<u>Christmas Tree Promotion Board</u>

CTPB Project Number: 21-05-OSU & 22-01-OSU

Project Title: Screening new herbicides to manage herbicide-resistant weeds in Christmas tree

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Final Report
Project 21-05-OSU and 2022-05-OSU

Screening new herbicides to manage herbicide-resistant weeds in Christmas tree

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Introduction

Oregon leads the United States in production of Christmas trees, with almost 8.5 million trees sold in 2015. Weed control is essential in Christmas trees to reduce competition for moisture and nutrients, allow fast and robust tree growth, and ensure growers top prices for high-quality trees. Despite its importance, little research has been conducted on weed management in Christmas trees. Herbicides are the primary weed control option for Christmas tree growers. Nonetheless, herbicide options are limited. Further, herbicide-resistant weeds challenge weed control in Christmas trees. Herbicide resistance has increased weed management costs in Christmas trees; growers must now turn to mixtures of herbicides or planned rotations. Increased diversity of herbicide modes of action is needed to manage herbicide-resistant weeds and to maintain the competitiveness of Oregon Christmas tree production. The present study evaluates the efficacy and crop safety of one preemergence herbicide (PRE), fluridone group 12, and two postemergence (POST) herbicides, florpyrauxifen benzyl group 4 and tiafenacil group 14, in Christmas trees.

Christmas Tree Response to Fluridone

This objective consisted of two study protocols: the crop safety study and the season-long study.

Crop tolerance study. This study was initiated at the Lewis Brown Research Farm in Corvallis, OR (44.56 °N, 123.27°W) in a Chehalis silt loam soil in April 2022. The field was plowed in the fall of 2021 and cultivated shallowly in early April 2022 before crop establishment. The spring of 2022 was colder and rainier than normal averages (Table 1), delaying both field preparation and transplant sourcing.

Christmas tree transplants were donated by a local commercial nursery. Plugs of five species were selected: Douglas fir, Grand fir, Noble fir, Nordman fir, and Turkish fir. Plugs were planted at 1.5 by 8 ft. The wider between-row spacing was adopted to minimize spray drift and cross-contamination between herbicide treatments and soil activity. The experiment was organized as a complete block design with four replicates. An experimental unit consists of three plants of each species, resulting in 15 plants planted in a single row. The experiment was rainfed until summer 2022 when rainfall was supplemented with irrigation. Weeds were removed from the field to avoid competition and to enhance monitoring of treatment effects on crop growth. We are following the OSU Christmas tree nutrient management guide recommendations for plant nutrition. The study was initiated on April 19, 2022, one day after planting. Treatments were reapplied on January 19, 2023.

Treatments consist of fluridone (Brake On!) applied at 0.19, 0.40, and 0.81 lb active ingredient (ai) per acre, representing one-, two-, and four-fold the expected label rate, respectively. A nontreated weed-free control was included as a reference for a total of four treatments. Treatments were applied by CO2-pressurized backpack sprayer calibrated to deliver 20 gallons per acre. The spray boom included four 11002 AI (Teejet) nozzles. A single pass delivered treatments over the top of transplants. Treatments were reapplied in the winter of 2022-23. Assessments included visual estimates of crop injury at 4, 8, 12, and 16 weeks after treatment (WAT). In mid-summer (July 2023), plant survival, height, and length of new growth were recorded for each plant.

***Season-long weed control*.** Four field studies were initiated between January and February of 2022 in commercial Christmas tree fields in Monroe (43.31°N, 123.29°W), and Corvallis, OR, in a Douglas fir and a Nordman fir field at each location. Fields were in their second year after transplanting at the start of the studies. Corvallis treatments were applied on February 11, 2022 and reapplied on March 30, 2023. Weed presence were low at both sites; predominant weeds were Italian ryegrass, mouse ear chickweed, and cat's ear. The Monroe treatments were applied on February 18, 2022 and reapplied on March 31, 2023. The Monroe Douglas fir site was primarily infested with wild carrots, and the Nordman fir site was infested with cat's ear, wild carrots, and rattail fescue.

Table 1. Treatments and rates for season-long weed control studies in Christmas tree.

