Final Report

Innovative and Environmentally Responsible Methods for Controlling Invasive Woody Plant Species in North Carolina Rights of Way

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16. Abstract

The North Carolina Department of Transportation (NCDOT) maintains approximately 78,000 miles (600,000 acres) of roadside rights-of-ways. In 2008, the NCDOT spent $30 million controlling woody brush. The primary method of woody vegetation control is mowing. Mowing only provides temporary control and is expensive in the long term. Traditional alternatives to mowing are using broadcast foliar applications of herbicides and cut-stump or basal herbicide applications. Broadcast foliar applications can have environmental and public relations concerns. Cut-stump and basal herbicide applications are expensive.

The purpose of this research was to test the effectiveness of two brush mowers with built in herbicide applicators, the Diamond Wet-Blade and the Brown Brush Monitor. The Diamond Wet-Blade mower applies low volume herbicide applications directly to the cut surface of stems simultaneously while cutting. The Brown Brush Monitor is similar to a normal brush mower; however, it has a spraying chamber mounted on the back of the mower unit. The mower cuts and discharges the debris through a side door. The spray chamber consists of spray nozzles that apply herbicide to a brush which wipes the herbicide to the cut stem.

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SUMMARY

Experiments were designed and initiated to determine the effectiveness of herbicide treatments using wet-blade technology for the control of woody vegetation along North Carolina roadsides. Evaluations were made on two wet-blade mowers, different herbicides, herbicide rates, and application timing.

Data collected will aid in determining if wet-blade technology is a feasible option for woody vegetation management.

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Introduction

North Carolina Department of Transportation (NCDOT) manages roadside vegetation along approximately 78,000 miles of rights of ways. In 2008, NCDOT spent approximately $30 million dollars controlling road side woody vegetation (D. Smith, personal communication). Controlling roadside vegetation improves road safety by reducing vegetation that can potentially fall into the roads after a major storm event, eliminating visual obstructions, making stationary objects/signs more visible, and allowing sunlight to penetrate to help melt snow and ice from road surfaces. Historically, the primary method of vegetation management used by NCDOT has been mowing. Mowing provides only temporary suppression of vegetation, particularly woody vegetation, and at times can produce unintended consequences such as increases in stems per acre from re-growth and increases in non-native invasive species. Current alternatives to mowing include spraying vegetation with herbicides or cutting woody weeds and treating the cut-stumps with herbicides. Broadcast sprays can result in significant off-target herbicide movement. And, cut-stem applications are labor intensive and costly. Furthermore, many DOT rights of way sites are in close proximity to water conveyances, riparian zones, populated areas, or plantings of susceptible crops that make herbicide applications undesirable or impossible. Alternative vegetation management procedures that would reduce re-sprouting of weedy species while reducing the potential for non-target effects are advantageous.

The Brown Brush Monitor™ (Brown Manufacturing Corporation) is a commercially available mower that combines mowing with cut-stem spray applications. The mower design features two chambers. In the first chamber, the blades cut brush 2 to 3 inches in diameter and the mowed debris is removed from the mower deck through a side door which allows the herbicide chamber to treat the remaining cut stubble (http://www.brownmfgcorp.com/index.html). The Brown Brush Monitor offers the efficiency of one pass mowing and herbicide application, yet little data is available evaluating the effectiveness of this mower / applicator. In the 1990's, Dr. Walter Skroch and co-workers reported effective control of weeds with herbicides applied to cut stems using "wet blade" technology (Wahlers et al. 1997a; Wahlers et al. 1997b; Henson et al., 2003). This technology differs from the Brown Brush Monitor by applying herbicides directly to the cutting blade. A commercially available product featuring wet blade technology is the Diamond Wet Blade™ mower (Diamond Mowers, Inc.). The Diamond Wet Blade mower cuts brush up to 4 inches in diameter and simultaneously applies herbicide to the cut portion of the stem (http://www.diamondmowers.com/).

