HERBICIDE SITE PREPARATION AND RELEASE OPTIONS FOR EUCALYPTUS PLANTATION ESTABLISHMENT IN THE WESTERN GULF

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ABSTRACT

Cold-tolerant species of eucalyptus (*Eucalyptus* spp.) are increasingly grown in the Western Gulf region as short-rotation pulpwood feedstock. Operational chemical suppression of competing vegetation has been relatively costly and inefficient because it requires frequent applications of glyphosate applied via backpack sprayers. A series of studies were conducted in eucalyptus plantations in southwest Louisiana to identify herbicides that can be broadcast-applied by aircraft or ground equipment, providing effective competition suppression without damaging eucalyptus. A trial of 12 herbicide treatments indicated that oxyflurofen and sulfometuron methyl were viable alternatives to directed glyphosate for release treatments of first-year *Eucalyptus macarthurii* seedlings because both herbicides reduced competing vegetation and promoted *E. macarthurii* height growth better than directed glyphosate. Further testing of sulfometuron methyl as a release herbicide for first- and second-year *E. macarthurii* plantations revealed that rates in excess of 1.13 oz ai/acre damaged *E. macarthurii* seedlings. A trial of four pre-plant site preparation herbicide treatments revealed that first-year *E. macarthurii* seedlings planted in bedded and non-bedded plots were not significantly damaged by triclopyr, imazapyr, and hexazinone applied two months pre-planting.

INTRODUCTION

Paper mills that require hardwoods as raw material often have difficulty acquiring sufficient supplies of local trees when conditions are wet. Mills rely on hardwoods grown in moist bottomlands that cannot be harvested during wet periods to protect soil and water quality. When mills cannot obtain enough local trees, they must bring in chips by rail and/or barge at high expense. The emergence of new markets for small-diameter hardwoods as raw material for biofuels such as wood pellets is likely to exacerbate limitations on hardwood availability. To overcome these hardwood supply problems, forest managers need new options for quickly growing plantations of hardwoods, preferably on upland soils that provide a wider harvesting window (Blazier and others 2010).

Eucalyptus plantations have the potential to boost the hardwood production potential in portions of the southeastern U.S. Under proper management, eucalyptus grows rapidly, is resistant to disease and insects, and has wood properties highly desired for multiple uses. Eucalyptus has excellent fiber properties for paper, engineered and reconstituted wood products, and bio-based products. When pelletized and direct-fired in a power plant, eucalyptus has heat energy values that exceed many native tree species. Eucalyptus plantations can reach a harvestable size (up to 70 ft. in height and 7 inches in DBH) for pulpwood or biofuel in as little as 6 to 8 years. Under proper management, eucalyptus has the ability to produce 20 green tons per acre per year. This growth rate compares favorably to the commonly planted loblolly pine, which produces up to 8 tons per acre per year. Eucalyptus plantations can achieve these high growth rates on upland soils, which may provide the forest products industry with a greater supply of hardwood trees grown relatively close to paper and biofuel production facilities (Blazier and others 2010).

Eucalyptus is grown in many countries as a short-rotation pulpwood feedstock. As a result, much of the world's paper of hardwood origin contains eucalyptus. However, many eucalyptus species are intolerant of frost, or only tolerate light frosts down to about 27°F. This susceptibility to cold damage has historically restricted the viability of eucalyptus plantation management in much of the U.S. Tree breeding research has recently identified cold-resistant eucalyptus trees. These trees are tolerant of temperatures down to 17°F. This cold tolerance makes eucalyptus plantation management viable in southern portions of most states in the southeast U.S. As a result of the identification of cold-tolerant eucalyptus, the forest products industry is beginning to plant some eucalyptus plantations. For example, there were approximately 3,000 acres of eucalyptus plantations throughout southwest Louisiana and southeast Texas as of January 2010 (Blazier and others 2010).

A substantial limitation to establishment and productivity of eucalyptus plantations is competing vegetation. Eucalyptus is highly intolerant of competition, particularly early in the rotation (Adams and others 2003, Garau and others 2009).

