AMINOCYCLOPYRACHLOR CUT STEM APPLICATIONS COMPARED TO STANDARD HERBICIDES FOR EUCALYPTUS CONTROL

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ABSTRACT

Eucalyptus (*Eucalyptus* spp.) plantations are grown on more than 44 million acres worldwide, yet some species are considered invasive. A new herbicide, aminocyclopyrachlor (AMCP) was evaluated to determine rate response and effect of stem diameter for control of planted eucalyptus trees by cut stem treatment compared to standard applications of imazapyr or triclopyr herbicides. Using an AMCP product containing 1.0-pound acid equivalent (ae) per gallon, the lowest rate tested, 12.5 percent in water, resulted in 100 percent eucalyptus crown reduction and greater control than the standard aqueous preparations of 8 percent imazapyr product containing 2.0-pound ae per gallon or 50 percent triclopyr amine product containing 3.0-pounds ae per gallon at 6 and 12 months after treatment. Increases in stem height and diameter at 24 months after treatment suggest that control obtained using imazapyr and triclopyr cut stem treatments may be impermanent. AMCP treated trees did not have regrowth by 24 months after treatment.

INTRODUCTION

Members of the diverse *Eucalyptus* genus are native to Australia and the bordering islands of Polynesia (González-Orozco and others 2014) and more than 70 species are naturalized elsewhere (Rejmánek and Richardson 2011). Because of their adaptability and fast growth rates, *Eucalyptus* species and hybrids have been grown for fiber, fuel, landscaping mulch, essential oils, phytoremediation, and as an ornamental (Rockwood 2012) on more than 44 million acres worldwide (Pires and others 2013). In the Southeastern United States, eucalyptus has historically been used for pulp, mulch, and windbreaks. There is interest in planting cold tolerant species, hybrids, and genetically modified stock to supply potential bioenergy markets. However, concerns have been raised over the potential for eucalyptus to become invasive in the Southeastern United States (Callaham and others 2013, Gordon and others 2011, Lorentz and Minogue 2015).

Existing recommendations for chemical control of naturalized eucalyptus generally entail cut stump, cut stem (hack and squirt), or basal bark applications using concentrated herbicide solutions or emulsions containing the active ingredients triclopyr, imazapyr, or glyphosate. Individual stem treatments using these herbicides are preferred for their ease of use and targeted application. Triclopyr and glyphosate may be applied to the stems of target vegetation with minimal impact to nearby vegetation because these herbicides have limited soil activity (Senseman 2007). However, imazapyr is a persistent soil-active herbicide, thus injury to nontarget vegetation is more likely.

Cut stump applications of these herbicides are also used in eucalyptus plantations for silviculture objectives such as managing tree disease and replacing rootstocks with genetically improved cultivars, with harvesting cycles at stand age 5 to 10 years. Most *Eucalyptus* species planted in commercial plantations resprout vigorously following felling and may be coppiced. Cold-hardy *Eucalyptus* species such as *E. amplifolia*, *E. benthamii*, and *E. macarthurii*, widely planted in the Southeastern United States, southern Brazil, and South Africa (Minogue

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and others 2018), are proving difficult to kill by existing cut stump methods (Little and van den Berg 2007).

Aminocyclopyrachlor (AMCP) is a relatively new herbicide developed by DuPont (Wilmington, DE) for use in noncrop areas such as rights-of-way, turf, range, and natural areas (E.I. du Pont de Nemours and Company 2009). AMCP has good selectivity to established cool- and warm-season perennial grasses (Westra and others 2009) and shows other positive stewardship attributes including low volatility, the absence of bioaccumulation in animals, and low toxicity to terrestrial and aquatic organisms (E.I. du Pont de Nemours and Company 2009). It has shown effectiveness at rates as low as 2-ounces acid equivalent (ae) per acre for difficult species to control such as kudzu (*Pueraria montana*) (Minogue and others 2011). However, its use in southern landscapes has severely damaged trees and other ornamentals (Wherley and others 2013).

In an early screening, Yeiser and others (2012) compared four rates from 2.5 to 15 percent AMCP (1-pound ae per gallon) to 30 percent triclopyr ester product (4-pounds ae per gallon) and combinations of these herbicides with 1-percent imazapyr (2-pounds ae per gallon) in basal oil for cut-stump treatments of Chinese tallow (*Triadica sebifera*), sweetgum (*Liquidambar styraciflua*), and yaupon (*Ilex vomitoria*). At 18 months after treatment (MAT) 10 percent AMCP, AMCP plus imazapyr, and triclopyr alone treatments provided 100 percent control of Chinese tallow. Whereas for sweetgum, the least sprouting and best control was obtained with triclopyr alone. For yaupon, a difficult species to control with herbicides, at 18 MAT 100 percent control was observed with triclopyr, triclopyr plus imazapyr, and AMCP plus imazapyr.