Two purported advantages of the mower/applicator and wet blade technologies are reduced herbicide use and reduced environmental exposure. Preliminary data using wet-blade technology for herbaceous plant control suggests that total herbicide use can be reduced compared to broadcast spray applications. Research on melaleuca trees (*Melaleuca quinquenervia*) in Florida showed that lower rates of Arsenal herbicide rates was needed to control this invasive woody plant species using a wet-blade mower as compared to a cut stump application (Mullahey and Williams, 2001). However, Mullahey and Williams, 2001, also found that wet-blade applications provided poor control of Southern Wax Myrtle (*Myrica cerifera).* Application systems that apply herbicides directly to the cut stem of the target weeds, may reduce non-target environmental exposure; and may improve herbicide translocation compared to treating cut stems after cuts have been made. For example, it has been shown that herbicides

applied using a wet blade resulted in rapid translocation of the applied herbicide to dogfennel roots. However, these claims have not been adequately documented with woody weeds.

Where woody brush control is required there are currently no alternatives to mowing or herbicide applications. However, Canadian researchers have reported control of many weedy tree species with an endemic pathogen, *Chondrostereum purpureum* (Chontrol™). Chontrol is being developed as a biocontrol agent to prevent re-sprouting of woody weeds following cutting. Data from utility rights of way tests in British Columbia, Canada, have demonstrated efficacy on many deciduous weedy tree species when applied to freshly cut stumps (Conlin et al. 2000). This pathogen has received tentative registration for use in the United States but has not been tested on the woody weed species important in North Carolina.

The objectives of this project were to:

1. Compare the efficacy of herbicides applied using the Diamond Wet Blade mower and Brown Brush Monitor, with traditional cut-surface and foliar spray application methods. Objective 1 included:
   (a) herbicide and dose comparisons simulated using hand held wet blade applications as well as wet blade mower treatments,
   (b) season of application comparisons, and
   (c) field comparisons of mower-applied treatments with traditional spray applications.
2. Compare environmental distribution, efficiency of application, and whole plant movement of herbicide applications from Diamond Wet Blade, Brown Brush Monitor, and traditional application methods.
3. Evaluate the effectiveness of an endemic biological control agent, *Chondrostereum purpureum* (Chontrol), for the prevention of cut-stem re-sprouting.

MATERIALS AND METHODS

Objective 1:

A. Herbicide and Dose Comparison

Simulated Wet-Blade Applications – Hand-held Pruner Applications

Experiments were conducted to compare commonly used woody vegetation herbicides and at several concentrations for control of three weedy tree species using "wet-blade" technology. In April 2005, a plantation was established in Goldsboro, NC, with approximately 800 trees each of red maple (*Acer rubrum*), tulip poplar (*Liriodendron tulipifera*), and sweet gum (*Liquidambar styraciflua*).

In November 2005, treatments were made by applying 0.5 ml of herbicide solution to the bottom of a hand lopper cutting blade and cutting a single tree approximately six inches above the ground. The experimental design was a randomized complete block design with 21 treatments and four single stem replications per tree species. Treatments included Garlon 3A (triclopyr), Rodeo (glyphosate), and Escort XP (metsulfuron) at rates of 0.02, 0.1, 0.2, 0.6, and 2.3 g/gal and Arsenal (imazapyr) at 0.5, 1, 2.5, 5, and 10% v/v. In November 2006, the experiment was repeated with exception of the Escort XP treatments which were ineffective the first year. Treatment combinations of Garlon 3A 50% + Arsenal 1% v/v, Garlon 3A 25% + Arsenal 1% v/v, Garlon 3A 50% + Rodeo 10% v/v, and Garlon 3A 25% + Rodeo 10% v/v were added. Stem diameters were larger in 2006. Therefore, a larger pair of lopping shears was used

and the volume of herbicide solution applied to the cutting blade was increased compared to the 2005 treatments. Re-growth heights were measured one year after treatment.

In March 2008, the experiment was repeated using tulip poplar and sweet gum trees that had re-grown following clipping in 2005 and 2006. In 2008, there were not enough surviving stems of red maple to include that species. Treatments were applied in a randomized complete block design with three replications. Re-growth heights were measured six months after treatment.

Diamond Wet Blade herbicide application comparisons -- Field Experiments

Using data collected from the hand-lopper experiment and other reports, field experiments were designed and established to test the efficacy of herbicides applied with the Diamond Wet-Blade (DWB) mower for the control of woody vegetation. Four experiments were established, three roadsides and one distribution line. The DWB was calibrated to apply 2.5 gallons of solution per acre. Herbicide treatments differed between experiments in response to preliminary data from these experiments as well as reports from ROW managers field testing wet blade equipment.

