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Harmonized site preparation and postplant herbaceous weed control for establishment of southern pine plantations on coastal bedded sites

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Research Article

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Abstract

Loblolly pine or slash pine response and vegetation colonization are summarized for a region-wide study that included five locations on coastal soils in the southern United States. The objective was to evaluate timing of postplant herbaceous weed control (HWC) treatments following preplant site preparation with imazapyr applied at two timings (August and November) and at three rates (0.56, 0.84, and 1.12 kg ha^{-1}). All imazapyr site preparation treatments were applied after bedding. Site preparation treatments resulted in fast-growing stands without HWC at all locations with average Year 3 dominant tree height ranging from 2.6 to 3.7 m. Imazapyr plus sulfometuron was an effective HWC treatment on loblolly pine. Vegetation control and pine response varied by surface soil texture. On coarser-textured soils, the site preparation treatments resulted in <10% vegetation cover in June of the first pine growing season. On these coarser-textured soils, loblolly pine growth was increased by second-year and not first-year HWC. On finer-textured soils, vegetation colonization was aggressive, with >20% cover in June of the first pine growing season, such that early first-year HWC provided the largest loblolly pine response of single-pass HWC treatments. Pines were highly tolerant to imazapyr site preparation treatments as evidenced by the lack of differences in slash or loblolly pine survival and growth from the doubling of imazapyr rates for applications in either August or November. There was little meaningful residual control of herbaceous vegetation into the second pine growing season from site preparation treatments or first-year HWC regardless of location. There was no consistent pine response benefit from increasing the imazapyr site preparation rate for included treatments. Cost-effective treatments would utilize low site-preparation herbicide rates followed by the appropriate timing of HWC if longer-term vegetation control is the objective.

Introduction

Cost-effective herbicide applications that control competing woody and herbaceous vegetation are an important part of pine plantation establishment in the southern United States. Integrated applied silvicultural practices of tree genetics, nursery management, site preparation, weed control, and fertilization have increased plantation acreage from 2 million to 32 million between the 1950s and 2000s and produced as much as a 4-fold increase in yield per acre (Fox et al. 2007). Plantations are established using genetically improved 1-0 bareroot or containerized seedlings, and advanced genetic stock is now available to all landowners (McKeand 2019). Haase et al. (2019) estimated that 1.9 million acres were planted in the 2017 to 2018 planting season. Integrated and cost-effective weed control is needed to fully realize the gains made through genetics, nursery management, mechanical site preparation, and fertilization.

The objectives of historical vegetation control studies were to estimate potential response to vegetation control; investigate response to operational treatments; or screen herbicides for pine tolerance, for preplant control of woody vegetation, and for postplant control of herbaceous weeds. Potential response studies often included other silvicultural practices, such as bedding and fertilization, but vegetation control treatments were of near-complete control of woody and/or herbaceous vegetation over multiple years (Jokela et al. 2010; Lauer et al. 1993; Lauer and Glover 1998; Miller et al. 1991; Shiver et al. 1990; Swindel et al. 1989). Growth potential studies provided a benchmark but should not be interpreted, as noted by Swindel et al. (1989), as necessarily advocating for or defining operational outcomes. Additionally, Coastal Plain postplant herbaceous weed control (HWC) studies were not necessarily performed under conditions that are now representative of current practice where woody vegetation has been controlled by site preparation (Jokela et al. 2000).

Nonarborescent woody species (shrubs) are generally more prevalent than arborescent (tree-forming) species on poorly drained coastal soils. Zutter and Miller (1998) noted the importance of controlling this woody component in terms of Year 11 pine response on a poorly drained spodosol and that nonarborescent occupancy increased over the 11-year period when not controlled. Lauer and Glover (1998, 1999) related pine response to herb and shrub occupancy and found cover of uncontrolled shrubs to be the largest limitation to loblolly pine and slash pine growth through age 5 yr on coastal sites. Lauer and Zutter (2001) compared bedding treatments and integration of herbicide applications with bedding. The operational logistics here are that long-term control of woody vegetation is provided by one herbicide site preparation treatment, whereas postplant HWC treatments provide relatively short-term control, and that the impact of additional treatments still needs to be investigated. There is also a need to understand how postplant HWC treatments work in harmony with preplant site preparation treatments that have a primary focus on woody vegetation control but also provide a level of residual HWC.

Imazapyr tank mixes with triclopyr, glyphosate, sulfometuron, or other herbicides are commonly used for preplant site preparation. Additions to imazapyr are typically for control of blackberry (*Rubus* spp.), volunteer pine (*Pinus* spp.), species in the Asteraceae family, legumes, and elms (*Ulmus* spp.). Site preparation applications are usually combined with mechanical bedding on poorly drained coastal soils because bedding is a standard operational practice to mediate depressional areas and improve control of planting spacing, planting quality, initial control of vegetation, and yield (Sarigumba and Anderson 1979; Shiver et al. 1990). Lauer and Quicke (2006a) found that imazapyr treatments could be applied over a wide range of timings before or after bedding. The postbed optimal timing was application from June to September at least 3 wk after bedding.

This region-wide experiment was installed across a range of Lower Coastal Plain soils to better understand crop tree response to timing and rate of preplant site preparation applications of imazapyr combined with postplant HWC treatments. The commercial objective was to increase crop tree response by extending control of competing vegetation using site preparation herbicide timing, site preparation herbicide rate, and postplant HWC applications in the first and second growing seasons. Imazapyr has both rapid foliar and root absorption and generally remains in the top 50 cm of the soil profile with a field half-life of 25 to 142 d (Senseman 2007). Important study objectives were to determine whether imazapyr soil activity can be used to improve residual herbaceous vegetation control through the use of later site preparation applications and/or higher imazapyr rates, evaluate pine tolerance and growth response to site preparation treatments combined with HWC, determine if there is pine response to second-year HWC, and document the dominant competing vegetation at the end of the second growing season that will likely persist until crown closure.

Materials and Methods

This experiment was installed at five locations (Table 1) in the southeastern United States on a range of soils characteristic of the Lower Coastal Plain region (Table 2) and blocked with respect to drainage class/soil characteristics at each location. Treatments were arranged as a randomized complete block split-plot design with three blocks at each location. Site preparation treatments were applied at least 6 wk after bedding to main plots 36.6 m long and eight tree rows wide (row width differed by location). The six preplant site preparation main plots consisted of August or November applications of three rates (0.56, 0.84, and 1.12 kg ha^{-1}) of imazapyr (32, 48, and 64 oz/A Chopper® Gen2™, BASF, Research Triangle Park, NC, USA) with a location-specific triclopyr (Garlon® 4, Dow Agrosciences, Indianapolis, IN, USA) tank mix rate, methylated seed oil (MSO) rate, and spray volume, as described in Table 3. Application rates on four sites were consistent with low-volume aerial applications. These four sites included MSO at a rate of 5% by volume of total spray volume. Ground application equipment usually requires a higher spray volume that makes MSO at 5% by volume impractical. The Mt. Pleasant, GA, location was selected to compare treatments using a higher spray volume without MSO. Broadcast site preparation applications were made using a CO_2-pressurized backpack research sprayer with a handheld boom equipped with Turbo FloodJet® (TeeJet® Technologies, Wheaton, IL, USA) nozzles, with each swath centered on beds. The target spray height was approximately 1 m, but this varied with bed condition and height of vegetation. Spray boom configuration and nozzles were selected for low drift, tree row spacing (3.0 to 3.7 m), spray volume (a TF-2 and TF-4 nozzle for 93.5 and 280.5 L ha^{-1}, respectively), and the ability to maintain an accurate spray pattern over a range of boom heights, as tested using a spray pattern test board. Six postplant HWC treatments (Table 4), including an untreated check, were randomized to the inner six tree rows (subplots) within each site preparation main plot. Banded postplant HWC treatments were selected to compare timing of application in the first 2 yr after planting. The HWC treatment for loblolly pine was a tank mix of 140 g ha^{-1} imazapyr (4 oz/A Arsenal® AC, BASF) with 105 g ha^{-1} sulfometuron (2 oz/A Oust® XP, Bayer, Cary, NC, USA). The HWC treatment for slash pine was 210 g ha^{-1} imazapyr (6 oz/A Arsenal® AC) without

Table 1. Geographic locations and crop species.