Eucalyptus benthamii is among the more promising eucalyptus species for widescale planting in the Southeastern United States because of its cold hardiness, success in outplantings under a variety of conditions, and fast growth rates (Zalesny and others 2011). This species is not among the eucalyptus species considered invasive (Rejmánek and Richardson 2013), but the ability of this species to withstand cold weather could contribute to its potential invasiveness at a geographic scale.

We initiated a study in a young *E. benthamii* plantation to evaluate the efficacy of AMCP for eucalyptus control. The objectives of this research were 1) to compare the effectiveness of four rates of AMCP to imazapyr and triclopyr amine operational standard herbicides for control of eucalyptus using cut stem applications, and 2) to determine the effects of herbicide treatments on nearby nontarget eucalyptus trees.

METHODS

Study Location

Our study was established in a 28-month *Eucalyptus benthamii* plantation at the University of Florida, North Florida Research and Education Center, south of Quincy (30.55° N, 84.60° W) at approximately 240 feet elevation. This location has a temperate climate with highest temperatures in July (mean 80.6 °F), lowest temperatures in January (mean 50 °F) and 56.3 inches mean annual precipitation (NOAA 2023). The prevalent soil series is Orangeburg fine sandy loam (fine-loamy, kaolinitic, thermic Typic Kandiudults) (USDA NRCS 2023).

Treatments and Experimental Design

Healthy trees with suitable diameters were ranked by basal stem diameter (b.s.d.) at 1 foot height and sequentially divided into eight groups of seven trees with like diameters. The seven treatments (table 1) were assigned in a randomized complete block design with eight replications. A hatchet was used to make cup-like downward incisions at b.s.d. One cut was made per inch of b.s.d. Cuts were evenly spaced around the stem circumference. A volumetric syringe was used to apply 0.03 ounces (1 ml) of aqueous herbicide mixture to each cut on November 5, 2011. Trees in the cut-only control were cut with a hatchet in the same manner as other treatments, but no herbicides were applied.

Table 1—Cut stem treatments for *Eucalyptus benthamii* control using aminocyclopyrachlor (AMCP) and standard herbicides in aqueous solution

Herbicide	Formulation tested	Formulation concentration	Applied formulation concentration in water	b.s.d. specific dose
		pounds ae per gallon	*percent*	*ounces ae 10^{-4}*
AMCP	DPX MAT28-159	1.0	12.5	5.3
AMCP	DPX MAT28-159	1.0	25.0	10.6
AMCP	DPX MAT28-159	1.0	50.0	21.2
AMCP	DPX MAT28-159	1.0	100.0	42.3
Imazapyr	Stalker®	2.0	7.8	6.7
Triclopyr amine	Garlon® 3A	3.0	50.0	63.5
Cut-only control	Cut-only	0.0	0.0	0.0

One cut was made per 1-inch basal stem diameter (b.s.d.) at 1-foot height with 0.03 ounces (1 ml) solution applied per cut.
b.s.d. specific dose is ounces 10^{-4} acid equivalent (ae) of active ingredient per inch of stem diameter at 1 foot above groundline.

AMCP (1-pound ae per gallon, DPX MAT28-159) was applied at four rates, 12.5, 25, 50, and 100 percent formulated product in water (vol:vol) to determine rate response. Standard cut stem treatments for eucalyptus control included aqueous preparations of 7.8 percent imazapyr (isopropylamine salt of imazapyr, 2-pounds ae per gallon, Stalker®, BASF, Research Park, NC) and 50 percent triclopyr amine (triethylamine salt of triclopyr, 3 pounds ae per gallon, Garlon® 3A, Dow AgroSciences, Indianapolis, IN) following label guidelines (BASF Corporation 2008, Dow AgroSciences LLC 2003). Herbicide treatments were compared to the cut-only method control.

Tree Assessments

Pretreatment b.s.d. (1 foot height) was measured to the nearest 0.0394 inch (1 mm) to determine b.s.d. and diameter at breast height (d.b.h. 4.5 feet from groundline), in October 2011. Pretreatment stem height was measured to the nearest inch using a height pole. To quantify stem dieback or growth, the live height was measured again 12 and 24 MAT. Additionally, at 2, 6, and 12 MAT, each tree was assessed for percent crown reduction. This standard variable (Miller and Glover 1991) is an ocular estimate of reduction relative to the pretreatment condition, and considers stem dieback, leaf necrosis, and defoliation. Estimates were made to the nearest 5 percent for values between 0 and 10 percent, and 90 and 100 percent; and to the nearest 10 percent for values between 10 and 90 percent. In place of crown dieback, live d.b.h. was measured as a more appropriate response variable at 24 MAT because some rootstocks recovered by that time. Additionally, phytotoxicity symptoms (mortality, foliar necrosis, defoliation, red foliage, chlorosis, stem sap flow, epinasty, basal sprouting, and adventitious buds on stems) were noted as present or not present for each treatment and buffer tree at 2, 6, and 12 MAT.

