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Vegetative Response to Weed Control in Forest Restoration

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1. Introduction

Longleaf pine (*Pinus palustris* Mill.) stands once occupied an estimated 24 million ha in the southeastern USA (Stout & Marion, 1993). Fire suppression, timber harvest, and land conversion reduced its extent to around one million ha (Outcalt & Sheffield, 1996). In recent times, widespread interest in restoring longleaf pine ecosystems or planting the species for timber production has motivated private landowners, industrial forest owners, and public agencies to establish more longleaf pine forest. Over 33 million longleaf pine seedlings were produced for the 2005-2006 planting season in the southeastern United States (McNabb & Enebak, 2008), and 54 million produced in 2008-2009 (Pohl & Kelly, 2011).

Longleaf pine ecosystems are fire-adapted and support a diverse understory plant community when ground fires are frequent (Peet & Allard, 1993). Longleaf pine seedlings germinate and develop into a grass-like clump, and later transition from this “grass stage” to become woody saplings. Seedlings in the grass stage resist fire, but become vulnerable to fire upon emergence from the grass stage until height growth elevates their terminal bud beyond reach of fire and their bark thickens (Boyer, 1990). Early fire resistance is thought to be an adaptation to frequent fire. During the grass stage, seedlings invest energy in root development in preparation for rapid shoot extension upon emergence. This strategy for re-occupying disturbed sites gives the slower-growing longleaf pine a competitive advantage over less fire-hardy pines and hardwood competitors (Outcalt, 2000). However, in the absence of fire, longleaf pine seedlings are quickly overtopped by competing vegetation. Therefore rapid restoration of longleaf pine forests will necessarily involve some disturbance of competing vegetation. Hardwood regeneration is usually prolific following disturbances such as removal of forest cover. A suite of hardwood species regenerate as stump sprouts and root suckers, developing quickly from established root systems. Grasses and vines also develop quickly after disturbance in the warm humid climate of southeastern USA. Various forms of above- and belowground competition impact on survival and growth of planted longleaf pine seedlings (Harrington et al., 2003; Pecot et al, 2007) and other pine species (e.g., Richardson et al., 1996b; Amishev & Fox, 2006).

Tools available for control of competing vegetation in longleaf pine forest restoration include prescribed fire, mechanical methods, and chemical weed control with herbicides. Prescribed fire most closely mimics the natural disturbance regime in longleaf pine forests, but it may not carry in areas with insufficient quantity or quality of fuels, and it may not be appropriate or acceptable on some ownerships. Mechanical weed control methods include portable saws and machine-mounted mowers or masticators. These methods are more expensive than prescribed fire treatments, but can have similar effects: competing vegetation is disturbed above ground but not always killed; much of it re-sprouts. Herbicides can provide effective and economical control of competing vegetation, but their use may not be appropriate or acceptable in some areas amid concerns over effects on non-target organisms, movement and drift, and persistence in the environment. Fire or broadcast herbicide treatments can eliminate live vegetation cover, exposing soil to erosive forces and temporarily reducing biodiversity. Applying herbicide in spots as opposed to broadcast applications has the advantage of reducing chemical usage while maintaining some continuity of vegetation cover and preserving biodiversity between treated spots (Richardson et al., 1996a).

Research into longleaf pine forest establishment and weed control has focused on the Coastal Plain region of the southeastern USA. Field research on the Coastal Plain indicated that mechanical weed control treatments were inferior to chemical weed control in terms of enhancing longleaf pine seedling survival and growth (Knapp et al., 2006). Chemical weed control with herbicide has proven effective in several longleaf pine restoration studies on the Coastal Plain (Brockway & Outcalt, 2000; Ramsay et al., 2003; Knapp et al., 2006; Haywood, 2007; Freeman & Shibu, 2009; Shibu et al., 2010). Longleaf pine is native to the Coastal Plain, but also occurs naturally in the mountainous regions further inland, and across the Piedmont Region. The Piedmont is a physiographic region extending from the State of New Jersey down to central Alabama, spanning over 200,000 km^2 of rolling foothills between the Appalachian Mountains and the Coastal Plain (Anon, 2000). Little has been reported on longleaf pine restoration in the Piedmont, but restoration experiments have been established (Berrill & Dagley, 2009).

Data from a replicated field experiment established on degraded Piedmont forest sites are presented here. To our knowledge no other experiment simultaneously addresses questions of repeat herbicide applications versus single treatments each of varying spot sizes, and compares all these weed control treatments to non-herbicide management options. We established non-contiguous single-tree plots in a randomized complete block design with multiple treatment levels nested in a split-plot arrangement within contiguous fixed-area treatment plots. Our objective was to determine the influence of frequency and extent of chemical weed control on planted trees and competing vegetation using commonly-used, widely-available herbicides, and to compare herbicide treatments with mechanical weed control and a no-treatment control. Specifically, we sought to answer the following four questions:

i. How does planted seedling survival and growth differ between various herbicide treatments and two alternative experimental treatments: mechanical weed control, and zero weed control?
ii. Is one herbicide treatment sufficient for control of vegetation competing with tree seedlings planted for restoration? Or, will a second 'repeat application' treatment be required?
iii. How large of an area needs to be treated with herbicides around each planted seedling (when making a single herbicide treatment, and/or when making a repeat application)?

More specifically, what is the trade-off between size of treated area (termed 'spot size') and tree seedling response in terms of both survival and growth?

iv. What is the response of weeds to the various treatments? How quickly did each type of weed (grasses, vines, woody vegetation) develop after treatment?

2. Study sites

The restoration experiment was established at four disturbed sites on the 1,900 ha Hitchiti Experimental Forest (N 33^0 02' W 83^0 42') in Jones County, Georgia, USA. Southern pine beetles (*Dendroctonus frontalis* Zimmerman) had killed patches of even-aged conifer plantation throughout the forest in 2007. The kill areas totalled 10% of the forest area. Salvage harvesting in 2007 was followed by broadcast burning that consumed most of the scattered woody debris and residual hardwoods. Fire failed to carry through some areas due to lack of fuels. Containerized 1-0 'mountain variety' longleaf pine seedlings were hand planted in late March 2008 at a spacing of approximately 3.65 x 3.65 m (740 stems/ha).

Vegetation naturally regenerating throughout the study sites consisted primarily of hardwood stump sprouts and root suckers, vines, forbs, and various grasses. Natural regeneration of 22 tree species was recorded, including an abundance of dogwood (*Cornus florida* L.), loblolly pine (*P. taeda* L.), persimmon (*Diospyros virginiana* L.), sweetgum (*Liquidambar styraciflua* L.), and water oak (*Quercus nigra* L.). Five shrub species, 49 forb species, and eight vine species were recorded. The most common forb was American burnweed (*Erechtites hieracifolia* (L.) Raf.). Throughout the four sites selected as experimental replicates for the restoration study, muscadine grapevines (*Vitis rotundifolia* Michx.) were abundant and expanding laterally to occupy the disturbed sites.

Elevation of the four study sites ranged from 120-150 m above sea level. Soils were classified as a mixture of Davidson and Vance soil series with remnants of loamy surface layer over clay subsoil. The rolling hills were incised by a series of narrow, shallow gullies (Brender 1952). Before the beetle attack in 2007, the four study sites were forested with planted stands of loblolly pine 24-100 years old. Site index ranged from 24.4 m to 27.4 m at base age 25 years for loblolly pine (Clutter & Lenhart, 1968).

Climate at the study site is humid and warm in summer months, and cool in winter. Monthly average low temperatures range from -1°C in January to 19°C in July, and monthly highs range from 13°C in January to 32°C in July. Extreme temperatures were the record high of 40°C in July 1986 and the record low of -20°C in January 1985. The average annual rainfall of 1180 mm is distributed throughout the year; March being the wettest month with 140 mm, and October the driest with 70 mm average monthly rainfall (www.weather.com).

