Southern Forest Nursery Management Cooperative

RESEARCH REPORT 20-03

POST-EMERGENT HERBICIDE SCREENINGS ON BAREROOT PINE SEEDBEDS: A SUMMARY OF MULTIPLE PRODUCT TRIALS 2016-2019

by
Nina Payne, Ryan Nadel, and Scott Enebak

INTRODUCTION

Fifty years ago, researchers from Auburn University's Agricultural Experiment Station began to work in a cooperative weed control program to test herbicides in bareroot pine seedling beds. This program was sponsored by the U.S. Forest Service and state forestry agencies in 12 southern states. The focus of these 1970 trials was to identify pre-emergent herbicides for control of grasses and annual weeds, with results published in 1972 reports (Dill and Carter, 1973). In 1975 and 1976, researchers included post-emergent herbicides in trials for longer duration of weed control during the growing season. These included bifenox, hexazinone, cyperquat, chloramben, perfluidone, oxadiazon and prometryne (South et al 1976).

Although the use of herbicides in major agricultural crops (mainly cotton, soybeans, corn, and peanuts) has increased tenfold from 35 million pounds of active ingredient in 1960 to 394 million pounds of active ingredient in 2008, few of these herbicides are labeled for use in forest-tree nurseries. It is of interest that the following comment on herbicide registration was included in the aforementioned 1972 report:

> "None of the pre-emergence herbicides we are testing are registered for use in nursery seedbeds and none of the manufacturers we have contacted are willing to apply for registration. The manufacturers feel that the cost of registration and the risk of damage claims are too great for the small potential market. We are dealing with a crop valued at several thousand dollars per acre and no one is willing to risk injury of this magnitude for a few dollars' worth of herbicides."

As forest-tree nurseries occupy a minor market share of herbicide purchases, the testing of post-emergent herbicides still falls to individual companies and to organizations such as the Southern Forest Nursery Management Cooperative (SFNMC). Through testing and research, the SFNMC has participated in the registration of 10 herbicides for use in conifer nurseries since 1973. Five of these have since been banned or are restricted from use in certain states. Bareroot conifer nurseries routinely depend on the remaining herbicides for weed control, including oxyfluorfen, lactofen, and fomesafen.

The need for safe post-emergent herbicides for use in bareroot conifer nurseries is not in question, but the identification and testing of products from other markets (agricultural crops, turf, and ornamentals) can be time-consuming and laborious. In an effort to compress the testing time needed to identify products for registration in conifer nurseries, the SFNMC has tested 17 herbicides in over-the-top post-emergent applications in bareroot

conifer nurseries since 2016. The objectives of these trials were to determine the tolerance of loblolly and slash pine to selected post-emergent herbicides applied later in the growing season. Weed control evaluations were not included in these studies, as each herbicide was selected for its listed weeds controlled or suppressed. The 17 herbicides tested over the four year period are listed below:

Herbicide active ingredient	Product used	Years tested	No. of loblolly pine test installations	No. of slash pine test installations
bentazon	Basagran®	2017	4	1
bispyribac	Velocity®	2017, 2018	4	2
clethodim	TapOut®	2017, 2018	6	2
flazasulfuron	Mission®	2018	2	1
florasulam	Defendor™	2016, 2017, 2018, 2019	13	4
flumioxazin	Valor®EZ	2017	4	1
imazapic	Plateau®	2018	1	1
mesotrione	Tenacity®	2019	4	1
orthosulfamuron	Strada®	2018, 2019	6	2
oxadiazon	Ronstar®Flo	2018, 2019	6	2
penoxsulam	Grasp®SC	2016, 2017, 2019	12	3
primisulfuron	Beacon®	2019	4	1
pyraflufen	Venue®	2018, 2019	6	2
sulfentrazone	Dismiss®	2016, 2017	5	2
tolpyralate	Shieldex®400SC	2018, 2019	6	2
topramezone	Frequency®	2017, 2018, 2019	10	3
trifloxysulfuron	Envoke®	2016, 2017, 2018, 2019	14	4

Descriptions of each herbicide, with the exception of mesotrione and primisulfuron, are included in previous research reports (Payne et al 2017, 2018, 2019). Two herbicides tested for the first time in 2019 include:

Mesotrione used as Tenacity® (Syngenta, North Carolina) is a HPPD inhibitor (Group 27), restricting photosynthesis in targeted plants in pre- and post-emergent applications. It is manufactured by Syngenta and was introduced to the U.S. market in 2001. Mesotrione labeled as Tenacity® is used in the turf market, while this active ingredient in Callisto® is labeled for use in corn. It is not currently labeled for use in conifer nurseries. Common nursery weeds listed as controlled on its labels include crabgrass, goosegrass, lovegrass, carpetweed, horseweed, morningglory, yellow nutsedge, and pigweed.

Primisulfuron used as Beacon® (Syngenta, North Carolina) is an ALS inhibitor (Group 2) and stops plant growth by blocking amino acid production in post-emergent applications. Beacon® is manufactured by Syngenta for weed control in corn. It is not currently labeled for use in conifer nurseries. Controlled weeds of interest to nurseries include Florida beggarweed, horseweed, Johnsongrass, morningglory, yellow nutsedge, pigweed and sicklepod.

METHODOLOGY

From June 2016 - July 2019, selected herbicides were sprayed as over-the-top applications in ten bareroot conifer SFNMC member nurseries. These nurseries are listed below:

Company/State	Location
ArborGen	Blenheim, SC
ArborGen	Selma, AL
ArborGen	Shellman, GA
ArborGen	Trenton, SC (was SCFC-owned during study)
Georgia Forestry Commission	Byromville, GA
IFCO	Jesup, GA
IFCO	Pine Hill, AL (was Weyerhaeuser-owned during study)
IFCO	Verbena, AL
K & L Forest Nursery	Buena Vista, GA
Rayonier	Elberta, AL

The number of nurseries used in this study provided a variety of soil types to test herbicidal tolerance. These soil types are listed in Table 3.