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However, there are relatively few herbicides with labeling for eucalyptus species in the U.S. that can be broadcast over trees and provide broad-spectrum control. Forest managers have therefore relied heavily upon glyphosate for site preparation and release of eucalyptus plantations in the Western Gulf region. Release treatments with glyphosate have proven to be relatively inefficient and costly because it is often necessary to apply the glyphosate as a directed spray via backpack. Relatively few contract crews are available for such work, which results in large acreages to be covered per crew. With large acreages to cover, some tracts have poor suppression of competing vegetation because spraying is done before there is sufficient foliage for adequate efficacy of glyphosate. Other tracts have inadequate control of competing vegetation because spraying is done after the vegetation has grown too large for sufficient glyphosate efficacy. It is also necessary to spray sites three to four times per season to sufficiently control competing vegetation with glyphosate due to its lack of residual activity. This lack of residual activity also inhibits the effectiveness of pre-plant broadcast applications of glyphosate done for site preparation.

A more cost-effective and efficient alternative to directed spray of glyphosate would be herbicides with broad-spectrum control of competing vegetation that can be broadcast by ground or air over eucalyptus plantations without damaging eucalyptus. The objective of this series of trials was to identify the efficacy and eucalyptus tolerance of herbicides applied after planting as release treatments and prior to planting for site preparation.

METHODS

In 2008, a trial (RELEASE1) was established in a first-year *Eucalyptus macarthurii* (H. Deane and Maiden) plantation near Merryville, LA (30° 42' 52.57" N, 93° 31' 17.91" W). Soil at the site was classified as a Malbis fine sandy loam, which is a fine-loamy, siliceous, subactive, thermic Plinthic Paleudult with a pH range of 4.5 to 5.0 (USDA NRCS 2002). Dominant vegetation of the site included wooly croton (*Croton capitatus*), rosette grass (*Dichanthelium spp.*), and purple cudweed (*Gamochaeta purpurea*). The previous stand had been a slash pine (*Pinus elliotti* Engelm.) plantation that had a burning cycle during its rotation. In April 2008, the herbicide treatments listed in Table 1 (with the exception of the directed glyphosate treatment) were applied via a backpack-mounted, CO2-powered sprayer with a KLC9 tip mounted atop a 15 ft. spray boom to simulate aerial broadcast of herbicide. Directed glyphosate treatments consisted of a 5 percent solution of glyphosate applied via hand-pump backpack sprayer in April, June, and August 2008. Three replications of each treatment were applied in a completely randomized design to plots that were 30 ft. wide and 100 ft. long. By June 2008 competing vegetation had returned to all plots, so all treatments were re-applied. At 5,10, and 15 weeks after the April 2008 application, ground coverage and tree condition were assessed. Ground coverage was determined as the proportion of ground covered by living vegetation within a 1-ft^2 quadrat at four random locations per plot. Tree condition score was measured by assigning a qualitative score of 1 to 9 to ten trees in the center of each plot. The scores, which accounted for increasing levels of damage severity, were: 1=no apparent damage, 2=chlorotic leaves, 3=dead leaves in upper stem, 4=dead leaves in lower stem, 5=tip dieback, second flush, 6=tip dieback, 7=dieback to bottom of tree with resprouting, 8=dieback to bottom of tree with no resprouting, 9=dead. Tree survival and total height was measured immediately prior to treatment, in October 2008, and December 2009. Height growth 1 and 2 years after treatment was calculated as the difference between the October 2008 and December 2009 height measurements and the April 2008 height measurements.

As of October 2008 it was apparent that sulfometuron methyl was an effective herbicide in the RELEASE1 trial, so follow-up trials (RELEASE2 and RELEASE3) were conducted to further elucidate *E. macarthurii* tolerance of sulfometuron. The RELEASE2 trial was established in a first-year *E. macarthurii* plantation, and the RELEASE3 trial was established in a second-year *E. macarthurii* plantation. Both trials were established near Merryville, LA (30° 44' 23.34" N, 93° 30' 16.49" W). Soil at the sites for both trials was classified as a Kolin silt loam, which is a fine-silty, siliceous, active, thermic Glossaquic Paleudalf with a pH range of 4.5 to 5.0 (USDA NRCS 2002). In April 2009, the treatments listed in Tables 2 and 3 were applied for the RELEASE2 and RELEASE3 trials, respectively. Previous stand conditions, application protocol, experimental design, and plot size of the RELEASE2 and RELEASE3 trials were identical to those of the RELEASE1 trial. For the RELEASE2 and RELEASE3 trials, ground coverage was assessed in June 2009 and tree condition was measured in June and October 2009 using the same protocol as in the RELEASE1 trial. Tree height was measured immediately prior to treatment and in December 2009 for the RELEASE2 and RELEASE3 trials as well.

