Attachment C

Christmas Tree Promotion Board

Final Research Report

CTPB Project Number: 18-04-NCSU

Project Title: Management options for herbicide resistant weeds in Christmas tree production

Principal Investigators: Joseph C Neal and Jeff Owen

Institution: North Carolina State University

Final Report

1. Technical report –

Herbicide tolerant and resistant weeds have changed weed control practices in most agronomic cropping systems and are now impacting Christmas tree producers. In this project, experiments were conducted to evaluate alternative control strategies, with an emphasis on multiple modes of action for herbicide resistance management.

The objectives of this study were to:

Objective 1. Survey growers to determine the prevalence of herbicide resistance and the most common modes of action for which resistance is a problem for Christmas tree growers. [notation: this objective was omitted from the final negotiated funded project, but PI Neal was able to accomplish this objective through a no-cost on-line survey.]

Objective 2. Identify safe doses and application timings (relative to tree phenology) for glyphosate-alternative herbicides (including FirstRate, Harmony, 2,4-D amine, and saflufenacil tank mixed with glyphosate).

Objective 3. Identify effective doses and application timings for control of glyphosate-tolerant weeds including horseweed (*Conyza canadensis*), lambsquarters (*Chenopodium album*), and ragweed (*Ambrosia artemisiifolia*). Research focused on glyphosate tolerant horseweed control options with preliminary research on the control of lambsquarters and ragweed.

Objective 4. Evaluate the safety of treatments from objective 3 on established white clover.

Objective 5. Evaluate use of a spray drone for postemergence herbicide applications in steep, uneven terrain.

Methods

Objective 1. An on-line grower survey was conducted to estimate the scope and importance of herbicide resistance. The survey was developed using Qualtrics (https://www.qualtrics.com/). Following review and approval by the North Carolina State University Institutional Review Board (IRB), the survey was distributed to growers and county extension agents throughout the U.S. via Cooperative Extension, USDA IR-4, and Industry list-serves. Data were summarized using the Qualtrics software.

Objectives 2 and 3.
On-farm field experiments were conducted to evaluate herbicide efficacy on glyphosate-tolerant horseweed (*Conyza candadensis*); and container experiments were conducted to test alternative options for control of lambsquarters (*Chenopodium* album) and ragweed (*Ambrosia artemisiifolia*). Herbicide safety was simultaneously evaluated. Additionally, the safety of herbicide treatments on Fraser fir trees was evaluated in on-farm experiments and in trials at the N.C. State Upper Mountain Research Station in Laurel Springs NC.

Based on preliminary research, the herbicides selected for assessment included cloransulam (FirstRate), thifensulfuron (Harmony), topramazone (Frequency), saflufenacil (Detail), and 2,4-D amine. Recently, researchers investigating weed management practices in living mulch systems reported florpyrauxifen-benzyl (Loyant / Rinskor) and flumetsulam (Python) to have safety to clover and to be effective on numerous broadleaf weeds (personal communication, Dr. N. Bassiger). Therefore in 2021, experiments were expanded to evaluate the safety and efficacy of these two new products,.

Herbicides were applied as a directed spray contacting the lower 12 to 18 inches of the trees. To ensure no drift from treatments affecting adjacent trees, a boarder row of nontreated trees was between each row of treated trees. In 2018 and 2019 experiments, herbicide safety and efficacy were evaluated at 3 growth stages: pre/at budbreak, rounded to early 'V' stage, and at 'flat' shoot stages (see **Photo 1**). Horseweed growth stages at these application dates are shown in **Photo 2**. Herbicides were applied with a CO_2 pressurized sprayer calibrated to deliver 15 gallons per acre of spray, using TeeJet TTI low-drift nozzles. In each study, treatments were arranged in a randomized complete block design with four replicates, and each test was repeated at a separate site or the following year.

B (bud) R (rounded) 'V' shape F (flat)

Photo 1. States of bud / shoot development used to describe bud stages at 3 application dates. Pre/at budbreak treatment was applied at the bud stage. The second application was at Rounded to 'V' stage; the third application was at the 'flat' stage.

Photo 2. Horseweed growth stages on the days of treatment. Left to right - at Fraser fir bud stages of: budbreak, V stage, and flat bud stages, respectively; Mitchell County 2019

Container experiments for weed control efficacy were conducted at the Horticulture Field Laboratory at N.C. State University. Four-liter pots were filled with a standard pine-bark substrate amended with slow release fertilizer. Horseweed plants were selected from naturally infested pots left on the container research area for this purpose. Lambsquarters was surface seeded. Ragweed seeds were mixed into the substrate to a depth of ~1 inch. Before herbicide applications, plants were selected and blocked for uniform size and number per pot. Herbicides were applied with the same spray system as described above. Percent weed control was visually evaluated and 4 to 6 weeks after herbicide application plants were cut at the ground level and weighed. Percent reduction in growth compared to non-treated plants was calculated.

Objective 4. Test sites for weed control studies (Objectives 2&3) were selected for weed population density and generally lacked sufficient white clover cover for evaluations. Therefore, a separate on-farm study was established at a grower site with a uniform and dense stand of white clover (*Trifolium repens*) ground cover. Herbicides were applied on June 7, 2021. Treatments included glyphosate alone and tank-mixed with high and low rates of cloransulam, and thifensulfuron with 0.25% nonionic surfactant. Percent ground cover of clover was visually estimated before and after applications.

A separate demonstration trial (non-replicated) was established in Jackson County in 2020 to assess the effects of cloransulam and thifensulfuron on established white clover ground cover. Rainy conditions on scheduled application dates delayed implementation until July 15 and 21 about one month after the field had been mowed by the grower. Treatments included glyphosate alone and tank-mixed with high and low rates of cloransulam, and thifensulfuron, with and without nonionic surfactant. Weed and ground cover responses were visually evaluated on August 6, about 2.5 weeks after treatment, and again in September. However, the grower practiced regular mowing and the September evaluation occurred about 2 weeks after mowing.

Objective 5. Uniformity of spray deposition from spray drone applications.

The Agras spray drone owned by the project proved to be inoperaple. Several attempts to repair the drone were unsuccessful and the manufacturer discontinued support of this model. In order to complete this phase of the project we sought help from other NCSU faculty and staff. Andrew Howell, a doctoral student of Dr. Robert Richardson, Soils and Crop Science, piloted his own DJI Agras to allow us to address this research objective.