Trt	Active ingredient (Trade name)	Rate (product/A)
1	Nontreated control	
2	Simazine + Oxyflurofen (GoalTender)	4 qt + 4 qt

3	Penoxsulam + oxyfluorfen(Cleantraxx)	4.5 pt
4	Flumioxazin (Sureguard)	12 oz
5	Indaziflam (Marengo SC)	15 fl oz
6	Flazasulfuron (Mission)	2.85 oz
7	Fluridone (Brake on!)	43 fl oz
8	Fluridone (Brake on!)	83 fl oz
9	Simazine + Oxyflurofen (GoalTender) + Fluridone (Brake on!)	4 qt + 4 qt + 43 fl oz
10	Penoxsulam + oxyfluorfen (Cleantraxx) + Fluridone (Brake on!)	4.5 pt + 43 fl oz
11	Flumioxazin (Sureguard) + Fluridone (Brake on!)	12 oz + 43 fl oz
12	Indaziflam (Marengo SC) Fluridone (Brake on!)	15 fl oz + 43 fl oz
13	Flazasulfuron (Mission)+ Fluridone (Brake on!)	2.85 oz + 43 fl oz

Treatments were applied by CO2-pressurized backpack sprayer calibrated to deliver 20 gallons per acre. The spray boom included three 11002 AI (Teejet) nozzles covering 2.5 ft to each side of the planting row. A single pass delivering treatments over the top of transplants was performed. The entire experiment was treated with a basal-directed application of glufosinate in August 2022. Preemergence treatments were reapplied in winter 2022-23. The data were submitted to analysis of variance (ANOVA) in JMP software.

Assessments:

Assessments included monthly visual estimates of crop injury, and percent weed control by species for 4 months after treatment. Crop injury was rated on a scale from 0 to 100%, where 0% represents no injury and 100% represents plant death. Weed control at the species level was rated 0 to 100%. Leader length and tree height were measured in the late summer of each year. Statistical analysis was performed using R. Plant height, fresh weight, and yield were analyzed with linear mixed models generated using R package. Weed control data were analyzed separately by experimental year and tree species because of differing weed species and density among sites. Weed densities were too low on the Corvallis sites for accurate efficacy assessments. The Monroe Douglas fir site was only assessed in 2022, as the extensive wild carrot population required the collaborating growers to control weeds to mitigate impacts on crop growth, disrupting the experimental protocol.

Results

Crop tolerance study. Fluridone applied twice up to 905 g ai ha^{-1} did not injure the Christmas tree crop studied, regardless of the evaluation timing. Fluridone injury symptoms would include leaf chlorosis followed by necrosis, symptoms not observed (Table 2). Treatments did not affect Christmas tree survival at 24 months after two applications of fluridone (Table 2). Survival rates were 58% in Douglas fir, 78% in Grand fir, 28% in Noble fir, 41% in Nordman fir, and 56% in Turkish fir. Similarly, tree height or leader length were unaffected by fluridone treatments, further supporting the high tolerance of Christmas trees to fluridone.

Table 2. Christmas tree survival, tree height and leader shoot growth in response to fluridone applied over the top of Christmas tree during the winter in Corvallis, OR in 2023. Treatments included two applications of fluridone, one shortly after transplanting and the second in January 2023.

Douglas fir	Crop Injury (%)	Survival (%)	Tree Height (in)	Leader length (in)
1.Nontreated	0	75	22.2	5.0
2.Fluridone 220	0	48	20.4	3.0
3. Fluridone 452	0	58	20.3	4.9
4. Fluridone 905	0	50	19.6	5.7
Grand fir				
1.Nontreated	0	75	11.8	4.2
2.Fluridone 220	0	85	19.1	4.1
3. Fluridone 452	0	75	15.12	4.1
4. Fluridone 905	0	78	15.4	3.8
Noble				
1.Nontreated	0	25	11.14	2.1
2.Fluridone 220	0	43	10.0	2.4
3. Fluridone 452	0	33	9.58	2.12
4. Fluridone 905	0	15	12.2	4.8
Nordman				
1.Nontreated	0	43	10.6	1.7
2.Fluridone 220	0	50	9.8	1.3
3. Fluridone 452	0	35	12.4	2.4
4. Fluridone 905	0	40	10.6	1.3
Turkish				
1.Nontreated	0	60	10.1	1.3
2.Fluridone 220	0	58	12.8	2.6
3. Fluridone 452	0	85	10.0	2.2
4. Fluridone 905	0	25	7.3	2.0

