Weed Technology

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Research Article

Cite this article: Clabo DC and Dickens ED (2022) Evaluations of alternative herbicides to glyphosate for wilding pine control during forestry site preparation in the southeastern United States. Weed Technol. **36**: 561–569. doi: 10.1017/wet.2022.53

Received: 6 May 2022
Revised: 21 June 2022
Accepted: 27 June 2022
First published online: 11 July 2022

Associate Editor:
Drew Lyon, Washington State University

Nomenclature:
choline triclopyr; florpyrauxifen-benzyl; flumioxazin; glufosinate; glyphosate; imazapyr; loblolly pine; *Pinus taeda* L.; slash pine; *Pinus elliottii* Engelm.

Keywords:
Site preparation timing; alternative herbicides; exploratory study

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Evaluations of alternative herbicides to glyphosate for wilding pine control during forestry site preparation in the southeastern United States

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Abstract

Control of southern pine species that easily establish from seed, such as loblolly pine and slash pine (wilding pines), has historically been achieved economically through the use of prescribed fire or application of glyphosate or glyphosate and saflufenacil during site preparation. Currently, alternatives to glyphosate are being investigated for wilding pine control because of health and safety concerns over glyphosate reported by some organizations. Two exploratory studies in the Coastal Plain Region of Georgia investigated the potential of several herbicides for wilding pine control with 0.56 to 0.70 kg ha^{-1} of 0.9-kg ae imazapyr included in all herbicide treatments. Application timings for Study 1 were July and September ($n = 8$ treatments per timing), whereas Study 2 took place in July and early November ($n = 4$ treatments per timing). In Study 1, various rates of choline triclopyr, ester triclopyr, fluroxypyr, aminopyralid + florpyrauxifen-benzyl, and aminopyralid + triclopyr were tested, while two treatments contained glyphosate. Study 2 investigated mixtures containing flumioxazin, glufosinate, and triclopyr. Results for Study 1 revealed that the two treatments containing glyphosate had the greatest percent loblolly pine control after 120 d (87.5% and 88.6% control, respectively), while the next best control was offered by a treatment containing imazapyr plus 3.36 kg ha^{-1} choline triclopyr (52.6% control). July treatments offered better control than September treatments, but the efficacy of September treatments may have been impacted by a severe drought. In Study 2, treatments applied during early November that contained imazapyr and glufosinate or imazapyr, glufosinate, and flumioxazin resulted in 100% control of mixed loblolly and slash pine seedlings and saplings. All November treatments offered better control than July treatments in Study 2. Promising results from Study 2 suggest that glufosinate may warrant additional study for use in forestry site preparation as an alternative to glyphosate to control wilding pines.

Introduction

Three of the four southern pine species commonly encountered in the Coastal Plain and Piedmont regions of the southeastern United States produce above average or bumper seed crops every 3 to 6 yr, with some seed produced each year. Loblolly pine, slash pine, and shortleaf pine (*Pinus echinata* Mill.) all disseminate seed mostly during October or November that germinates the following late winter or spring. Seeds are easily dispersed by wind or animals (Baker and Langdon 1990; Lawson 1990; Lohrey and Kossuth 1990). Stand disturbances that expose mineral soil can promote establishment of new seedlings, as less carbohydrate stores are required for newly germinated seedling radicles than when an organic duff layer is present (e.g., Yocom and Lawson 1977). When seed sources are nearby and conducive conditions occur, tens of thousands of wilding pine stems per hectare can establish and develop on undisturbed sites (Ezell and Yeiser 2010). Regular, cyclic prescribed fire in southern pine forest types has historically been the method of choice for limiting or suppressing competition from wilding pines and other woody competition. Since 2011, prescribed fire use has decreased in the southeastern United States (number of hectares burned) (Melvin 2018). Corporations and nonindustrial private forest landowners own approximately 86% of the total forest land in this region, and these ownerships are where burning has decreased the most (Butler and Wear 2013; Melvin 2018). These ownerships may have greater constraints for prescribed burning than government agencies, thus necessitating greater dependency on forest herbicide use. Corporate ownerships' and forest industry's use of prescribed fire has decreased steadily over the past several decades as their land ownership in the region has decreased (Wade and Outcalt 1999). As urbanization and other constraints to prescribed burning across the region increase, private landowners have become less willing to use prescribed fire applied as understory or site preparation burns to manage understory vegetation prior to the next timber rotation (Wigley et al. 2004). Reasons for this include limited days with suitable weather, capacity and resources to conduct burns, smoke management concerns, and liability and insurance concerns (Melvin 2018). Use of herbicides will be increasingly required to manage vegetation, including wilding pines, on many ownerships in the southern United States to establish new pine plantations.