The research focus narrowed to a foundational spray deposition study in Christmas trees. While we only used water and dye, an evaluation of coverage could illustrate the potential of this alternative application technique for herbicides or other uses. To accommodate Howell’s functional but older Agras drone model, we concentrated our efforts on a small, relatively flat 5-year-old stand of Fraser fir trees.

The field was first mapped using a remote-sensing drone (Photo 3). This map was used as a guide for subsequent DJI Agras spray drone testing. The study was first conducted in July 2021 and repeated in October 2021. On each day, eight flights were made to test different spray volumes at two elevations. As with most calibration studies, only a single pass was made with each drone flight. Dye in water was applied at 4 spray volumes (2, 4, 8, and 16 GPA). Different spray volumes were obtained by adjusting drone flight speed. The four spray volumes were tested at both 10- and 15-foot elevations above the Christmas trees. The two dates served as study replications with treatment replications occurring with deposition card placement. Before each application, thirtytwo 2 in. x 3 in. cards were placed in a linear pattern across wooden stakes next to 5 trees and the ground between (Diagram 1 below). Only the center tree was fitted with an array of twelve cards across four stakes in the cardinal directions and three heights on each stake. Four replications of these cards were placed in the field along the flight route of the spray drone. Spray deposition cards were allowed to briefly dry in place, collected, and later scanned to measure spray deposition.

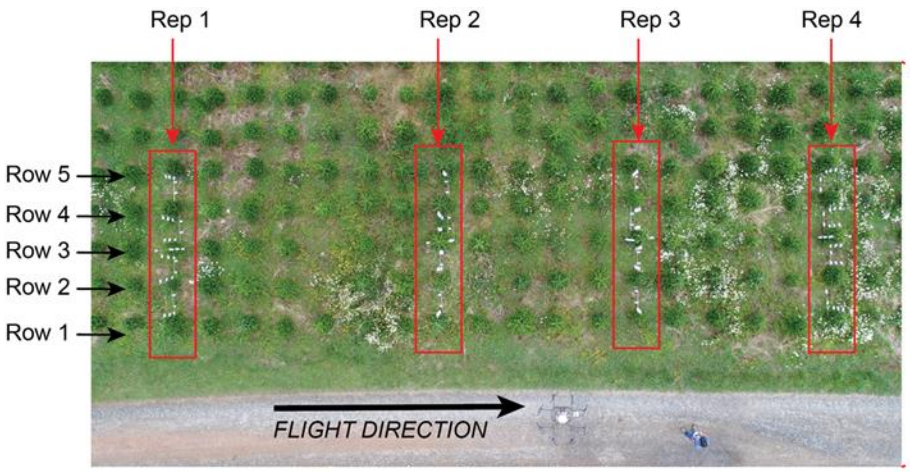

Photo 3. An overhead drone image of the portion of the study field showing the array of cards placed at each replication.

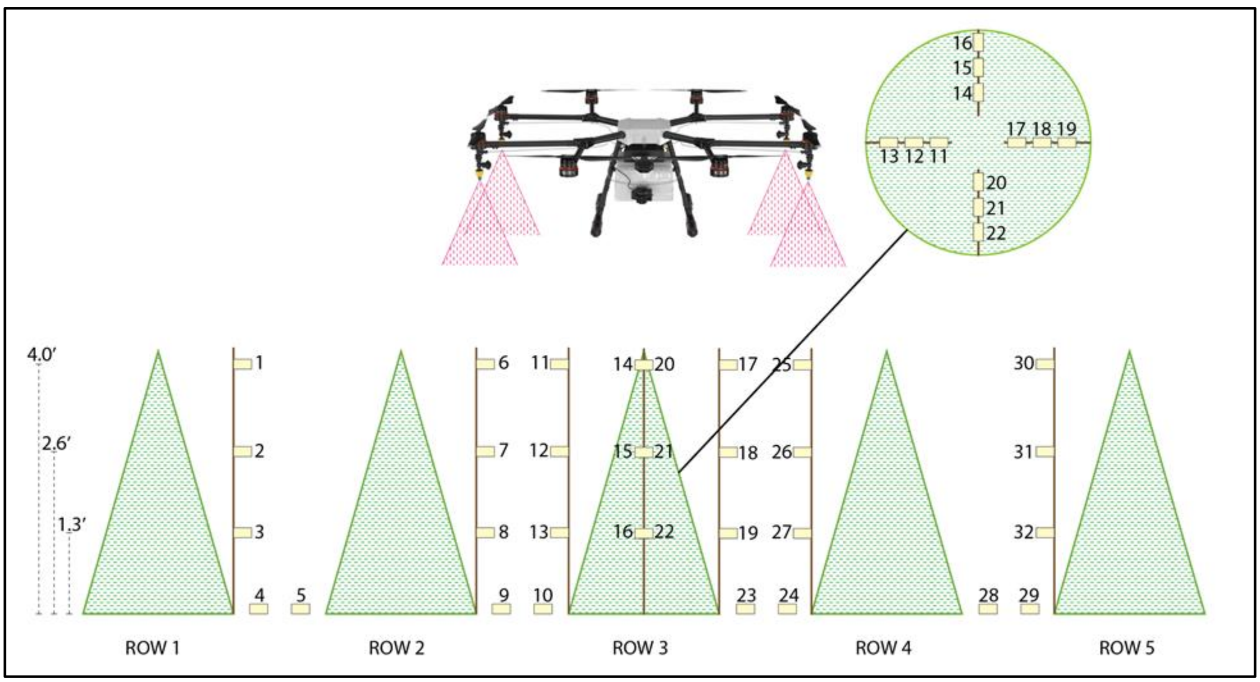

Figure 1. Array of spray deposition cards in relation to the Agras spray drone in each of four deposition card replicates.

Results.

Results; Objective 1: Grower Survey.

Over 50% of Christmas tree growers responding to the survey reported that they had "personally observed herbicide resistance weeds on their properties". Among those observing resistance, over half reported glyphosate-resistant weeds; 27% reported triazine herbicide resistance and 12% reported resistance to ALS-inhibiting herbicides (Table 1). These results demonstrate and confirm that the issue of herbicide resistance is widespread in the industry and integrated solutions for herbicide-resistant weed control are needed.

Table 1. Survey participant responses to the question: "If you have observed herbicide resistance: To what herbicide(s)?" Note: 52 percent of survey respondents reported having personally observed herbicide resistance in their fields.

Herbicides	% of respondents
glyphosate	51
ALS inhibitor,	12
triazine	27
synthetic auxin	4
other	6
Total of responses	100

Source: Derr, J., Neal, J., and Bhowmik, P. 2020. Herbicide Resistance in the Nursery Crop Production and Landscape Maintenance Industries. Weed Technology 34(3):437-446;

Results; Objective 2: efficacy evaluations.