Location	Latitude	Longitude	Crop species
Oakdale, LA	30.82°N	92.70°W	Loblolly pine
Kings Ferry, FL	30.80°N	78.54°W	Loblolly pine
Green Swamp, NC	34.21°N	78.54°W	Loblolly pine
Mt. Pleasant, GA	31.42°N	81.72°W	Loblolly pine
Tennille, FL	29.78°N	83.29°W	Slash pine

Table 2. Soil characteristics.[a]

Location	Soil order	Drainage	Soil series	Surface texture
Oakdale, LA	Alfisol	P to MW	Glenmora/Caddo-Messer[b]	Silt loam
Kings Ferry, FL	Alfisol	P	Meggett[c]	Sandy clay, clay
Green Swamp, NC	Alfisol	VP to P	Nakina/Grifton[d]	Sandy loam
Mt. Pleasant, GA	Spodosol	P	Leon/Ona[e]	Sand
Tennille, FL	Spodosol	P	Chaires[f]	Fine sand

[a]Abbreviations: MW, moderately well drained; P, poorly drained; VP, very poorly drained.
[b]Glenmora series is fine-silty, siliceous, active, thermic Glossaquic Paleudalfs; Caddo is fine-silty, siliceous, active, thermic Typic Glossaqualfs. Plot placement avoided the Messer series (“pimple” mounds).
[c]Meggett series is fine, mixed, active, thermic Typic Albaqualfs. Fine sandy loam with an argillic sandy clay, clay horizon within 0.5 m.
[d]Nakina series is fine-loamy, siliceous, active, thermic Umbric Endoaqualfs; Grifton series is fine-loamy, siliceous, semiactive, thermic Typic Endoaqualfs. Sandy loam with a sandy clay loam horizon within 1 m.
[e]Leon series is sandy, siliceous, thermic Aeric Alaquods; Ona series is sandy, siliceous, hyperthermic, Typic Alaquods. Sand with spodic horizon within 1 m.
[f]Chaires series is sandy, siliceous, thermic Alfic Alaquods. Fine sand with a spodic horizon within 1 m and a sandy clay loam horizon below 1.4 m.

Table 3. Preplant site preparation herbicide tank mix partners and timing of bedding and planting.[a,b]

Location	Additions to imazapyr treatment		Total volume	Bed date	Application timing		Plant date
	Triclopyr[c]	MSO[d]			Aug.	Nov.	
	kg ha^{-1}	L ha^{-1}	L ha^{-1}				
Oakdale, LA	1.12	4.7	93.5	25 Jul 2001	11 Sep 2001	16 Nov 2001	14 Jan 2002
Kings Ferry, FL[e]	0.56	4.7	93.5	18 May 2001	22 Aug 2001	7 Nov 2001	7 Dec 2001
Green Swamp, NC	0.56	4.7	93.5	29 May 2001	16 Aug 2001	13 Nov 2001	11 Feb 2002
Mt. Pleasant, GA	1.12	0	280.5	15 June 2001	30 Aug 2001	8 Nov 2001	9 Feb 2002
Tennille, FL	1.12	4.7	93.5	18 May 2001	21 Aug 2001	3 Nov 2001	1 Feb 2002

[a]Imazapyr rates of 0.56, 0.84, and 1.12 kg ha^{-1} (1.0×, 1.5×, 2.0×) were tested in tank mixes with triclopyr for each site preparation date.
[b]Abbreviation: MSO, methylated seed oil.
[c]Triclopyr as Garlon® 4 for site preparation tank mixes.
[d]Methylated seed oil.
[e]Kings Ferry location was fertilized with 280 kg ha^{-1} TSP on April 18, 2002.

Table 4. Postplant HWC treatments applied to subplots within site preparation treatment main plots in the first or second year after planting.

Treatment	Code	Treatment description	Loblolly pine herbicide[a]	Slash pine herbicide[b]
1	None or No	Untreated check	None	None
2	Mar Y1	March of first year	Imazapyr + sulflometuron	Imazapyr
3	Jun Y1	June of first year	Imazapyr + sulflometuron	Imazapyr
4	Mar Y2	March of second year	Imazapyr + sulflometuron	Imazapyr
5	Jun Y1+Mar Y2	June of first year and March of second year	Imazapyr + sulflometuron	Imazapyr
6	Mar Sulf Y1	March of first year	Sulfometuron[c]	Sulfometuron[c]

[a]Tank mix of 140 g ha^{-1} imazapyr + 105 g ha^{-1} sulfometuron (4 oz/A Arsenal AC + 2 oz/A Oust XP).
[b]210 g ha^{-1} imazapyr (6 oz/A Arsenal AC).
[c]158 g ha^{-1} sulfometuron (3 oz/A Oust XP).

sulfometuron. Additional subplot treatments at all locations included an untreated check and a March first growing season treatment of sulfometuron at 158 g ai ha^{-1} (3 oz/A Oust® XP). HWC applications were made without surfactants using a CO_2-pressurized backpack research sprayer with a handheld two-nozzle (TF-2) boom to achieve a 1.8-m spray width. All HWC applications were made over the top of pines at a spray volume of 140 L ha^{-1}, except for a spray volume of 164 L ha^{-1} at Oakdale.

Vegetation was visually assessed in the first 2 yr after planting, and pines were measured in Years 1, 2, and 3. Vegetation cover (excluding crop pine cover) was assessed in June, August, and October of the first year and in June and October of the second year of pine growth on the bedded portion of two 15.2-m-long competition measurement plots within each herbaceous treatment plot. Cover was evaluated by vegetation groupings of total, total woody, and total herbaceous. Woody vegetation was evaluated by subgroups of tree, vines, shrubs, and blackberry. Some species were classified as shrubs rather than trees because they are more shrub-like in this management context. Herbaceous vegetation was evaluated by subgroups of grass, rushes and sedges, and forbs. Individual taxa (Table 5) were also recorded for both woody and herbaceous vegetation, except for trace species (<1% cover). Pines were counted and flagged before application of first-year herbaceous treatments to track survival. Groundline diameter (GLD), total height, and condition were assessed on pines within competition measurement plots (30.4-m length of planted tree row) at the end of the first, second, and third growing seasons. GLD was measured to the nearest millimeter using electronic calipers. Height was measured to the nearest centimeter. Year 2 pine response and a limited summary of vegetation control were reported by Lauer and Quicke (2006b). This article summarizes Year 3 pine response and provides a more detailed summary of vegetation response and composition.

Separate analyses were performed for each location because of the need to describe response in terms of location-specific vegetation, soils, and pine species. The analysis of this split-plot design treated blocks as random effects and site preparation (main plot) and HWC treatments (subplots) as fixed effects. The arcsine–square root transform was used for analysis of percentage cover to normalize variation. The analysis of Year 1 survival considered tree survival a binomial random variable using a logit link function. The analysis of Year 3 pine response was performed for groundline diameter; dominant height (DH), defined as total height of the tallest 70% of trees in a treatment plot; tree density per hectare (TPH); groundline basal area per hectare (GBA); and stem volume index per hectare (SVI). DH is used as a proxy for average height of trees likely to become dominant and codominant after crown closure, which is a common measure of site productivity in forestry. GBA was calculated by summing the groundline cross-sectional area of each tree, and SVI was calculated by summing the volume of each tree (1/3 × groundline basal area × total height). GLD and DH were analyzed as normal random variables. The analysis of TPH, GBA, and SVI addressed increasing variation with size using the gamma distribution with a log link function as recommended by Schabenberger and Pierce (2002). The analyses of TPH, GBA, and SVI were performed with initial planting density as a covariate, when significant, because the number of operationally planted pines could vary per subplot. Data were analyzed using SAS/STAT® software version 9.4 of the SAS® system for Windows. The analysis of variance was performed using the SAS PROC GLIMMIX procedure (Littell et al. 2006). Treatment means were compared using the Tukey–Kramer adjustment for multiplicity.

Table 5. Vegetation genera/species (excluding minor species <1% cover) present post site preparation application by location.[a]

Life-form	Genus/species	Common name	Location(s)
Tree	*Liquidambar styraciflua* L.	sweetgum	KF
Shrub	*Cyrilla racemiflora* L.	white titi	TN
	Hypericum spp.	St.-John's-wort	GS, TN
	Ilex glabra (L.) A. Gray	gallberry	TN, MP
	Lyonia fruticosa (Michx.) G.S. Torr.	staggerbush	MP
	Lyonia lucida (Lam.) K. Koch	fetterbush	GS, MP
	Myrica cerifera L.	wax myrtle	GS
	Rhus spp.	sumac	GS, KF
	Serenoa repens (W. Bartram) Small	saw palmetto	MP, TN
Semi-woody	*Rubus* spp.	blackberry	GS, KF, MP, OK, TN
Vines	*Smilax* spp.	greenbriar	GS, MP
	Vitis spp.	grape	GS, KF, MP
Fern	*Pteridium aquilinum* (L.) Kuhn	brackenfern	GS, MP, TN
	Athyrium spp.	fern	GS
Forbs	*Chamaecrista fasciculata* (Michx.) Greene	partridge pea	KF
	Croton spp.	croton	OK
	Diodia spp.	buttonweed/poorjoe	KF
	Erechtites hieracifolia (L.) Raf. ex DC.	American burnweed	GS, KF
	Eupatorium capillifolium (Lam.) Small	dogfennel	GS, KF, OK
	Eupatorium spp.	bonesets	GS
	Helianthus angustifolius L.	swamp sunflower	OK
	Hypericum gentianoides (L.) Britton, Sterns & Poggenb.	pineweed	TN
	Iva microcephala Nutt.	piedmont marsh elder	TN
	Mecardonia acuminata (Walter) Small	purple mecardonia	OK
	Phytolacca americana L.	common pokeweed	GS, KF
	Polypremum procumbens L.	rust weed	KF
	Pyrrhopappus carolinianus (Walter) DC.	Carolina false dandelion	KF
	Rhexia spp.	meadowbeauty	KF
	Solidago spp.	goldenrod	GS, OK
Grasses	*Andropogon* spp.	bluestems	GS, KF, MP, OK, TN
	Dichanthelium spp.	low panic grass	KF, MP, TN
	Muhlenbergia spp.	muhly grass	TN
	Panicum spp.	panic grass	GS, KF, MP, OK
	Piptochaetium avenaceum (L.) Parodi	needlegrass	TN
Rush/sedge	*Cyperus* spp.	sedges	GS
	Juncus spp.	rushes	MP
	Rhynchospora spp.	beakrush	MP, TN
	Scleria spp.	nutrushes	GS, OK, TN

[a]Abbreviations: GS, Green Swamp; KF, Kings Ferry; MP, Mt. Pleasant; OK, Oakdale; TN, Tennille.