In August 2007, a field experiment was established along a roadside in Chatham County, NC. Treatments were: mow only, Garlon 3A (triclopyr) 3.75 lb ae/A + Arsenal (imazapyr) 0.25 lb ae/A, Arsenal 0.5 lb ae/A, Arsenal 0.25 lb ae/A, Garlon 3A 3.75 lb ae/A + Weedar 64 (2,4-D) 3.8 lb ae/A, and Weedar 64 3.8 lb ae/A + Arsenal 0.25 lb ae/A. Plots were arranged in a randomized complete block design with four replications with each plot measuring 8 feet by 125 feet. The majority of the trees present were 4 to 10 feet tall with 0.5 to 3 inch diameter stems. Percent of stems that re-grew was recorded three and nine months after treatment, visual rating of percent suppression of re-growth was recorded nine months after treatment, and re-growth heights were recorded one year after treatment. The ten tallest sweet gums, five tallest tulip poplars and oaks (*Quercus* sp.), and three tallest red maples and red buds (*Cercis canadensis)* in each plot were measured. The plots were retreated in September 2008, with exception of the Weedar 64 3.8 lb ae/A + Arsenal 0.25 lb ae/A due to poor results and label recommendation about mixing these two products. The majority of the trees were 2 to 7 feet tall with less than one inch stem diameters. Percent of stems that re-grew was recorded 8 months after treatment and re-growth heights were measured 10 months after treatment. The ten tallest sweet gums, five tallest tulip poplars, and three tallest red maples in each plot were measured.

In early April 2008, a field experiment was established under a power distribution line right-of-way in Efland, NC. Treatments were selected based on preliminary results from the first Chatham County roadside experiment. Treatments were: mow only, Garlon 3A 3.75 lb ae/A, 3.75 lb ae/A Garlon 3A ae/A+ 0.25 lb ae/A Arsenal ae/A, and Garlon 3A 3.75 lb ae/A + Weedar 64 3.8 lb ae/A. Plots were arranged in a randomized complete block design with three replications with each plot measuring 12 feet by 80 feet. The majority of the trees were 1 to 6 feet tall with 0.25 to 1.5 inch diameter stems. The percent of stems that re-sprouted was recorded five months after treatment and the height of the re-growth of the ten tallest sweet gums and three tallest sycamores (*Platanus occidentalis*) in each plot were measured 12 months after treatment.

In early April 2008, a field experiment was established to compare doses of Garlon 3A plus Weedar 64 along a second roadside in Chatham County, NC. Treatments were selected based on preliminary results from the Garlon 3A and Weedar 64 treatment from the first Chatham County roadside experiment. Treatments were: mow only and factorial combinations

of Garlon 3A at 1.87 or 3.75 lbs ae/A plus Weedar 64 at 1.9 or 3.8 lbs ae/A. Plots were arranged in a randomized complete block design with four replications with each plot measuring 8 feet by 125 feet. The majority of the trees were 3 to 7 feet tall with 0.5 to 3 inch diameter. The percent of stems that re-sprouted was recorded five months after treatment and re-growth heights of the ten tallest sweet gums in each plot were measured 12 months after treatment.

In October 2007, an experiment was established along a roadside near Hillsborough, NC to evaluate the efficacy of the ester formulations of 2,4-D and Garlon. Treatments were: mow only, 3 lb ae/A Garlon 4 ae/A, 1.29 lb ae/A Patron 170 (2,4-D + 2,4-DP) ae/A, and 3 lb ae/A Garlon 4 ae/A+ 1.29 lb ae/A Patron 170ae/A. Plots were arranged in a randomized complete block design with four replications with each plot measuring 8 feet by 125 feet. The majority of the trees present were 6 to 16 feet tall with 2 to 6 inch diameter stems. The percent of stems that re-sprouted was recorded 11 months after treatment and the height of the re-growth of the ten tallest sweet gums in each plot were measured 12 months after treatment.