Horseweed was not controlled by glyphosate alone or by thifensulfuron (data not shown). In field experiments, FirstRate (cloransulam) + glyphosate provided nearly complete control of glyphosate-tolerant horseweed (**Tables 2 & 3; photo 4, below**). However, in the container experiments cloransulam was less effective providing $\leq$75% control (Table 3). Reasons for different results between container and field tests are unclear. Besides different environmental conditions, the experiments were conducted with different seed sources of horseweed (local, natural spread). In both container and field experiments, horseweed was also controlled by topramezone + MSO and by 2,4-D amine (Table 3). Saflufenacil + MSO controlled horseweed in one of two years. In 2021, pre-budbreak applications of flumetsulam controlled horseweed but post budbreak applications were less effective (**Figure 2**) and caused significant chlorosis. Florpyrauxifen-benzyl controlled horseweed but caused severe injury to Fraser fir trees even when applied before budbreak.


Photo 4. Horseweed control with FirstRate + glyphosate (0.3 oz/A + 8 oz/A), Mitchell Co. 2019

Table 2. Horseweed control in Fraser fir production. Mitchell County, NC. Percent control of horseweed following applications made on April 15, May 8, and June 13, 2019; evaluated on July 10th when horseweed plants in the glyphosate-only plots were about 3 ft tall, necessitating control measures by the grower. The experiment was conducted in a Fraser fir production field in Mitchell County NC with a history of high populations of horseweed.

Herbicide	Dose oz/A	Pre-budbreak (subplot A)		Round to V stage (subplot B)		Flat shoots (subplot C)	
	------	-------------------------		% control		------------------	
glyphosate* (Razor Pro)	8 / 4 oz	7	b	23	bc	20	e
glyphosate (Razor Pro) + NIS	8 / 4 oz	0	b	13	c	23	de
cloransulam (FirstRate) + glyphosate + NIS	0.3 oz	90	a	97	a	93	a
cloransulam (FirstRate) + glyphosate + NIS	0.6 oz	90	a	98	a	95	a
cloransulam (FirstRate) + glyphosate +NIS	1.2 oz	100	a	99	a	95	a
cloransulam (FirstRate) + glyphosate (no NIS)	0.6 oz	93	a	100	a	93	a
thifensulfuron (Harmony) + glyphosate + NIS	0.25 oz	3	b	18	c	50	bc
thifensulfuron (Harmony) + glyphosate + NIS	0.5 oz	3	b	12	c	38	cd
thifensulfuron (Harmony) + glyphosate + NIS	1 oz	10	b	40	b	58	b
thifensulfuron (Harmony) + glyphosate (no NIS)	0.5 oz	0	b	13	c	47	bc

*Per grower practice, glyphosate (Razor Pro) was included with all treatments. Pre-budbreak applications were at 8 oz/A. Because Fraser fir trees are more sensitive to glyphosate injury following budbreak, post-budbreak applications (Round / V stage and flat shoots) were made at 4 oz/A (as per grower practice).
Means within columns followed by the same letter do not significantly differ (p=0.05, LSD)
Subplot A treated 4/15/2019; Subplot B treated 5/8/2019; Subplot C treated 6/13/2019

Table 3. Postemergence control of horseweed (*Conyza canadensis*) in container and 2018 field experiment.

Herbicide & adjuvant	Dose (oz/A)	Dose (g ai/ha)	Container tests, 5 WAA 2018		Container tests, 5 WAA 2019		Field test 60 DAA	
Glyphosate	8	280	15	e	32	e	7	c
Saflufenacil + 1% MSO	0.5	12.5	20	e	60	cde	68	b
Saflufenacil + 1% MSO	1	24.9	18	e	80	abc	100	a
Saflufenacil + glyphosate (no MSO)	0.5 8	12.5 280	40	d	92	ab	70	b
Saflufenacil + 1% MSO + glyphosate	0.5 8	12.5 280	--		100	a	--	
Topramezone + 1% MSO	4	98	73	bc	68	bcd	97	a
Topramezone + 1% MSO	8	196	81	ab	94	ab	98	a
Topramezone + glyphosate (no MSO)	4 8	98 280	20	e	76	a-d	66	
Topramezone + 1% MSO + glyphosate	4 8	98 280	--		97	a	--	
Cloransulam + 0.25% NIS	0.3	2.82	73	bc	48	de	93	
Cloransulam + 0.25% NIS	0.6	5.64	75	bc	55	cde	95	
Cloransulam + 0.25% NIS	1.2	11.29	65	c	60	cde	95	
2,4-D amine		1120	94	a	96	ab	99	a

*Visual evaluations and fresh weighs were highly correlated (R_{2019}= -0.98). Means within a column followed by the same letter are not significantly different based on an LSD test with α = 0.05). DAT = Days after treatment.