Comparisons of treatments to No HWC used the SAS simulate option or Dunnett's, as appropriate, to account for multiplicity.

Results and Discussion

Treatment efficacy and duration of control were dependent on soil texture of the upper soil horizons. This provides a useful framework for summarizing results because soil drainage and horizon characteristics are commonly used in the prescription of pine management activities (Jokela et al. 2000). Oakdale and Kings Ferry locations are finer-textured soils (silt loam, sandy clay/clay), Green Swamp is of intermediate-course soil texture (sandy loam), and Mt. Pleasant and Tennille are coarser-textured sandy soils (Table 2). Vegetation was generally more aggressive on finer-textured soils after site preparation (Table 6). In all tables, the locations are ordered from highest to lowest vegetation levels, which corresponds to a change from finer to coarser surface soil textures.

Vegetation Response on Finer-Textured Soils at Oakdale and Kings Ferry

Oakdale First-Year Response

In the absence of HWC, first-year vegetation colonization was aggressive on this silt loam soil, with cover increasing from 27% to 94% between June and October (Table 6). For June cover, there were significant site preparation timing and rate interactions with HWC resulting from lower cover for August than November imazapyr site preparation without HWC, decreasing cover for increasing imazapyr site preparation rates without HWC, and no more than 7% average cover across all site preparation timings and rates following March Y1 HWC (Figure 1). Lower June cover for August compared to November site preparation was largely driven, in the absence of HWC, by better control of panic grass (*Panicum* spp.) (13% vs. 18%) and swamp sunflower (*Helianthus angustifolius* L.) (1% vs. 5%). Decreasing June cover with site preparation herbicide rate was driven by decreasing cover of panic grass with increasing imazapyr rate (22%, 17%, 9%). By August, there was no longer a difference in cover related to site preparation application timing, but site preparation rate differences persisted, decreasing from 39% to 25% with increasing site preparation herbicide rate (Table 6). For August cover, there were no significant interactions between site preparation treatments and HWC. All HWC treatments were effective, reducing average August cover from 73% to <17% (Table 6). Efficacy of HWC treatments dwarfed the increased efficacy from increasing site preparation rate (Figure 2). By October, all HWC treatments were still reducing cover relative to No HWC, but cover had increased on all HWC treatments to an average of 43% (Table 6). First-year total grass

Table 6. First-year vegetation cover (%) in June, August, and October compared by site preparation application timing, site preparation imazapyr rate, and postplant HWC treatment.[a,b]

Effect	Level[c]	Oakdale	Kings Ferry	Green Swamp	Mt. Pleasant	Tennille
		June evaluation				
Timing	Aug	16b	24a	2b	3b	2a
	Nov	22a	13b	4a	5a	4a
Rate	1.0×	25a	21a	5a	5a	4a
	1.5×	21a	20a	3ab	4ab	3a
	2.0×	11b	14b	2b	3b	2a
HWC[d]	None	27a	26a	4a	5a	3a
	Mar Y1	2b*	4b*	2b*	3ab*	2b*
	Jun Y1	28a	25a	4a	4a	4a
	Mar Sulf Y1	2b*	3b*	3ab	2b*	2ab
Interactions[e]		T,R	T×R			
		August evaluation				
Timing	Aug	31a	21a	12b	5a	7a
	Nov	33a	14b	17a	7a	3a
Rate	1.0×	39a	20a	19a	9a	6a
	1.5×	33ab	20a	14ab	6ab	5a
	2.0×	25b	13b	10b	4b	3a
HWC[d]	None	73a	37a	29a	11a	8a
	Mar Y1	13bc*	12b*	10b*	5b*	3b*
	Jun Y1	9c*	4c*	4c*	3b*	3b*
	Mar Sulf Y1	17b*	12b*	10b*	4b*	4b*
Interactions[e]			T,R,T×R	T,R		R
		October evaluation				
Timing	Aug	55b	29a	17a	10a	10a
	Nov	64a	27a	21a	10a	5a
Rate	1.0×	67a	28a	26a	13a	10a
	1.5×	61a	29a	17ab	10a	8a
	2.0×	50b	27a	13b	6a	4a
HWC[c]	None	94a	41a	37a	18a	12a
	Mar Y1	40b*	31b*	14b*	7bc*	6b*
	Jun Y1	40b*	11c*	6c*	4c*	4b*
	Mar Sulf Y1	49b*	33b*	14b*	9b*	6b*
Interactions[d]		T		T		T

[a]Locations are ordered from most to least vegetation without HWC.
[b]Abbreviation: HWC, herbaceous weed control.
[c]Means for a given effect in a column followed by the same letter are not significantly different at the 5% level using Tukey's adjustment.
[d]HWC means followed by an asterisk differ from the No HWC (None) at the 5% level using a simulation adjustment for multiplicity.
[e]T = Timing × HWC interaction; R = Rate × HWC interaction; T×R = Timing × Rate × HWC interaction at the 5% level of significance.

cover was similar between October and November site preparation, averaging 31%, but an interesting species shift occurred. With October site preparation, bluestem grasses (*Andropogon* spp.) accounted for only 6% of grass cover, whereas bluestem grasses accounted for nearly all grass cover following November site preparation (data not shown). From an operational perspective, first-year HWC in March or June would be considered successful, but March Y1 HWC would be preferred to maintain low weed cover early in the first growing season.

Oakdale Second-Year Response

Aggressive vegetation colonization continued into the second year after treatment. Without HWC, vegetation cover was 86% in June and 97% in October. There were small residual effects of site preparation timing and site preparation rate in the second year, but differences were <10% (Table 7). There was little residual vegetation control from Mar Y1 or Jun Y1 HWC treatments, with average cover of 72% in June and 92% October. Second-year HWC treatments significantly reduced cover compared to first-year-only treatments. Cover for Mar Y2 or Jun Y1+MarY2 averaged 22% in June and 77% in October. Second-year vegetation cover by life-form is provided in Figure 3. Note that the sum of covers for individual life-forms can be greater than total cover because of overlapping crowns. Oakdale cover was dominated by forbs and grasses with second-year HWC treatments favoring grass cover (almost entirely bluestem grasses). Forb cover consisted of dogfennel [*Eupatorium capillifolium* (Lam.) Small], goldenrod (*Solidago* spp.), swamp sunflower, and other minor species, with less swamp sunflower following August site preparation.

Kings Ferry First-Year Response

In the absence of HWC, first-year vegetation colonization was aggressive on this clay soil, with cover increasing from 26% to 41% between June and October (Table 6). This was not as aggressive as Oakdale, where October cover increased to 94%. First-year efficacy was largely driven by American burnweed [*Erechtites hieracifolia* (L.) Raf. ex DC.] early in the year and colonization of other species later in the year. The significant site preparation date × rate