Season-long weed control. Crop tolerance. The season-long weed control further validated Christmas tree tolerance to fluridone applied over the top during the dormant season. No crop injury was observed during the two years of the study regardless of fluridone rate (data not shown). No treatment injured the crop, including indaziflam (Marengo), flazasulfuron (Mission), flumioxazin (Sureguard). Tolerance was supported by similar initial and final tree height over two seasons in all treatments (Figure 2), and leader shoot length (Figure 1).

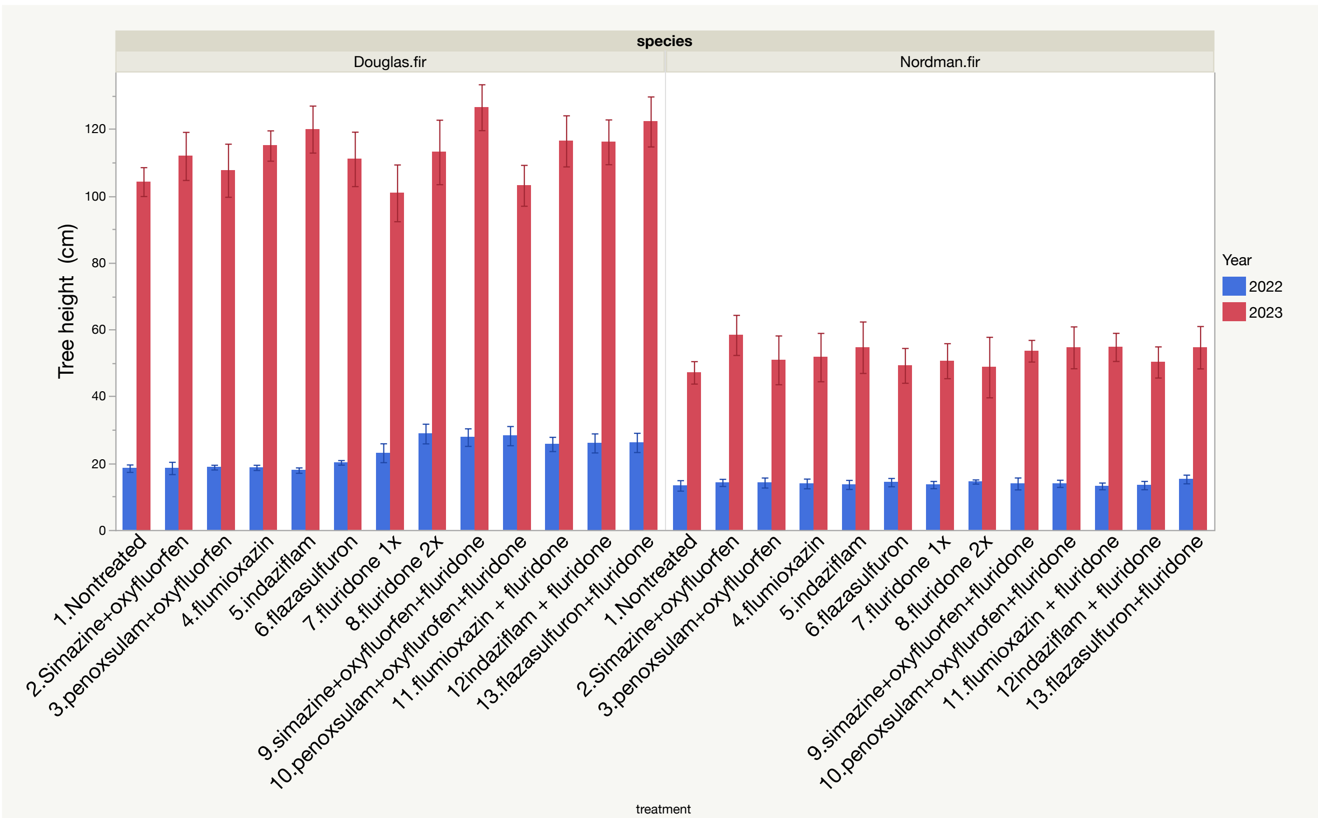

Figure 1. Christmas tree Douglas fir (left) and Nordman fir (right) height in response to different preemergence herbicides applied over the-top during winter during a 2-year crop tolerance study. Means and standard errors are averaged across two locations and represent eight replicates (n=8) and 24 trees.