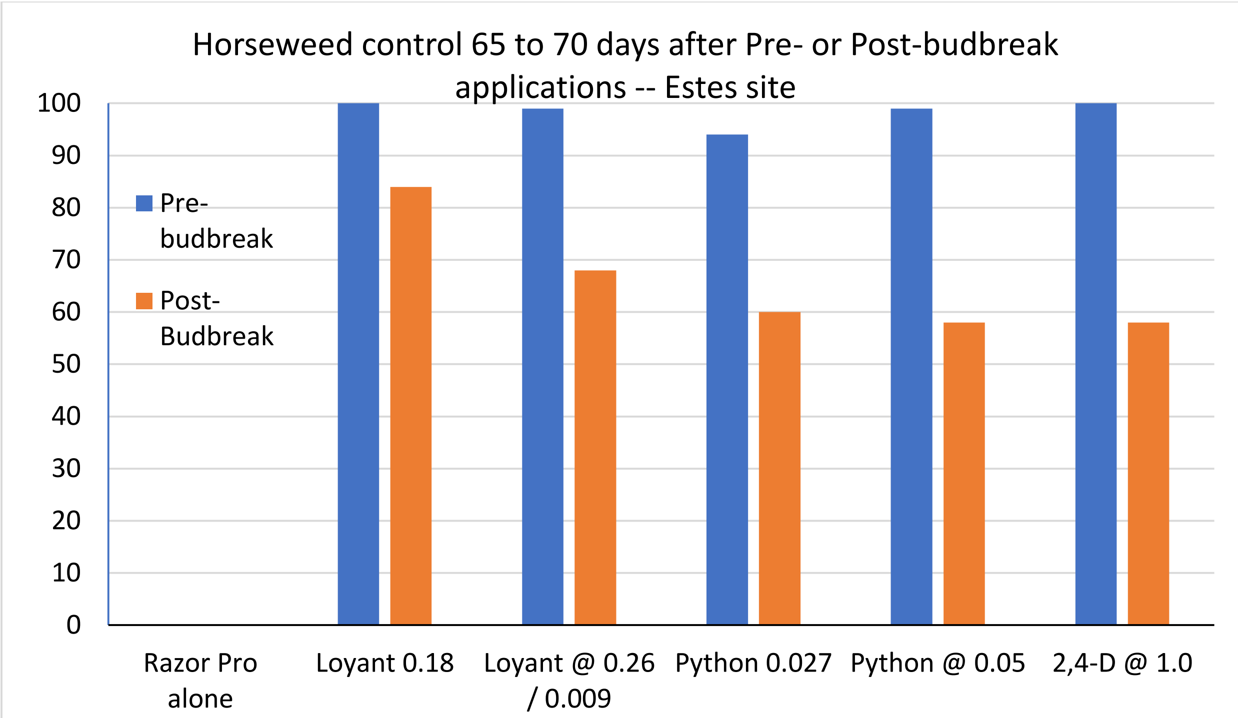

Figure 2. Postemergence horseweed control with Flumetsulam (Python) or florpyrauxifen-benzyl (Loyant / Rinskor), compared to glyphosate or 2,4-D, each applied before or after budbreak; 10 weeks after application. Experiment conducted on a natural stand of horseweed in a 4-year old planting of Fraser fir.

In separate container experiments, herbicide efficacy on lambsquarters and ragweed were evaluated. Ragweed was controlled by topramazone, saflufenacil, the high dose of cloransulam, 2,4-D and Florpyrauxifen-benzyl (**Figure 3**). Thifensulfuron and flumetsulam were ineffective. Lambsquarters was controlled by topramezone, thifensulfuron, or 2,4-D (**Figure 4**). Florpyrauxifen-benzyl (Loyant) controlled both ragweed and lambsquarters, but in field experiments caused excessive injury to Fraser fir trees. The most effective treatments for each weed, based on above ground fresh weight data are summarized below. These treatments were not significantly different from the most effective treatment(s) that provided ~ 100% control.

Ragweed

Frequency @ 4 oz/A + MSO
Detail 0.5 oz/A or 1 oz/A + MSO
2,4-D – effective in 2021, less in 2019
Loyant
FirstRate was more effective in 2021 than 2019.

Lambsquarters

Frequency 4 oz/A + MSO
Harmony 0.5 oz/A + NIS
2,4-D Amine
Loyant

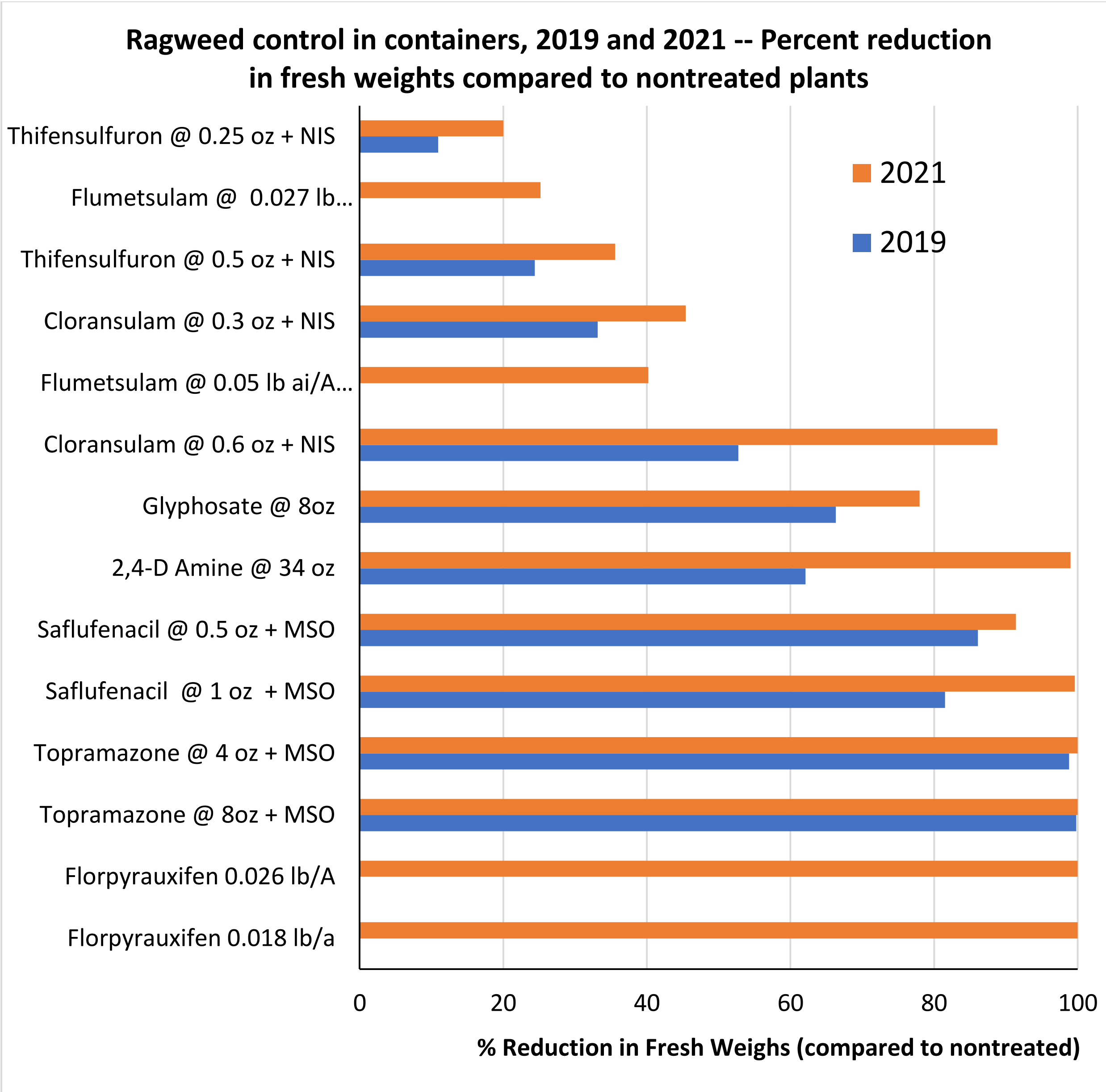

Figure 3. Postemergence ragweed control in containers – Container experiments conducted in Raleigh NC, 2019 and 2021. Plant fresh weight measured about 4 weeks after herbicide applications. *Florpyrauxifen and flumetsulam were included in 2021, not in 2019.