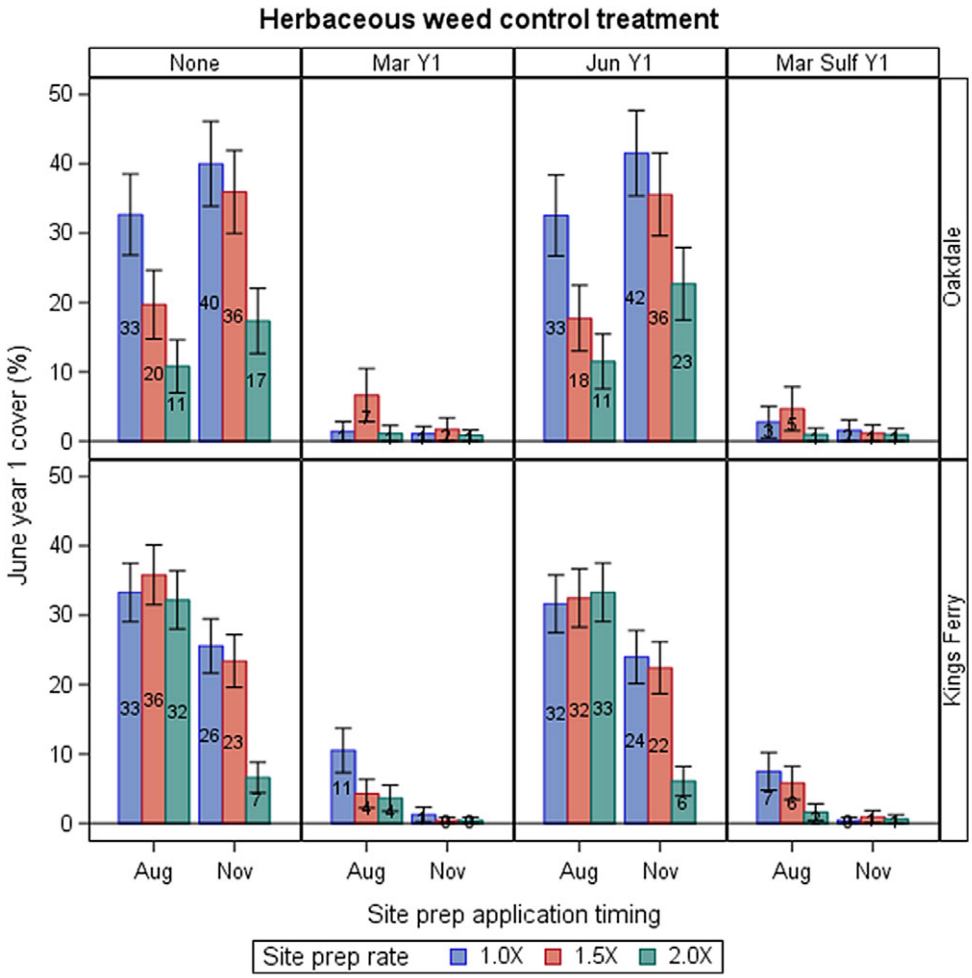

Figure 1. Vegetation cover in June of Year 1 for first-year (Y1) HWC treatments of imazapyr + sulfometuron in March (Mar Y1) or June (Jun Y1) and sulfometuron alone in March (Mar Sulf Y1) after August (Aug) or November (Nov) imazapyr site preparation at the Kings Ferry and Oakdale locations. The Jun Y1 HWC treatment had not yet been applied. Error bars are ± approximate standard error.

× HWC interaction for June cover was the result of November site preparation having lower cover than August site preparation, a low level of cover (7%) for the November 2.0× imazapyr rate, and no higher than 11% cover following March HWC, regardless of site preparation treatment (Figure 1). For Mar Y1 HWC, August cover averaged across all site preparation rates was 18% following August site preparation and 6% following November site preparation. For Jun Y1 HWC, cover averaged 4% following all site preparation treatments (Figure 2). From an operational perspective, the 2.0× November site preparation application rate with No HWC or any of the first-year HWC treatments would be considered successful. March Y1 HWC would be preferred to June Y1 HWC to maintain low weed cover early in the first growing season.

Kings Ferry Second-Year Response

There were no residual effects of site preparation timing and rate in the second year. Without HWC, vegetation cover increased from 41% in October of the first year to 68% in June of the second year and to 75% in October of the second year (Table 7). There was little residual vegetation control form Mar Y1 or Jun Y1 HWC treatments, with average cover of 55% in June and 62% in October. Second-year HWC treatments significantly reduced cover compared to first-year-only treatments. Cover for Mar Y2 or Jun Y1+MarY2 averaged 11% in June and 34% in October. Second-year vegetation cover by life-form is provided in Figure 3. Cover was dominated by forbs, with higher forb cover for HWC treatments following November than August site preparation. Forb cover consisted mostly of dogfennel and rustweed for No HWC and first-year HWC treatments. Total grass cover was similar between October and November site preparation, but an interesting species shift occurred. Grass cover was dominated by bluestem grasses for first-year HWC treatments following August site preparation (11%) compared to November site preparation (1%) and by panic and low panic grasses (*Dichanthelium* spp.) for November site preparation (18%) compared to August site preparation (2%) (data not shown).

Vegetation Response on Coarser-Textured Soils at Green Swamp, Mt. Pleasant, and Tennille

First-Year Response

Vegetation control from site preparation treatments on coarser-textured soils was exceptional through June of Year 1, with cover not exceeding 5% for any treatment effect average at any location (Table 6). Without HWC, average cover on the sandy loam alfisol at Green Swamp increased to 29% in August and 37% in October. Without HWC, August cover on the sandy spodosols increased to no more than 11% for both the high-volume

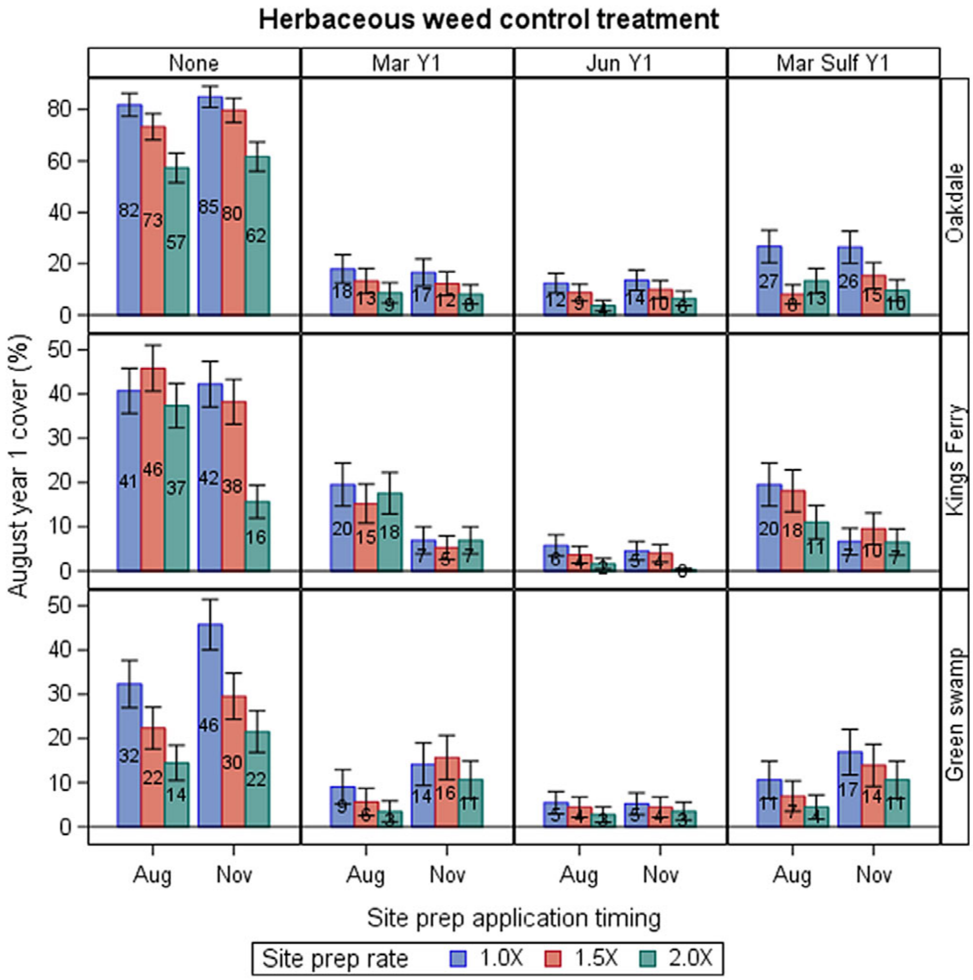

Figure 2. Vegetation cover in August of Year 1 for first-year (Y1) HWC treatments of imazapyr + sulfometuron in March (Mar Y1) or June (Jun Y1) and sulfometuron alone in March (Mar Sulf Y1) after August (Aug) or November (Nov) imazapyr site preparation at the Oakdale, Kings Ferry, and Green Swamp locations. Error bars are ± approximate standard error.

without MSO and the low-volume with MSO site preparation applications at Mt. Pleasant and Tennille, respectively. On all three sites, first-year HWC treatments reduced cover to no more than 10% cover in August and no more than 14% cover in October (Table 6). The significant August cover interactions for Green Swamp were due to larger reductions in cover from August site preparation, reductions from increasing site preparation rate for No HWC, and lesser differences with increasing rate for the other HWC treatments (Figure 2).

Second-Year Response

There was little residual control from site preparation treatments or first-year HWC treatments in the second year. Without HWC, cover across the three sites increased from a range of 58% to 72% in June to 62% to 90% in October (Table 7). There was more aggressive vegetation recolonization on the sandy loam soil at Green Swamp compared to the sands at Mt. Pleasant and Tennille. There was also little residual vegetation control into the second year from first-year HWC treatments (Table 7). Second-year HWC treatments (Mar Y2 and Jun Y1+Mar Y2) significantly reduced June and October cover at all three sites, with June cover not exceeding 12% and October cover not exceeding 36% at any location (Table 7).

Vegetation occupancy by life-form in October of Year 2 (Figure 4) was dominated by grasses. These were primarily bluestem and low panic grasses at these three locations, with most of the October cover reduction from second-year HWC due to control of low panic grasses and suppression of bluestem grasses. Woody vegetation cover in shrubs, vines, and trees remained less than 10% cover for all treatments at Mt. Pleasant and Tennille. October Y2 blackberry cover was higher for November site preparation at Green Swamp but did not exceed 18%, and there was poorer shrub control (mostly sumac [*Rhus* spp.] at 10% vs. 3%) from November imazapyr at Green Swamp following No HWC or March HWC (Figure 4). Grass cover at Green Swamp was primarily bluestem grasses for first-year HWC following August imazapyr site preparation or second-year HWC, in contrast to an approximately equal mix of bluestem and panic grasses for first-year HWC following November site preparation or No HWC (data not shown).