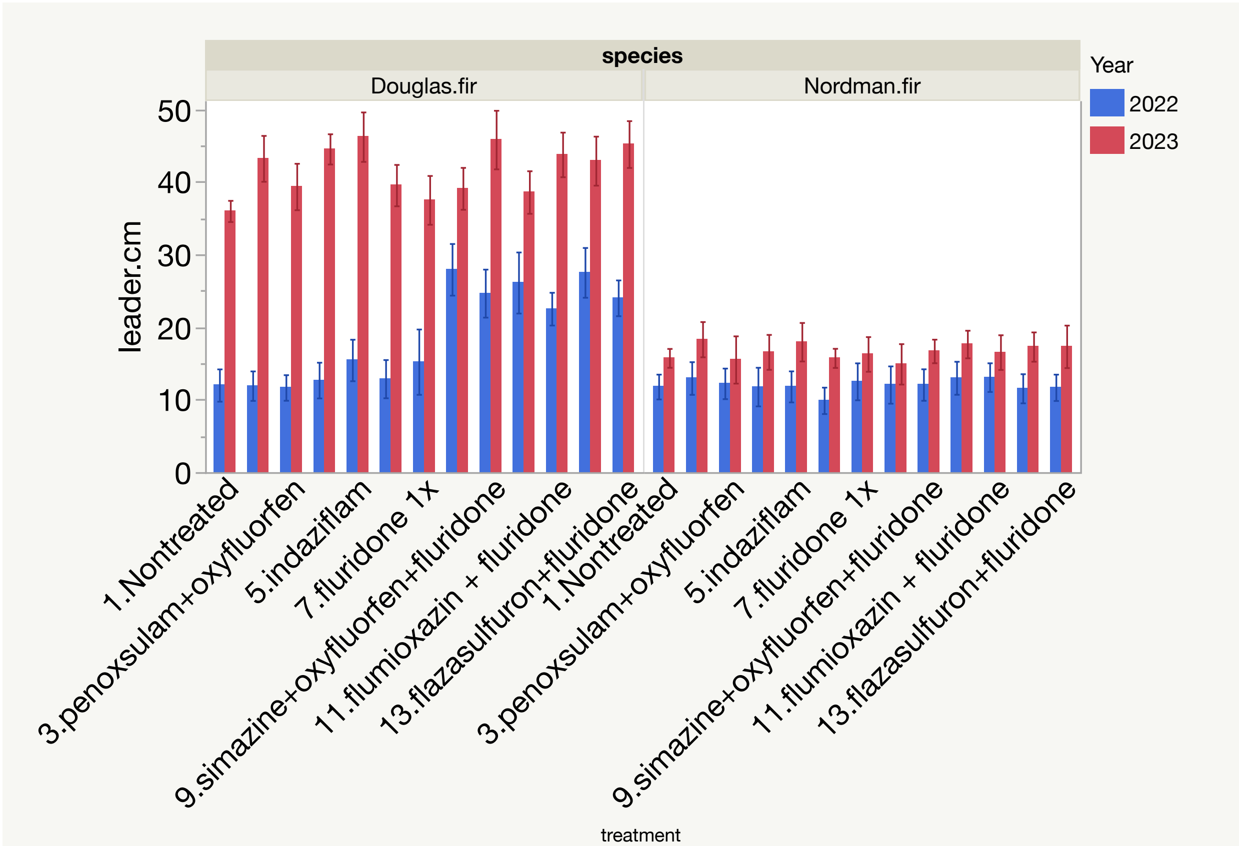

Figure 2 Christmas tree Douglas fir (left) and Nordman fir (right) leader shoot length in response to different preemergence herbicides applied over-the-top during the winter period during a 2-year crop tolerance study. Means and standard errors are averaged across two locations and represent eight replicates (n=8) and 24 trees.