B. Optimal Season of Treatment

Two field experiments were established to determine if there is a seasonal effect on control using the Diamond Wet-Blade (DWB). Each study was set-up having a mow only and Garlon 3A at 3.75 lb ae/A for each season (spring, summer, fall, and winter).

The first study was established early April 2006 at the East Carolina University Research Campus in Greenville, NC. The spring treatments were applied April 5, 2006 and the summer treatments were applied July 20, 2006. The fall and winter treatments were not applied due to the site flooding. Plots were arranged in a randomized complete block design with four replications of 20 feet by 200 feet plots. Visual ratings of woody species control were recorded on November 3, 2006 and August 7, 2007. Tree re-growth heights of the five tallest sweet gums and black gums and the three tallest red maples in each plot were recorded on November 13, 2007.

The second study was established early May 2008 under a Progress Energy transmission line in Wilson's Mills, NC. The spring treatments were applied May 7, 2008, summer treatments on August 6, 2008, and fall treatments on November 3, 2008. The winter treatments were not applied due site flooding. Plots were arranged in a randomized complete block design with four replications of 8 feet by 100 feet plots. Re-growth heights of the ten tallest sweet gums in each plot were recorded on June 3, 2009.

C. DWB and BBM Field Comparison

Six field experiments were established to compare the efficacy of two mechanical wet-blade pieces of equipment, the Diamond Wet-Blade (DWB) and the Brown Brush Monitor (BBM). The equipment was compared to standard mow only and mow then spray techniques. The DWB is calibrated to apply 2.5 gallons per acre and BBM is calibrated to apply 20 gallons per acre.

The first study was established mid-November 2005 at the East Carolina University Research Campus in Greenville, NC. Treatments applied were: mow only, Garlon 3A at 3.75 lb ae/A applied with the DWB, Garlon 3A at 3.75 lb ae/A applied with the BBM, mow then spray immediately after with Garlon 3A at 3.75 lb ae/A using a backpack sprayer calibrated to spray 50 gallons per acre, and mow in November then spray the re-growth in the spring with Garlon 3A at 6 lb ae/A. Plots were arranged in a randomized complete block design with four replications of 20 feet by 200 feet. The majority of the trees were 4 to 8 feet tall with 1 to 3 inch diameter stems.

Visual ratings of woody species control were recorded 12 and 21 months after treatment and tree re-growth heights of the ten tallest sweet gums and the five tallest red maples in each plot were recorded 24 months after treatment.

The second study was established at the Goldsboro plantation, which was used for the hand-lopper study, in late November 2006. Treatments were: mow only, mow then spray cut stumps immediately after with Garlon 3A 50% v/v using a backpack sprayer, DWB Garlon 3A 3.75 lb ae/A, DWB Arsenal 0.05 lb ae/A, DWB Garlon 3A 3.75 lb ae/A + Arsenal 0.05 lb ae/A, BBM Garlon 3A at 30 lb ae/A, BBM Arsenal 0.4 lb ae/A, and BBM Garlon 3AGarlon 3A at 30 lb ae/A + Arsenal at 0.4 lb ae/A. The dose of Garlon 3AGarlon 3A with the BBM exceeded label rate on a per acre basis because the herbicide solution was mixed according to label directions for cut stump applications (50% v/v in water). Plots were arranged in a randomized complete block design with four replications with each plot measuring 8 feet by 50 feet and contained at least eight sweet gums and tulip poplars. The majority of the trees were 3 to 6 feet tall with 1 to 3 inch diameter stems. Re-growth height measurements were recorded nine and 24 months after treatment.

The third study was established mid-October 2007 under a power distribution line near Washington, NC. Treatments were:

- mow only,
- mow in the fall then spray re-growth in mid-June 2008,
- DWB applied Garlon 3A at 3.75 lb ae/A,
- DWB applied Garlon 3A at 3.75 lb ae/A + Arsenal 0.05 lb ae/A,
- BBM applied Garlon 3A at 3.75 lb ae/A [actual dose: ~11 lb ae/A], and
- BBM applied Garlon 3A at 3.75 lb ae/A + Arsenal 0.05 lb ae/A [actual dose: 11 + 0.15 lb ae/A].