Chemical site preparation is essential for successful pine plantation establishment on most cutover and former pasture sites with competing and interfering woody trees, vines, and shrubs. Imazapyr is the primary herbicide used in most forestry site preparation mixtures, but imazapyr alone does not offer control of wilding loblolly, shortleaf, or Virginia pines (*Pinus virginiana* Mill.), while other southern pine species, such as slash and longleaf pine (*Pinus palustris* Mill.), are more susceptible (Grogan et al. 2015; Miller and Mitchell 1990; Minogue et al. 1991). Herbicides added to forestry site preparation mixtures for wildling pine control must be chemically compatible with imazapyr and not cause reduced control of other undesirable vegetation. This excludes imazapyr mixtures with herbicides like picloram for wilding pine control, as decreased vegetation control has been observed in some mixture combinations (Self 2018).

Glyphosate is usually the choice herbicide for control of wilding pines (all species), as it offers additive control of most vegetation when mixed with imazapyr without site preparation burning, can act as a burn-down herbicide to facilitate site preparation burning, and is relatively inexpensive (Ezell et al. 2000; Harrington et al. 1998; Self and Ezell 2019b; Yeiser et al. 2012). Typically, better control of wildling pine has been observed with higher labeled rates of glyphosate (Ezell et al. 2000; Ezell and Yeiser 2002). Rates can be reduced by mixing glyphosate with saflufenacil to improve efficacy at lower, more economical application rates than applying glyphosate alone or mixed with imazapyr (Ezell and Self 2016, 2017; Self and Ezell 2019a). Though glyphosate alone or in mixtures with other forestry site preparation herbicides has been accepted as the industry standard for wilding pine control, results with glyphosate have not always been consistent. Studies have shown that control may differ significantly by glyphosate formulation, application rate, season of application, wilding pine size (height), surfactant types and formulations, and pine species (Yeiser et al. 2012). This has resulted in tests of other herbicides for wildling pine control (Cargill et al. 1987; Lauer et al. 2002; Voth 1989; Yeiser et al. 2012).

Alternative herbicides to glyphosate have been tested for wilding pine control with varying levels of success. Fosamine (e.g., Krenite® S, Bayer AG, Cary, NC, USA), ester triclopyr, and a premixed product containing aminopyralid and ester triclopyr (Milestone® VM Plus, Dow AgroSciences, Indianapolis, IN, USA) have shown varying levels of control, and these herbicides can be mixed with imazapyr (Cargill et al. 1987; Lauer et al. 2002; Yeiser et al. 2012). Fosamine control of wilding pine in early studies in Oklahoma has been reported as excellent (>96% control) for shortleaf pine, which is considered to have greater herbicide tolerance than loblolly pine (Cargill et al. 1987; Yeiser 1999). Ester triclopyr (1.8-kg ae product) applied alone during May at rates of 0.56, 1.12, and 1.68 kg ae ha^{-1} resulted in 23% to 59% loblolly pine mortality in a 7-yr-old stand in Virginia and was not recommended for broadcast release of loblolly pine (Campbell 1982). In another study, the same ester triclopyr formulation was applied during July in Georgia at four rates, and minimal mortality or growth losses were reported (Fitzgerald and Griswold 1984). Growth resumed on most damaged trees during the following growing season. Another study conducted in Texas reported no improvements in wilding pine control with three rates of 0.9-kg ae imazapyr and 1.8-kg ae ester triclopyr (Yeiser 2002). In an Oklahoma study, Milestone® VM Plus was added to glyphosate, but wilding pine control was not greater than glyphosate alone (Yeiser et al. 2012). Studies investigating wilding pine control using a variety of forestry-labeled herbicides or experimental herbicides with potential for forestry uses have not been conducted.

In recent years, glyphosate has come under increased scrutiny due to a 2015 ruling by the cancer-research division of the World Health Organization that glyphosate is a probable carcinogen to humans (Guyton et al. 2015). As of 2021, this ruling was followed by approximately 125,000 plaintiffs filing lawsuits against Monsanto Company or its parent company Bayer AG, with a handful of plaintiffs awarded large monetary settlements (Benbrook 2020). In addition, the potential for cancellation or suspension of glyphosate by the U.S. Environmental Protection Agency has caused some glyphosate buyers and producers to seek alternative herbicide options. These events and attitudes resulted in the justification for research investigating glyphosate alternatives for wilding pine control during forestry site preparation.

The objective of the two studies was to investigate wilding pine control performance of herbicides that could serve as glyphosate alternatives and that are compatible with imazapyr in forestry site preparation herbicide mixtures.

Materials and Methods

Studies were installed at two locations (Table 1) in the southeastern United States. Study 1 was located in the Atlantic Southern Loam Plain ecoregion of Georgia, whereas Study 2 was located in the Okefenokee Plains ecoregion of Georgia (Griffith et al. 2001; Figure 1). The study area for Study 1 averages 1,200 mm of rain yr^{-1}, with July the warmest and January the coldest months on average. The study area for Study 2 averages 1,207 mm of rain yr^{-1} with similar monthly temperature patterns. Monthly averages over the duration of the studies compared to historic averages (1981 to 2010 climate normal for Studies 1 and 2) are presented in Figures 2 and 3, respectively (NOAA 2022a, 2022b; University of Georgia Weather Network 2022a, 2022b).