At each nursery, studies were installed in randomized block designs with each treatment being one seedling bed wide and between 5 and 10 feet in length, depending on bed space availability. These treatments were repeated in four or five replications depending on available bed space. Each trial included a non-treated control and 4 to 11 herbicides, based on year of study. All herbicides were applied by SFNMC staff using CO_2 sprayers configured to broadcast spray the width of one bed in a single pass. Handheld spray equipment was calibrated to an equivalent application of 25 gallons per acre.

Each herbicide was applied at its lowest labeled rate, as listed in Table 4. Adjuvants or surfactants were added and products were watered in based on label recommendations. All applications were made at 8 - 11 weeks post-sowing, with the exception of the first year of study. The 2016 study testing florasulam, penoxsulam, sulfentrazone and trifloxysulfuron had additional application timings at sowing and at 13 and 16 weeks post-sowing, but results of those sprays were not included in this summary report to maintain spray timing consistency at 8 to 11 weeks post-sowing.

After spray applications were made, nursery managers were instructed to maintain operational procedures (irrigation, fertilization, and mechanical treatments) in the beds including the test areas. As weed control was not evaluated in these studies, hand-weeding was allowed as a sanitation procedure.

Bed density measurements and seedling sample collections and measurements were made each year in November or December of the growing year or in January or February of the following year. In order to quantify seedling density, a 4-foot by 9-inch counting frame (3 square feet) was placed in each plot (non-treated control and each herbicide plot), and seedlings from the two outside rows were removed, bundled, and labeled. These were added to seedlings collected from interior rows within the counting frame. In the first year of study, seedlings from rows 2, 4 and 6 within the counting frame were bundled and labeled as such, then placed in the bag with exterior

rows and remaining interior row seedlings. In the remaining years (2017 – 2019), seedlings from all interior rows within the counting frame were removed and placed in the same bag with the corresponding bundled seedlings from exterior rows. Counts of all seedlings within counting frames were made at the SFNMC lab to determine total bed density of each plot.

In 2016, measurements of seedling characteristics were made on all seedlings collected from rows 2, 4 and 6 in each plot, with an average of 33 seedlings per plot measured. Random samples of 25 interior row seedlings per plot were measured in the 2017, 2018, and 2019 studies. Root collar diameter, seedling height, dry weight of roots and dry weight of tops were measured on each seedling, with over 22,000 seedlings measured over the four-year period of this study. To quantify seedling tolerance to each herbicide, comparisons were made of measurements of non-treated control seedlings to treated seedlings, by herbicide. All data was analyzed and examined using Duncan's Multiple Range test, Dunnett's t-test and Wilcoxon Method for Nonparametric Comparisons, all at alpha = 0.05.

RESULTS OF 2019 TRIALS

Results of studies conducted in 2016, 2017, and 2018 were included in reports in the years following the field studies (Payne et al 2017, 2018, 2019). Results of 2019 trials are reported by herbicide active ingredients.

Florasulam (used as Defendor™) was tested at four bareroot loblolly pine nurseries in 2019. No negative effects of the herbicide were quantified in 5 seedling characteristics (bed density, shoot height, root collar diameter, root dry weight and shoot dry weight) at 2 nurseries. In one of the remaining nurseries, treated seedlings' root collar diameters were statistically smaller (by 0.24 mm) than non-treated seedlings at one nursery. At the second nursery, shoots of treated seedlings were statistically shorter (by 1.0 cm) than non-treated seedlings. All other seedling characteristics measured showed no negative effects (Table 5).

This herbicide was tested in bareroot slash pine seedlings at one nursery in 2019. No negative effects of the herbicide treatment were quantified when treated seedlings were compared to seedlings from non-treated plots (Table 6).

Mesotrione (used as Tenacity®) was tested for the first time by the SFNMC in 2019. In the four loblolly pine nurseries tested, only one negative effect of the herbicide was quantified in one nursery. Shoot heights of treated seedlings at one nursery were statistically shorter (by 1.1 cm) than those of non-treated seedlings. No other statistically significant differences were measured (Table 7).

In the single slash pine nursery included, no negative effects of the herbicide were quantified (Table 8).

Orthosulfamuron (used as Strada®) was tested in four loblolly pine nurseries and one slash pine nursery in 2019. No negative effects of the use of the herbicide were quantified, with the exception of statistically significant shorter shoot heights in treated seedlings at 3 of the 4 nurseries. Those shoot heights were 1.0 cm, 0.5 cm, and 0.9 cm shorter than non-treated seedlings. It should be

noted that shoot height differences in seedlings that are top-clipped during the growing season should not be attributed solely to herbicidal effect (Table 9).

No negative effects of orthosulfamuron treatments were quantified in slash pine in one nursery included in this study (Table 10).

Oxadiazon (used as Ronstar®Flo) was tested in an over-the-top application in 4 loblolly pine nurseries and one slash pine nursery, although it is labeled for use as a preemergent herbicide or in directed spray post-emergent applications in conifer nurseries. The product label recommends watering-in by overhead irrigation or rainfall after application, so treated plots were watered manually after spray applications. The only seedling characteristic with statistically significant lower measurements in treated vs. non-treated seedlings was shoot height. Lower heights in two loblolly pine installations (1.0 cm and 0.7 cm) and lower shoot heights in slash pine (1.1 cm) were quantified (Tables 11 and 12).

It should be noted that one SFNMC nursery independently testing Ronstar®Flo in 2018 in a postemergent over-the-top spray on loblolly pine reported visible seedling damage attributed to the herbicide application.