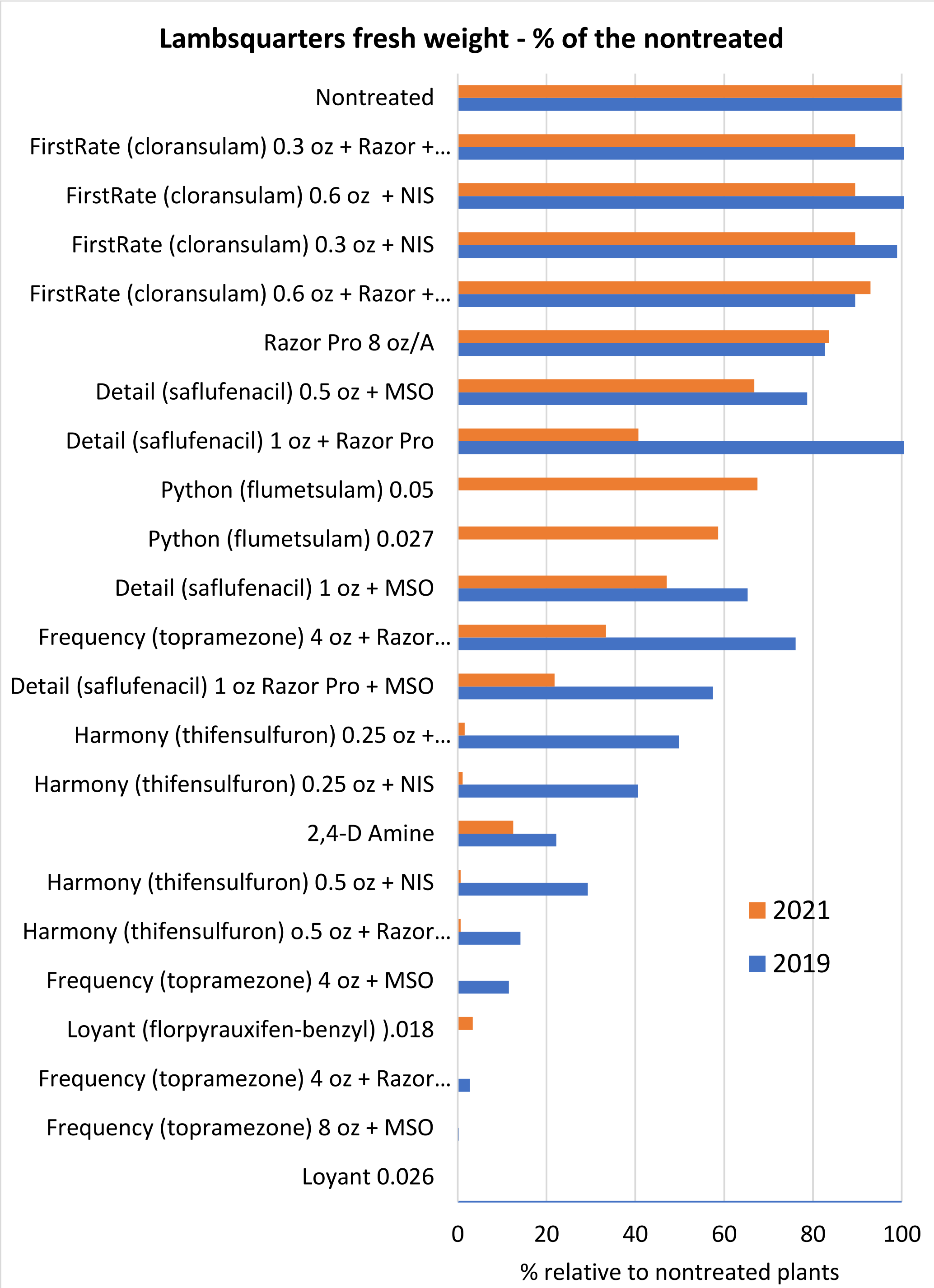

Figure 4. Postemergence lambsquarters control in containers.. Lambsquarters fresh weights were measured about 4 weeks after herbicide applications in 2019 and 2021. Data were converted to percentage of the nontreated plants for presentation. Container experiments were conducted in Raleigh NC, 2019 and 2021

Results; Objective 3: Herbicide safety evaluations, Fraser fir

Safety of herbicide treatments were evaluated on Fraser fir trees in on-farm trials. Herbicides were applied as directed sprays to both sides of the trees, contacting the lower 18 to 20 inches of the tree, at three growth stages: pre/at budbreak, rounded to early 'V' stage, and at 'flat' shoot stages (see **Photo 1**). Pre-budbreak applications of cloransulam, thifensulfuron, saflufenacil, topramezone, or 2,4-D amine were not injurious to Fraser fir. In one year of two, cloransulam applied at the 'V' stage of growth caused needle chlorosis that was persistent through the growing season (see **Photo 5**). Thifensulfuron applied post-budbreak caused general chlorosis of the treated shoots in one of two years. When applied post-budbreak, 2,4-D caused significant necrosis on the branches where spray contacted new growth. Saflufenacil did not injure Fraser fir trees when applied pre-budbreak but caused necrotic spots on the needles when applied after budbreak (data not shown). Topramezone did not injure Fraser fir when applied as a directed spray pre- or post-budbreak. However, tompramazone controlled all white clover in the plots and thus we do not consider this a viable treatment for growers in southern Appalachian Fraser fir production where white clover ground cover is maintained for erosion control. In sites or regions where maintenance of clover ground cover is not a high priority, topramazone could be a very effective alternative for control of glyphosate-tolerant horseweed, lambsquarters or ragweed.

Photo 5.   Cloransulam @ 0.6 oz/A + glyphosate + NIS (left) and saflufenacil (Right) applied early May, when buds were round to early 'V' stage. Photos taken mid-June.

In 2021 experiments flumetsulam did not injure Fraser fir when applied before budbreak but caused significant chlorosis of the new growth when applied after budbreak (See photo 6). Florpyrauxifen-benzyl injured Fraser fir applied before or after budbreak (Photo 7). Injury from florpyrauxifen-benzyl was significantly greater than that caused by 2,4-D.