Soils at the Study 1 site belonged to University of Florida Cooperative Research in Forest Fertilization (CRIFF) Group E soils. These soils are considered moderately to well drained and are characterized by a loamy sand or sandy loam surface (A) horizon texture and a subsurface clay or argillic (Bt) horizon within 50 cm of the surface (Fox 2004; Table 2). The site had a slope of 0% to 3%. Soils at the Study 2 site were CRIFF Group B soils. These soils are characterized by poor to very poor drainage and a loamy surface texture, and they contain a fine-textured clayey subsoil deeper than 50 cm (Fox 2004; Table 2). This site had no measurable slope. The Study 1 site was a 42.6-ha former loblolly pine plantation that had been thinned twice and clear-cut during summer 2018. The stand had no recent history of prescribed burning, and an understory of loblolly pine seedlings and saplings had developed. Stem densities averaged 38,800 ha^{-1} and 0.91 m tall, with a height range of less than 0.3 m to greater than 2.7 m. Study 2 was established on

https://doi.org/10.1017/wet.2022.53 Published online by Cambridge University Press

Table 1. Geographic locations and wilding pine species for two study sites located in the Coastal Plain physiographic region of Georgia.

Location	Study	Lat.	Long.	Wilding pine species
Unadilla, GA	1	32.27°N	83.65°W	loblolly
Alapaha, GA	2	31.36°N	83.23°W	loblolly and slash

a former cattle pasture totaling 8.1 ha that had been abandoned approximately 6 yr prior to study establishment during July 2020. Wind-dispersed seed from adjacent mature loblolly and slash pines resulted in an average of 3,700 ha^{-1} wilding loblolly and slash pine seedlings and saplings across the site. Average seedling and sapling height were 1.4 m for stems from 0.3 to 2.7 m tall.

Study 1 consisted of eight treatments and two application timings. Treatments did not differ by application timing. Treatment and application timing information is provided in Table 3. Treatments were arranged as a randomized complete block split-plot design with three blocks of each application timing. The site was blocked with respect to slope position. All treatments, excluding the control, received 0.7 kg ae ha^{-1} imazapyr as a 0.9-kg ae product (Chopper® Gen2, BASF Corp., Research Triangle Park, NC, USA). In addition, a nonionic surfactant was added to all treatments at a rate of 0.46 l ha^{-1} (ACTIVATOR 90, Loveland Products, Greeley, CO, USA). Study 2 consisted of six treatments and two application timings. Treatments differed between July and early November application timings due to the likelihood of pine seedlings being dormant and less receptive to herbicide application during November. Treatment and application timing information is provided in Table 4. Treatments were arranged as a completely randomized design with a split-plot design with three replications of each treatment and application timing combination. All treatments and timings, excluding the control, received 0.56 kg ha^{-1} of a 0.9-kg ae imazapyr (Polaris® SP, Nufarm Americas Inc., Burr Ridge, IL, USA). July treatments received 2.34 L ha^{-1} methylated seed oil (MSO), while November treatments received 4.68 L ha $^{-1}$ MSO due to the potential for less herbicide uptake by dormant trees (Bovey 2001; Schultz 1997).

Experimental units in both studies were 9.14 × 9.14 m with a 3.04 × 6.10 m interior sampling plot arranged along the center of the experimental unit. The interior sampling plot had to have five or more pines less than 2.7 m tall to be included in the study. Pines greater than 2.7 m tall were chainsaw-felled and removed from the experimental unit prior to treatment application to avoid issues with spray impediments. Treatments were applied on July 22 and September 19, 2019, in Study 1 and on July 15 and November 1, 2020, in Study 2. A CO_2-pressurized backpack sprayer (model 4F) with a pole extension and KLC-9 nozzle was used to apply treatments (Bellspray Inc., DBA R&D Sprayers, Opelousas, LA, USA). Sprayer pressure was kept constant at 165 kPa for all treatments to maintain a 9.14-m spray swath. Total spray solution applied per experimental unit was 187 L ha^{-1} for Study 1 and 140 L ha^{-1} for Study 2. These simulated moderate ground or heavy aerial applications commonly utilized for forestry site preparation.

Data collection occurred at 0, 60, and 120 d after treatment (DAT) in Study 1 and at 0, 30, 60, 120, and 365 DAT in Study 2. Data collection at 365 DAT was intended for Study 1, but a v-blade tree planter damaged most plots shortly after the September application 120 DAT inventories were taken in January 2020. Tree heights and stem densities were collected at each DAT inventory. When a pine was partially top-killed, a knife test was used to peel back bark and determine the height where living cambium tissue ended (Miller and Glover 1991). Wilding pine stem density per hectare and percent control (total height reduction of individual stems) from 0 DAT to 120 or 365 DAT were the dependent variables used in data analysis. Percent control is calculated using the following equation:

$$\text{Percent control} = \frac{\text{Treated plot response}}{\text{Untreated plot response}} \times 100$$

Data were analyzed using analysis of variance (ANOVA) as a randomized complete block design with a split-plot treatment design. Treatment, application timing, and assessment date were considered fixed model terms, while block (Study 1) or replication (Study 2) was a random model term for the stem density analyses in Studies 1 and 2 to accommodate a repeated-measures analysis. Treatment and date were fixed terms and block (Study 1) or replication (Study 2) a random term for percent control analyses. All analyses were conducted using mixed models (PROC MIXED) in SAS (Version 9.4, SAS Institute Inc., Cary, NC, USA). Means were separated using Tukey's honest significant difference and $\alpha = 0.05$. Normality for each dependent variable was tested using the Shapiro–Wilk test (Littell et al. 2006). Equal variance was also investigated for fixed factors within each analysis. Percentage data were transformed using arcsine square root transformation to stabilize variances.