BBM treatments were mixed to apply Garlon 3A at 3.75 lb ae/A and Arsenal at 0.05 lb ae/A, but due to rough terrain the tractor operator slowed causing the equipment to apply more solution. The estimated rate of application was Garlon 3A at 11 lb ae/A and Arsenal at 0.15 ae/A. The Garlon 3A applied with the BBM exceeded the maximum amount allowed by the herbicide label. Plots were arranged in a randomized complete block design with four replications; each plot measuring 12 feet by 105 feet. The majority of the trees were 3 to 10 feet tall. Visual ratings of woody species control were recorded eight months after equipment applications and re-growth heights of the ten tallest sweet gums in each plot were measured 12 months after treatment. Under the same power line about 1 mile away, three treatments were added: DWB Weedar 64 at 3.8 lb ae/A, DWB Garlon 3A at 3.75 lb ae/A + Weedar 64 at 3.8 lb ae/A, DWB Weedar 64 at 3.8 lb ae/A + Arsenal at 0.25 lb ae/A. Data were not recorded on these plots due to property owner mowing the plots.

The fourth study was established in early July 2008 on private land in Guilford County, NC. The land owner reported the land had been fallow for 15 to 20 years. Due to the size of the experiment, several days were needed to apply all treatments. Mowing and herbicide treatments were made between July 1 and July 9, 2008 to 3 to 20 year old sweet gum, tree of heaven (*Ailanthus altissima*), sycamore, black walnut (*Juglans nigra*), and tulip poplar that were 3 to 15 feet tall with stem diameters of 0.5 to 4 inches. The mowing equipment, treatment list, and date of treatments are listed in Table 1. Plots were arranged in a randomized complete block design with five replications with plot size of approximately 12 x 160 feet, but varied by the number of trees present. All treatments covered ±10% the same amount of land area. Percent of stems that

re-grew was recorded 10 months after treatment and re-growth heights of the ten tallest sweet gums and five tallest sycamores and tulip poplars were measured 12 months after treatment.

The fifth study was established in mid-July 2008 on private land near Red Oak, NC. The land had been fallow for five years. The mowing and herbicide treatments were made on July 16, 2008 to 1 to 5 year old sweet gum that were 1 to 5 feet tall with stem diameters of 1.5 inches or less. Four treatments: mow only with the Diamond Wet Blade, Diamond Wet Blade with Garlon 3A 6 lbs ae/A, Brown Brush Monitor with Garlon 3A 6 lbs ae/A, and Tiger Flail Mower with Garlon 3A 6 lbs ae/A were arranged in a randomized complete block design with five replications of 12 x 125 feet plots. The Tiger Flail Mower was an added piece of equipment that was calibrated to apply 5 gallons of spray volume per acre. The Tiger Flail Mower has a similar spray system as the BBM; however, uses a flail style mower instead of the rotary style of the BBM and DWB. Percent of stems that re-grew was recorded 2 and 10 months after treatment and re-growth heights of the ten tallest sweet gums in each plot were measured 12 months after treatment. A separate area was treated with the Brown Brush Monitor, half the area was mowed only and the other half was mowed and treated with Garlon 3A 6 lbs ae/A. Percent stems that re-grew were recorded for observational reasons. Two foliar applications of Garlon 3A 6 lbs ae/A were made on October 7, 2008 using re-growth in the drive lanes between the third replication plots. Applications were made using a pressurized backpack sprayer calibrated to apply 50 gallons per acre. Percent stems that re-grew were recorded for observational reasons.

In early October 2008, the Red Oak study was repeated in a nearby field. The Tiger Flail Mower was not included in this trial as the equipment was not available at time of the treatment. The Tiger Flail Mower treatment was replaced with the DWB with Arsenal 0.5 lbs ae/A. Plots were arranged in a randomized complete block design with four replications of 12 x 125 feet plots. Percent of stems that re-grew was recorded 7 months after treatment and re-growth heights of the ten tallest sweet gums were measured 9 and 11 months after treatment.