Penoxsulam (used as Grasp®SC) was selected for retesting even though studies conducted in 2016 and 2017 resulted in lower shoot heights and root collar diameters in several nurseries. The list of weeds controlled on the Grasp®SC label includes rice flatsedge *(Cyperus iria)*, which continues to be a problem weed in conifer nurseries. Similar results were found in this repeated trial, as lower seedling heights, root collar diameters and shoot weights were measured in the four loblolly pine installations (Table 13).

No herbicidal damage was quantified in the single slash pine installation. These results are similar to those found in 2016 (2 nurseries) and 2017 (1 nursery) studies in slash pine, where the only negative effect measured was lower shoot height (by 1.5 cm) at one nursery (Table 14).

Primisulfuron (used as Beacon®) was tested in 2019 in one slash pine and four loblolly pine nurseries. In the loblolly nurseries, shorter seedling heights (by 1.1 cm and 0.5 cm) were measured in 2 nurseries and lower root weights (by 1.3 grams) were measured at one nursery when treated seedlings were compared to non-treated control seedlings (Table 15).

No negative effects were quantified when comparing treated slash pine seedlings with non-treated seedlings (Table 16).

Pyraflufen (used as Venue®) was tested in 2019 in four loblolly pine nurseries and one slash pine nursery. Smaller root collar diameters (by 0.44 mm) were measured in one loblolly pine nursery and lower shoot heights (by 2.9 cm and 1.0 cm) were measured in two loblolly pine nurseries (Table 17).

No negative effects of the herbicide were measured when comparing treated slash pine seedlings to non-treated seedlings (Table 18).

Tolpyralate (used as Shieldex®400SC) was tested at four loblolly pine and one slash pine seedling nurseries in 2019. No negative effects of herbicide treatments were measured in any of the five installations (Tables 19 and 20).

Topramezone (used as Frequency®) was tested in 2019 in one slash pine and four loblolly pine nurseries. The single negative effect measured in the installations was lower shoot heights (by 1.1cm) in one loblolly pine nursery. No other negative effects of the herbicide were found in any of the loblolly nurseries or the single slash pine nursery (Tables 21 and 22).

Trifloxysulfuron (used as Envoke®) was included in studies in one slash pine nursery and four loblolly pine nurseries. No negative effects of herbicide treatments were measured in either loblolly or slash pine with the exception of lower shoot heights (by 0.7 cm) at one loblolly pine nursery (Tables 23 and 24).

SUMMARY RESULTS OF MULTIPLE PRODUCT TRIALS 2016-2019

As these trials progressed, it became evident that the 17 herbicides tested could be grouped into three categories: 1) those herbicides causing visible, evident damage to seedlings, 2) those herbicides causing little or no visible and/or quantifiable effects on seedlings, and 3) those herbicides showing inconsistent effects on seedlings varying by installation site and testing year. A method of determining which herbicides to retest became necessary, so Tables 1 and 2 were created to identify those herbicides warranting repeated trials in order to adequately quantify herbicidal effects.

Of the 17 herbicides listed, two will not be tested again as they are currently labeled for use in conifer nurseries. **Clethodim** was tested at the request of SFNMC member nurseries since it had not been previously tested, and **oxadiazon** was tested in a different application than is currently on the product label. Results of 3 - 4 years of testing three herbicides, namely **florasulam**, **topramezone** and **trifloxysulfuron**, may be made available to the product manufacturers to be evaluated for potential labeling for use in conifer nurseries. Seven herbicides were eliminated from further testing due to negative tolerance results in loblolly pine. These were **bentazon**, **bispyribac**, **flazasulfuron**, **flumioxazin**, **imazapic**, **penoxsulam**, and **sulfentrazone**.

After analyzing data from the 2019 loblolly pine trials, five herbicides were considered for retesting based on seedling tolerance. There are mesotrione, orthosulfamuron, primisulfuron, pyraflufen, and tolpyralate. In order to reduce the size of 2020 installations, three of these (**mesotrione, orthosulfamuron**, and **tolpyralate**,) have been selected for possible retesting in 2020. Each of these three herbicide active ingredients offers specific advantages to conifer nursery growers. Tenacity® (mesotrione) includes grasses, broadleaf weeds and yellow nutsedge on its labeled list of controlled weeds. Strada® (orthosulfamuron) lists a distinctly problematic nursery weed, rice flatsedge, in its controlled weeds list. Shieldex® (tolpyralate) had no negative effects on any seedling characteristic when tested in 6 loblolly pine nurseries in 2018 and 2019. It includes grasses and broadleaf plants as controlled weeds on its label.

MANAGEMENT IMPLICATIONS

- **When considering the use of a new herbicide, a small test area at the site where it may be used should always be installed**, with visible results documented. Of the 17 herbicides tested, some resulted in mixed seedling tolerance levels, even when applied by the same method (in the same nursery, same year and time of year, by the same applicator and application method, on the same species, and using the same rate). Use of soil type comparisons will be helpful in determining similar-site suitability for new herbicides.

- **Herbicides with the active ingredients of bentazon**, **bispyribac**, **flazasulfuron**, **flumioxazin**, **imazapic**, **penoxsulam**, **or sulfentrazone should be used with extreme caution** in loblolly pine seedling nurseries, when application is to be made over-the-top of seedlings due to negative tolerance levels quantified in these studies. Although slash pine seedlings appear to be more tolerant of these herbicides, sample sizes in slash pine were much smaller than those in loblolly pine, providing less data for analysis. Similar repeated studies in slash pine would be necessary to quantify tolerance levels in slash pine. However, if **rice flatsedge** (*Cyperus iria*) is a problem in slash pine seedling beds, a test plot using Grasp® (penoxsulam) may provide control with minimal slash pine seedling damage, based on three years of testing in four installations.

- **Additional testing is warranted for herbicides with the active ingredients of mesotrione, orthosulfamuron, primisulfuron, pyraflufen, and tolpyralate** due to positive results on seedling tolerance in loblolly and slash pine. Applications of herbicides containing these five active ingredients were made in only 2 of the 4 years covered by this report, so additional rounds of testing are suggested.