Results and Discussion

Study 1 showed significant differences for the treatment × assessment date (DAT) × application timing interaction term for wilding pine stem densities ($P = 0.001$), but only the treatment factor was significant for percent control ($P < 0.001$). The ester triclopyr and glyphosate (ETG) and ester triclopyr, glyphosate, and aminopyralid plus triclopyr (ETGAT) treatments applied during July, which both contained glyphosate, had the greatest reductions in stem densities from 0 to 120 d (87.9% and 98.7%, respectively) (Table 5). They also offered the best percent wilding pine control and averaged 86.8% (ETG) and 88.2% (ETGAT) control, respectively (Table 6). The addition of Milestone® VM and reduction of glyphosate to 4.48 kg ha^{-1} (Accord® XRT II, Dow AgroSciences) in the ETGAT treatment resulted in numerically fewer stems per hectare compared to the ETG treatment, which had 6.78 kg ha^{-1} glyphosate applied alone with ester triclopyr and imazapyr in the mixture (Table 5). These results were similar to a study conducted in Oklahoma where addition of Milestone® VM to Accord® XRT II offered nonsignificant improved wilding pine control over Accord® XRT II (6.2% improvement) applied alone (Yeiser et al. 2012).

The best treatment and application timing combination for reduction in wilding pine stem densities that did not include glyphosate was the fluroxypyr and choline triclopyr (FCT) July treatment (56.8% reduction), but this treatment would not meet acceptable standards for wilding pine control with chemical site preparation, as it offered only moderate control (Frans et al. 1986). Information on choline triclopyr control of wilding pine is limited, but results suggest that efficacy can be improved with addition of fluroxypyr. Results from past studies with fluroxypyr and damage to southern pines are conflicting. Fluroxypyr rates of 0.56, 1.12, and 2.24 kg ae ha^{-1} were applied during

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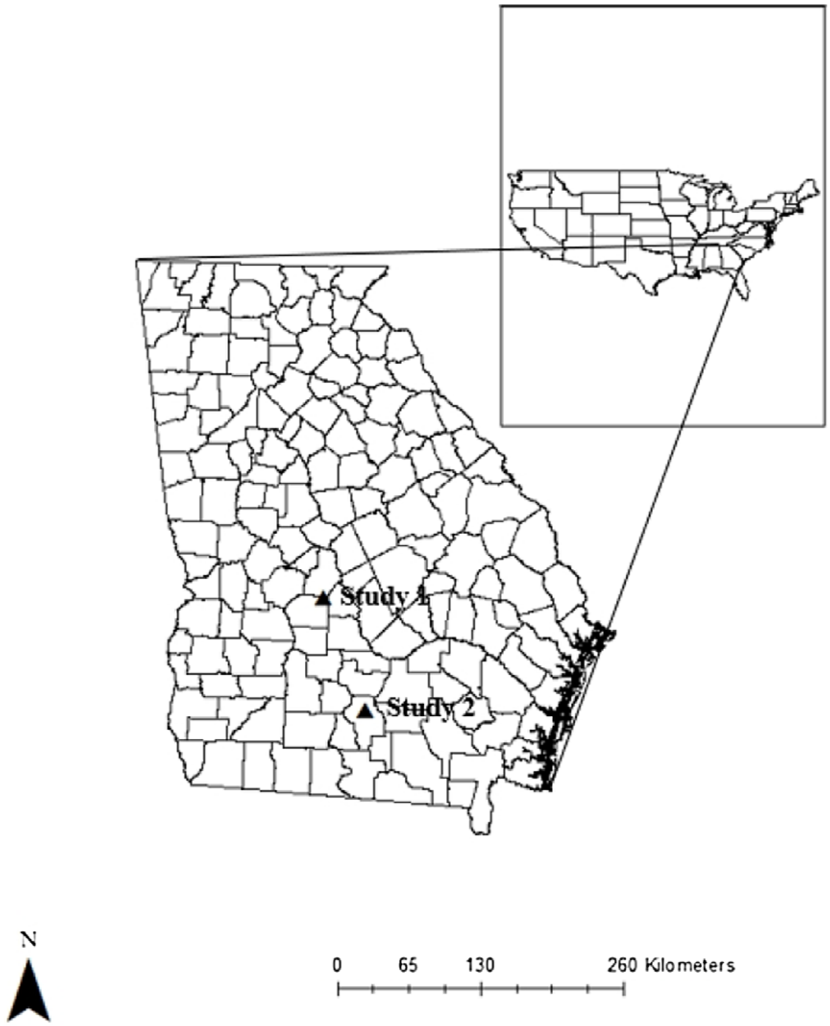

Figure 1. Locations of wilding pine control study areas in Georgia. Background maps are courtesy of ESRI (2017) and Geospatial Data Gateway (2019).