HWC Limitations

The HWC herbicides included in this study were generally effective for the growing season of application. Limitations of Year 1 and Year 2 March HWC treatments are demonstrated in Figure 5 using

Table 7. Second-year vegetation cover (%) in June and October compared by site preparation application timing, site preparation imazapyr rate, and postplant HWC treatment.[a]

Effect	Level[b]	Oakdale	Kings Ferry	Green Swamp	Mt. Pleasant	Tennille
		June evaluation				
Timing	Aug	55b	42a	39b	35a	42a
	Nov	64a	44a	53a	39a	39a
Rate	1.0×	63a	41a	50a	41a	47a
	1.5×	59ab	47a	45ab	40a	40a
	2.0×	56b	40a	42b	31a	34a
HWC[c]	None	86a	68a	72a	58a	59ab
	Mar Y1	74b*	56b*	63b*	51ab	60a
	Jun Y1	71b*	54b*	61b*	44b*	50b*
	Mar Y2	17d*	11c*	9c*	7c*	12c*
	Jun Y1+Mar Y2	28c*	11c*	6c*	8c*	10c*
	Mar Sulf Y1	80ab	58b*	64ab*	54ab	61a
Interactions[d]				T		
		October evaluation				
Timing	Aug	86b	54a	65b	44a	63a
	Nov	90a	56a	70a	49a	63a
Rate	1.0×	90a	53a	70a	48a	69a
	1.5×	87a	62a	66a	49a	62a
	2.0×	87a	51a	66a	42a	59a
HWC[c]	None	97a	75a	90a	62a	77a
	Mar Y1	92b*	61b*	88a	60a	79a
	Jun Y1	92b*	63b*	86a*	57a	73a
	Mar Y2	79c*	38c*	29b*	20b*	36b*
	Jun Y1+Mar Y2	76c*	31c*	24b*	19b*	34b*
	Mar Sulf Y1	92b*	64b*	87a	59a	77a
Interactions[d]			T×R	T		

[a]Abbreviation: HWC, herbaceous weed control.
[b]Means for a given effect in a column followed by the same letter are not significantly different at the 5% level using Tukey's adjustment.
[c]HWC means followed by an asterisk differ from the No HWC (None) at the 5% level using Dunnett's adjustment.
[d]T = Timing × HWC interactions; R = Rate × HWC interactions; T×R = Timing × Rate × HWC interactions at the 5% level of significance.

August imazapyr site preparation as the example. Second-year HWC did not hold up as well as the first-year HWC in that Mar Y2 HWC cover in Oct Y2 was greater than Mar Y1 HWC cover in Oct Y1. First-year HWC did not persist into Year 2 in that Oct Y2 cover and composition are comparable between No HWC and Mar Y1 HWC treatments, with grasses being the dominant component at four of five locations. Grasses were also the dominant herbaceous component at four of five locations for Mar Y2 HWC in Oct Y2. There is opportunity for innovation of a selective HWC treatment that could provide similar broadleaf control and better control of grasses than the traditional imazapyr + sulfometuron treatment for a one- or two-pass program on finer-textured soils and a single-pass system in the second year on coarser-textured soils. It would also be advantageous to develop a HWC treatment with better selectivity over slash pine.

Year 1 Pine Planting Survival and Density

Pine survival 1 yr after planting (YAP) is compared by site preparation timing, site preparation imazapyr rate, and HWC treatment in Table 8. Second-year HWC treatments had not yet been applied. The concern here is primarily pine tolerance to the herbicide treatments. Except for the Green Swamp location, survival was operationally acceptable (>85%) across all treatments. Survival averaged 100%, 96%, 100%, and 90% for Oakdale, Kings Ferry, Mt. Pleasant, and Tennille, respectively, with a range of 4% or less across all treatments within a location. Survival averaged 69% at the Green Swamp location, with a significant difference in survival between August and November site preparation (74% vs. 63%, respectively). However, at Green Swamp, there was no site preparation rate effect or interaction between site preparation timing and rate. This means no negative impact from even the highest imazapyr rate applied in November. Factors other than residual imazapyr in the soil are likely responsible for the better survival with August site preparation. The application timing survival differences at Green Swamp may be related to differences in vegetation control, planting conditions influenced by the length of time it takes vegetation to die and decompose after treatment, C/N ratios, soil–water relationships, or some other factor. Pine density 3 YAP (Table 9) was significantly lower for November imazapyr site preparation at Green Swamp and Kings Ferry, but there were no significant differences due to imazapyr site preparation rate, HWC, or interactions of site preparation timing and rate with HWC at any location.

Pine Response 3 YAP

Across all locations, there were no significant pine response differences in terms of average tree GLD or DH (Table 10) or stand-level GBA or SVI (Table 11) due to imazapyr site preparation rate. There were also no significant pine response differences due to imazapyr site preparation timing, except for the Green Swamp location. At Green Swamp, pine response was higher for August than November application, and this can best be explained by differences in vegetation control. At this location, cover in June of the second year was significantly lower following August (39%)

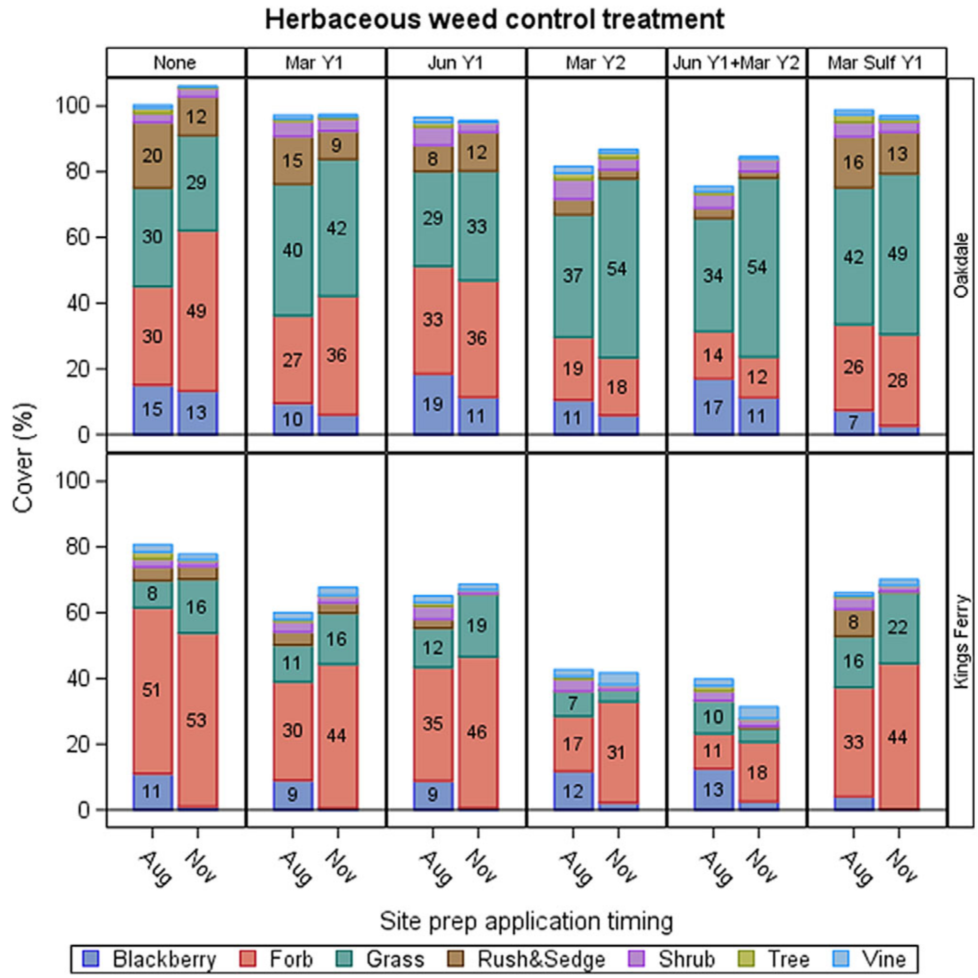

Figure 3. Vegetation cover by life-form on finer-textured soils in October at the end of the second growing season for HWC treatments following August (Aug) or November (Nov) imazapyr site preparation. HWC treatments were imazapyr + sulfometuron in March (Mar Y1) or June (Jun Y1) of Year 1, March of Year 2 (Mar Y2), and June of Year 1 + March of Year 2 (Jun Y1 + Mar Y2) and sulfometuron alone in March of Year 1 (Mar Sulf Y1). Cover can sum to more than 100% due to overlap.

than November (53%) site preparation (Table 7). There were no significant interactions between HWC and imazapyr site preparation timing or rate at any location for any pine response variable.

There were positive loblolly pine responses 3 YAP to most HWC treatments at both the Oakdale and Kings Ferry locations (Tables 10 and 11, respectively) due to rapid colonization of vegetation on these finer-textured soils. At both sites, the best-ranked response for single-pass HWC was an application early in the first year. Without HWC, Oakdale had aggressive recolonization of vegetation dominated by panic grasses. In this situation, the next best alternative to early first-year HWC was a delayed application in June of the first year. Vegetation recolonization at Kings Ferry was not as aggressive as at Oakdale and was dominated by American burnweed. In this situation, the next best alternative to early first-year HWC was early second-year HWC. At both sites, 2 consecutive years of HWC (Jun YI + Mar Y2) resulted in the best-ranked response. Since an early first-year treatment was the preferred single-pass HWC at both locations, it is likely that application early in the first year followed by application early in the second year would result in a better response, but this treatment was not tested in this study.