- Herbicides developed for use in agricultural crops are generally tested for potential damage to subsequent crops and plant-back intervals on product labels are included. Because these herbicides have not been tested by their manufacturers in conifer bareroot nurseries, **the potential for carryover exists with any new herbicide tested.** Procedures should be in place to monitor test site areas into the next crop year. During the course of these studies, one carryover event has been documented in the spring germination season following use in the prior summer. Although exact plot locations could not be identified due to the layout of the nursery beds, the *probable* cause of the carryover was the herbicide Mission® (flazasulfuron). This product was not included in these studies after 2018.

ACKNOWLEDGEMENTS

The authors thank the following companies for providing product samples: Bayer CropScience, DowDupont, FMC, Nichino America, Summit Agro USA, Syngenta and Valent. Our gratitude is sent to the management and staff of the ten SFNMC member nurseries in which these studies were installed for their willingness to donate bed space and seedlings, for their assistance in the field, and for their continued support in conducting these studies.

REFERENCES

Dill, T. R. and M. C. Carter. 1973. Pre-emergence weed control in southeastern forest nurseries. *Weed Science* 21(4):363-366.

Fernandez-Cornejo, J., R. Nehring, C. Osteen, S. Wechsler, A. Martin, and A. Vialou. Pesticide Use in U.S. Agriculture: 21 Selected Crops, 1960-2008, EIB-124, U.S. Department of Agriculture, Economic Research Service, May 2014.

Payne, N. and S. Enebak. 2017. Herbicide trials with florasulam, penoxsulam, trifloxysulfuron and sulfentrazone in loblolly and slash pine seedbeds. Southern Forest Nursery Management Cooperative, Auburn University. Research Report 17-02. 10 pp.

Payne, N., R. Nadel and S. Enebak. 2018. Postemergent herbicide screening trials on loblolly and slash pine seedbeds. Southern Forest Nursery Management Cooperative, Auburn University. Research Report 18-04. 15 pp.

Payne, N., R. Nadel and S. Enebak. 2019. Postemergent herbicide screening trials on loblolly and slash pine seedbeds II. Southern Forest Nursery Management Cooperative, Auburn University. Research Report 19-04. 19 pp.

Pesticide Product and Label System. U. S. Environmental Protection Agency, www.iaspub.epa.gov/apex/pesticides/f?p=PPLS:1. Accessed May 1, 2020.

South, D., R. Crowley, and D. Gjerstad. 1976. Herbicide weed control results in pine seedbeds, pp. 95-106. In Proceedings, Southeastern Area Nurserymens' Conference, Charleston, South Carolina.

Web Soil Survey, NRCS, 1 May 2020, websoilsurvey.sc.egov.usda.gov/.

Weed Science Society of America. 2007. Herbicide Handbook. Weed Science Society of America, Lawrence, KS. 458 pp.

Zar, J. (1984) Biostatistical Analysis. Englewood Cliffs, New Jersey: Prentice-Hall, Inc.

Table 1. Summary table of 17 postemergent herbicides tested in loblolly pine 2016 – 2019.

Herbicide active ingredient	Product used	Years tested	SFNMC Research Report(s)	Total no. of loblolly pine test installations	No. of installations reporting negative seedling characteristics in treated seedlings[1]				
					Density	Height	RCD	Root wt.	Shoot wt.
bentazon	Basagran®	2017	18-04	4	2 of 4	2 of 4	1 of 4	0 of 4	0 of 4
bispyribac	Velocity®	2017, 2018	18-04, 19-04	4	0 of 4	2 of 4	1 of 4	0 of 4	0 of 4
clethodim	TapOut®	2017, 2018	18-04, 19-04	6	0 of 6	1 of 6	0 of 6	0 of 6	0 of 6
flazasulfuron	Mission®	2018	19-04	2	0 of 2	1 of 2	2 of 2	0 of 2	0 of 2
florasulam	Defendor™	2016[2], 2017, 2018, 2019	17-02, 18-04, 19-04, 20-03	13	0 of 13	3 of 13	2 of 13	0 of 13	0 of 13
flumioxazin	Valor®EZ	2017	18-04	4	1 of 4	2 of 4	0 of 4	0 of 4	0 of 4
imazapic	Plateau®	2018	19-04	1	0 of 4	1 of 1	1 of 1	1 of 1	1 of 1
mesotrione	Tenacity®	2019	20-03	4	0 of 4	1 of 4	0 of 4	0 of 4	0 of 4
orthosulfamuron	Strada®	2018, 2019	19-04, 20-03	6	0 of 6	3 of 6	0 of 6	0 of 6	0 of 6
oxadiazon	Ronstar®Flo	2018, 2019	19-04, 20-03	6	0 of 6	2 of 6	0 of 6	0 of 6	0 of 6
penoxsulam	Grasp®SC	2016[2], 2017, 2019	17-04, 18-04, 20-03	12	0 of 12	6 of 12	3 of 12	0 of 12	1 of 12
primisulfuron	Beacon®	2019	20-03	4	0 of 4	2 of 4	0 of 4	1 of 4	0 of 4
pyraflufen	Venue®	2018, 2019	19-04, 20-03	6	0 of 6	2 of 6	1 of 6	0 of 6	0 of 6
sulfentrazone	Dismiss®	2016[2], 2017	17-02, 18-04	5	0 of 5	2 of 5	4 of 5	2 of 5	2 of 5
tolpyralate	Shieldex®	2018, 2019	19-04, 20-03	6	0 of 6	0 of 6	0 of 6	0 of 6	0 of 6
topramezone	Frequency®	2017, 2018, 2019	18-04, 19-04, 20-03	10	0 of 10	1 of 10	1 of 10	0 of 10	0 of 10
trifloxysulfuron	Envoke®	2016[2], 2017, 2018, 2019	17-02, 18-04, 19-04, 20-03	14	0 of 14	1 of 14	0 of 14	0 of 14	0 of 14

[1] The information in these columns shows the number of nurseries in which statistically significant lower measurements of treated seedlings compared to non-treated seedlings were reported for that seedling characteristic. For instance, when bed densities of bentazon-treated seedlings were compared to densities of non-treated seedlings, lower seedling counts were made in 2 of the 4 nurseries included.