September in a Virginia study, and no damage was reported for loblolly pine, whereas another study that applied the same three rates during July in Mississippi reported 40% of trees with mortality or extensive damage at a rate of 2.24 kg ae ha^{-1} and 24% mortality or extensive damage with a 1.12 kg ae ha^{-1} rate (Freyman and Zedaker 1987; Karr et al. 1987). On the basis of results from these studies and Study 1, fluroxypyr activity for wilding pine control may be increased with July applications. The best treatment for percent control that did not contain glyphosate was the CT2 treatment, which had 3.36 kg ha^{-1} choline triclopyr. Performance differences across triclopyr formulations are likely (José Luiz et al. 2017), but choline triclopyr is reported to control similar species at equal application rates for forestry site preparation as 1.8-kg ae ester triclopyr products (Corteva Agriscience 2020). This Corteva Agriscience report suggests along with findings from Study 1 that deficient to moderate wildling pine control may be attainable with choline triclopyr and imazapyr mixtures, depending on application timing (Frans et al. 1986). This level of control is likely not acceptable for most site preparation scenarios with wilding pine control as an objective. Stem density reductions were poor with aminopyralid + florpyrauxifen-benzyl and lower application rates of choline triclopyr when applied alone with imazapyr. In general, July applications resulted in fewer living stems per hectare than September applications, but it should be noted that July experimental units averaged 34,900 ± 14,700 stems ha^{-1}, while September experimental units averaged 42,800 ± 15,600 stems ha^{-1}, though this difference was nonsignificant. These results agree with findings by Ezell and Self (2017), who applied June and September application timings with several rates of glyphosate to control wilding loblolly pine in northern Mississippi. Their results noted better control with the earlier applications across all tested mixtures.

In Study 1, September applications were likely impacted by severe drought and high temperatures that occurred in southern and middle Georgia during late August and all of September 2019 (Figure 2). Precipitation was 27% of normal during this period. Poor foliar uptake and translocation of herbicides due to these climatic conditions may have affected herbicide efficacy (Lowery and Gjerstad 1991).

Study 2 results indicated a significant treatment × assessment date (DAT) × application timing interaction for stem density ($P = 0.005$) and significant treatment ($P < 0.001$) and application timing ($P = 0.003$) factors, whereas the treatment × timing interaction was not significant ($P = 0.229$) for percent control. The

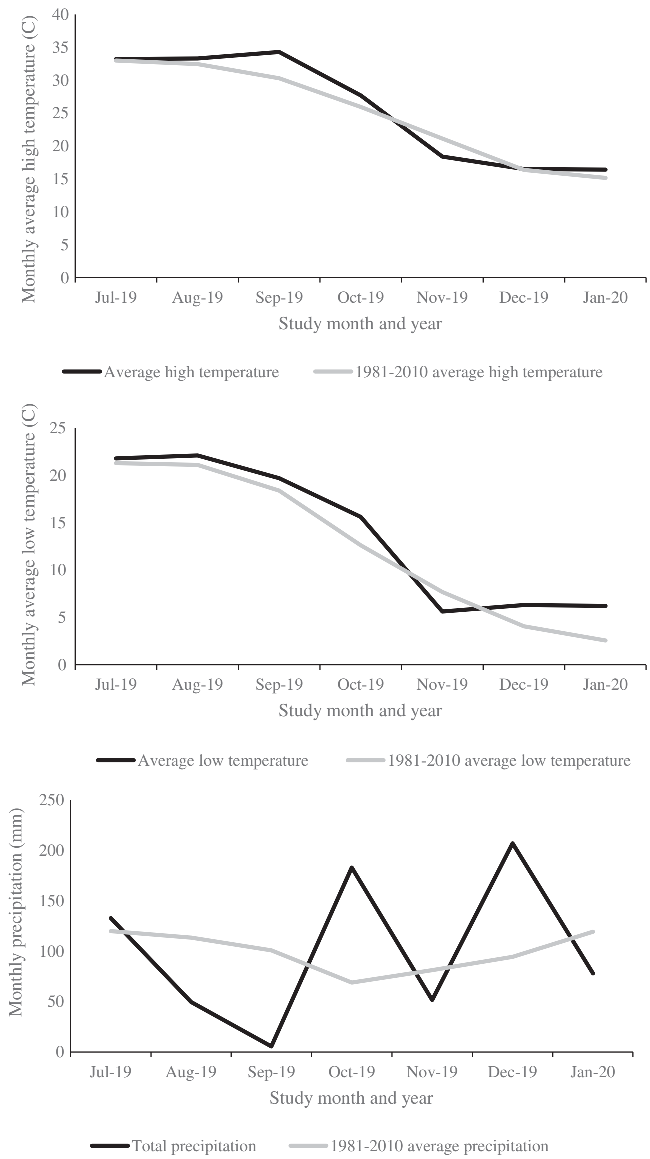

Figure 2. Climatic data for the duration of Study 1, located in Dooly County, Georgia.