Herbicide Impacts to Nontarget Trees

To measure the potential for herbicide flashback via root grafting or injury through soil uptake by nonherbicide-treated trees, at various distances from treated trees, symptoms of phytotoxicity were assessed for both cut-only control trees (n = 56) and buffer trees (n = 64) in the stand. Buffer trees were those directly adjacent to herbicide-treated trees on the row (5 feet away), whereas cut-only control trees were randomly assigned to trees that were not adjacent to herbicide-treated trees (≥10 feet away). For each tree assessment date given above, crown reduction, live stem height, and live diameter were measured.

Statistical Analysis

Data for stem live height, diameter, and crown reduction were analyzed using SAS PROC GLM (SAS v. 9.3, SAS Institute Inc., Cary, NC) to determine differences among treatment groups for change in stem live height at 12 and 24 MAT and for change in d.b.h. at 24 MAT. Tukey's HSD test was used to compare means at $\alpha = 0.05$. Crown reduction response values were primarily near the fixed limits of 0 and 100 percent. Homogeneity of variances and normality could not be achieved by standard data transformations (arcsine, arcsine square root, and log), so traditional parametric and nonparametric tests could not be used to determine if there were differences among treatment groups. Instead, Welch's analysis of variance on ranked data was performed using SAS PROC GLM to determine if there were differences between treatments. The Ryan-Einot-Gabriel-Welsch multiple range test was performed to compare treatment means at $\alpha = 0.05$. These procedures are recommended for analysis of data that is simultaneously heteroscedastic and nonnormal, and they have been shown to provide good power and acceptable control for type I error rates (Cribbie and others 2007). To assess herbicide impacts to nontarget trees data for buffer trees were compared to cut-only control trees using Fisher's exact test for absent versus present responses.

RESULTS

Crown Reduction

The treatment effect for crown reduction was highly significant (P <0.0001) and all herbicide treatments resulted in greater crown reduction than the cut-only control at each assessment (table 2). Crown reduction did not differ among the AMCP rates tested and provided 100 percent control by 6 MAT. AMCP resulted in greater crown reduction than imazapyr at each assessment with imazapyr providing 58-percent crown reduction at 12 MAT. Triclopyr amine resulted in 49-percent crown reduction at 2 MAT which was less than observed with AMCP treatments (91–100 percent) but not different from the results using imazapyr (19 percent). However, at the 6 and 12 MAT assessments crown reduction obtained with triclopyr amine (80–81 percent) did not differ from AMCP treatments (100 percent) but was greater than observed for imazapyr (49–58 percent).

Table 2—Crown reduction, stem live height change, and change in diameter at breast height (d.b.h.) of *Eucalyptus benthamii* from pretreatment to assessments at 2, 6, 12, and 24 months after treatment (MAT) with herbicide

		Crown reduction			Stem live height change		d.b.h. change
Herbicide	b.s.d. dose	2 MAT	6 MAT	12 MAT	12 MAT	24 MAT	24 MAT
	ounce 10^{-4}		*percent*		*feet*		*inch*
AMCP	5.3	91a	100a	100a	-26.6a	-26.6a	-2.9ab
AMCP	10.6	100a	100a	100a	-23.9a	-23.9a	-2.5ab
AMCP	21.2	99a	100a	100a	-26.9a	-26.9a	-3.0a
AMCP	42.3	100a	100a	100a	-25.6a	-25.6a	-2.7ab
Imazapyr	6.7	19bc	49b	58b	-9.4b	-6.7b	0.8c
Triclopyr amine	63.5	49b	80a	81a	-11.4b	-6.0b	-0.9bc
Cut-only control	0.0	3c	0c	2c	14.0c	31.4c	3.6d

b.s.d. specific dose, ounce 10^{-4} acid equivalent of active ingredient per inch of stem diameter at 1 foot above groundline.

Crown reduction and stem live height change treatment means in a column followed by the same letter were not significantly different according to the Ryan-Einot-Gabriel-Welsch multiple range test on ranked data at $\alpha = 0.05$.

Change in d.b.h. treatment means within a column followed by the same letter were not significantly different according to Tukey's HSD at $\alpha = 0.05$.

b.s.d. = basal stem diameter; d.b.h. = diameter at breast height; MAT = months after treatment; AMCP = aminocyclopyrachlor.