2.1 Experimental design

One experimental replicate block was established in each of four beetle-killed areas at different locations across the forest. Within each replicate block (study site), four treatment plots were established. The 25 x 25 m square treatment plots were surrounded by 4 m wide buffers. Treatments applied to each plot were either mechanical weed control, chemical weed control (repeated in two plots), and control (i.e., no weed control). In a split-plot arrangement, each chemical weed control treatment measurement plot (considered the experimental unit for main treatments) was divided into approximately 12 replicates of three single-tree plots where a single longleaf pine seedling became the experimental unit. Within a split-plot replicate of three adjacent longleaf pine seedlings, each of the three seedlings was randomly assigned a different 'spot size' spray area treatment: a small, medium, or large circular herbicide spot sprayed around the planted seedling.

2.1.1 Weed control treatments

Chemical and mechanical treatments were applied approximately three months after planting, in late June 2008. The objective of the chemical weed control treatment was to reduce above- and belowground competition in the vicinity of longleaf pine seedlings. Glyphosate in the form of isopropylamine salt of N-(phosphonomethyl) glycine was delivered using a backpack sprayer with 2% active ingredient in water at a rate of 6.9 liters active ingredient in 360 liters of solution per ha (D'Anieri et al., 1990). Longleaf pine seedlings were covered with large paper cups prior to spraying. One week after glyphosate application, competing vegetation was mowed close to ground level, and cut stumps of woody species within each randomly-assigned spot treatment area immediately treated with an 8% triclopyr water-based solution of triethylamine salt (5.74% triclopyr acid equivalent). Triclopyr was only used when woody vegetation was present within the treatment spots. Therefore the volume of triclopyr applied differed between small, medium, and large spots, and due to variations in density of woody vegetation within and between study sites. Across all sites, the sum of all spot areas in herbicide plots (0.133 ha) and surrounding buffers (0.060 ha) was 0.193 ha. A total of 0.132 liters of triclopyr active ingredient was applied in these spots, giving an average application rate of 0.69 liters per hectare. These application rates would equate to the volume applied per hectare if the entire area was treated. We applied much less volume to our herbicide treatment plots (total area 0.89 ha at four sites) because it was only applied in spots. The chemical weed control treatment applied in circular spots around each longleaf pine seedling resulted in very different volumes of active ingredient being applied in small, medium, and large spots. We calculated that if, for example, three land managers each prescribed one of the spot size treatments we tested, then the prescription with medium size spots would require approximately four times more active ingredient per hectare than the small spots we tested, and four times less herbicide than if the large spots were prescribed (Table 1). Therefore, even with a second 'repeat' application of herbicide in the same spot size, total chemical usage in small spots sprayed a second time would be half the volume used in a single application in medium size spots, and so forth. Implementing the largest spot size across an area would result in 74% of the ground area being treated if 740 stems/ha were planted (Table 1).

Spot size	Small	Medium	Large
Spot radius (m)	0.455	0.892	1.784
Spot area (m^2)	0.650	2.500	10.000
Treated area (ha)	0.048	0.185	0.740
Glyphosate usage (liters ai/ha)	0.332	1.280	5.110

Table 1. Herbicide spot treatment sizes, and comparison of anticipated chemical usage assuming each spot size treatment was applied to 740 seedlings planted on one hectare i.e., treated area is the combined area of 740 spots, and glyphosate usage is the total volume of active ingredient (ai) needed to implement 740 small, medium, or large herbicide spots.

Mowing in the chemical weed control treatment plots extended beyond the circular spots to cover the entire plot area to uniformly reduce aboveground competition. Vegetation in the mechanical treatment plot was also mowed close to ground level manually using motorized brush saws.

Prior to treatment in late June 2008, the following data were collected in all 25 x 25 m measurement plots: longleaf pine seedling status (live/dead), health and physical condition (brown spot infection, sparseness of live foliage, damaged/covered), and total height (if emerging from grass stage). Within 30 cm of each longleaf seedling (0.3 m^2 sample area), herbaceous ground cover percent was estimated occularly and maximum height of herbaceous cover was measured. Within approximately 50 cm of each longleaf seedling (1 m^2 sample area), vine cover percent and woody vegetation cover percent were recorded, and the maximum height of woody vegetation measured. Survival was also assessed at the end of the first growing season, in October 2008. This did not include assessment of competing vegetation due to seasonal discrepancies in cover caused by loss of leaf area among annual plants and deciduous perennials (Fig. 1).

The vegetation assessments were repeated in early June 2009, 11 months after the first assessment and the first set of weed control treatments were applied. All competing vegetation within 1 m^2 quadrats centred on each longleaf pine seedling was assessed. Immediately after the year-two assessment, chemical weed control was re-applied in one of the two chemical treatment blocks at each study site. This repeat herbicide application treatment was named treatment “H2”. No treatments were applied in year two to the other chemical weed control plot at each study site. This ‘single application’ herbicide treatment was named treatment “H1”. The mechanical weed control treatment (named “M”) was repeated at each study site in year two, reducing aboveground competition from herbaceous vegetation, vines, and woody perennials in the measurement plot and surrounding buffer. Mowing was also applied in the H2 treatment in year two, completing reduction of above- and belowground competition. No treatments were applied to control plots (named “C”). We returned annually thereafter to monitor the development of planted longleaf pine seedlings and competing vegetation, assessing longleaf pine seedling survival, emergence from the grass stage, height of emerged longleaf pine seedlings, and competing vegetation height and cover percent.

Seedling survival and growth data were subjected to monthly growth adjustment assuming an 8-month growing season from April to November. This procedure gave seasonally-adjusted age estimates for seedlings at each assessment event i.e., data for assessments in the first growing season were assigned age 0.5 years (end of June) and 0.875 years (October), with subsequent assessments at age 1.375 years in June of the second growing season, age 2.25 years in May of the third season, and age 3.5 years in July of the fourth growing season. Seedlings were assigned age 0 years at the time of planting in the winter month of March 2008.

3. Survival of planted seedlings

Survival of longleaf pine seedlings was assessed post-treatment, twice in the first growing season, and annually thereafter. Survival over the year immediately following the first treatment (herbicide and mechanical) was highest following chemical control of competing