[2] Results of 2016 trials are based on the 8-week post-sowing data.

Table 2. Summary table of 17 postemergent herbicides tested in slash pine 2016 – 2019.

Herbicide active ingredient	Product used	Years tested	SFNMC Research Report(s)	Total no. of slash pine test installations	No. of installations reporting negative seedling characteristics in treated seedlings[1]				
					Density	Height	RCD	Root wt.	Shoot wt.
bentazon	Basagran®	2017	18-04	1	0 of 1	0 of 1	0 of 1	0 of 1	0 of 1
bispyribac	Velocity®	2017, 2018	18-04, 19-04	2	0 of 2	2 of 2	0 of 2	0 of 2	0 of 2
clethodim	TapOut®	2017, 2018	18-04, 19-04	2	0 of 2	0 of 2	0 of 2	0 of 2	0 of 2
flazasulfuron	Mission®	2018	19-04	1	0 of 1	1 of 1	0 of 1	0 of 1	0 of 1
florasulam	Defendor™	2016[2], 2017, 2018, 2019	17-02, 18-04, 19-04, 20-03	4	0 of 4	1 of 4	0 of 4	0 of 4	0 of 4
flumioxazin	Valor®EZ	2017	18-04	1	0 of 1	0 of 1	0 of 1	0 of 1	0 of 1
imazapic	Plateau®	2018	19-04	1	0 of 1	1 of 1	1 of 1	1 of 1	1 of 1
mesotrione	Tenacity®	2019	20-03	1	0 of 1	0 of 1	0 of 1	0 of 1	0 of 1
orthosulfamuron	Strada®	2018, 2019	19-04, 20-03	2	0 of 2	1 of 2	0 of 2	0 of 2	0 of 2
oxadiazon	Ronstar®Flo	2018, 2019	19-04, 20-03	2	0 of 2	1 of 2	0 of 2	0 of 2	0 of 2
penoxsulam	Grasp®SC	2016[2], 2017, 2019	17-04, 18-04, 20-03	4	0 of 4	1 of 4	0 of 4	0 of 4	0 of 4
primisulfuron	Beacon®	2019	20-03	1	0 of 1	0 of 1	0 of 1	0 of 1	0 of 1
pyraflufen	Venue®	2018, 2019	19-04, 20-03	2	0 of 2	0 of 2	0 of 2	0 of 2	0 of 2
sulfentrazone	Dismiss®	2016[2], 2017	17-02, 18-04	2	0 of 2	0 of 2	1 of 2	0 of 2	0 of 2
tolpyralate	Shieldex®	2018, 2019	19-04, 20-03	2	0 of 2	0 of 2	0 of 2	0 of 2	0 of 2
topramezone	Frequency®	2017, 2018, 2019	18-04, 19-04, 20-03	3	0 of 3	0 of 3	0 of 3	0 of 3	0 of 3
trifloxysulfuron	Envoke®	2016[2], 2017, 2018, 2019	17-02, 18-04, 19-04, 20-03	4	0 of 4	0 of 4	0 of 4	0 of 4	0 of 4

[1] The information in these columns shows the number of nurseries in which statistically significant lower measurements of treated seedlings compared to non-treated seedlings were reported for that seedling characteristic. For instance, when shoot heights of bispyribac-treated seedlings were compared to heights of non-treated seedlings, shorter seedlings were measured in 2 of the 2 nurseries included.

[2] Results of 2016 trials are based on the 8-week post-sowing data

Table 3. Soil types of ten nurseries used in four years of post-emergent herbicide screening studies 2016 -2019.

Nursery	Soil Type
ArborGen Blenheim, SC	Foxworth sand
ArborGen Selma, AL	Wickham fine loamy sand
ArborGen Shellman, GA	Lucy loamy sand
ArborGen Trenton, SC	Wagram sand
GFC Byromville, GA	Eustis loamy sand
IFCO Jesup, GA	Norfolk loamy sand
IFCO Pine Hill, AL	Lenoir silt loam
IFCO Verbena, AL	Troup loamy sand
K & L Forest Buena Vista, GA	Lucy loamy sand
Rayonier Elberta, AL	Lakeland loamy fine sand

Table 4. Rates of 17 post-emergent herbicides tested in 10 bareroot loblolly and slash pine nurseries 2016 – 2019.

Herbicide active ingredient	Product	Rate per acre
bentazon	Basagran®	24 oz.
bispyribac	Velocity®	6 oz.
clethodim	TapOut®	9 oz.
flazasulfuron	Mission®	2.14 oz.
florasulam	Defendor™	4 oz.
flumioxazin	Valor®EZ	2 oz.
imazapic	Plateau®	4 oz.
mesotrione	Tenacity®	4 oz.
orthosulfamuron	Strada®	1.7 g
oxadiazon	Ronstar®FLO	80 oz.
penoxsulam	Grasp®SC	2 oz.
primisulfuron	Beacon®	21.5 g
pyraflufen	Venue®	2 oz.
sulfentrazone	Dismiss®	4 oz.
tolpyralate	Shieldex®400SC	1 oz.
topramezone	Frequency®	4 oz.
trifloxysulfuron	Envoke®	0.1 g

Table 5. Bareroot loblolly pine seedling characteristics treated with florasulam (Defendor™) at 9-11 weeks post-sowing at four nurseries.