The best single-pass HWC treatment on the coarse-textured soils at Green Swamp and Mt. Pleasant was an application early in the second year after treatment (significantly different than No HWC in Tables 10 and 11 for all but DH at Mt. Pleasant). This is explained by the very low first-year vegetation cover of 4% to 5% without HWC, compared to 58% to 72% cover in the second year. There was little additional benefit from 2 consecutive years of HWC on these sites. There was also a significant site preparation timing difference at Green Swamp. June Y2 average cover was significantly lower following August (39%) than November (53%) site preparation at Green Swamp, and pine response 3 YAP for August site preparation was significantly greater than November site preparation for GLD (7.8 vs. 6.7 cm), DH (3.3 vs. 2.9 m), GBA (4.9 vs. 3.2 m^2 ha^{-1}), and SVI (5.2 vs. 3.1 m^3 ha^{-1}). Lower first-year survival contributes to lower GBA and SVI for November applications at Green Swamp.

Slash pine at Tennille was tolerant of all imazapyr site preparation treatments regardless of site preparation timing or rate of application. Site preparation treatments made first-year HWC treatments unnecessary because June and August Y1 cover without HWC was 3% and 8%, respectively. Height development and subsequent pine response were limited by postplant imazapyr HWC, especially when trees were responding vigorously to weed-free conditions achieved by site preparation applications (Tables 10 and 11). Tolerance, in terms of tree response, to sulfometuron

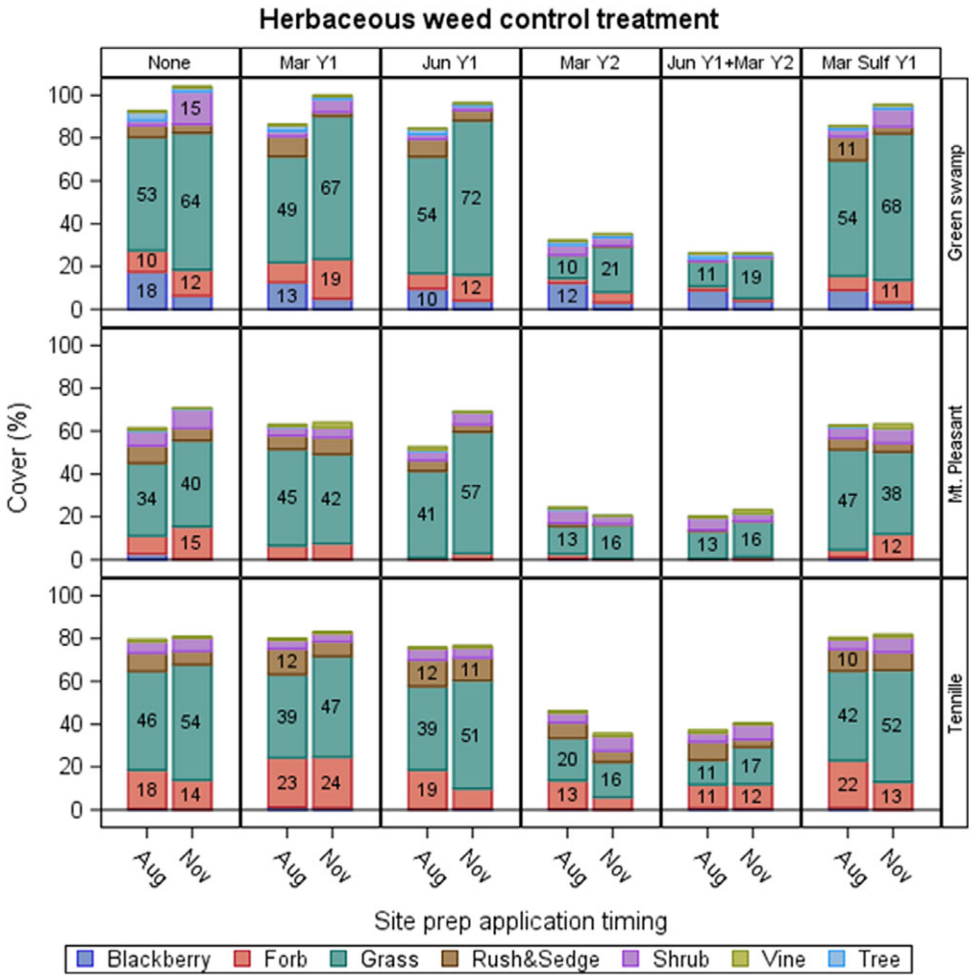

Figure 4. Vegetation cover by life-form on coarser-textured soils in October at the end of the second growing season for HWC treatments following August (Aug) or November (Nov) imazapyr site preparation. HWC treatments were imazapyr + sulfometuron (imazapyr alone for slash pine at Tennille) in March (Mar Y1) or June (Jun Y1) of Year 1, March of Year 2 (Mar Y2), and June of Year 1 + March of Year 2 (Jun Y1 + Mar Y2) and sulfometuron alone in March of Year 1 (Mar Sulf Y1). Cover can sum to more than 100% due to overlap.

HWC or imazapyr HWC treatments applied over trees in March was not dependent on imazapyr site preparation timing or rate (no significant interactions with HWC). The Mar Sulf Y1 HWC treatment was tolerated by slash pine at Tennille, as evidenced by the lack of any significant difference in pine response between this treatment and No HWC (No HWC was essentially weed-free in Year 1).

Conclusions and Operational Strategies

Several key concepts based on results from these five study locations can simplify the prescription process. Key concepts are as follows: (1) imazapyr-based site preparation treatments can be used to control woody and herbaceous vegetation without concern for slash or loblolly pine tolerance for the application rates and timings tested in this study series on bedded Lower Coastal Plain sites, (2) use HWC treatments on loblolly pine only in the year they are needed (Year 1 or Years 1 and 2 for fine-textured soils, Year 2 for coarse-textured soils), and (3) favor the earlier March HWC timing (operationally, the March to April period instead of the May to June period). Last, this study contrasts two methods of improving pine response with the combination of site preparation and HWC treatments. Year 3 pine response and extended vegetation control were rarely improved by the higher site preparation herbicide rates. The cost-effective allocation of treatments is to combine the 1.0× site preparation rate with later HWC treatments if extended control is the objective.

HWC treatment recommendations are explained in terms of Year 3 pine stand volume index response relative to No HWC (Figure 6). The comparison of HWC averages is possible because there was no evidence that tolerance to HWC treatments was related to soil activity from site preparation imazapyr application timing or rate (no significant interactions). HWC was not required in Year 1 on coarser-texture soils, which averaged less than 10% cover in June Y1 without HWC (Table 6). Finer-textured soil locations averaged more than 20% cover in June Y1 without HWC but serve two contrasting situations. The Oakdale location had perennial grasses that were important to control in Year 1 such that single-pass first-year and double-pass first- plus second-year HWC resulted in significant responses. The Kings Ferry location was dominated by an annual forb that overtopped pines early but did not persist into Year 2 such that Jun Y1 HWC response was not significant but March single-pass HWC in Year 1 or 2 and the first- plus