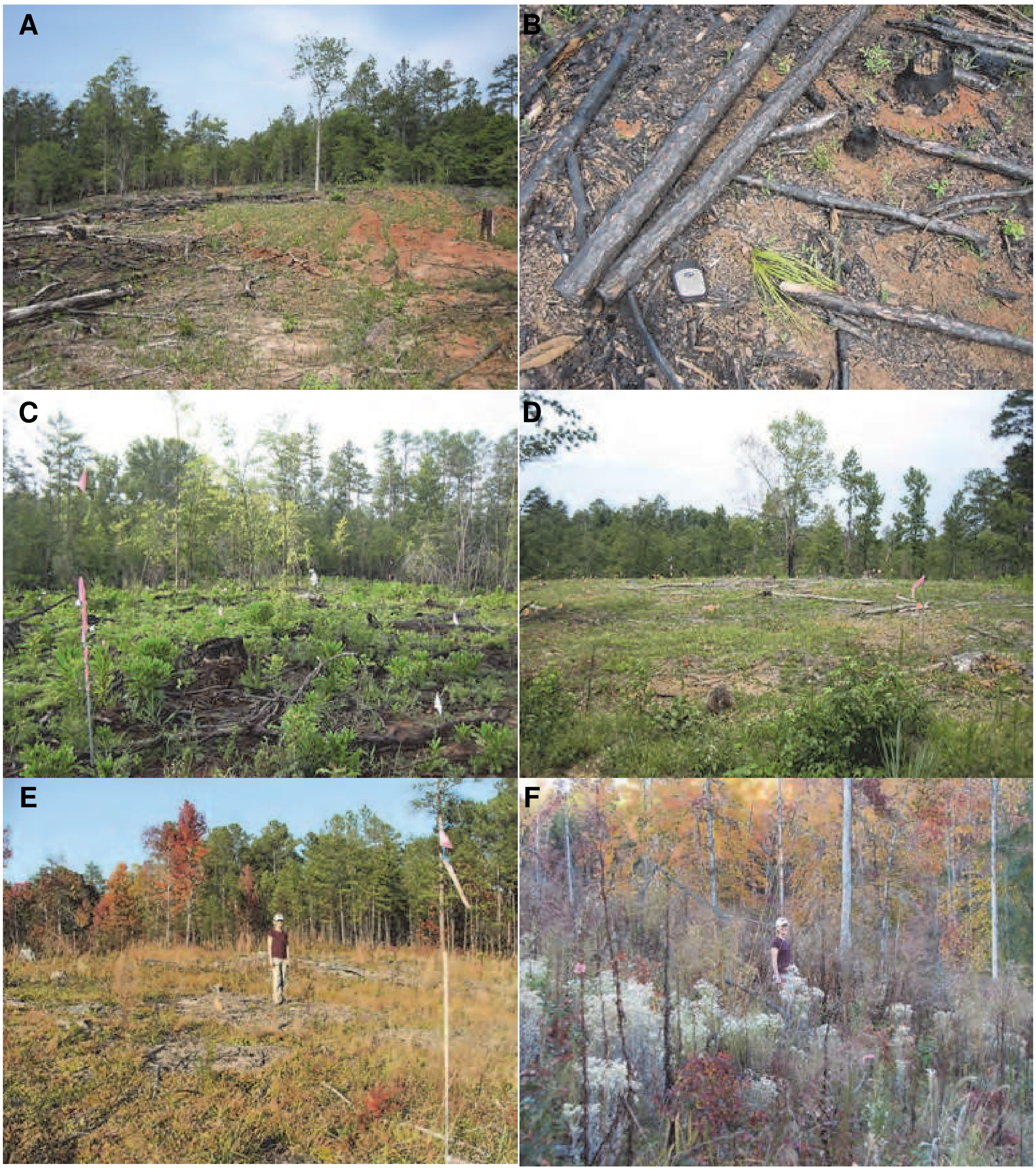

Fig. 1. Study sites at Hitchiti Experimental Forest in the first spring after broadcast burning and planting of longleaf pine seedlings (A), close-up of newly-planted seedling (B), middle of first growing season, before treatment (C) and immediately following mechanical treatment (D), herbicide spots at end of first growing season (E), and no-treatment control at end of first growing season. *Photo credit: J-P. Berrill (A-D) & Rex Dagley (E, F).*

vegetation (treatments H1 & H2), intermediate following mowing of competing vegetation (M), and lowest in the no-treatment control (C). The repeat application of herbicide to competing vegetation in the second growing season (H2) enhanced survival, whereas survival declined in the mechanically-treated areas where competing vegetation was rapidly recovering from mowing (Fig. 2).

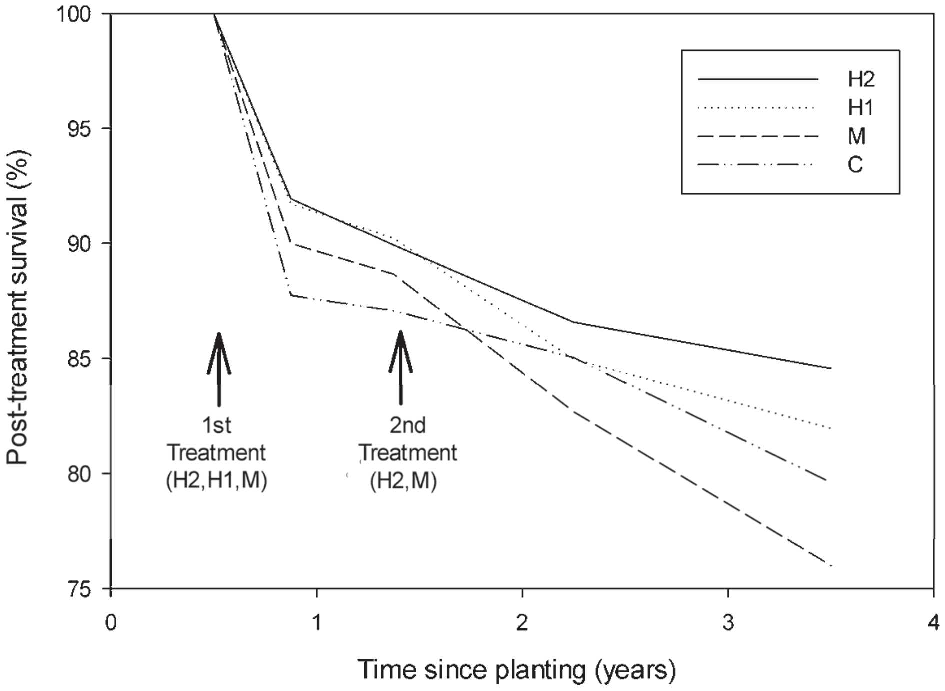

Fig. 2. Survival of planted longleaf pine seedlings from the time of application of the first series of weed control treatments: herbicide applied once in year 1 (H1), herbicide applied twice (H2), mechanical weed control (M), and no-treatment control (C). Sample size: n=627 (H2: n=157, H1: n=145, M: n=159, C: n=166).

4. Growth of planted seedlings

Rapid restoration of longleaf pine forest requires that seedlings emerge from the grass stage and sustain a higher rate of height growth than adjacent competing vegetation (Fig. 3).

Fig. 3. Longleaf pine seedlings in grass stage (left) and emerged from grass stage (right). *Photo credit: David Combs, USDA Forest Service Southern Research Station, Athens, GA.*

4.1 Emergence from grass stage

The number of seedlings emerging from the grass stage was compared between mechanical and chemical weed control treatments, and between different herbicide spot sizes.

4.1.1 Mechanical vs. chemical weed control

Longleaf pine seedlings treated with herbicide were more likely to emerge from the grass stage sooner than seedlings receiving mechanical weed control or no weed control. Over 60% of seedlings receiving a single herbicide treatment had emerged from the grass stage by the fourth growing season. The repeat application of herbicide in year two resulted in a modest enhancement in emergence with 75% of seedlings emerging by the time of assessment midway through the fourth growing season (Fig. 4). By this time, across the four study sites, the number of emerged seedlings in measurement plots equated to 468, 368, 284, and 236 stems/ha in the H2, H1, M, and C treatments, respectively. The highest frequency of emergence among seedlings occurred sometime between consecutive assessments of the experiment in the months of June in the second growing season and May in the third growing season.

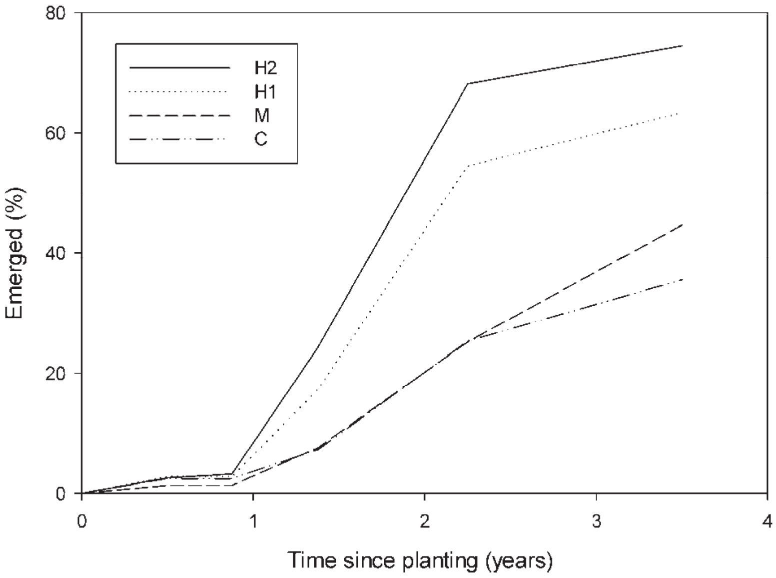

Fig. 4. Proportion of longleaf pine seedlings emerged from grass stage in each weed control treatment: herbicide applied once in year 1 (H1), herbicide applied twice (H2), mechanical weed control (M), and no-treatment control (C). Sample size: n=627 (H2: n=157, H1: n=145, M: n=159, C: n=166).