In 2008, a trial (PREP) was established at the same location as the RELEASE2 and RELEASE3 trials to determine the effects of several herbicides applied prior to planting on eucalyptus survival, condition, and growth. The PREP trial also explored the influence of bedding after herbicide application on eucalyptus survival, condition, and growth. Herbicide treatments, listed in Table 4, were applied in August 2008. Previous stand conditions, application protocol, and plot size of the PREP trial were identical to those of the trials described above. Bedding was done in appropriate plots in September 2008 with a skidder-drawn bedding plow. Three replications of all bedding and herbicide treatment combinations were conducted. *Eucalyptus macarthurii* seedlings were planted in all plots in October 2008. In December 2009, survival, tree condition, total height, and groundline diameter were measured.

All treatment effects were analyzed for variance (ANOVA) at an alpha of 0.05 using the MIXED procedure of the SAS System (SAS Institute, Inc. 2006). When an ANOVA indicated significant treatment effects, treatment means were calculated and separated by the DIFF option of the LSMEANS procedure. The DIFF option provided multiple comparisons of treatment means by invoking t-tests to determine significant differences between all possible treatment combinations. All variables for the RELEASE1, RELEASE2, and RELEASE3 trials were analyzed with a model that had herbicide treatment as a fixed effect. All variables for the PREP trial were analyzed with a model that had herbicide treatment, bedding treatment, and all possible combinations of the herbicide and bedding treatments as fixed effects.

RESULTS AND DISCUSSION

Ground coverage differed among treatments of the RELEASE1 trial at only five weeks post-treatment (Table 1). Ground coverage in response to oxyflurofen applied at 0.89 pt ai/acre was the lowest among all treatments. Among other treatments, both rates of sulfometuron methyl, the lower rate of oxyflurofen, the lower rate of quizalofop, and sulfosulfuron had lower ground coverage than the unsprayed control. Each of these herbicides, particularly oxyflurofen and sulfometuron methyl, are formulated for control of a relatively broad array of broadleaf and grass competition and residual activity in soil. Interestingly, ground coverage of the directed glyphosate treatment (which was included in this trial because it was analogous to operational spray treatments) was similar to the control even five weeks after treatment. This result is likely due to glyphosate's lack of residual soil activity, which permitted re-establishment of vegetation. However, by ten weeks after treatment the effects of all herbicides on ground coverage had subsided as indicated by the similarities in ground coverage among all treatments.

None of the herbicides and rates tested in the RELEASE1 trial significantly affected tree survival and condition score (data not shown). However, differences among the treatments in tree height growth were observed (Table 1). At one and two years post-treatment, trees treated with the higher rates of oxyflurofen and sulfometuron methyl tested had the greatest height growth among treatments. The relatively low ground coverage observed five weeks post-treatment for these treatments as well suggests that the better suppression of competing vegetation of these treatments led to improvements in tree height growth as late as two years post-treatment.

Although oxyflurofen and sulfometuron methyl were the most effective herbicides in the RELEASE1 trial, sulfometuron methyl is a substantially cheaper herbicide. As a result, the RELEASE2 trial was developed to determine first-year eucalyptus tolerance to a wider array of sulfometuron methyl rates. Ground coverage of all sulfometuron methyl rates was similarly lower than that of the control, so there was no appreciable benefit to applying rates greater than 0.38 oz ai/acre in terms of increased control of competing vegetation at this site (Table 2). Applying a rate as high as 1.50 oz ai/acre induced damage to the eucalyptus trees, as evidenced by the higher damage scores of this treatment relative to most others as of June 2009. In the RELEASE2 trial, sulfometuron methyl applied at rates lower than and greater than 1.13 oz ai/acre was associated with eucalyptus height growth lower than directed glyphosate. These results suggest that competition control of a single application of sulfometuron methyl at rates lower than 1.13 oz ai/acre did not adequately control competition through the growing season as well as the multiple applications of glyphosate and that the significant increase in eucalyptus damage caused by a single application at 1.50 oz ai/acre was substantial enough to reduce height growth.