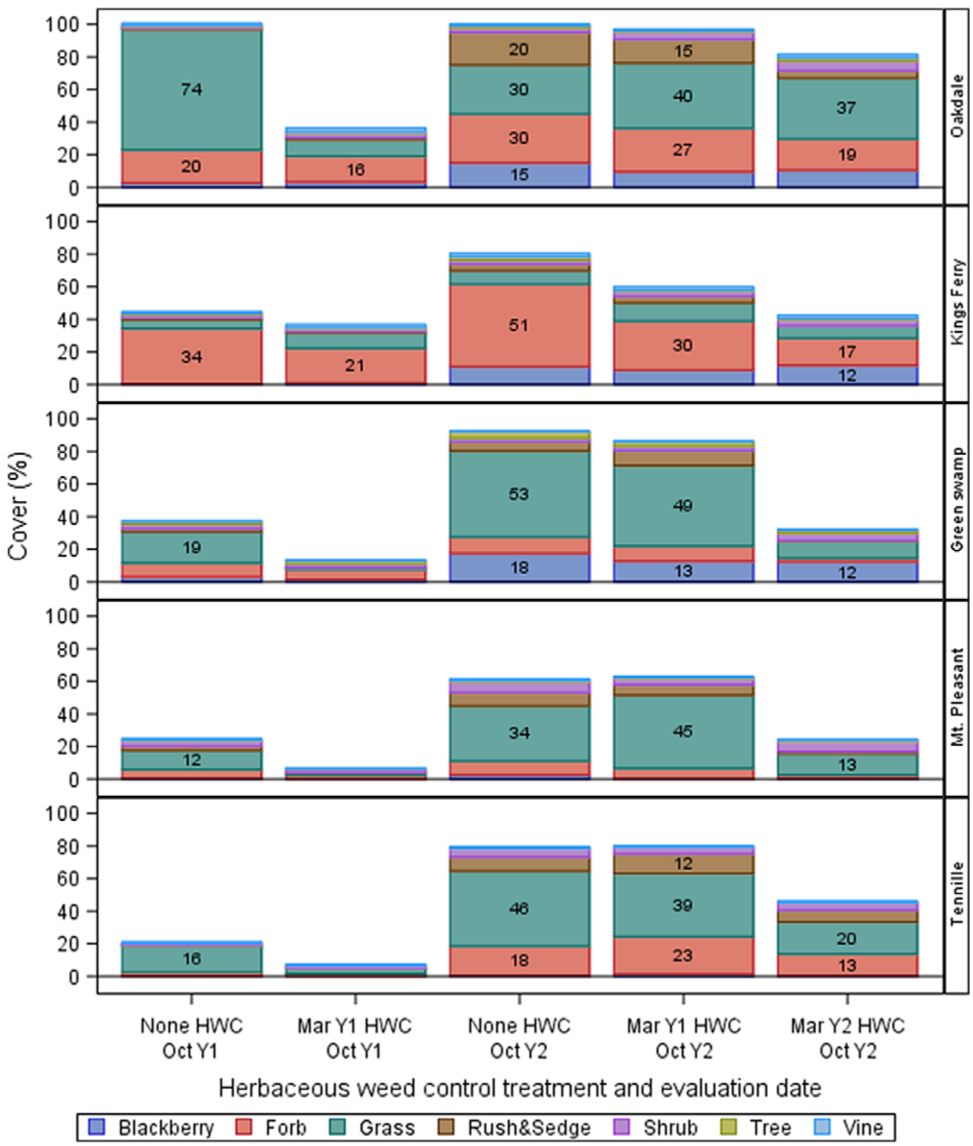

Figure 5. Vegetation cover by life-form in October of Years 1 (Oct Y1) and 2 (Oct Y2) for No HWC and imazapyr + sulfometuron (imazapyr alone at the slash pine Tennille location) HWC treatments applied in March of Year 1 (Mar Y1) or March of Year 2 (Mar Y2) following August imazapyr site preparation.

Table 8. Pine survival (%) 1 YAP by study location.[a,b]

Effect	Level[c]	Oakdale	Kings Ferry	Green Swamp	Mt. Pleasant	Tennille Slash
		Loblolly				
Timing	Aug	100a	98a	74a	100a	88a
	Nov	100a	94b	63b	100a	91a
Rate	1.0×	100a	97a	69a	100a	88a
	1.5×	100a	96a	72a	100a	89a
	2.0×	100a	96a	65a	100a	91a
HWC	None	100a	97ab	67a	100a	90a
	Mar Y1	100a	97ab	71a	100a	91a
	Jun Y1	100a	94b	69a	99a	90a
	Mar Sulf Y1	100a	98a	69a	100a	88a

[a]There were no significant interactions except Timing x HWC (P = 0.013) at Tennille. Interaction was not of practical significance (87% vs. 92% with HWC and 91% vs. 88% without HWC for August and November site preparation, respectively).
[b]Abbreviation: HWC, herbaceous weed control.
[c]Means for a given effect in a column followed by the same letter are not significantly different at the 5% level using Tukey's adjustment.

Table 9. Pine density 3 YAP by study location.[a,b]

Effect	Level[c]	Oakdale	Kings Ferry	Green swamp	Mt. Pleasant	Tennille Slash
		Loblolly				
		trees ha^{-1}				
Timing	Aug	1,236a	2,025a	1,023a	1,612a	1,404a
	Nov	1,231a	1,939b	884b	1,623a	1,469a
Rate	1.0×	1,224a	2,025a	957a	1,624a	1,410a
	1.5×	1,238a	1,962a	998a	1,607a	1,431a
	2.0×	1,238a	1,961a	905a	1,620a	1,467a
HWC	None	1,242a	1,965a	929a	1,605a	1,446a
	Mar Y1	1,235a	2,012a	976a	1,598a	1,458a
	Jun Y1	1,215a	1,929a	973a	1,602a	1,410a
	Mar Y2	1,252a	2,001a	955a	1,655a	1,463a
	Jun Y1+Mar Y2	1,231a	1,967a	946a	1,620a	1,420a
	Mar Sulf Y1	1,225a	2,019a	942a	1,622a	1,418a
Initial[d]	Planting density	1,256	2,105	1,419	1,669	1,654

[a]Initial planting density was a significant covariate ($P<0.01$) at all locations. There were no significant interactions at the 5% level.
[b]Abbreviation: HWC, herbaceous weed control.
[c]Means for a given effect in a column followed by the same letter are not significantly different at the 5% level using Tukey's adjustment.
[d]Location average of initial planting density.

Table 10. Average tree groundline diameter and average total height of the tallest 70% of trees 3 YAP.[a,b]

Effect	Level[c]	Oakdale	Kings Ferry	Green Swamp	Mt. Pleasant	Tennille Slash
		Loblolly				
		GLD cm				
Date	Aug	5.9a	8.2a	7.8a	7.3a	7.5a
	Nov	6.1a	8.5a	6.7b	7.0a	7.7a
Rate	1.0×	6.1a	8.4a	7.1a	7.2a	7.3a
	1.5×	5.9a	8.3a	7.4a	7.3a	7.8a
	2.0×	6.1a	8.3a	7.3a	7.0a	7.8a
HWC[d]	None	5.0c	7.5c	6.6c	7.0bc	8.0ab
	Mar Y1	6.4ab*	8.5ab*	6.7c	6.8c	7.0c*
	Jun Y1	6.1ab*	8.2b*	7.1c	7.2abc	7.4abc
	Mar Y2	5.6bc	8.4ab*	7.8b*	7.5ab*	8.1a
	Jun Y1+Mar Y2	6.8a*	8.8a*	8.4a*	7.6a*	7.3bc*
	Mar Sulf Y1	6.1ab*	8.5ab*	7.0c	6.9c	7.7abc
		DH m				
Date	Aug	2.77a	3.94a	3.31a	3.31a	2.52a
	Nov	2.84a	3.95a	2.91b	3.23a	2.69a
Rate	1.0×	2.86a	4.04a	3.10a	3.31a	2.45a
	1.5×	2.73a	3.92a	3.15a	3.29a	2.71a
	2.0×	2.82a	3.88a	3.08a	3.20a	2.66a
HWC[d]	None	2.55c	3.70b	2.96c	3.29ab	2.84a
	Mar Y1	2.93a*	4.04a*	3.01bc	3.16ab	2.49bc*
	Jun Y1	2.87ab*	3.90ab	3.10bc	3.29ab	2.66ab
	Mar Y2	2.63bc	3.87ab	3.19ab*	3.34ab	2.57abc*
	Jun Y1+Mar Y2	2.99a*	4.09a*	3.32a*	3.38a	2.31c*
	Mar Sulf Y1	2.87ab*	4.07a*	3.09bc	3.14b	2.77a

[a]There were no significant interactions at the 5% level.
[b]Abbreviations: DH, dominant height; GLD, groundline diameter; HWC, herbaceous weed control.
[c]Means for a given effect in a column followed by the same letter are not significantly different at the 5% level using Tukey's adjustment.
[d]HWC means followed by an asterisk differ from the No HWC (None) at the 5% level using Dunnett's adjustment.

second-year HWC treatments had significant responses. This is evidence of how detrimental an overtopping annual can be to pine growth.

The use of imazapyr site preparation prior to HWC is important because imazapyr can be used at rates that provide initial control of all vegetation and shift composition of vegetation to herbaceous and semi-woody species not likely to persist after pine crown closure. Imazapyr site preparation was effective at control of woody vegetation at all five locations (Figures 3 and 4). Pines were highly tolerant to imazapyr site preparation treatments, as evidenced by the lack of differences in slash or loblolly pine survival and growth from the doubling of imazapyr rates for August or November application timings. The higher imazapyr site preparation rates should be used if needed to target hard-to-control species. The shifts away from woody competitors and sizable pine response from these management regimes are shown in Figures 7, 8, and 9. Figure 7 shows the level of vegetation control achieved with the August application of

Table 11. Groundline stand basal area and stand volume index 3 YAP.[a,b]

Effect	Level[c]	Oakdale	Kings Ferry	Green Swamp	Mt. Pleasant	Tennille Slash
		Loblolly				
		GBA m^2 ha^{-1}				
Date	Aug	3.53a	10.81a	4.87a	6.93a	6.37a
	Nov	3.74a	10.99a	3.20b	6.65a	7.15a
Rate	1.0×	3.60a	11.44a	3.74a	6.91a	6.02a
	1.5×	3.62a	10.70a	4.35a	6.86a	7.16a
	2.0×	3.69a	10.59a	3.78a	6.60a	7.14a
HWC[d]	None	2.60c	8.91c	3.17c	6.41b	7.69a
	Mar Y1	4.23ab*	11.54ab*	3.61bc	6.05b	6.00b*
	Jun Y1	3.64ab*	10.02bc	3.80bc	6.70ab	6.39ab
	Mar Y2	3.30bc*	11.31ab*	4.50ab*	7.72a*	7.93a
	Jun Y1+Mar Y2	4.69a*	12.28a*	5.35a*	7.68a*	6.23ab
	Mar Sulf Y1	3.71ab*	11.72ab*	3.62bc	6.34b	6.50ab
		SVI m^3 ha^{-1}				
Date	Aug	3.22a	13.73a	5.22a	7.48a	5.22a
	Nov	3.53a	14.19a	3.09b	7.06a	6.21a
Rate	1.0×	3.39a	14.90a	3.79a	7.49a	4.77a
	1.5×	3.29a	13.64a	4.47a	7.36a	6.30a
	2.0×	3.44a	13.39a	3.82a	6.96a	6.14a
HWC[d]	None	2.20c	10.73c	3.09c	6.92ab	7.12a
	Mar Y1	4.15a*	15.31ab*	3.62bc	6.32b	4.87bc*
	Jun Y1	3.45ab*	12.74bc	3.81bc	7.19ab	5.53abc
	Mar Y2	2.83bc	14.22ab*	4.70ab*	8.44a*	6.53ab
	Jun Y1+Mar Y2	4.66a*	16.19a*	5.77a*	8.46a*	4.65c*
	Mar Sulf Y1	3.56ab*	15.36ab*	3.64bc	6.57b	5.85abc