4.1.2 Herbicide spot size

The number of seedlings emerging from the grass stage in the year after the initial herbicide treatment ranged from 11-23% and was not significantly affected by size of herbicide spot. The repeat application of herbicide appeared to promote a modest 'wave' of emergence from the grass stage, but without any apparent relation to herbicide spot size (Fig. 5).

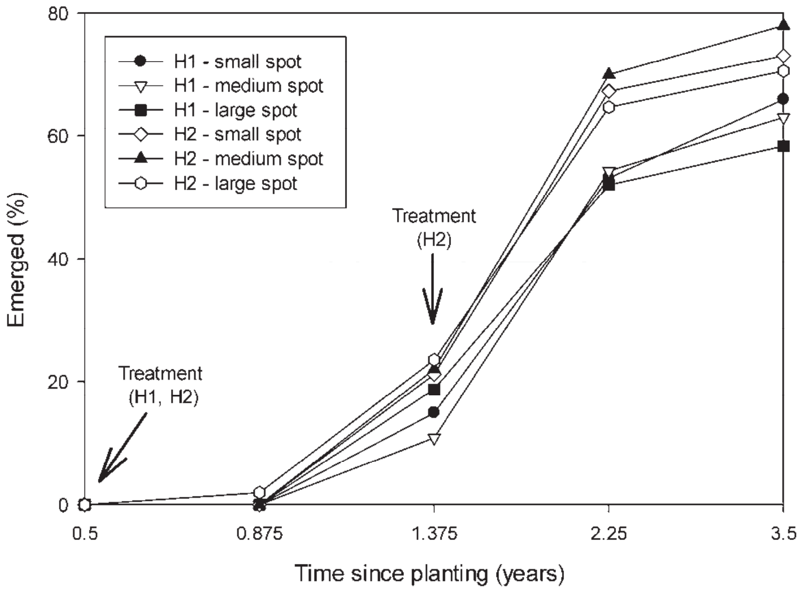

Fig. 5. Proportion of longleaf pine seedlings emerged from grass stage in each herbicide spot size weed control treatment: herbicide applied once in year 1 (H1) and herbicide applied twice (H2), in small (0.65 m^2), medium (2.5 m^2), and large (10 m^2) spots around each planted seedling. Sample size: n=302 (H1-S: n=49, H1-M: n=47, H1-L: n=49, H2-S: n=53, H2-M: n=52, H2-L: n=52).

4.2 Planted seedling height growth

The height development of longleaf pine seedlings that had emerged from the grass stage was compared between mechanical and chemical weed control treatments, and between different herbicide spot sizes.

4.2.1 Mechanical vs. chemical weed control

Height growth of individual seedlings was variable within and between treatments (Fig. 6). Among seedlings that emerged from the grass stage within a year of the first treatments being applied, average height development was most rapid after repeat application of herbicide. Height growth was similar in plots receiving either mechanical treatment or a single herbicide treatment, and slowest in the un-treated control (Fig. 7).

Seedlings emerging at different times caused the average height to rise and fall; the average height of seedlings emerging early increased over time, while later emergence introduced new, shorter seedlings to the calculation of average height. This presented challenges for analysis and testing for differences between treatments. Isolating height data for seedlings that emerged between two consecutive re-measurements somewhat mitigated the problem, and allowed us to test for differences in periodic height increment (rate of growth over a specified period) among seedlings that emerged within the same time period. The periodic average height increment between the third and fourth growing seasons was significantly greater after repeat application of herbicide (78 cm/yr; $p = 0.03$). Periodic height growth was similar in plots receiving either mechanical treatment (64 cm/yr) or a single herbicide treatment (63 cm/yr), and slowest on average in the un-treated control (48 cm/yr).

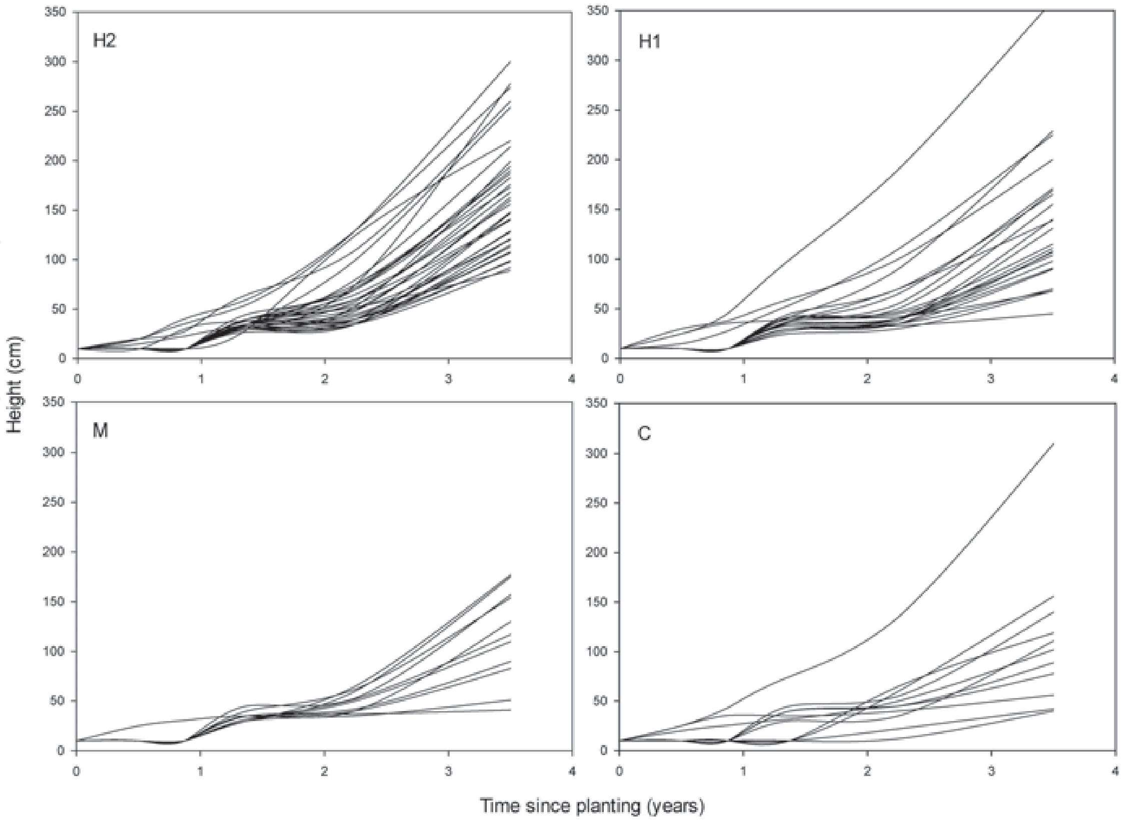

Fig. 6. Height development of individual longleaf pine seedlings that had emerged from grass stage between the time of planting and the middle of the second growing season in each weed control treatment: herbicide applied once in year 1 (H1), herbicide applied twice (H2), mechanical weed control (M), and no-treatment control (C). Sample size: n=83 (H2: n=37, H1: n=24, M: n=11, C: n=11).

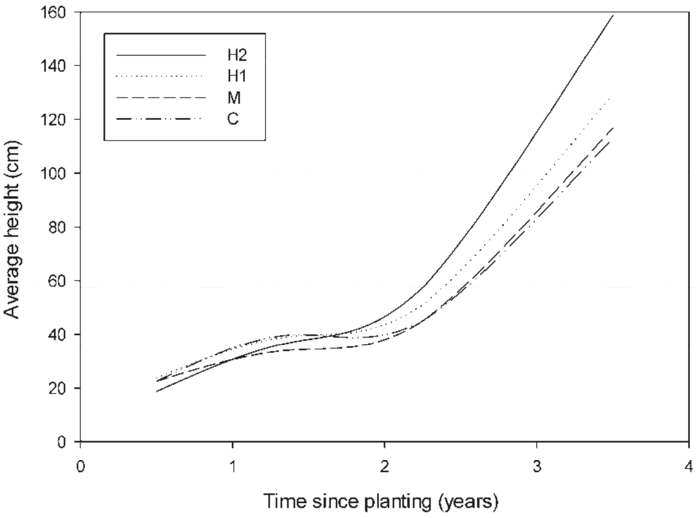

Fig. 7. Average height of longleaf pine seedlings that had emerged from grass stage between the time of planting and the middle of the second growing season in each weed control treatment: herbicide applied once in year 1 (H1), herbicide applied twice (H2), mechanical weed control (M), and no-treatment control (C). Sample size: n=83 (H2: n=37, H1: n=24, M: n=11, C: n=11).