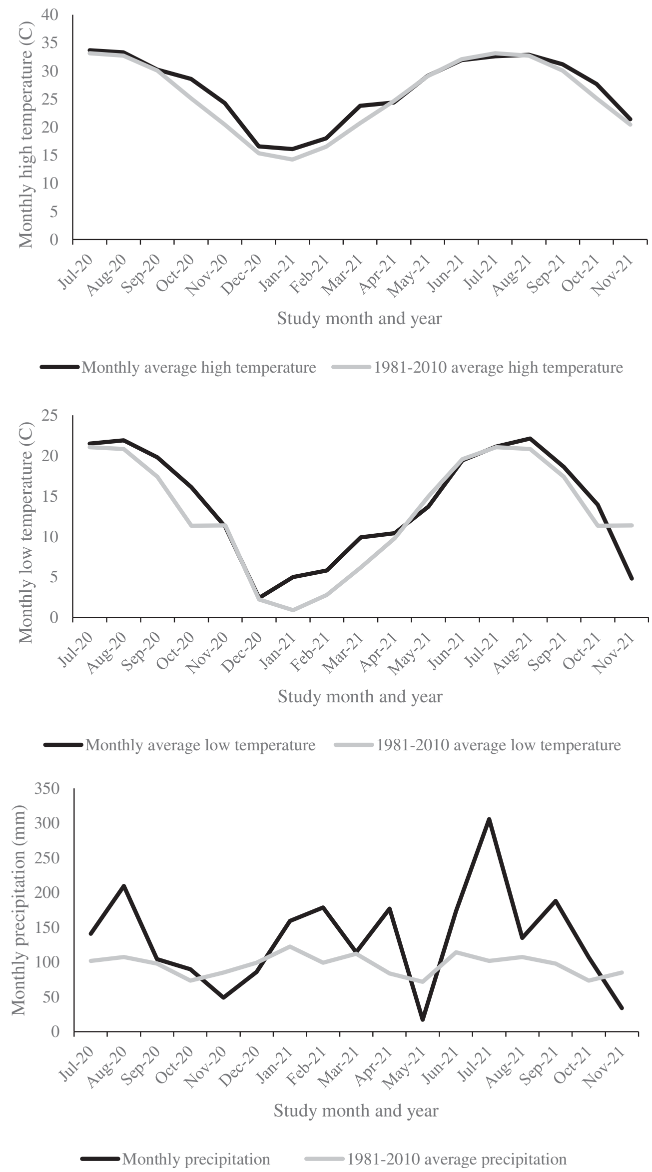

Figure 3. Climatic data for the duration of Study 2, located in Berrien County, Georgia.

November G and GF treatments had 100% control 365 DAT (Tables 7 and 8). Glufosinate belongs to Group 10$^{(H)}$ herbicides, and some glufosinate products are labeled for use in natural areas, for use in noncropland areas, and for conifer or hardwood site preparation (e.g., Cheetah®) (WSSA 2014). Glufosinate is primarily a contact herbicide, killing only those plant parts that the herbicide touches, and does not translocate in plants (Zhou et al. 2020). Given that wilding pine resprouts were not observed in treatments G or GF, contact control only appeared to be sufficient 365 DAT. The addition of flumioxazin in the GF treatment did not alter percent control in the November application timing and only numerically improved percent control for July applications. As shown by other studies, ester triclopyr mixed with imazapyr can result in deficient to moderate control of wilding pine (Campbell 1982; Frans et al. 1986; Lauer et al. 2002). Ester triclopyr mixed with imazapyr in Study 2 tended to offer better control than what was observed with choline triclopyr in Study 1.

November application timing showed improved wilding pine control (62% control) over July applications (33% control). Two reasons are likely for this finding other than the consistent average or above average monthly precipitation observed throughout Study 2 (Figure 3). First, the additional MSO added to the November application treatments could have improved herbicide uptake into wilding pine stems. Loblolly pine determinate and indeterminate growth typically ceases by mid-September, and greater rates of MSO could have improved herbicide uptake into dormant leaf and bud tissues, which often do not uptake herbicide as well as actively growing tissues do (Bovey 2001; Schultz 1997). A second reason is potential evaporative losses during the July applications. Wind speeds less than 1.3 m s^{-1} were observed during some weather checks during application. Some herbicides, such as glufosinate, have a reported increased risk of evaporative losses when applied with wind speeds less than 1.3 m s^{-1} (Anonymous 2017). These factors could have

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Table 2. Soil characteristics at the two wilding pine control study sites located in the Coastal Plain physiographic region of Georgia.[a]

Location	Study	Soil order	Soil series	Surface texture/drainage class
Unadilla, GA	1	Ultisol	Orangeburg[b]/Red Bay[c]	loamy sand/WD
Alapaha, GA	2	Ultisol	Leefield[d]/Alapaha[e]	loamy sand/PD or SWPD