Objective 2:

Herbicide movement in plants after application

Plant Sampling

March 2008, two-year old, container grown red maple seedlings were potted in three gallon containers using a pine bark based substrate. June 2008, three stems were treated by applying a 50% solution of Garlon 3A to the cutting blade of hand-held clippers and then cutting the stem 6 inches above the soil surface. Two stems were cut with no herbicide treatment to use as a control. Stems were removed from the pots approximately 72 hours after treatment. The potting mix was removed from the roots and then the roots were washed clean. The stem and roots were collected and stored in a cooler until the extraction process was performed.

Late July 2008 (about 2 weeks after treatment), field samples were taken from the summer Red Oak field comparison site. One sweet gum stem was removed from each of three different replications for plots treated with Garlon 3A using the Diamond Wet-Blade and the Brown Brush Monitor, and from the mow only control. The stems and roots were removed one week after treatment. The stem and roots were collected and stored in a cooler until the extraction process was performed.

October 2008 (about 2 weeks after treatment), field samples were collected from the fall Red Oak field comparison site. One sweet gum stem was removed from each replication for plots treated with Garlon 3A using the Diamond Wet-Blade and the Brown Brush Monitor and

for the untreated control. The stems and roots were removed one week after treatment. The stem and roots were collected and stored at 4° C until the extraction process was performed.

Sample Preparation

The samples from the summer field comparison site were cut into 4 sections using hand-held clippers: main stem (MS: from soil line to cut surface); lower stem (SS: from soil line to branching of main roots); major roots (MR: major/large diameter roots); and fine roots (FR). The fine roots were removed and collected from the red maple samples and the fall field comparison site and ground using a Foss Cyclotec Model 1093 grinder with a 0.5 mm mesh screen. For the other plant tissue, a hand held saw was used to make cuts on three different locations of the samples: one inch below the cut (MS), at the soil surface (SS), and on the main root (MR). The saw dust from each sample was collected.

Extraction and Analysis

Extraction process was modified from the method by Wendelburg and Olberding (2008) and Olberding, et al., (1997). Tissue was extracted (1 g tissue : 20 ml extraction solvent) in a methanol/2.5 N NaOH (90:10) solvent, in a blender for 60 seconds, and then centrifuged at 2000 rpm for 5 min. One ml of the supernatant was combined with 2 ml of 0.5 N HCl, which was then stored at 4° C. The extracted tissue was subjected to solid phase and liquid phase partitioning prior to analysis via GC-MS. The solid phase partitioning utilized a Phenomenex Strata-X 30-mg SPE column. The column was equilibrated with 1 mL of acetonitrile, followed by 1 mL of 0.5 N hydrochloric acid, and dried under full vacuum for 5 sec between solvents. The sample was transferred in two 750 µl aliquots to the column at a flow rate of 1 ml/min, and the eluate discarded. The column was then rinsed with two 750-µL aliquots of an acetonitrile/water/1 N hydrochloric acid (30:69:1) solution, and the eluate discarded. The column was then dried under full vacuum for 10 min. The triclopyr was eluted from the solid phase partitioning column with two 500-µL aliquots of an acetonitrile/water/1 N hydrochloric acid (60:39:1) solution, under full vacuum for 30 seconds after each aliquot, and collected in a screw-top vial. The samples were capped and stored in at -20 C.

For liquid phase partitioning, 4 ml H_2O was added to the eluted sample. The sample was partitioned three times with 3.0 ml of dichloro-methane (DCM) (9.0 ml total). For each phase separation, the DCM was added, the vial was capped, vortexed for 20 sec, and centrifuged for two min for complete phase separation. The combined DCM fractions were dried with sodium sulfate (Na2SO4) for 24 hrs. To derivatize the samples, they were initially evaporated to dryness under a stream of N2 at 40° C, and 200 µL of derivatization solvent [acetonitrile with TFA (Trifluoroacetic acid), NMM (N-methylmorpholine), and ISTDs (dibutylpyridine, 4-butylphenol, and octyl-B-D-glucoside)] was added. This was followed by the addition of 50 µL of derivatization reagent [10% HMDS (Hexamethyldisilazane) in TMSDMA (N-Trimethylsilyldimethyl-amine)]. The samples were then heated to 60° C for 1 hour. The derivatized samples were then transferred to GC vials.