4.2.2 Herbicide spot size and height growth

Average height development of longleaf pine seedlings that emerged within the year following application of herbicide treatments in year one was enhanced by the repeat application of herbicide. Among spot sizes tested, average height was greatest within large spots and lowest in medium-sized spots (Fig. 8). Part of these differences between treatments was likely caused by a random variable that we were not able to control for: variations in timing of emergence from the grass stage and initiation of height growth. This problem was mitigated by examining the rate of longleaf pine seedling height growth between the third and fourth growing seasons. This 'periodic' height increment was greater on average among seedlings receiving a repeat application of herbicide (Fig. 9). However, differences in height growth between the repeat herbicide applications in small, medium, and large spots were not significant (p = 0.43). These repeat treatments resulted in significantly greater seedling height growth than among seedlings treated once with the smallest size of herbicide spot (p = 0.03). The statistical significance of differences between spot size treatments was likely understated because: (i) our sample sizes decreased when we restricted the analysis to seedlings emerging within one year of the first herbicide, and (ii) due to variability in periodic height growth data among young longleaf pines in each treatment.

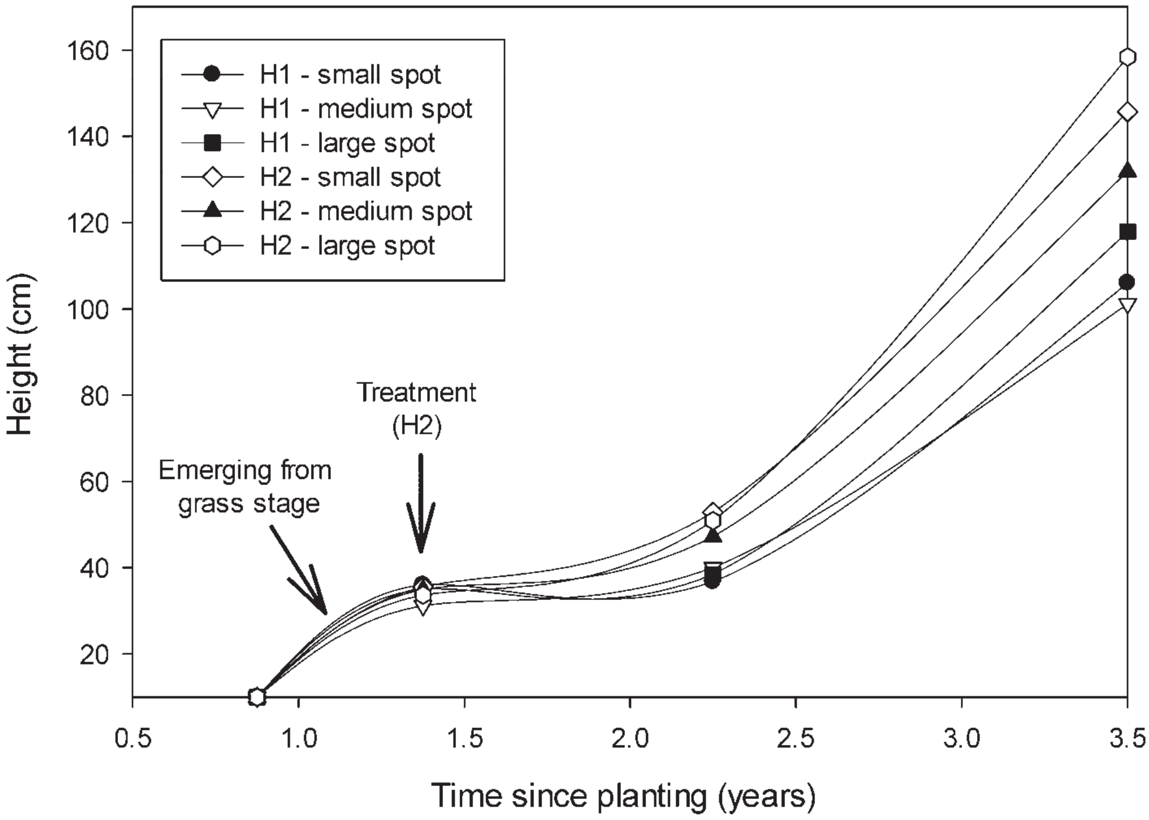

Fig. 8. Average height of longleaf pine seedlings receiving herbicide weed control treatment once (H1) and twice (H2) in small (0.65 m^2), medium (2.5 m^2), and large (10 m^2) spots around each planted seedling. Height data represent average height of seedlings that emerged from grass stage within one year of the first herbicide application. Sample size: n=51 (H1-S: n=7, H1-M: n=4, H1-L: n=8, H2-S: n=11, H2-M: n=10, H2-L: n=11).

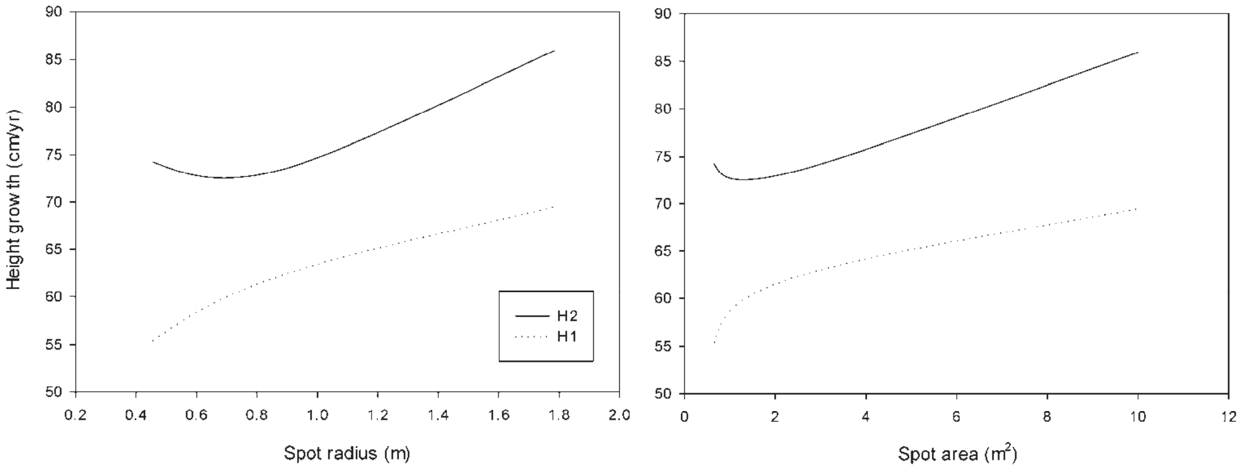

Fig. 9. Relationship between herbicide spot size, number of herbicide applications, and height growth of longleaf pine seedlings emerging from grass stage within one year of the first herbicide application. Height growth calculated as the periodic height increment between the third and fourth growing seasons. Sample size: n=51 (H1-S: n=7, H1-M: n=4, H1-L: n=8, H2-S: n=11, H2-M: n=10, H2-L: n=11).

5. Control of competing vegetation

The extent of competing vegetation cover and its composition were monitored over consecutive growing seasons. Assessment of 1m^2 quadrats centred on each longleaf pine seedling gave estimates of the percent cover and type of vegetation adjacent to, and presumably competing with, the planted seedlings.