[a]Initial planting density was a significant covariate for GBA and SVI at Green Swamp, Kings Ferry, and Mt. Pleasant locations ($P < 0.05$). There were no significant interactions at the 5% level.
[b]Abbreviations: GBA, groundline stand basal area; HWC, herbaceous weed control; SVI, stand volume index.
[c]Means for a given effect in a column followed by the same letter are not significantly different at the 5% level using Tukey's adjustment.
[d]HWC means followed by an asterisk differ from the No HWC (None) at the 5% level using Dunnett's adjustment.

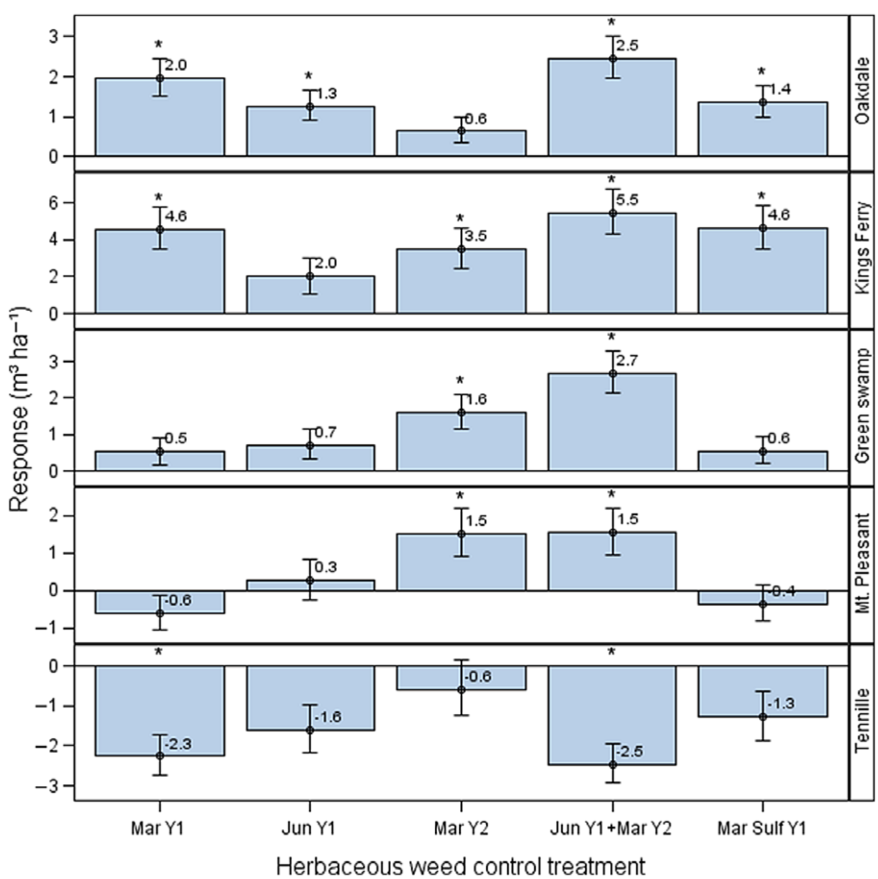

Figure 6. Stand volume index response 3 YAP averaged over all imazapyr site preparation treatments. HWC treatments were imazapyr + sulfometuron (imazapyr alone for slash pine at Tennille) in March (Mar Y1) or June (Jun Y1) of Year 1, March of Year 2 (Mar Y2), and June of Year 1 + March of Year 2 (Jun Y1 + Mar Y2) and sulfometuron alone in March of Year 1 (Mar Sulf Y1). Response is the difference between HWC treatment and No HWC. Error bars are ± standard error. An asterisk denotes that the treatment is significantly different from No HWC.

Figure 7. Edge bed of August 2.0× imazapyr site preparation treatment without HWC at the Tennille slash pine location: August of first growing season (top) and November of third growing season (bottom).

Figure 8. Edge of 2.0× November imazapyr site preparation looking into untreated buffer in August of the first year at the Mt. Pleasant, GA, location. This application was high volume without MSO.

the 2.0× site preparation rate on a treated outer buffer row without HWC (Figure 7, top) at Tennille and slash pine response for the same row in November of the third growing season (Figure 7, bottom). Slash pines surrounded by waxy-leafed

Figure 9. November site preparation with the 2.0× rate of imazapyr site preparation at Kings Ferry loblolly pine location: June of first growing season (top) and December of second growing season (bottom).

shrubs are difficult to see on the adjacent untreated bed, and the bed on the far right received an operational HWC treatment without imazapyr site preparation. The aggressiveness of untreated woody vegetation in the first growing season is contrasted with control achieved by the November 2.0× treatment at Mt. Pleasant in Figure 8. Figure 9 shows the high level of control achieved in June of the first growing season for the November 2.0× rate site preparation treatment on the finer-textured soil at Kings Ferry (Figure 9, top) and second-year loblolly pine response (Figure 9, bottom).

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References

Fox TR, Jokela EJ, Allen HL (2007) The development of pine plantation silviculture in the southern United States. J For 105:337–347

Haase DL, Pike C, Enebak S, Mackey L, Ma Z, Rathjen M (2019) Forest nursery seedling production in the United States—fiscal year 2018. Tree Planter's Notes 62(2):20–24

Jokela EJ, Martin TA, Vogel JG (2010) Twenty-five years of intensive forest management with southern pines: important lessons learned. J For 108:338–347

Jokela EJ, Wilson DS, Allen JE (2000) Early growth responses of slash and loblolly pine following fertilization and herbaceous weed control treatments at establishment. South J Appl For 24:23–30

Lauer DK, Glover GR (1998) Early pine response to control of herbaceous and shrub vegetation in the Flatwoods. South J Appl For 15:201–208

Lauer DK, Glover GR (1999) Stand level pine response to occupancy of woody shrub and herbaceous vegetation. Can J For Res 29:979–984

Lauer DK, Glover GR, Gjerstad DH (1993) Comparison of duration and method of herbaceous weed control on loblolly pine response through mid-rotation. Can J For Res 23:2116–2125

Lauer DK, Quicke HE (2006a) Timing of Chopper herbicide site preparation on bedded sites. South J Appl For 30:92–101

Lauer DK, Quicke HE (2006b) Timing of herbaceous weed control in Lower Coastal Plain loblolly pine plantations. Pages 158–160 *in* Proceedings of the 13th Biennial Southern Silvicultural Research Conference. Gen. Tech. Rep. SRS-92. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station

Lauer DK, Zutter BR (2001) Vegetation cover response and second-year loblolly and slash pine response following bedding and pre- and post-plant herbicide applications in Florida. South J Appl For 25:75–83

Littell RC, Milliken GA, Stroup WW, Wolfinger RD, Schabenberger O (2006) SAS for Mixed Models. 2nd ed. Cary, NC: SAS Institute Inc. 813 p

McKeand SE (2019) The evolution of a seedling market for genetically improved loblolly pine in the southern United States. J For 117:293–301

Miller JH, Zutter BR, Zedaker SM, Edwards MB, Haywood JD, Newbold RA (1991) A regional study on the influence of woody and herbaceous competition on early loblolly pine growth. South J Appl For 15:169–179

Sarigumba TI, Anderson GA (1979) Response of slash pine to different spacings and site-preparation treatments. South J Appl For 3:91–94

Schabenberger O, Pierce FJ (2002) Contemporary Statistical Models for the Plant and Soil Sciences. Boca Raton, FL: Taylor and Francis. 738 p

Senseman SA, ed. (2007) Herbicide Handbook. Lawrence, KS: Weed Science Society of America. 458 p

Shiver BD, Rheney JW, Oppenheimer MJ (1990) Site-preparation method and early cultural treatments affect growth of Flatwoods slash pine plantations. South J Appl For 14:183–188

Swindel BF, Smith JE, Neary DG, Comerford NB (1989) Recent research indicates plant community responses to intensive treatment including chemical amendments. South J Appl For 13:152–156

Zutter BR, Miller JH (1998) Eleventh-year response of loblolly pine and competing vegetation to woody and herbaceous plant control on a Georgia Flatwoods site. South J Appl For 22:88–95