Nursery	Application Date	Treatment	Density/ft^2	Shoot Height (cm)	RCD (mm)	Root Weight (g)	Shoot Weight (g)
Georgia Forestry Commission, GA	7/9/19	Control	20.7	28.3	4.21	0.63	2.45
		Defendor™	20.5	28.5	4.25	0.66	2.54
IFCO Jesup, GA	7/8/19	Control	27.9	24.6	4.41	0.57	2.44
		Defendor™	30.5	25.3	4.17	0.50	2.13
IFCO White City, AL	7/3/19	Control	29.3	27.8	4.74	0.74	3.05
		Defendor™	24.8	27.2	5.13	0.89	3.57
K & L, GA	7/2/19	Control	26.8	29.3	4.63	0.82	3.21
		Defendor™	25.1	28.3	4.59	0.78	2.92

Single underlined means within a seedling characteristic indicate significant treatment difference from that of the non-treated control at that rate according to Dunnett's T-test at alpha = 0.05.

Double underlined means within a seedling characteristic indicate a significant treatment difference from that of the non-treated control at that rate according to nonparametric Wilcoxon test at alpha = 0.05.

Table 6. Bareroot slash pine seedling characteristics treated with florasulam (Defendor™) at 9 weeks post-sowing at one nursery.

Nursery	Application Date	Treatment	Density/ft^2	Shoot Height (cm)	RCD (mm)	Root Weight (g)	Shoot Weight (g)
Georgia Forestry Commission, GA	7/9/19	Control	22.7	24.1	4.46	0.71	2.76
		Defendor™	21.7	26.0	4.73	0.78	3.04

Single underlined means within a seedling characteristic indicate significant treatment difference from that of the non-treated control at that rate according to Dunnett's T-test at alpha = 0.05.

Table 7. Bareroot loblolly pine seedling characteristics treated with mesotrione (Tenacity®) at 9-11 weeks post-sowing at four nurseries.

Nursery	Application Date	Treatment	Density/ft^2	Shoot Height (cm)	RCD (mm)	Root Weight (g)	Shoot Weight (g)
Georgia Forestry Commission, GA	7/9/19	Control	20.7	28.3	4.21	0.63	2.45
		Tenacity®	21.5	29.0	4.37	0.68	2.54
IFCO Jesup, GA	7/8/19	Control	27.9	24.6	4.41	0.57	2.44
		Tenacity®	30.4	<u>23.5</u>	4.28	0.51	2.20
IFCO White City, AL	7/3/19	Control	29.3	27.8	4.74	0.74	3.05
		Tenacity®	26.0	26.8	4.92	0.83	3.00
K & L, GA	7/2/19	Control	26.8	29.3	4.63	0.82	3.21
		Tenacity®	22.5	29.5	4.77	0.77	3.34

Double underlined means within a seedling characteristic indicate a significant treatment difference from that of the non-treated control at that rate according to nonparametric Wilcoxon test at alpha = 0.05.

Table 8. Bareroot slash pine seedling characteristics treated with mesotrione (Tenacity®) at 9 weeks post-sowing at one nursery.

Nursery	Application Date	Treatment	Density/ft^2	Shoot Height (cm)	RCD (mm)	Root Weight (g)	Shoot Weight (g)
Georgia Forestry Commission, GA	7/9/19	Control	22.7	24.1	4.46	0.71	2.76
		Tenacity®	23.1	<u>26.3</u>	4.57	0.73	2.97

Single underlined means within a seedling characteristic indicate significant treatment difference from that of the non-treated control at that rate according to Dunnett's T-test at alpha = 0.05.

Table 9. Bareroot loblolly pine seedling characteristics treated with orthosulfamuron (Strada®) at 9-11 weeks post-sowing at four nurseries.

Nursery	Application Date	Treatment	Density/ft²	Shoot Height (cm)	RCD (mm)	Root Weight (g)	Shoot Weight (g)
Georgia Forestry Commission, GA	7/9/19	Control	20.7	28.3	4.21	0.63	2.45
		Strada®	20.3	27.3	4.28	0.65	2.49
IFCO Jesup, GA	7/8/19	Control	27.9	24.6	4.41	0.57	2.44
		Strada®	28.8	24.1	4.31	0.57	2.28
IFCO White City, AL	7/3/19	Control	29.3	27.8	4.74	0.74	3.05
		Strada®	25.1	28.3	4.95	0.74	3.52
K & L, GA	7/2/19	Control	26.8	29.3	4.63	0.82	3.21
		Strada®	23.8	28.4	4.76	0.93	3.27

Double underlined means within a seedling characteristic indicate a significant treatment difference from that of the non-treated control at that rate according to nonparametric Wilcoxon test at alpha = 0.05.

Table 10. Bareroot slash pine seedling characteristics treated with orthosulfamuron (Strada®) at 9 weeks post-sowing at one nursery.

Nursery	Application Date	Treatment	Density/ft²	Shoot Height (cm)	RCD (mm)	Root Weight (g)	Shoot Weight (g)
Georgia Forestry Commission, GA	7/9/19	Control	22.7	24.1	4.46	0.71	2.76
		Strada®	23.8	23.7	4.32	0.68	2.64

Table 11. Bareroot loblolly pine seedling characteristics treated with oxadiazon (Ronstar®Flo) at 9-11 weeks post-sowing at four nurseries.