5.1 Weed coverage and composition

Competing vegetation developed quickly in the first growing season. Approximately half of the bare ground around planted seedlings was covered by grasses and forbs, vines, and woody vegetation by the time of the first treatments, three months after planting longleaf pine. The herbicide treatment removed competing vegetation cover in the vicinity of planted seedlings, but only temporarily. Competing vegetation re-occupied herbicide-treated spots at a slower rate than before treatment. Total vegetation cover at the end of the first growing season was only 20% after herbicide treatment, whereas it had attained over 60% cover in the absence of any treatment and following mechanical treatment. In the second growing season, competing vegetation expanded to cover approximately 90% of ground area surrounding planted seedlings in the no-treatment control area and after mechanical treatment. It only covered approximately 50% of ground area in plots receiving a single herbicide treatment by the end of year two, and approximately 25% of ground area in plots receiving a repeat herbicide application in the second growing season. Grasses increased in relative abundance following mechanical treatment. Vine cover increased at the same rate in the control and mechanical treatment areas. Woody vegetation increased in relative abundance, at the expense of grass cover, in the no-treatment control areas. Herbicide treatments had a lasting impact on the development of woody vegetation cover, especially after herbicide was re-applied in the second growing season (Fig. 10).

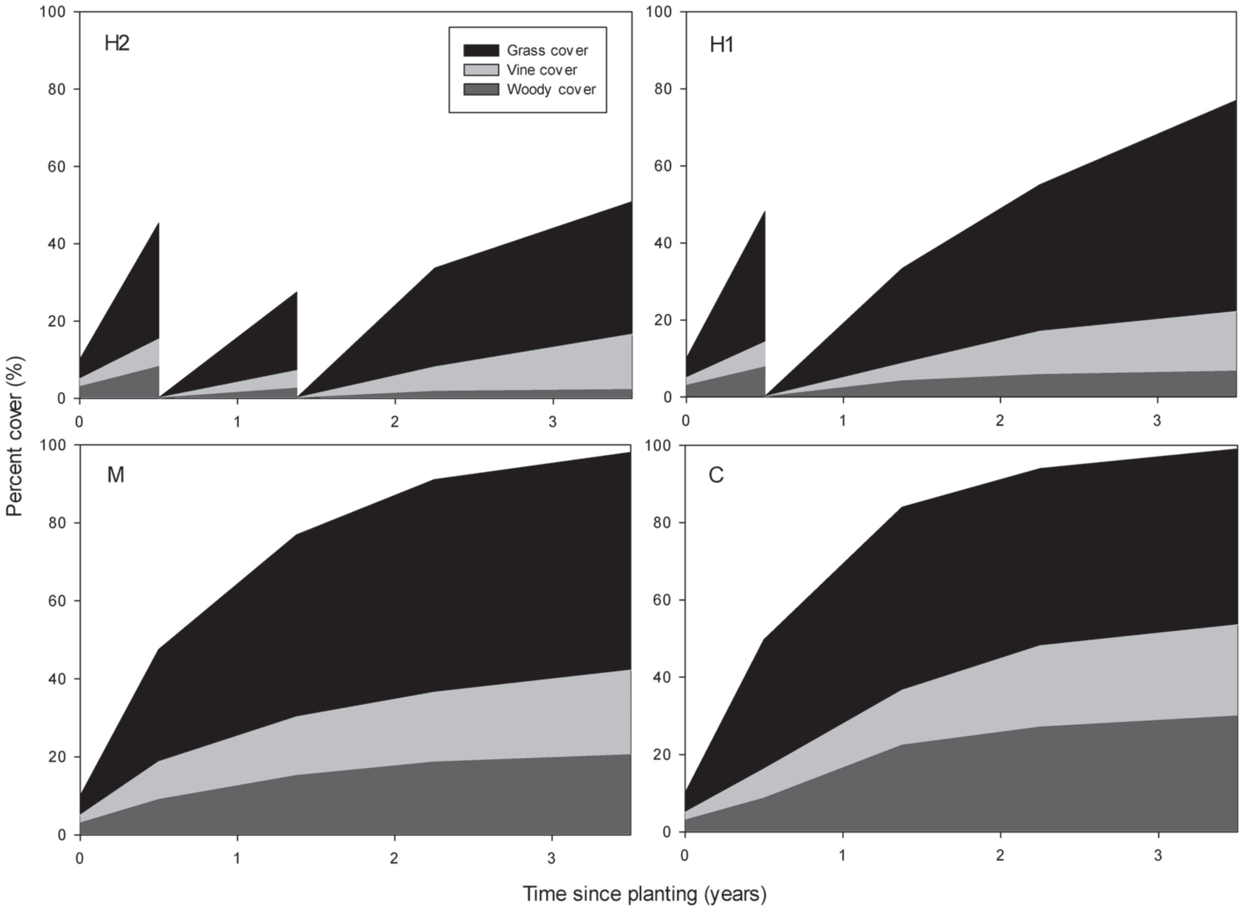

Fig. 10. Weed coverage of ground around planted longleaf pine seedlings. Cover percent is the average cover of each type of competing vegetation in each treatment: herbicide applied once in year 1 (H1), herbicide applied twice (H2), mechanical weed control (M), and no-treatment control (C). Sample size: n=627 (H2: n=157, H1: n=145, M: n=159, C: n=166).

5.2 Weed height development

Calculating the average of height data for the tallest competing vegetation adjacent to each longleaf pine seedling gave an approximation of the 'top height' or 'dominant height' of the vegetation canopy. The dominant height and percent cover of competing vegetation recovered from each treatment at similar rates, with one exception: mechanical treatment appeared to stimulate height growth of competing vegetation (Fig. 11). Calculating dominant height for different components of the competing vegetation gave separate estimates for woody vegetation and for herbaceous vegetation (grasses and forbs). The height of woody vegetation increased steadily, whereas the height of herbaceous vegetation appeared to attain its maximum within two years of treatment. The time taken for vegetation cover or height to return to pre-treatment levels – referred to as 'treatment persistence' – was shorter (rapid recovery; low treatment persistence) for herbaceous vegetation height than for woody vegetation height or total vegetation cover. The repeat application of herbicide doubled herbicide treatment persistence in terms of vegetation cover, and checked hardwood height development by approximately three years (Fig. 11).