Stem Live Height

The treatment effect on stem live height change at 12 and 24 MAT was highly significant (P <0.0001). All herbicide treatments reduced stem height due to stem dieback and apparent mortality, whereas cut-only control trees grew 31.4 feet by 24 MAT (table 2). At 12 MAT all AMCP treatments had no live stem height, with the change from pretreatment stem height ranging from -23.9 to -26.6 feet, and there was no regrowth at 24 MAT. Imazapyr and triclopyr amine standards had less stem height change than AMCP treatments and did not differ. Stem dieback continued from 12 to 24 MAT for the standards with -6.7- and -6.0-foot height change for imazapyr and triclopyr amine, respectively.

Stem Live Diameter

The treatment effect on stem live d.b.h. change at 24 MAT was highly significant (P <0.0001) and all herbicide treatments reduced d.b.h. relative to the cut-only control (table 2). AMCP treatments had no live d.b.h. and the change from pretreatment ranged from -2.5 to -3.0 inches, as compared to 3.6 inches growth for the cut-only control. The imazapyr standard treatment grew 0.8 inches and differed from all treatments except the -0.9-inch change observed for the triclopyr standard treatment.

Herbicide Impacts to Nontarget Trees

There were no significant treatment differences in crown reduction at 12 MAT or for the change in stem live height and diameter at 24 MAT when buffer trees (5 feet away from herbicide treated trees) were compared to cut-only control trees (≥10 feet away from herbicide treated trees) (data not shown). By 24 MAT, buffer trees grew 25.9 feet taller and gained 2.9 inches in diameter. Similarly, cut-only control trees grew 25.2 feet taller and gained 2.7 inches in diameter. The most frequently observed phytotoxicity symptoms for both buffer and cut-only control trees were foliar necrosis, defoliation, chlorosis, and red foliage. Other symptoms observed included epinasty, a symptom characteristic of the growth regulator herbicides triclopyr and AMCP. In general, symptoms in buffer and cut-only control trees began to appear by 6 MAT, but remained uncommon throughout the study period. At 6 MAT the presence of foliar necrosis was greater (P = 0.0236) for adjacent buffer trees (28 percent of trees) than for cut-only control (13 percent of trees), but no differences were observed for any other symptoms or assessment (data not shown). At 6 MAT mortality was observed in one buffer tree bordered by AMCP treatments on both sides, but no mortality occurred in cut-only control trees.

DISCUSSION

Whereas no other literature reporting results for AMCP cut stem application for the control of woody plants was found, this application method, also known as stem injection or “hack and squirt,” is described by many herbicide product labels and widely used because of the ease of use and low cost (Miller and others 2015). Our results demonstrate that AMCP cut stem treatment is an effective alternative to more labor-intensive cut stump applications, which have been the focus of several studies (Little and van den Berg 2007, Yeiser and others 2012). In addition, the determined cut stem AMCP b.s.d. dose (5.3 ounces 10^{-4}) for complete control demonstrated the greater method efficiency as compared to the basal spray AMCP b.s.d. dose (21.2 ounces 10^{-4}) for complete control of *Eucalyptus benthamii* (Minogue and Lorentz 2021).

Herbicide injury was observed in buffer and nontreated control trees as expected for AMCP and imazapyr, which are absorbed from the soil by roots. This may be of concern when making applications in very close proximity to desirable trees. These plantations were established at high density (871 trees per acre) for short-rotation bioenergy production, and the risk of herbicide injury to crop trees may be less for more typical wide spacings. However, the use of triclopyr amine, which has negligible soil activity, would provide greater safety to residual trees in thinning or cultivar replacement. While we did not quantify impacts to herbaceous vegetation in this study, no obvious symptoms of injury such as necrosis or chlorosis were observed for herbaceous vegetation near treated stems. Moreover, during the study several newly established pine and oak seedlings were discovered throughout the *E. benthamii* understory.

CONCLUSIONS

While there have been serious concerns about the effects of AMCP on nontarget trees and vegetation (Durkin 2012), this may not be a concern for stand eradication of nuisance or invasive eucalyptus species. Our results suggest that the risk of injury to nontarget vegetation may be reduced when low rate, low volume directed applications are used away from desired trees. Based on this research, cut stem applications at 1 foot above groundline using 0.03 ounces (1 ml) of 12.5-percent AMCP solution (diluted 1-pound ae AMCP per gallon product) per inch of basal diameter provides complete control, greater than observed for standard treatments. This rate equates to 5.3 ounces 10^{-4} ae AMCP per inch stem diameter, and there is a clear need to examine lower doses for eucalyptus control and other tree species.

Although we tested AMCP rate response in comparison to the efficacy of standard herbicides, the potentially important effects of application timing and eucalyptus species susceptibility were not determined. This would require experiments across multiple seasons for commonly grown *Eucalyptus* species, such as *E. camaldulensis*, *E. grandis*, *E. urograndis*, *E. amplifolia*, and others. The strong control of *E. benthamii* in this study represents significant progress in the development of effective herbicide recommendations for eucalyptus management and indicates that future research with different species and timings would be worthwhile.

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