Photo 6. Flumetsulam (Python) did not injure plants when applied prior to budbreak (left) but caused yellowing of the new growth when applied after budbreak (right)

Photo 7. florpyrauxifen-benzyl (Loyant) injured Fraser fir applied pre- and post budbreak.

Results Objective 4:   Safety of cloransulam and thifensulfuron on established white clover ground cover.

Cloransulam or thifensulfuron applied at manufacturers' recommended doses with nonionic surfactant discolored and stunted white clover about 20% but did not reduce percent ground cover of white clover 30 days after application (data not shown). It should be noted that neither cloransulam nor thifensulfuron suppressed grasses. The addition of glyphosate to these treatments provided suppression of grasses such as nimblewill, tall fescue and orchardgrass.

Similarly, in the 2020 demonstration trial in Jackson County, both cloransulam and thifensulfuron caused temporary stunting and yellowing of the clover, but clover had resumed normal growth by 6 weeks after treatment. (**Photos 8 & 9**). Thifensulfuron injury / stunting of clover was about half that of cloransulam. Clover in the cloransulam plots and higher rates of thifensulfuron had more prostrate petioles, in contrast the vegetative growth in lower rate plots of thifensulfuron and all glyphosate plots displayed a more 'normal' upright growth habit. At the September evaluation, percent ground cover of clover in all treated and nontreated plots was nearly 90%.

Photo 8. Clover regrowth across demonstration plots treated in July and mowed in September

Photo 9. September regrowth of white clover is shown in plots treated in July with cloransulam 0.3 oz. / acre (left) and 0.6 oz / acre (right).

General results summary for efficacy and safety of herbicide evaluations.
The table below summarizes our observations. Green is good; red is bad. From this table we can see that several herbicide options were both safe to Fraser fir and white clover, and effective on horseweed when applied before budbreak. However, after budbreak fewer options are both safe and effective. Both ragweed and lambsquarters emerge later, typically after budbreak. For lambsquarters control only thifensulfuron was both effective and safe to the Fraser fir and white clover cover. Topramazone was effective on lambsquarters and safe to the crop, but severely injured white cover ground cover. Ragweed was also controlled by topramazone

Summary of herbicide safety to Fraser fir and white clover ground cover, and efficacy on three high priority weeds.

Herbicides	Fraser fir safety		White clover safety	Weed Control		
	Pre / At Budbreak	Post Budbreak		Horse-weed	Lambs-quarters	Rag-weed
2,4-D amine	G	X	G	G	G	G
Cloransulam (FirstRate)	G	G	G	G	X	G
Thifensulfuron (Harmony)	G	G	G	X	G	X
Topramzone (Frequency)	G	G	XX	G	G	G
Saflufenacil (Detail)	variable	X	unknown	G	F	G
Flumetsulam (Python)	G	X	G		X	X
florpyrauxifen-benzyl (Loyant)	temporary injury	X	G	G	G	G
Clopyralid (Stinger, others)	G	G	XX	G	X	G

**clopyralid is labeled for use in conifer production and was not included in these experiments. It is included herein for comparisons with the experimental treatments.*
Key: G= good control or safety; F = fair / variable control or safety; X = poor control or safety.

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Results Objective 5: Drone spray deposition

The results from this study are an analysis of the portion of cards covered with spray droplets marked by dye separated from the white portion of the cards. Mapping software was used to capture that ratio which is represented as a percent of coverage. In Figure 4, the rates are represented as lines for each date and altitude. While a slight rate effect was observed in the percent coverage across the four rates / drone speeds, it was not as much as one might expect where the lowest rate, 2 gallons, represents only an eighth of the highest 16-gallon rate. The increased speed of the drone used to reduce rate and the resulting shift in the angle at which the drone flew influenced the air dispersal below the craft. Just as with air blast sprayers, the air is the carrier, not strictly the water. Dispersal of droplets was as good or better at the lower rates and higher speeds as at the higher rates associated with slower flights. A separation of rate and drone speed as distinct variables may provide additional insights with the potential for increased coverage.

When the two flight altitudes are examined by the gallons per acre applied, no clear pattern was observed. Greater coverage occurred with different altitudes on the different dates. Our results are a reflection of drone performance and reflect microsite wind conditions at the time of each flight. Daylight flights will be influenced by gusts and rising air currents. Only on still nights with these ambient influences be minimized. While the lift of the drone was greater than any gust of wind, their influence can not be ignored.

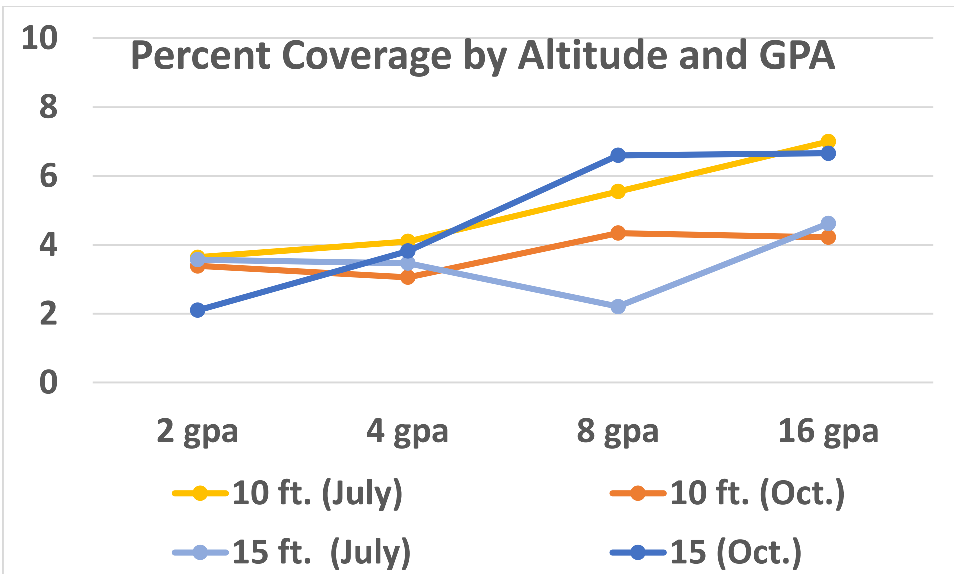

Figure 4. Percent total coverage of spray dye droplets averaged across deposition cards collected for 10 and 15 foot altitudes across 2,4,8, and 16 gallons per acre on two application dates.