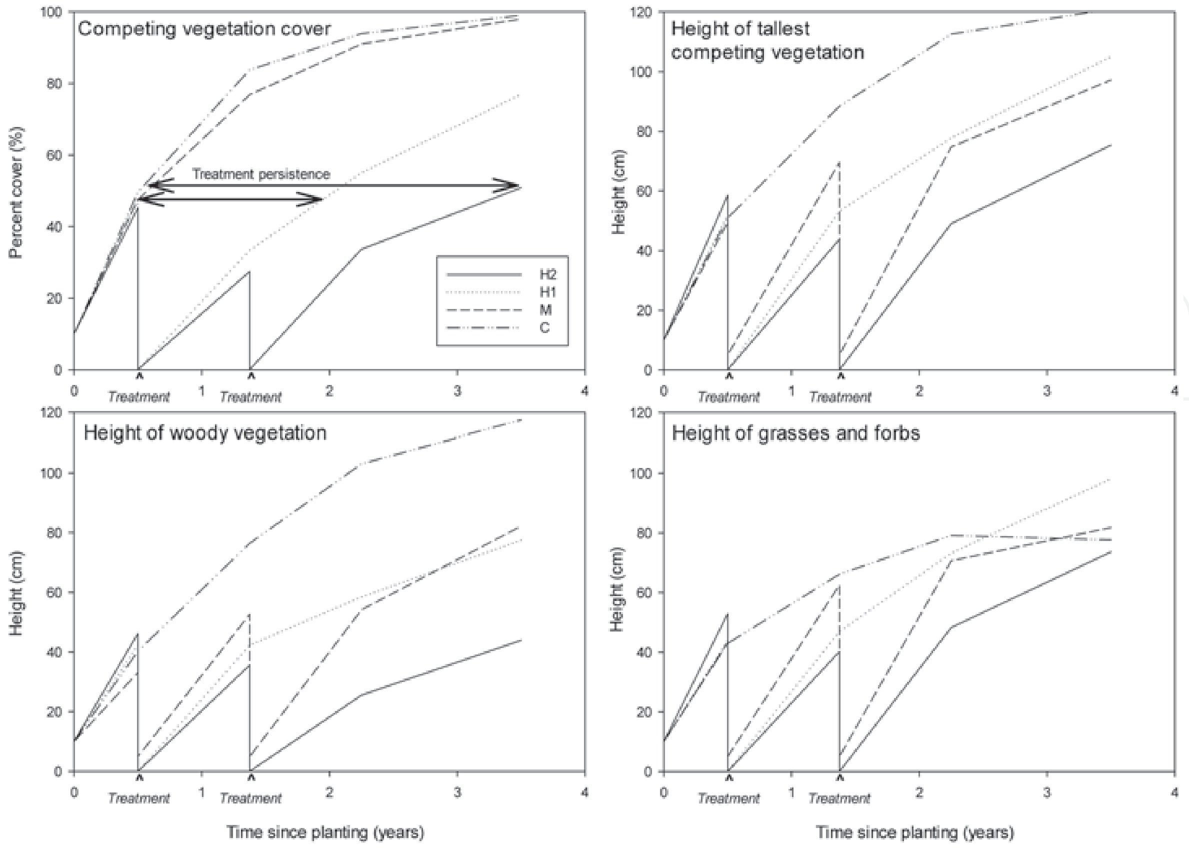

Fig. 11. Development of competing vegetation cover and height in each treatment: herbicide applied once in year 1 (H1), herbicide applied twice (H2), mechanical weed control (M), and no-treatment control (C). Height of competing vegetation represented by average height of the tallest individual competitor (herbaceous or woody vegetation) in 1 m^2 quadrat centred on each longleaf pine seedling. Sample size: n=627 (H2: n=157, H1: n=145, M: n=159, C: n=166).

6. Comparing growth of crop trees and woody competitors

The most vigorous individuals in any cohort of planted trees are of notable importance in forest restoration. The expectation is that these trees will dominate and form the main forest canopy. Woody vegetation could represent an ongoing threat to successful restoration of longleaf pine because, unlike herbaceous vegetation, it can sustain height growth and compete with the longleaf pines for light and growing space over the longer term. Longleaf pines that outsize their competitors by several meters should be able to maintain long live crowns, remain vigorous, and retain dominance over competing vegetation. We compared height growth of the tallest longleaf pine seedlings, in terms of average height of the tallest 200 stems/ha, with height growth of their major competitor: naturally-regenerating woody vegetation. The repeat application of herbicide in year two was the only treatment that allowed longleaf pine seedlings to gain a substantial height advantage over adjacent woody vegetation by the fourth growing season. The average height of the tallest 200 stems/ha of longleaf pine in the H2 treatment was 115 cm greater than the average height of competing woody vegetation. By the fourth growing season, the tallest 200 longleaf pine seedlings/ha in no-treatment control plots were an average of 45 cm shorter than the average height of competing woody vegetation in the absence of mechanical or herbicide treatment (Fig. 12).

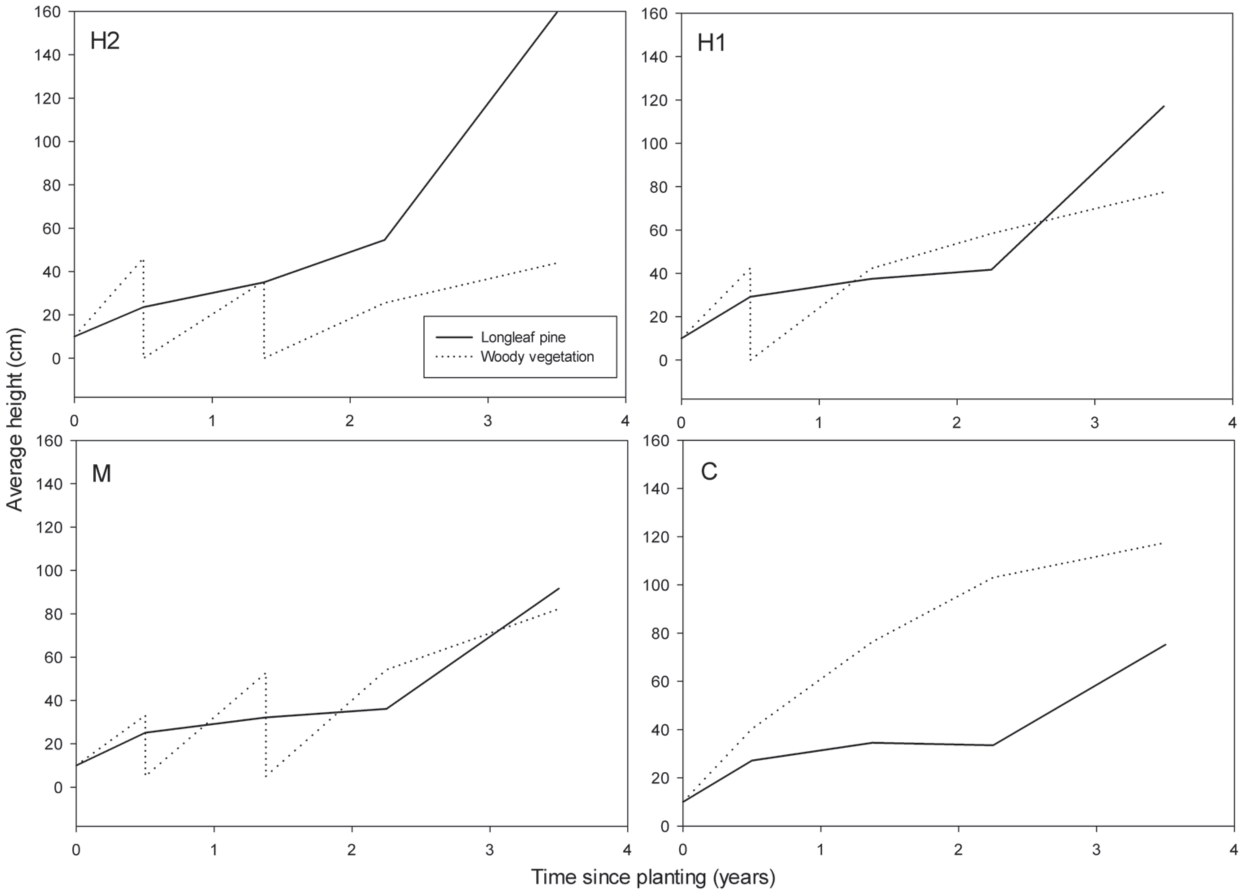

Fig. 12. Height development of the tallest 200 stems/ha longleaf pine seedlings and competing woody vegetation in each treatment: herbicide applied once in year 1 (H1), herbicide applied twice (H2), mechanical weed control (M), and no-treatment control (C). Height of competing vegetation represented by average height of the tallest woody vegetation in 1 m^2 quadrat centred on each longleaf pine seedling. Sample size: n=200 longleaf pine seedlings (n=50 per treatment, representing 200 stems/ha), and n=454 quadrats containing woody vegetation (H2: n=113, H1: n=105, M: n=120, C: n=116).

7. Conclusion

Mechanical control of competing vegetation provided an early enhancement in survival and emergence of longleaf pine seedlings planted in beetle-killed areas, but the beneficial effects were short lived. Herbaceous vegetation exhibited the most aggressive early response to mechanical treatment. The mechanical treatment also appeared to stimulate height development of woody vegetation, resulting in low treatment persistence. Our data suggest that mechanical treatments may need to be repeated regularly if sufficient numbers of longleaf pine are to overtop the competing vegetation. Repeat application of herbicide provided lasting control of competing vegetation, enhanced survival and emergence from the grass stage, and promoted rapid height growth of longleaf pine seedlings planted on the four sites in the central Georgia Piedmont region.

Seedlings emerging from the grass stage began their height growth at different times, providing challenges for summary and analysis of treatment effects on height growth. The problem was not completely mitigated by examining a subset of data for seedlings that emerged during a single time period between consecutive re-measurements of the experiment; sample size was reduced and differences in timing of emergence still introduced variability in height growth estimates. More frequent re-measurements should overcome this problem by allowing for the study of subsets of seedlings emerging from the grass stage at similar times.