Nursery	Application Date	Treatment	Density/ft²	Shoot Height (cm)	RCD (mm)	Root Weight (g)	Shoot Weight (g)
Georgia Forestry Commission, GA	7/9/19	Control	20.7	28.3	4.21	0.63	2.45
		Ronstar®Flo	21.6	28.6	4.21	0.63	2.49
IFCO Jesup, GA	7/8/19	Control	27.9	24.6	4.41	0.57	2.44
		Ronstar®Flo	29.0	23.6	4.34	0.50	2.26
IFCO White City, AL	7/3/19	Control	29.3	27.8	4.74	0.74	3.05
		Ronstar®Flo	24.8	28.5	5.07	0.86	3.41
K & L, GA	7/2/19	Control	26.8	29.3	4.63	0.82	3.21
		Ronstar®Flo	23.7	29.0	4.60	0.80	3.18

Double underlined means within a seedling characteristic indicate a significant treatment difference from that of the non-treated control at that rate according to nonparametric Wilcoxon test at alpha = 0.05.

Table 12. Bareroot slash pine seedling characteristics treated with oxadiazon (Ronstar®Flo) at 9 weeks post-sowing at one nursery.

Nursery	Application Date	Treatment	Density/ft²	Shoot Height (cm)	RCD (mm)	Root Weight (g)	Shoot Weight (g)
Georgia Forestry Commission, GA	7/9/19	Control	22.7	24.1	4.46	0.71	2.76
		Ronstar®Flo	23.2	23.0	4.49	0.70	2.68

Single underlined means within a seedling characteristic indicate significant treatment difference from that of the non-treated control at that rate according to Dunnett's T-test at alpha = 0.05.

Table 13. Bareroot loblolly pine seedling characteristics treated with penoxsulam (Grasp®) at 9-11 weeks post-sowing at four nurseries.

Nursery	Application Date	Treatment	Density/ft^2	Shoot Height (cm)	RCD (mm)	Root Weight (g)	Shoot Weight (g)
Georgia Forestry Commission, GA	7/9/19	Control	20.7	28.3	4.21	0.63	2.45
		Grasp®	24.8	25.3	3.91	0.60	2.05
IFCO Jesup, GA	7/8/19	Control	27.9	24.6	4.41	0.57	2.44
		Grasp®	30.7	22.5	4.24	0.59	2.12
IFCO White City, AL	7/3/19	Control	29.3	27.8	4.74	0.74	3.05
		Grasp®	23.2	23.4	5.02	1.09	3.32
K & L, GA	7/2/19	Control	26.8	29.3	4.63	0.82	3.21
		Grasp®	26.3	28.5	4.58	0.74	2.91

Single underlined means within a seedling characteristic indicate significant treatment difference from that of the non-treated control at that rate according to Dunnett's T-test at alpha = 0.05.

Double underlined means within a seedling characteristic indicate a significant treatment difference from that of the non-treated control at that rate according to nonparametric Wilcoxon test at alpha = 0.05.

Table 14. Bareroot slash pine seedling characteristics treated with penoxsulam (Grasp®) at 9 weeks post-sowing at one nursery.

Nursery	Application Date	Treatment	Density/ft^2	Shoot Height (cm)	RCD (mm)	Root Weight (g)	Shoot Weight (g)
Georgia Forestry Commission, GA	7/9/19	Control	22.7	24.1	4.46	0.71	2.76
		Grasp®	21.6	23.6	4.55	0.74	2.63

Table 15. Bareroot loblolly pine seedling characteristics treated with primisulfuron (Beacon®) at 9-11 weeks post-sowing at four nurseries.

Nursery	Application Date	Treatment	Density/ft^2	Shoot Height (cm)	RCD (mm)	Root Weight (g)	Shoot Weight (g)
Georgia Forestry Commission, GA	7/9/19	Control	20.7	28.3	4.21	0.63	2.45
		Beacon®	21.9	27.2	4.18	0.62	2.36
IFCO Jesup, GA	7/8/19	Control	27.9	24.6	4.41	0.57	2.44
		Beacon®	27.8	25.2	4.43	0.57	2.45
IFCO White City, AL	7/3/19	Control	29.3	27.8	4.74	0.74	3.05
		Beacon®	27.3	27.8	4.68	0.72	3.04
K & L, GA	7/2/19	Control	26.8	29.3	4.63	0.82	3.21
		Beacon®	24.5	28.8	4.47	0.69	2.83

Single underlined means within a seedling characteristic indicate significant treatment difference from that of the non-treated control at that rate according to Dunnett's T-test at alpha = 0.05.

Double underlined means within a seedling characteristic indicate a significant treatment difference from that of the non-treated control at that rate according to nonparametric Wilcoxon test at alpha = 0.05.

Table 16. Bareroot slash pine seedling characteristics treated with primisulfuron (Beacon®) at 9 weeks post-sowing at one nursery.

Nursery	Application Date	Treatment	Density/ft^2	Shoot Height (cm)	RCD (mm)	Root Weight (g)	Shoot Weight (g)
Georgia Forestry Commission, GA	7/9/19	Control	22.7	24.1	4.46	0.71	2.76
		Beacon®	23.7	26.1	4.59	0.73	2.87

Single underlined means within a seedling characteristic indicate significant treatment difference from that of the non-treated control at that rate according to Dunnett's T-test at alpha = 0.05.

Table 17. Bareroot loblolly pine seedling characteristics treated with pyraflufen (Venue®) at 9-11 weeks post-sowing at four nurseries.

Nursery	Application Date	Treatment	Density/ft²	Shoot Height (cm)	RCD (mm)	Root Weight (g)	Shoot Weight (g)
Georgia Forestry Commission, GA	7/9/19	Control	20.7	28.3	4.21	0.63	2.45
		Venue®	19.3	27.9	4.20	0.61	2.51
IFCO Jesup, GA	7/8/19	Control	27.9	24.6	4.41	0.57	2.44
		Venue®	31.2	21.7	3.97	0.49	1.98
IFCO White City, AL	7/3/19	Control	29.3	27.8	4.74	0.74	3.05
		Venue®	29.2	27.9	4.82	0.76	3.11
K & L, GA	7/2/19	Control	26.8	29.3	4.63	0.82	3.21
		Venue®	23.9	28.3	4.41	0.72	2.86

Double underlined means within a seedling characteristic indicate a significant treatment difference from that of the non-treated control at that rate according to nonparametric Wilcoxon test at alpha = 0.05.