Weed Control efficacy. Wild carrot control was poor (<50%) for most of the treatments in the Douglas fir study near Monroe (Table 3). The site was heavily infested, and treatments were applied without any postemergence treatments (e.g., glyphosate). The only treatment that controlled wild carrot contained flazasulfuron (70-73%) with or without fluridone. Fluridone did not control wild carrot.

Table 3. Wild carrot and weed ground coverage in response to preemergence treatments applied in winter of 2022 in a Douglas fir field near Monroe, OR.

Trt		Wild carrot (%)			Weed Cover (%)		
		28 DAT	56 DAT	88 DAT	28 DAT	56 DAT	88 DAT
1	NTC	0 b	0 b	0 b	3	14	43
2	Sim+oxy	8 b	10 b	18 ab	1	3	26
3	Penox+oxy	3 b	3 b	13 b	1	6	20
4	flum	8 b	8 b	10 b	1	3	28
5	ind	0 b	3 b	8 b	2	6	31

6	flaz	78 a	60 a	83 a	2	13	31
7	Flur 1x	8 b	30 b	28 b	1	10	25
8	Fluri 2x	10 b	20 b	8 b	2	5	32
9	Sim+oxy + fluri	10 b	5 b	3 b	2	7	25
10	Penox+oxy + fluri	18 b	10 b	10 b	1	10	28
11	Flum + fluri	18 b	15 b	18 b	1	2	28
12	Ind + fluri	20 b	15 b	7 b	2	4	27
13	Flaz + fluri	73 a	65 a	60 a	1	7	16
	P value	*	*	*	NS	NS	NS

Abbreviations: Sim – simazine; oxy – oxyfluorfen, pen – penoxsulam; flum – flumioxazin; ind – indaziflam, flaz- flazasulfuron; flur – fluridone; 1 x- 43 fl oz of Brake On!; 2 x – 86 fl oz/A of Brake On!. *Statistically significant; NS non-significant
Means followed by the same letter are not statistically different according to Tukey's test.

Most treatments satisfactorily controlled cat's ear (>80%) in a Nordman fir field near Monroe, OR, in 2022 (Table 4). Simazine plus oxyfluorfen and penoxsulam plus oxyfluorfen controlled 78% and 61% of cats ear, respectively, at 28 DAT. Control was somewhat stable up to 88 DAT. Fluridone improved control of simazine+ oxyfluorfen by 16% and penoxsulam + oxyfluorfen by 26% at 28 DAT, but treatments were not different in subsequent evaluations. Fluridone alone did not control cat's ear.

Table 4. Cat's ear control in response to preemergence treatments applied in winter of 2022 and 2023 in a Nordman fir field near Monroe, OR.

Trt		2022						2023					
		28 DAT		56 DAT		88 DAT		28 DAT		56 DAT		88 DAT	
1	NTC	0	e	0	c	0	d	0	b	0	d	0	e
2	Sim+oxy	78	ac	50	ac	47	ac	98	a	76	ac	78	ac
3	Penox+oxy	61	bd	64	ab	71	a	98	a	43	bc	61	bd
4	flum	59	bd	35	ac	44	ac	98	a	62	ac	59	bd
5	ind	27	d	18	ac	15	bd	98	a	37	bc	27	d
6	flaz	31	d	17	bc	11	cd	98	a	33	c	31	d
7	Flur 1x	34	cd	48	ac	27	ad	99	a	31	bd	34	cd
8	Fluri 2x	41	cd	52	ac	31	ad	98	a	41	bc	41	cd
9	Sim+oxy + fluri	94	a	55	ac	33	ad	98	a	93	a	94	a
10	Penox+oxy + fluri	87	ab	74	a	64	ab	98	a	80	ab	87	ab
11	Flum + fluri	66	ad	20	bc	18	bd	98	a	54	bc	66	ad
12	Ind + fluri	46	bd	36	ac	10	cd	97	a	49	bc	46	bd
13	Flaz + fluri	37	cd	46	ac	26	ad	98	a	40	bc	37	cd

Abbreviations: Sim – simazine; oxy – oxyfluorfen, pen – penoxsulam; flum – flumioxazin; ind – indaziflam, flaz- flazasulfuron; flur – fluridone; 1 x- 43 fl oz of Brake On!; 2 x – 86 fl oz/A of Brake On!. *Statistically significant; NS non-significant
Means followed by the same letter are not statistically different according to Tukey's test.

