in the 2020 MSU PGR trial.

	Foliar applications		
Soil rate	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

Evaluation

We evaluated coning and leader growth in 2021, 2022, and 2023 at all farms. We also assessed coning and growth at Allegan in 2024 (tree harvest began at the other farms in 2023). Coning was evaluated shortly after cone emergence by picking and counting cones on each tree (Photo 2). Leader growth was assessed after shoot growth was complete (late July/August) by measuring total length of the terminal leaders with a meter stick. We counted lateral buds on each terminal leader and bud density was calculated as the number of buds divided by the leader length.

We assessed the effect of paclobutrazol application on leader quality in 2023 at the Sidney location in response to observations by the grower-cooperator. For all trees we assessed the number of terminal leaders and straightness of the terminal leader. Leader angle was rated as 0 = straight, 1 = 30% lean, 2=60% lean, 3= 90% lean (photo 4). Trees with a leader lean greater than 30% were deemed unacceptable for most growers.

Results

Coning

The effect of paclobutrazol on coning increased over time (Table 2). In the first season after treatment (2021), paclobutrazol application did not affect ($p>0.05$) coning. However, the highest combination of soil and foliar treatments reduced coning by 50, 57, and 81% in 2022, 2023, and 2024, respectively. Both soil and foliar application affected coning and the effects of soil and foliar treatments were additive.

Leader growth and bud density
Soil and foliar paclobutrazol application, alone or in combination, reduced ($p<0.05$) in all three years following initial application (Table 3). The maximum growth reductions observed were 16.6, 18.4, and 23.2 cm in 2021. 2022, and 2023, respectively.

In contrast to the effects on coning, paclobutrazol increased ($p<0.05$) bud density in 2021, the first year after application, but the effect decreased over time and there was no effect ($p>0.05$) of paclobutrazol on bud density by 2023.

Negative effects of paclobutrazol
We did not observe any typical phytotoxicity symptoms associated with plant growth regulators (foliar scorch, shoot or needle curling or twisting) during any assessment for coning or growth at any of the farms. However, paclobutrazol application reduced leader straightness and up to 40% of treated trees had leaders that likely be unacceptable for growers (Table 4). In contrast, paclobutrazol reduced the incidence of multiple leaders and reduced the mean number of leaders per tree (Table 4).

Discussion
As in our previous trials, paclobutrazol reduced cone production and leader growth in Fraser fir (Crain and Cregg, 2017; Cregg et al. 2022). These results indicate that the GA-inhibiting effects of paclobutrazol are effective in controlling coning and internode extension in Fraser fir. Moreover, the results of the current trial demonstrate the paclobutrazol can be effective as a soil application or a foliar spray and that their effects are additive. It is worth noting that in this trial and our previous trials, the effect of paclobutrazol increased over time and soil-applied paclobutrazol reduced coning four years after initial application. The effect of paclobutrazol on bud density was transitory. The initial increase in bud density was associated with a sharp drop in internode extension in 2021. In subsequent years, bud formation and leader growth became balanced, resulting in no net effect of bud density by 2023.

Although leader control and coning reduction are both potentially positive effects from a grower perspective, paclobutrazol application produced some negative effects that suggest caution in expanding application. The growth reduction observed in this trial with paclobutrazol would be considered over-regulation, with average leader lengths less than 30 cm (12”) for nearly all treatment combinations. Moreover, the effects of paclobutrazol on leader straightness is problematic, especially as trees approach harvestable size.

Conclusion

From a biological perspective, it is clear that paclobutrazol can control cone formation and leader growth of Fraser fir trees. However, the question remains how to incorporate these benefits into a practical Christmas tree management program. The longevity of soil-applied paclobutrazol in our trials is consistent with reports from the arboriculture industry where 5-years or more of growth control is often observed (Bai et al. 2004). The next iteration of research should address paclobutrazol application earlier in the rotation (e.g., 2 or 3 years after planting) with lower application rates than used here. Applying paclobutrazol earlier in the rotation should reduce the likelihood of adverse impacts, such as loss of leader straightness, prior to harvest. Applying lower rates should also reduce the potential for over-regulation of leader growth and would improve the economics of application. Based on a current retail cost of $200 for a gallon of concentrate, 100 ml of ready-to-use product for soil drench is approximately $0.50 per tree. Soil applications are likely to be more cost-effective given they only need to be applied once versus repeated foliar applications. In addition, applying paclobutrazol to recently established trees could provide additional benefits such as improved stress tolerance and disease resistance associated with paclobutrazol in other systems (Soumya et al., 2017; Van den Driessche, R. (1996).