Table 18. Bareroot slash pine seedling characteristics treated with pyraflufen (Venue®) at 9 weeks post-sowing at one nursery.

Nursery	Application Date	Treatment	Density/ft²	Shoot Height (cm)	RCD (mm)	Root Weight (g)	Shoot Weight (g)
Georgia Forestry Commission, GA	7/9/19	Control	22.7	24.1	4.46	0.71	2.76
		Venue®	20.9	24.5	4.68	0.78	3.16

Table 19. Bareroot loblolly pine seedling characteristics treated with tolpyralate (Shieldex®400SC) at 9-11 weeks post-sowing at four nurseries.

Nursery	Application Date	Treatment	Density/ft²	Shoot Height (cm)	RCD (mm)	Root Weight (g)	Shoot Weight (g)
Georgia Forestry Commission, GA	7/9/19	Control	20.7	28.3	4.21	0.63	2.45
		Shieldex®	24.5	27.7	4.01	0.56	2.26
IFCO Jesup, GA	7/8/19	Control	27.9	24.6	4.41	0.57	2.44
		Shieldex®	28.8	24.8	4.35	0.55	2.46
IFCO White City, AL	7/3/19	Control	29.3	27.8	4.74	0.74	3.05
		Shieldex®	28.9	28.0	4.80	0.75	3.10
K & L, GA	7/2/19	Control	26.8	29.3	4.63	0.82	3.21
		Shieldex®	24.8	29.2	4.72	0.77	3.26

Table 20. Bareroot slash pine seedling characteristics treated with tolpyralate (Shieldex®400SC) at 9 weeks post-sowing at one nursery.

Nursery	Application Date	Treatment	Density/ft²	Shoot Height (cm)	RCD (mm)	Root Weight (g)	Shoot Weight (g)
Georgia Forestry Commission, GA	7/9/19	Control	22.7	24.1	4.46	0.71	2.76
		Shieldex®	21.2	24.5	<u>4.74</u>	0.81	3.14

Single underlined means within a seedling characteristic indicate significant treatment difference from that of the non-treated control at that rate according to Dunnett's T-test at alpha = 0.05.

Table 21. Bareroot loblolly pine seedling characteristics treated with topramezone (Frequency®) at 9-11 weeks post-sowing at four nurseries.

Nursery	Application Date	Treatment	Density/ft^2	Shoot Height (cm)	RCD (mm)	Root Weight (g)	Shoot Weight (g)
Georgia Forestry Commission, GA	7/9/19	Control	20.7	28.3	4.21	0.63	2.45
		Frequency®	22.4	27.7	4.25	0.67	2.42
IFCO Jesup, GA	7/8/19	Control	27.9	24.6	4.41	0.57	2.44
		Frequency®	28.3	24.4	4.40	0.57	2.56
IFCO White City, AL	7/3/19	Control	29.3	27.8	4.74	0.74	3.05
		Frequency®	24.2	28.4	5.23	0.94	3.87
K & L, GA	7/2/19	Control	26.8	29.3	4.63	0.82	3.21
		Frequency®	22.3	28.2	4.56	0.74	3.03

Single underlined means within a seedling characteristic indicate significant treatment difference from that of the non-treated control at that rate according to Dunnett's T-test at alpha = 0.05.

Double underlined means within a seedling characteristic indicate a significant treatment difference from that of the non-treated control at that rate according to nonparametric Wilcoxon test at alpha = 0.05.

Table 22. Bareroot slash pine seedling characteristics treated with topramezone (Frequency®) at 9 weeks post-sowing at one nursery.

Nursery	Application Date	Treatment	Density/ft^2	Shoot Height (cm)	RCD (mm)	Root Weight (g)	Shoot Weight (g)
Georgia Forestry Commission, GA	7/9/19	Control	22.7	24.1	4.46	0.71	2.76
		Frequency®	22.7	24.5	4.60	0.75	2.83

Table 23. Bareroot loblolly pine seedling characteristics treated with trifloxysulfuron (Envoke®) at 9-11 weeks post-sowing at four nurseries.

Nursery	Application Date	Treatment	Density/ft^2	Shoot Height (cm)	RCD (mm)	Root Weight (g)	Shoot Weight (g)
Georgia Forestry Commission, GA	7/9/19	Control	20.7	28.3	4.21	0.63	2.45
		Envoke®	21.1	28.5	4.22	0.67	2.46
IFCO Jesup, GA	7/8/19	Control	27.9	24.6	4.41	0.57	2.44
		Envoke®	29.1	24.7	4.35	0.54	2.41
IFCO White City, AL	7/3/19	Control	29.3	27.8	4.74	0.74	3.05
		Envoke®	26.5	27.6	4.87	0.81	3.21
K & L, GA	7/2/19	Control	26.8	29.3	4.63	0.82	3.21
		Envoke®	25.5	<u>28.6</u>	4.57	0.84	2.96

Double underlined means within a seedling characteristic indicate a significant treatment difference from that of the non-treated control at that rate according to nonparametric Wilcoxon test at alpha = 0.05.

Table 24. Bareroot slash pine seedling characteristics treated with trifloxysulfuron (Envoke®) at 9 weeks post-sowing at one nursery.

Nursery	Application Date	Treatment	Density/ft^2	Shoot Height (cm)	RCD (mm)	Root Weight (g)	Shoot Weight (g)
Georgia Forestry Commission, GA	7/9/19	Control	22.7	24.1	4.46	0.71	2.76
		Envoke®	22.1	<u>25.3</u>	4.67	0.76	2.95

Single underlined means within a seedling characteristic indicate significant treatment difference from that of the non-treated control at that rate according to Dunnett's T-test at alpha = 0.05.