[a]Abbreviations: PD, poorly drained; SWPD, somewhat poorly drained; WD, well drained.
[b]Fine-loamy, kaolinitic, thermic, Typic Kandiudult. Loamy sand with an argillic sandy clay loam horizon within 0.3 to 1.8 m.
[c]Fine-loamy, kaolinitic, thermic Rhodic Kandiudult. Sandy loam with an argillic sandy loam or sandy clay loam horizon within 0.15 to 1.83 m.
[d]Loamy, siliceous, subactive, thermic Arenic Plinthaquic Paleudult. Loamy sand with an argillic sandy loam or sandy clay loam horizon within 0.58 to 1.9 m.
[e]Loamy, siliceous, subactive, thermic Arenic Plinthic Paleaquults. Loamy sand with an argillic sandy clay loam horizon from 0.84 to 1.78 m.

Table 3. Treatment and application timing list for Study 1, located near Unadilla, GA.[a,b,c]

		Additions to imazapyr treatment							
Treatment	Code	Choline triclopyr[d]	Fluroxypyr[e]	Aminopyralid + florpyrauxifen-benzyl[f]	Ester triclopyr[g]	Glyphosate[h]	Aminopyralid + triclopyr[i]	Nonionic surfactant[j]	Total volume
		kg ha^{-1}					g ha^{-1} and kg ha^{-1}	L ha^{-1}	
1	CT1	2.24	—	—	—	—	—	0.46	187
2	CT2	3.36	—	—	—	—	—	0.46	187
3	FCT	2.24	0.51	—	—	—	—	0.46	187
4	AFPET	—	—	0.14 + 0.012	1.16	—	—	0.46	187
5	AFPET2	—	—	0.24 + 0.022	1.16	—	—	0.46	187
6	ETG	—	—	—	1.16	6.73	—	0.46	187
7	ETGAT	—	—	—	1.16	4.48	0.877 + 0.06	0.46	187
8	CON	—	—	—	—	—	—	—	none

[a]All herbicide mixtures excluding the control contained 0.70 kg ha^{-1} of a 0.9-kg ae imazapyr (Chopper® Gen2).
[b]Application timings were July 22, 2019, and September 19, 2019.
[c]A dash denotes that a herbicide or application timing was absent from a specific treatment.
[d]Choline triclopyr as Vastlan®, Dow AgroSciences.
[e]Fluroxypyr as Vista® XRT, Dow AgroSciences.
[f]Aminopyralid + florpyrauxifen-benzyl as TerraVue® with Rinskor™ active (i.e., TerraVue®), Dow AgroSciences.
[g]Ester triclopyr as Forestry Garlon® XRT, Dow AgroSciences.
[h]Glyphosate as Accord® XRT II, Dow AgroSciences.
[i]Aminopyralid + triclopyr as Milestone® VM.
[j]Nonionic surfactant as ACTIVATOR 90.

Table 4. Treatment and application timing list for Study 2, located near Alapaha, GA.[a,b]

		Additions to imazapyr treatment					
Treatment	Code	Glufosinate-ammonium[c]	Flumioxazin[d]	Triclopyr[e]	MSO[f]	Total volume	Application date
		kg ha^{-1}			L ha^{-1}		
1	G	1.68	—	—	2.34	140	15 Jul 2020
2	GF	1.68	0.14	—	2.34	140	15 Jul 2020
4	ET	—	—	2.24	2.34	140	15 Jul 2020
6	CON	—	—	—	—	—	—
1	G	1.68	—	—	4.68	140	1 Nov 2020
2	GF	0.07	0.14	—	4.68	140	1 Nov 2020
4	ET	—	—	2.24	4.68	140	1 Nov 2020
6	CON	—	—	—	—	—	—

[a]All herbicide mixtures excluding the control contained 0.56 kg ha^{-1} 0.9-kg ae imazapyr (Polaris® SP).
[b]A dash denotes that a herbicide or application timing was absent from a specific treatment.
[c]Glufosinate-ammonium as Cheetah®, Nufarm Americas.
[d]Flumioxazin as Lock Down™ SC, Nufarm Americas.
[e]Triclopyr as Relegate®, Nufarm Americas.
[f]Methylated seed oil as Dyne-Amic®, Helena Chemical Company, Collierville, TN, USA.

been synergistic on decreased pine control with the July applications, as these results differed from most other wilding pine control herbicide application timing studies and previous trials investigating wilding pine control (e.g., Ezell and Self 2017; Self and Ezell 2019b; Yeiser et al. 2012).