Table 2. Mean cone density (cones per tree) of Fraser fir trees following soil and foliar application of paclobutrazol at three farms in Michigan

		Cone density (number of cones per tree)			
Soil rate	Foliar application	2021	2022	2023	2024*
0 ml	0x	10.5a	22.6abc	28.9a	60.6a
	1x	15.1a	25.5ab	26.5ab	49.0abc
	2x	14.5a	23.3abc	22.1abc	37.1abcd
200 ml	0x	17.5a	26.7a	26.5ab	51.8ab
	1x	16.3a	17.7abc	19.0abc	23.0cd
	2x	10.9a	12.6bc	13.6bc	15.7d
400 ml	0x	18.2a	19.0abc	21.6abc	17.3d
	1x	9.4a	12.9bc	14.1bc	31.4bcd
	2x	12.1a	11.4c	12.4c	11.6d

Soil treatment applied in May 2020; foliar treatments applied annually in June
Means within a column followed by the same letter are not different at P = 0.05
*2024 cone data for Allegan location only

Table 3. Mean terminal leader length and bud density (bud per cm of leader length) of Fraser fir trees following soil and foliar application of paclobutrazol at three farms in Michigan

		Leader length (cm)		
Soil rate	Foliar Application	2021	2022	2023
0 ml	0x	41.4a	36.5a	42.9a
	1x	29.8b	25.9b	28.7bc
	2x	26.5bcd	20.4de	25.1cde
200 ml	0x	29.4bcd	23.8bc	31.3b
	1x	24.9d	19.3b	23.3ef
	2x	25.8cd	18.5de	20.9f
400 ml	0x	28.0bcd	21.2cd	27.2cd
	1x	27.5bcd	19.4de	23.4def
	2x	26.4bcd	18.1e	19.7f
		Bud density (buds per cm)		
		2021	2022	2023
0 ml	0x	0.44a	0.47a	0.48a
	1x	0.51bc	0.50ab	0.49a
	2x	0.53bc	0.52ab	0.48a
200 ml	0x	0.51b	0.53ab	0.48a
	1x	0.57c	0.54b	0.50a
	2x	0.56bc	0.53ab	0.54a
400ml	0x	0.53bc	0.55b	0.52a
	1x	0.54bc	0.54b	0.51a
	2x	0.55bc	0.54b	0.49a

Soil treatment applied in May 2020; foliar treatments applied annually in June
Means within a column followed by the same letter are not different at P = 0.05

Table 4. Mean angle of terminal leader, proportion of trees with unacceptable leader and mean number of leaders per tree for Fraser fir trees following soil and foliar application of paclobutrazol

Soil rate	Foliar applications	Leader angle (deviation from 0 degrees)	Unacceptable leaders (% of trees)	Leaders per tree
0 ml	0x	9.0a	2a	2.58a
	1x	20.4ab	10ab	1.70b
	2x	28.8bcd	16abc	1.40b
200 ml	0x	25.8bc	10ab	1.80b
	1x	37.2cd	32bc	1.58b
	2x	37.2cd	38c	1.62b
400 ml	0x	30.0bcd	20abc	1.66b
	1x	39.0d	40c	1.60b
	2x	39.0d	36c	1.38b

Photo 1. Cone removal has become a major labor expenditure for Christmas tree producers that grow Fraser fir.

Photo 2. Michigan State University undergraduate research assistant Elle Brandt applies paclobutrazol as a soil drench at Korson's Tree Farm, Sidney, MI in June 2020.

Photo 3. Michigan State University undergraduate research assistant Rebecca Myatt assesses cone density of Fraser fir trees at Gwinn's Tree Farm, Horton, MI in May 2022.