The data were also analyzed across the array of deposition cards across the five rows of trees for the two different altitudes flown. Averages of 10-foot altitude flights provided a distinct indication of where spray droplets were and were not being deposited as shown in Figure 5. Neither outside trees nor outside rows received as much coverage as the center three rows of trees and the two row-middles between them. With trees set on five-foot spacing, this indicates about a ten-foot-wide swath of adequate coverage with some overlap beyond the ten foot margins. This conformed with Agras sprayer bandwidths observed by Andrew Howell for other crops he had calibrated and treated with this particular drone at that altitude.

At 15 foot altitudes shown in Figure 6, average spray deposition exhibited lower deposition levels but with greater consistency across all five rows of trees. On the average, patterns appeared to be distributed well enough for most postemergence herbicide treatments to be effective. Additional analysis is needed to determine the distribution of poor coverage. For farmers managing weeds, the extremes of too much or too little are equally important to averages of coverage. Consistency of the 15-foot altitude flights may be more useful than higher but less uniform result flown at 10 foot altitudes.

For the cards placed at different heights, top and middle cards tended to get higher rates of deposition than the cards placed at the bottom of the stakes next to trees. While it is possible that with vertical placement of cards, the upper cards shielded the lower ones, it is more likely that cards with lower deposition were in the shadow of the trees themselves. Spray deposition did not appear to be a uniform curtain of falling mist but rather a spiral of down-forced air with visible patterns of thick and thin clouds of spray

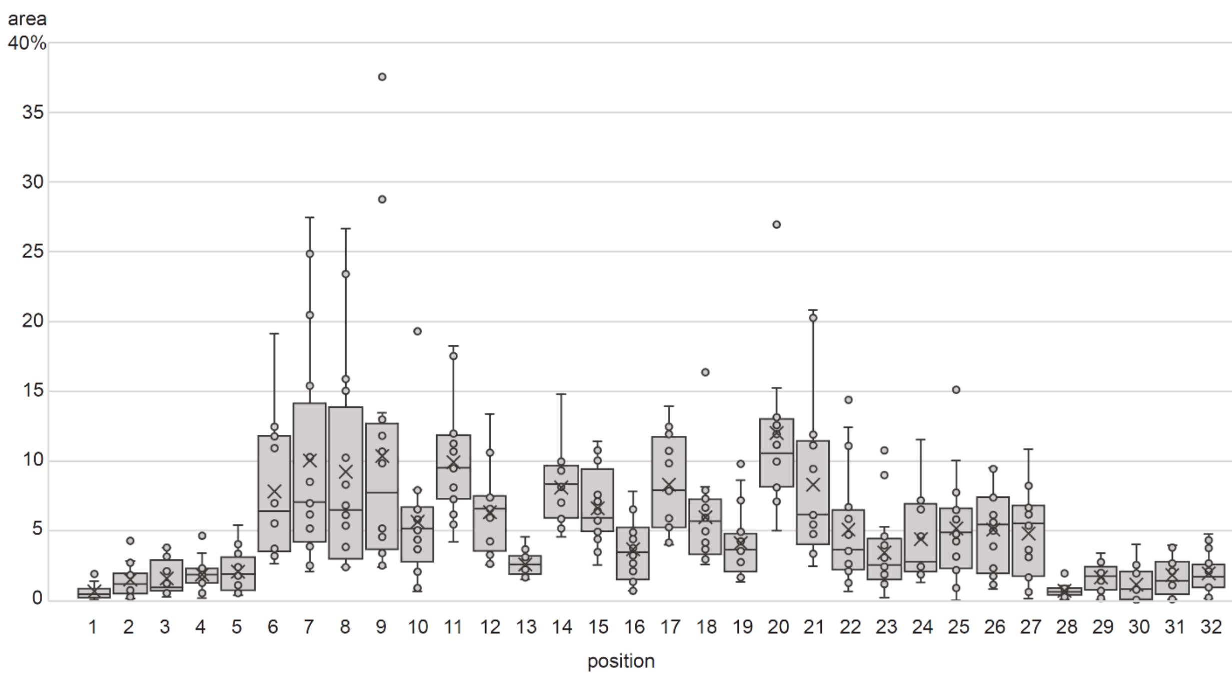

Figure 5. Distribution of average spray coverage across the array of deposition cards across the five rows of trees for the flights flown at 10-foot elevation.

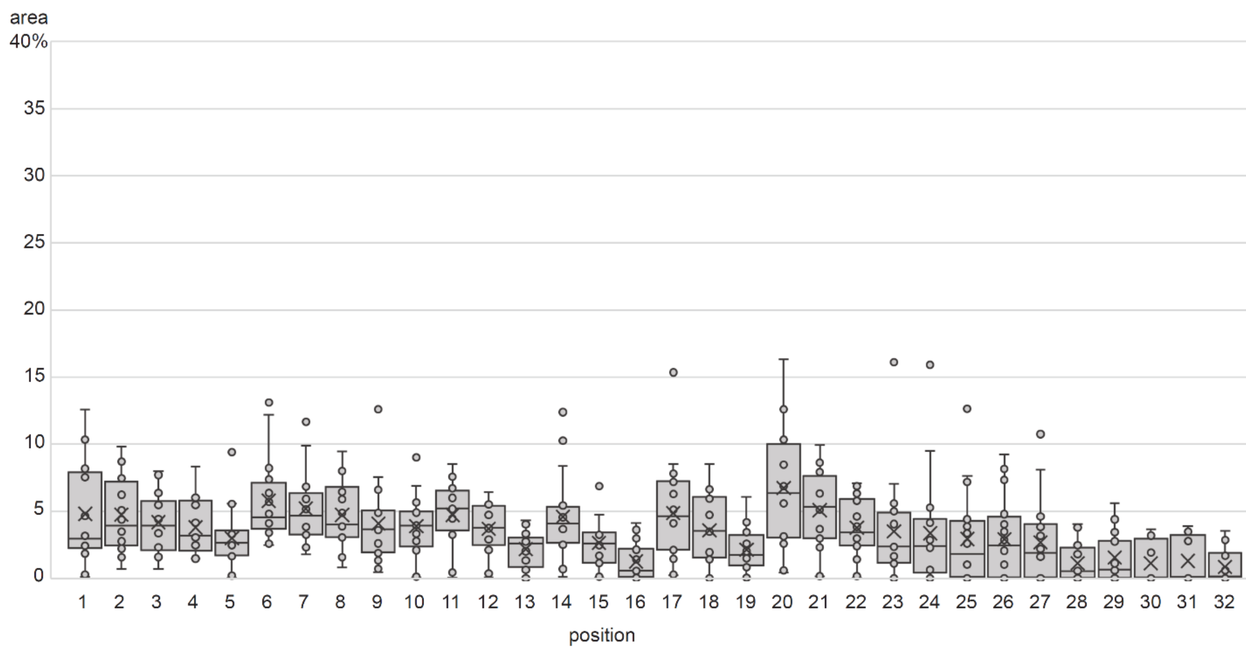

Figure 6. Distribution of average spray coverage across the array of deposition cards across the five rows of trees for the flights flown at 15-foot elevation.