In 2023, all treatments provided excellent control of cat's ear (>90%) at 28 DAT. Efficacy declined over time, but simazine + oxyfluorfen provided 78% control. Adding fluridone increased the cat' ear control by 16% in simazine plus oxyfluorfen, 26% with penoxsulam plus oxyfluorfen, and 7% with flumioxazin compared to the same treatments without fluridone. A similar response was observed with rattail fescue in 2022 (data not shown).

In summary, fluridone was safe when applied over the top of several important Christmas tree species cultivated in the Pacific Northwest. Fluridone alone did not provide adequate weed control, but it increased control of the cat's ear and rattail fescue. Fluridone will improve weed control in Christmas trees and provide a new mode of action for resistance management.

Christmas tree tolerance to post-emergence herbicides tiafenacil and florpyrauxifen benzyl.

This study evaluated Christmas tree response to tiafenacil and florpyrauxifen benzyl. They included two study protocols: a crop safety study and an efficacy and crop safety study. The crop safety study followed the same planting protocols described for objective 1. Treatments were initiated in June 2022, two months after transplanting, to allow plants to acclimate and initiate growth. The experiment included ten treatments, as shown in Table 2. All treatment applications were directed at the base of the plants using a three-nozzle shielded sprayer.

Table 5. List of proposed treatments, rates, and application timings for the POST study.

Trt	Active ingredient	Rate (lb ai/A)	Application timings
1	nontreated		
2	Tiafenacil	0.04	Spring + Summer + Dormant (3 times/yr)
3	Tiafenacil	0.08	Spring + Summer + Dormant (3 times/yr)
4	Tiafenacil	0.16	Spring + Summer + Dormant (3 times/yr)
5	Florpyrauxyfen (Loyant)	0.02	Dormant (once/yr)
6	Florpyrauxyfen	0.04	Dormant (once/yr)
7	Florpyrauxyfen	0.08	Dormant (once/yr)
8	Florpyrauxyfen	0.02	Spring +Summer + Dormant (3 times/yr)
9	Florpyrauxyfen	0.04	Spring +Summer + Dormant (3 times/yr)
10	Florpyrauxyfen	0.08	Spring +Summer + Dormant (3 times/yr)

The second study protocol was conducted at a commercial Douglas fir site near Banks, OR in March 2023, about three weeks before bud break. The field was infested with cat's ear. Treatments were applied by a backpack shielded boom for the no foliar spray, and non-shielded boom for the foliar exposure treatments. The latter plats received direct herbicide application to the lower 2 ft of the trees. Herbicides were tested at two rates, 1x and 2X the label rate, and with or without foliar exposure (Table 6).

Table 6. List of proposed treatments, rates, and application timings for the POST study.

Trt	Active ingredient	Rate (lb ai/A)	Foliar exposure
1	Untreated check		
2	Tiafenacil	0.04	No foliar exposure
3	Tiafenacil	0.08	No foliar exposure
4	Tiafenacil	0.04	Foliar exposure
5	Tiafenacil	0.08	Foliar exposure
6	Florpyrauxyfen	0.02	No foliar exposure
7	Florpyrauxyfen	0.04	No foliar exposure
8	Florpyrauxyfen	0.02	Foliar exposure
9	Florpyrauxyfen	0.04	Foliar exposure

Assessments included evaluating tree injury, tree growth, and weed control on a scale of 0-100 %, where 0 represents no control and 100% represents complete control. The experiment was organized as a randomized complete block with four replicates and three plants per plot. Tree age varied within a plot because of replants.

Results:

The application of tiafenacil or florpyrauxifen did not affect the growth of Douglas, Grand, or Noble fir. Nordman 25and Turkish fir were removed from the analysis because of low tree survival regardless of treatment. Tree damage was observed when the spray solution drifted into the plants (data not shown). Damage was more common in the study's first year because of the plant's small size.

Table 4. Christmas tree height after banded application of tiafenacil or florpyrauxifen benzyl in a field study in Corvallis, OR in the summer of 2023.