We found no evidence that treating larger areas around planted seedlings with herbicide would promote earlier emergence from the grass stage. Once emerged, the seedlings grew marginally more rapidly, on average, in larger spots. Height growth was significantly more rapid following the repeat application of herbicide in the second growing season than among seedlings receiving only one herbicide treatment in the smallest spot size. Therefore if only one treatment will be applied in future restoration projects, we recommend a larger size of herbicide spot treatment. However, total chemical usage is lower when implementing smaller spots, and more vegetation cover is maintained between the smaller spots. If repeat herbicide treatments are planned, then our results suggest that smaller spot sizes applied twice will provide adequate enhancement of survival, emergence, and growth among planted longleaf pine seedlings.

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9. References

Amishev, D. Y. & Fox, T. R. (2006). The effect of weed control and fertilization on survival and growth of four pine species in the Virginia Piedmont. *Forest Ecology and Management* 236: 93-101.

Anon. (2000). *Piedmont*. The Columbia Gazetteer of North America. University of Columbia Press. New York, NY.

Berrill, J-P.; Dagley, C.M. (2010). Assessing longleaf pine (*Pinus palustris*) restoration after southern pine beetle kill using a compact experimental design. *Scandinavian Journal of Forest Research* 25(8): 75-85.

Boyer, W. D. (1990). Longleaf pine *Pinus palustris* Mill. In R. M. Burns, & B. H. Honkala (Eds.), *Silvics of North America. Agriculture Handbook 654, Vol. 1: Conifers* (pp. 405-412). USDA Forest Service. Washington, D.C.

Brender, E. V. (1952). *A guide to the Hitchiti Forest Research Center*. (USDA Forest Service Station Paper No.19). USDA Forest Service. Southeastern Forest Experiment Station, Asheville, North Carolina.

Brockway, D. G. & Outcalt, K. W. (2000). Restoring longleaf pine wiregrass ecosystems: Hexazinone application enhances effects of prescribed fire. *Forest Ecology and Management* 137: 121-138.

Clutter, J. L. & Lenhart, J. D. (1968). *Site index curves for old-field loblolly pine plantations in the Georgia Piedmont* (Rep. No. 22, Series No. 1). Georgia Forest Research Council. Macon, Georgia.

D'Anieri, P., Zedaker, S. M., Seiler, J. R. & Kreh, R. E. (1990). Glyphosate translocation and efficacy relationships in red maple, sweetgum, and loblolly pine seedlings. *Forest Science* 36(2): 438-447.

Freeman, J.E., & Shibu, J. (2009). The role of herbicide in savanna restoration: effects of shrub reduction treatments on the understory and overstory of a longleaf pine flatwoods. *Forest Ecology and Management* 257: 978-986.

Harrington, T. B., Dagley, C.M. & Edwards, M. B. (2003). Above- and belowground competition from longleaf pine plantations limits performance of reintroduced herbaceous species. *Forest Science* 49(5): 681-695.

Haywood, J. D. (2007). Influence of herbicides and felling, fertilization, and prescribed fire on longleaf pine establishment and growth through six growing seasons. *New Forests* 33: 257-279.

Knapp, B. O., Wang, G. G., Walker, J. L. & Cohen, S. (2006). Effects of site preparation treatments on early growth and survival of planted longleaf pine (*Pinus palustris* Mill.) seedlings in North Carolina. *Forest Ecology and Management* 226: 122-128.

Littell, R. C., Milliken, G. A., Stroup, W. W., Wolfinger, R. D. & Schabenberger, O. (2006). *SAS for Mixed Models* (2nd ed.). SAS Institute Inc. Cary, North Carolina.

McNabb, K. & Enebak, S. (2008). Forest tree seedling production in the southern United States: the 2005-2006 planting season. *Tree Planters' Notes* 53(1): 47-56.

Outcalt, K. W. (2000). The longleaf pine ecosystem of the South. *Native Plants Journal* 1(1): 43-51.

Outcalt, K. W. & Sheffield, R. M. (1996). *The longleaf pine forest: trends and current conditions*. (USDA Forest Service Station Resource Bulletin SRS-9). USDA Forest Service. Southern Research Station, Asheville, North Carolina.

Pecot, S.D., Mitchell, R.J., Palik, B.J. Moser, E.B. & Heirs, J.K. (2007). Competitive responses of seedlings and understory plants in longleaf pine woodlands: separating canopy influences above and below ground. *Canadian Journal of Forest Research* 37: 634-648.

Peet, R. K. & Allard, D. J. (1993). Longleaf pine vegetation of the southern Atlantic and eastern Gulf Coast regions: a preliminary classification. In S. M. Herman (Ed.), *Proceedings of the Tall Timbers Fire Ecology Conference, No. 18, The longleaf pine ecosystem: ecology, restoration, and management* (pp. 45-81). Tall Timbers Research Station. Tallahassee, Florida.

Pohl, R., Kelly, S. 2011. Growing trees in Georgia. *Tree Planters' Notes* 54(1): 4-9.

Ramsay, C. L., Jose, S., Brecke, B. J. & Merritt, S. (2003). Growth response of longleaf pine (*Pinus palustris* Mill.) seedlings to fertilization and herbaceous weed control in an old field in southern USA. *Forest Ecology and Management* 172: 281-289.

Richardson, B., Davenhill, N., Coker, G., Ray, J., Vanner, A. & Kimberley, M. (1996a). Optimising spot weed control: first approximation of the most cost-effective spot size. *New Zealand Journal of Forestry Science* 26(1/2): 265-275.

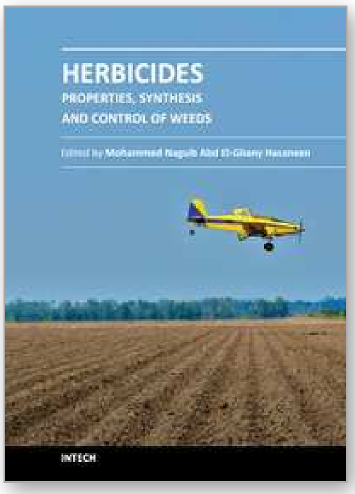
Richardson, B., Vanner, A., Ray, J., Davenhill, N. & Coker, G. (1996b). Mechanisms of *Pinus radiata* growth suppression by some common forest weed species. *New Zealand Journal of Forestry Science* 26(3): 421-437.

SAS Institute Inc. (2004). *SAS/STAT 9.1 user's guide, Vols. 1-7* (1st ed.). SAS Institute Inc. Cary, North Carolina.

Shibu, J., Ranasinghe, S. & Ramsey, C.L. (2010). Longleaf pine (*Pinus palustris* P. Mill.) restoration using herbicides: overstory and understory vegetation responses on a coastal plain flatwoods site in Florida, U.S.A. *Restoration Ecology* 18(2): 244-251.

Stout, I. J. & Marion, W. R. (1993). Pine flatwoods and xeric pine forest of the southern (lower) coastal plain. In W. H. Martin, S. G. Boyce & A. C. Echternacht (Eds.), *Biodiversity of the southeastern United States, lowland terrestrial communities* (pp. 373-446). John Wiley and Sons. New York, NY.

Thatcher, R. C., Searcy, J. L., Coster, J. E. & Hertel, G. D. (Eds.). (1980). *The Southern Pine Beetle*. (USDA Technical Bulletin 1631). Expanded Southern Pine Beetle Research and Application Program, Science and Education Administration, USDA Forest Service. U.S. Government Printing Office. Pineville, Louisiana.



Herbicides - Properties, Synthesis and Control of Weeds
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This book is divided into two sections namely: synthesis and properties of herbicides and herbicidal control of weeds. Chapters 1 to 11 deal with the study of different synthetic pathways of certain herbicides and the physical and chemical properties of other synthesized herbicides. The other 14 chapters (12-25) discussed the different methods by which each herbicide controls specific weed population. The overall purpose of the book, is to show properties and characterization of herbicides, the physical and chemical properties of selected types of herbicides, and the influence of certain herbicides on soil physical and chemical properties on microflora. In addition, an evaluation of the degree of contamination of either soils and/or crops by herbicides is discussed alongside an investigation into the performance and photochemistry of herbicides and the fate of excess herbicides in soils and field crops.

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