Spray coverage from spray drone applications appears to be adequate for herbicide applications in conifer production. Yet, significant challenges remain before wide-spread adoption of this application system including:

- Applicator and pilot licensing challenges
- Battery life and payload
- Operational conditions: uneven terrain, wind, etc.
- Confirmation of product efficacy

Despite these challenges, the use of spray drones for weed management in Christmas tree production has great potential to mitigate labor shortages for spray applications, particularly on farms with steep terrain that currently rely on backpack sprayer applications.

Publications / Presentations

1. Derr, J., Neal, J., and Bhowmik, P. 2020. Herbicide Resistance in the Nursery Crop Production and Landscape Maintenance Industries. Weed Technology 34(3):437-446; DOI: https://doi.org/10.1017/wet.2020.40

2. Neal, J., C. Harlow, and J. Owen, 2019. Controlling glyphosate-tolerant *Conyza* in NC Fraser fir production. Proc. Northeast. Plants, Pests, and Soils Conf. 4:71 https://www.newss.org/wp-content/uploads/2019-NEPPSC-Proceedings-FINAL.pdf

3. Neal, J. C. and J. Derr. 2020. Herbicide resistance issues in nursery crops, Christmas trees and landscape plantings. Proc. Weed Sci. Soc. Amer. (http://apexwebstudio.com/WeedSciAbstracts/WSSA/WSSA2020-Abstracts-Proceedings.html)

Presentations:

NC Christmas Tree Growers Association Summer meeting and tour, 2021 (Christmas Tree Promotion Board;s support was acknowledged).

- Preemergence and Postemergence herbicide safety and efficacy trials were presented.
- Drone application system was demonstrated

International Christmas Tree Research and Extension meeting 2022. Glyphosate Resistant Weed Control Research, poster presentation June 2022. (Christmas Tree Promotion Board;s support was acknowledged).

Other outcomes and impacts:
1. Weedar 64 (2,4-D amine) label was expanded to include pre-budbreak applications in Fraser fir production.

2. Based on this research, the USDA IR-4 program prioritized and funded additional research to generate the required data for registration of FirstRate and Harmony for use in Christmas tree production (registration status is questionable due to changes in product marketing agreements and ownership).

3. The potential for use of Python for horseweed control was demonstrated and results will be shared with the manufacturers and the USDA IR-4 program to assess the potential for registration.

4. Results demonstrated that ragweed will be particularly difficult to control in Fraser fir fields where living ground covers are desirable. Preliminary results have been shared with Extension agents and growers through the NC State Extension communication portal system. https://content.ces.ncsu.edu/common-ragweed-a-problem-weed-in-nc-fraser-fir-production

2. Summary of Research Report for Public Release by CTPB- Summary should be suitable for non-scientific audience and should not exceed one page. Photograph(s) of research aspects suitable for publication are requested.

Over 50% of Christmas tree producers report herbicide-resistant weeds to be present in their operations. With support from the CTPB, the USDA-IR4 Environmental Horticulture program, and the North Carolina Christmas Tree Growers Association, the Fraser fir ground cover vegetation management research team at North Carolina State University has identified several potential options for the control of glyphosate-tolerant weeds in Fraser fir production. The underlying challenge of this project was to identify control options for glyphosate-tolerant weeds while maintaining a living ground cover for erosion control, dominated by white clover. In this research, pre-budbreak applications of 2,4-D amine, saflufenacil, flumetsulam, or cloransulam controlled horseweed, the most wide-spread glyphosate tolerant weed in southern Appalachian Fraser fir production fields. After budbreak, control options are more restrictive but cloransulam was generally safe and effective when combined with suppression rates of glyphosate. Other weeds will require different herbicide mixtures or rotations. Thifensulfuron combined with glyphosate controlled lambsquarters but was less effective on horseweed or ragweed. Ragweed was controlled by saflufenacil, florpyrauxifen, topramazone, or 2,4-D amine. However, ragweed emerges after Fraser fir plants had started growth in the spring. At that timing, 2,4-D, saflufenacil and florpyrauxifen caused unacceptable injury to Fraser fir. Topramazone was an effective treatment for horseweed, ragweed and lambsquarters, and was not injurious to the Fraser fir trees. However, topramazone was very injurious to the white clover ground cover. Resistance management will be an important part of Fraser fir ground cover programs in the future. Research is continuing, but thus far this research has identified promising herbicide options with three different modes of action that could be used in rotation or mixtures. Data from these studies will be used to advance herbicide registration efforts to provide useful tools for Christmas tree producers. Spray drone applications of herbicides show promise for controlling weeds in conifer production, yet significant challenges remain before wide-spread adoption is possible. Our studies demonstrated adequate spray coverage, but actual herbicide efficacy evaluations are needed. Furthermore, terrain, wind, battery life, payload capacity, and overall dependability of the equipment will limit spray drone adoption.

Based on these results, we can draw the following conclusions:

- When glyphosate-tolerant weeds are present, the control strategies will need to be tailored to the target weed species.
- Horseweed control:
  - Pre-budbreak applications of 2,4-D amine were effective and did not injure Fraser fir trees. Based on this research, Nufarm has added this use to the Weedar 64 label.

    - Research results support continued work and possible registration of cloransulam and flumetsulam for horseweed control
    - Where maintenance of clover ground cover is not an objective, several preemergence and postemergence control options are possible including clopyralid, flumioxazin, topramazone, indaziflam, and others.
- Lambsquarters control
    - Thifensulfuron controlled lambsquarters with only mild, and temporary chlorosis on the new growth of Fraser fir trees.
    - While other treatments were effective for the control of lambsquarters, post-budbreak applications were injurious to Fraser fir.
    - Data support continued evaluation of topramazone for lambsquarters control where maintenance of clover ground cover is not an objective.
- Ragweed control:
    - Few effective options where maintenance of a clover ground cover is desired.
    - Combinations of cloransulam plus glyphosate suppressed seedling ragweed.
    - Where maintenance of clover ground cover is not a goal, clopyralid or topramazone may be applied to control glyphosate-tolerant ragweed.