Photo 4. Example of terminal leader with approximately 30% lean.

References

Bai, S., Chaney, W., & Qi, Y. (2004). Response of cambial and shoot growth in trees treated with paclobutrazol. Journal of Arboriculture, 137-145.

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-Smith, D., & Rouse, R. (2022). Managing cone formation and leader growth in Fraser fir Christmas tree plantations with plant growth regulators. Forests, 14(1), 25.

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.

Owens, J. N., & Molder, M. (1977). Vegetative bud development and cone differentiation in Abies amabilis. Canadian Journal of Botany, 55(8), 992-1008.

Owens, J. N., & Singh, H. (1982). Vegetative bud development and the time and method of cone initiation in subalpine fir (Abies lasiocarpa). Canadian Journal of Botany, 60(11), 2249-2262.

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

Powell, G. R. (1977). Biennial strobilus production in balsam fir: a review of its morphogenesis and a discussion of its apparent physiological basis. Canadian Journal of Forest Research, 7(4), 547-555.

Rademacher, W. (2015). Plant growth regulators: backgrounds and uses in plant production. Journal of plant growth regulation, 34(4), 845-872.

Soumya, P. R., Kumar, P., & Pal, M. (2017). Paclobutrazol: a novel plant growth regulator and multi-stress ameliorant. Indian Journal of Plant Physiology, 22, 267-278.

Van den Driessche, R. (1996). Drought resistance and water use efficiency of conifer seedlings treated with paclobutrazol. New forests, 11, 65-83.

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

Fraser fir is among the most popular conifers grown for Christmas trees in the United States due to its form, needle color, scent, and needle retention. However, Fraser fir trees produce copious quantities of cones, which are a significant challenge for producers as cones must be removed by hand, resulting in a major labor investment. In this trial we investigated the utility of applying a plant growth regulator (paclobutrazol) to reduce cone production in Fraser fir trees at three Christmas tree farms in Michigan. Trees in the study were 1.3 to 1.6 m (4.3’ to 5.2’) tall at the start of the trial, depending on the farm. We found that paclobutrazol, applied either as a one-time soil drench or as an annual foliar spray, reduced cone production for up to four years after initial application. Paclobutrazol also reduced leader growth, which could provide an additional benefit to growers by producing more compact trees with less need for shearing. However, application rates used in this trial resulted in over-regulation of growth and the production of terminal leader that were shorter than growers would desire. Moreover, we observed a loss of straightness in terminal leaders of trees as application rates increased. We suggest additional trials to investigate the benefit of applying lower rates of paclobutrazol earlier in the crop rotation to provide growth control, reduce coning, and minimize potential negative effects of over-regulation of growth and loss of tree straightness.

3. List of all Publications related to this Research Grant

Research publications and presentations

Cregg, B., Ellison-Smith, D., & Rouse, R. (2022). Managing cone formation and leader growth in Fraser fir Christmas tree plantations with plant growth regulators. Forests, 14(1), 25.

Cregg, B and 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. Hidden Leaf Lake, CA, June 5-8, 2022.

Extension presentations and publications

Cregg, B. 2023. Managing cone formation in Fraser fir. Christmas Tree Farmers Association of New York, Johnstown, NY, July 2, 2023. (85 attendees)

Lindberg, B., B. Cregg, and R. Rouse. 2023. The cone wars: How do we stop them? MSU Extension News, May 8, 2023. (904 pageviews)

Cregg, B. 2021. Use of PGR's for leader growth control. Michigan Christmas Tree Association Summer Meeting Michigan Christmas. July 29-30, 2021. Rothbury, MI. (237 attendees)

Rouse, R. & Cregg, B. 2021. MSU Research update. Michigan Seedling Growers Association. Sept. 8, 2021. Saugatuck, MI (20 attendees)

Anticipated manuscript submission

Cregg, B. and R. Johnson. 2025. Controlling leader growth and cone formation in Fraser fir with soil- and foliar-applied paclobutrazol. Target journal Forests. Estimated submission date November 2024.