Trt	Active ingredient	Rate (lb ai/A)	Application timings	Douglas Fir	Grand Fir	Noble Fir
1	Weed free nontreated			21.5	15.3	9.5
2	Tiafenacil	0.04	ABC	21.4	15.9	5.9
3	Tiafenacil	0.08	ABC	22.8	13.3	9.0
4	Tiafenacil	0.16	ABC	23.3	14.1	9.5
5	Florpyrauxyfen	0.02	A	19.5	14	6.1
6	Florpyrauxyfen	0.04	A	23.8	14.2	7.8
7	Florpyrauxyfen	0.08	A	20.0	13.1	8.5
8	Florpyrauxyfen	0.02	ABC	21.1	15.3	8.0
9	Florpyrauxyfen	0.04	ABC	23.3	15.6	8.2
10	Florpyrauxyfen	0.08	ABC	19.9	16.4	5.8

Tiafenacil and florpyrauxifen efficacy and crop safety study.

Regardless of foliar exposure, tiafenacil did not injure Douglas fir at 0.04 and 0.08 lb ai/A. Tiafenacil suppressed cat’s ear for four weeks, followed by plant regrowth and new germination. By contrast, foliar exposure to florpyrauxifen injured the trees when targeting the tree foliage (Figure 3). The injury was more severe in younger plants (figure 4). Florpyrauxifen provided suppressed cat’s ear for up to two months (data not shown).

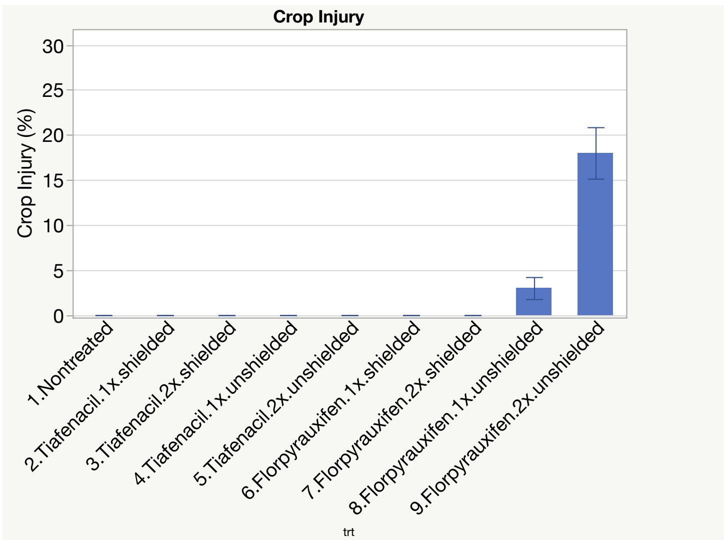

Figure 3. Douglas fir injury in response to tiafenacil or florpyrauxifen 114 days after treatment. Treatments were applied with or without foliar exposure. The study was conducted in a commercial Christmas tree field near Banks, OR, in 2023. (left). An example of the most severe damage observed was florpyrauxifen benzyl applied with foliar exposure.

1. Summary of Research Report for Public Release by CTPB- The summary should be suitable for a non-scientific audience and should be at most one page. Photograph(s) of research aspects suitable for publication is requested.

Summary of Research Report

- Project Objectives. The long-term goal of this study was to develop new practical, economical, and environmentally sound weed management options for Christmas trees that enable growers to deliver high-quality trees to market. This project was initiated in 2021-22. The fluridone project is now completed and the manufacturer has the data in hands to support future registrations.
- All five studies confirmed Christmas tree tolerance to fluridone in Douglas fir, Grand fir, Noble fir, and Nordman fir. Application over the top did not affect tree growth.
- *The season-long studies conducted on commercial farms have shown that Cleantraxx does not effectively control cats' ears and rattail fescue. Fluridone, in combination with Goaltender plus Simazine,* improved control of these weeds as well.
- Tiafenacil was safe for Christmas trees when applied to dormant plants, even if foliage was exposed. It also temporarily controlled the cat's ear.
- Florpyrauxifen was safe for Christmas trees in winter and summer when the foliage was not exposed.
- These data will support the registration of new herbicides in Christmas trees.