Wilding pine control continues to be an issue for forestry site preparation throughout much of the southeastern United States. Glyphosate has historically been the most effective and consistent site preparation herbicide that can be mixed with imazapyr for control of wilding pine when site preparation burning is not

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Table 5. Means and standard errors for the significant treatment × assessment date × application timing interaction term for wilding loblolly pine stems ha^{-1} in Study 1, Dooly County, GA.[a,b]

		Mean stems ha^{-1} ± SE	
Treatment	DAT	July application	September application
CT1	0	33,000 ± 10,800	30,300 ± 15,200
CT1	60	36,200 ± 8,000	28,500 ± 15,700
CT1	120	32,500 ± 6,300	25,100 ± 15,100
CT2	0	17,000 ± 3,300	38,900 ± 9,000
CT2	60	12,400 ± 2,962	24,600 ± 6,700
CT2	120	7,500 ± 4,500	23,100 ± 5,200
FCT	0	60,600 ± 34,900	35,900 ± 10,700
FCT	60	40,700 ± 22,200	29,200 ± 8,500
FCT	120	26,200 ± 14,100	22,000 ± 5,900
AFPET	0	5,900 ± 600	41,400 ± 9,800
AFPET	60	6,300 ± 900	38,200 ± 7,200
AFPET	120	4,300 ± 300	34,800 ± 12,100
AFPET2	0	58,300 ± 22,900	42,900 ± 20,000
AFPET2	60	36,600 ± 23,400	25,800 ± 9,000
AFPET2	120	25,800 ± 20,600	22,400 ± 8,400
ETG	0	23,700 ± 11,400	36,900 ± 10,000
ETG	60	3,200 ± 2,700	15,600 ± 4,300
ETG	120	2,900 ± 2,600	8,300 ± 3,100
ETGAT	0	41,600 ± 15,900	37,000 ± 12,600
ETGAT	60	900 ± 400	17,600 ± 5,600
ETGAT	120	500 ± 300	9,300 ± 3,300
CON	0	39,100 ± 17,700	78,800 ± 37,200
CON	60	45,400 ± 20,600	67,800 ± 30,200
CON	120	38,900 ± 18,600	64,200 ± 27,700

[a]The Tukey's honest significant difference average significant difference was 33,502 stems ha^{-1} at the $\alpha = 0.05$ level.
[b]Abbreviation: DAT, days after treatment.

Table 6. Study 1, Dooly County, GA, percentage control of wilding loblolly pine means and standard errors, by treatment.

Treatment	Mean (%)	SE (%)	Letter group[a]
CT1	23.5	7.4	c
CT2	50.6	8.8	a–c
FCT	45.6	8.4	bc
AFPET	22.4	5.9	c
AFPET2	39.8	7.8	c
ETG	86.8	11.6	ab
ETGAT	88.2	11.6	a
CON	18.3	7.9	c

[a]Treatments that do not share a letter are significantly different at the $\alpha = 0.05$ level.

an option. Study 1 in this trial tested several Group 4 herbicides for control of wilding loblolly pine and found poor to moderate control at best with July and September applications, which was poorer than the two treatments that contained glyphosate. The two treatments that contained glyphosate offered satisfactory to good weed control, though the high number of stems per hectare on this site would make better control more desirable. In Study 2, the only acceptable control of wilding slash and loblolly pine was with the two glufosinate treatments, which offered excellent control, especially with later applications in early November. More information on application rates and additional application timings are needed for using glufosinate as a potential site preparation herbicide.

Table 7. Means and standard errors for the significant treatment × assessment date × application timing interaction term for wilding loblolly and slash pine stems ha^{-1} in Study 2.[a,b]

		Mean stems ha^{-1} ± SE	
Treatment	DAT	July application	November application
G	0	1,597 ± 290	1,524 ± 251
G	30	1,452 ± 384	217 ± 125
G	60	798 ± 316	0 ± 0
G	120	580 ± 290	0 ± 0
G	365	580 ± 290	0 ± 0
GF	0	1,306 ± 217	0 ± 0
GF	30	1,234 ± 145	580 ± 192
GF	60	653 ± 125	0 ± 0
GF	120	435 ± 251	0 ± 0
GF	365	435 ± 251	0 ± 0
ET	0	1,597 ± 508	1,887 ± 192
ET	30	1,542 ± 435	1,887 ± 192
ET	60	1,669 ± 580	1,379 ± 72
ET	120	1,524 ± 435	943 ± 363
ET	365	1,379 ± 404	508 ± 72
CON	0	1,452 ± 72	1,669 ± 476
CON	30	1,379 ± 72	1,089 ± 628
CON	60	1,524 ± 125	1,524 ± 332
CON	120	1,452 ± 72	1,452 ± 261
CON	365	1,379 ± 72	1,524 ± 332

[a]The Tukey's honest significant difference average significant difference was 1,416 stems ha^{-1} at the $\alpha = 0.05$ level.
[b]Abbreviation: DAT, days after treatment.

Table 8. Study 2, Berrien County, GA, percentage wilding loblolly and slash pine control means and standard errors, by treatment.

Treatment	Estimate (%)	SE (%)	Letter group[a]
G	80.8	11.1	a
GF	86.6	6.7	a
ET	49.4	8.8	b
CON	−26.0	9.3	c

[a]Treatment and application timing combinations that do not share a letter are significantly different at the $\alpha = 0.05$ level.

Acknowledgments. The authors thank Corteva AgriScience and Nufarm US for their support of this research. In addition, special thanks go to Cassandra Waldrop and Pamela Halliday for their assistance in the field and with data entry. The authors declare no conflicts of interest.

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