The RELEASE3 trial was developed to determine second-year eucalyptus tolerance to a wider array of sulfometuron methyl rates because operational experience has shown that competition control through at least the second year of the rotation is needed for sufficient *E. macarthurii* growth. All sulfometuron methyl rates tested in this trial significantly reduced competition, as shown by the lower ground coverage of all rates relative to the control (Table 3). However, all rates tested were high enough to induce *E. macarthruii* damage as evidenced by the greater October 2009 tree condition scores and lower tree height growth of all sulfometuron treatments relative to the control. The damage of *E. macarthurii* in the RELEASE3 trial, in which all rates tested were 1.50 oz ai/acre and greater, is similar to the increased damage observed in response to the 1.50 oz ai/acre rate in the RELEASE2 trial. Thus, *E. macarthurii* was damaged by sulfometuron methyl rates as high as 1.50 oz ai/acre at this site irrespective of whether the plantations were in the first or second year of the rotation.

Tree height, survival, and condition scores did not differ among treatments in the PREP trial. Groundline diameter of the imazapyr treatment was greater than that of all other treatments in both non-bedded and bedded plots (Table 4). These results suggest that *E. macarthurii* at this site was tolerant of the herbicides tested even when they were applied within two months of planting to simulate a "worst-case" management scenario and that imazapyr promoted tree growth better than the other herbicides tested. The imazapyr result was unexpected because although imazapyr is highly effective for relatively long competition suppression it has relatively long residual activity in soil. The lack of damage from imazapyr may have been due to the formulation of Chopper Gen2 imazapyr product. Chopper Gen2 is formulated to enter plants more readily than conventional imazapyr herbicides, so if it was more rapidly absorbed by vegetation there was less potential for the herbicide to enter and remain in soil. Bedding significantly improved seedling survival across all herbicide treatments, with average survival of bedded and non-bedded plots being 83.7 and 50.5 percent, respectively. Survival benefits of bedding in the PREP trial are similar to those reported for *Eucalyptus tereticomis* in previous studies (Chamshama and Hall 1987).

CONCLUSIONS

Oxyflurofen and sulfometuron methyl were viable alternatives to directed glyphosate for release treatments of first-year *E. macarthurii* seedlings at this study site because both herbicides reduced competing vegetation and promoted *E. macarthurii* height growth better than directed glyphosate. However, applying sulfometuron methyl at these sites in excess of 1.13 oz ai/acre damaged *E. macarthurii* seedlings. Triclopyr, hexazinone, and imazapyr did not damage *E. macarthurii* seedlings irrespective of whether plots were bedded or non-bedded at this site even though the herbicides were applied only two months before the site was planted. There was also modest evidence that the imazapyr formulation tested led to greater seedling groundline diameters relative to triclopyr and hexazinone. It must be stressed that although these trials provide information useful for *E. macarthurii* plantations managed on similar loamy soils, these trials were conducted on a single soil type with a single eucalyptus species. Before broader inferences can be made, it is essential to conduct similar tests over a greater array of soil types and eucalyptus species.

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Table 1—Proportion of ground covered in live vegetation 5, 10, and 15 weeks after treatment (WAT) and tree height growth 1 and 2 years after treatment (YAT) in response to herbicides applied to a newly planted Eucalyptus macarthurii plantation in April 2008

	Ground Coverage (%)			Tree Height Growth (ft)	
Treatment	5 WAT	10 WAT	15 WAT	1 YAT	2 YAT
Control	20.0 a	11.8 a	57.5 a	1.63 cde	4.22 de
Directed glyphosate	21.3 a	12.3 a	52.9 a	1.15 e	5.22 cde
Sulfometuron 0.38 oz ai/ac	9.6 cde	5.9 a	33.3 a	1.59 cde	4.98 cde
Sulfometuron 0.94 oz ai/ac	11.7 bcde	9.9 a	55.8 a	2.37 ab	8.04 a
Oxyflurofen 0.45 pt ai/ac	7.9 de	18.1 a	48.8 a	1.64 cde	5.51 cd
Oxyflurofen 0.89 pt ai/ac	2.9 f	4.3 a	37.3 a	2.77 a	7.59 ab
Clopyralid 0.12 pt ai/ac	19.2 abc	10.9 a	47.5 a	1.99 bcd	4.84 cde
Clopyralid 0.28 pt ai/ac	13.8 abcd	13.7 a	57.5 a	2.17 abc	6.26 bc
Quizalofop 1.24 oz ai/ac	10.8 bcde	9.0 a	47.1 a	1.90 bcd	4.92 cde
Quizalofop 2.06 oz ai/ac	15.0 abc	8.9 a	40.4 a	1.52 de	3.77 e
Fluazifop 3.9 oz ai/ac	16.7 ab	8.3 a	43.8 a	1.87 bcd	4.86 cde
Sulfosulfuron 0.98 oz ai/ac	9.6 e	10.7 a	52.1 a	1.75 cde	5.97 bc

NOTE: Glyphosate applied as Accord, sulfometuron applied as Oust XP, oxyflurofen applied as Goal 2XL, clopyralid applied as Transline, quizalofop at 1.24 oz ai/ac applied as Targa, quizalofop at 2.06 oz ai/ac applied as Assure II, fluazifop applied as Fusilade, and sulfosulfuron applied as Outrider. Within each column, means followed by different letters differ significantly at $P < 0.05$.

Table 2—Proportion of ground covered in live vegetation in June 2009, tree condition score, and tree height growth from April to October 2009 in response to herbicides applied to a newly planted Eucalyptus macarthurii plantation in April 2009

		Tree Condition Score		
Treatment	Ground Coverage (%)	June 2009	October 2009	Tree Height Growth (ft.)
Control	16.5 a	1.00 b	1.92 a	1.34 d
Directed glyphosate	4.1 b	1.14 ab	1.25 a	2.95 a
Sulfometuron 0.38 oz ai/ac	5.0 b	1.00 b	1.34 a	2.28 bc
Sulfometuron 0.75 oz ai/ac	6.6 b	1.00 b	1.14 a	1.80 cd
Sulfometuron 1.13 oz ai/ac	4.6 b	1.09 b	1.59 a	2.50 ab
Sulfometuron 1.50 oz ai/ac	1.9 b	1.43 a	1.62 a	1.87 cd

NOTE: Glyphosate applied as Accord and sulfometuron applied as Oust XP. Tree condition scores were defined as 1=no apparent damage, 2=chlorotic leaves, 3=dead leaves in upper stem, 4=dead leaves in lower stem, 5=tip dieback, second flush, 6=tip dieback, 7=dieback to bottom of tree with resprouting, 8=dieback to bottom of tree with no resprouting, and 9=dead. Within each column, means followed by different letters differ significantly at $P < 0.05$.

Table 3—Proportion of ground covered in live vegetation in June 2009, tree condition score, and tree height growth from April to October 2009 in response to herbicides applied to a second-year Eucalyptus macarthurii plantation in April 2009

		Tree Condition Score		
Treatment	Ground Coverage (%)	June 2009	October 2009	Tree Height Growth (ft.)
Control	38.3 a	1.19 a	1.94 b	5.10 a
Sulfometuron 1.50 oz ai/ac	8.3 c	1.13 a	2.87 a	3.96 b
Sulfometuron 2.25 oz ai/ac	10.8 bc	1.07 a	2.30 a	3.42 bc
Sulfometuron 3.00 oz ai/ac	21.3 b	1.38 a	2.62 a	2.56 c

NOTE: Sulfometuron applied as Oust XP. Tree condition scores were defined as 1=no apparent damage, 2=chlorotic leaves, 3=dead leaves in upper stem, 4=dead leaves in lower stem, 5=tip dieback, second flush, 6=tip dieback, 7=dieback to bottom of tree with resprouting, 8=dieback to bottom of tree with no resprouting, and 9=dead. Within each column, means followed by different letters differ significantly at $P < 0.05$.

Table 4—Groundline diameter (in inches) in response to herbicide and bedding treatments conducted prior to planting of Eucalyptus macarthurii in southwest Louisiana

Treatment	Non-bedded	Bedded
Control	0.30 b	0.34 b
Triclopyr 1.2 oz ai/acre	0.35 b	0.46 b
Imazapyr 8.5 oz ai/acre	0.60 a	0.55 a
Hexazinone 1 qt ai/acre	0.31 b	0.42 b

NOTE: Triclopyr applied as Garlon4, imazapyr applied as Chopper Gen2, and hexazinone applied as Velpar L. Within each column, means followed by different letters differ significantly at $P < 0.05$.