The samples were analyzed utilizing an Agilent GC-MS (HP 5890-HP 5971). The run conditions included an inlet temp of 275˚C, a flow rate 7.7 psi (36.3 cm/sec), and an injection volume of 1 µl (splitless). The run program began at 50˚C for 0.5 min, then 50˚C to 80˚C at 15˚C/min, then 80˚C to 320˚C at 10˚C/min; ending the run at 320˚C for 5 min. The total runtime was 31.5 min. The detector operated at 300˚, and the column was a Restek Rtx-5MS (Crossbond 5% diphentl - 95% dimethyl polysiloxane) 30 m x 0.25 mm ID x 0.25 µm df.

Environmental distribution

Samples were collected from DWB treated plots for analysis. However, given that poor efficacy was observed in field experiments the questions of environmental distribution were placed on a lower priority with greater time and effort directed toward Objective 1. Furthermore, we learned that Dr. Shawn Askew at Virginia Tech was concluding off-target movement and worker exposure studies with the wet-blade mower system demonstrating significant reductions in worker exposure compared to traditional spray application systems.

Objective 3:

Biological Control of Stem Re-sprouting with *Chondrostereum purpureum* (Chontrol™)

Three field trails were established to evaluate the effectiveness of an endemic fungus, *Chondrostereum purpureum* (Chontrol™), as a biological control agent for the prevention of cut-stem re-sprouting.

In April 2005, a plantation was established in Goldsboro, NC, with eight rows of approximately 100 trees each of red maple (*Acer rubrum*), tulip poplar (*Liriodendron tulipifera)*, and sweet gum (*Liquidambar styraciflua*). Five treatments were applied in November 2005: cut only, cut stump treatment with Garlon 3A (50% v/v), cut stump treatment with Chontrol paste, cut stump treatment with Chontrol liquid, and wet-blade application with Chontrol liquid. The experimental design was a randomized complete block design with four single stem replications per tree species. The study was repeated in December 2006 on new stems.

In a separate, but related experiment, a plantation was established in March 2005 at the North Carolina State University's Horticultural Field Lab in Raleigh, NC, with Chinese wisteria (*Wisteria chinensis)*, princess tree (*Paulownia tomentosa),* and Chinese privet (*Ligustrum sinense*). Five treatments were applied in November 2005: cut only, cut stump treatment with Garlon 3A (50% v/v), cut stump treatment with Chontrol paste, cut stump treatment with Chontrol liquid, and wet-blade application with Chontrol liquid. The experimental design was a randomized complete block design with eight single stem replications for Chinese privet and Chinese wisteria and six single stem replications for princess tree. The study was repeated in December 2006 on new stems. The re-growth heights of the princess tree and Chinese privet and percent control of Chinese wisteria were recorded 12 months after treatment.

In December 2005, a study was established in Chapel Hill, NC on a natural stand of oriental bittersweet (*Celastrus orbiculatus).* Five treatments were applied: cut only, cut stump treatment with Garlon 3A (50% v/v), cut stump treatment with Chontrol paste, cut stump treatment with Chontrol liquid, and wet-blade application with Chontrol liquid. The oriental bittersweet vines were classified into three categories: small (0 to 0.5" diameter), medium (0.5 to 1.5"), and large (1.5 to 3"). The experimental design was a randomized complete block design with four replications with one small, medium, and large vine per plot. The vine re-growth length was measured 12 months after treatment.

FINDINGS AND CONCLUSIONS

Objective 1:

Herbicide and Dose Comparison

Simulated Wet-Blade Applications – Hand-held Pruner Applications

In 2005, Arsenal at rates of 1% v/v and greater controlled red maple, sweet gum, and tulip poplar (Table 2). Plant height was reduced by 75 to 100%. Sweet gum was also controlled by Garlon 3A at 25 and 50% v/v providing 82 and 100% reduction in height, respectively. Rodeo and Escort XP were not effective on sweet gum. Rodeo (10 and 50% v/v) provided 86 and 80% reduction in tulip poplar height, respectively. Garlon 3A (10, 25, and 50% v/v), Rodeo (1 and 5% v/v), and Arsenal (0.5% v/v) yielded approximately 50% reduction in tulip poplar height. Red Maple was also controlled by Garlon 3A (50% v/v) and Rodeo (5 and 50% v/v) providing 75, 60, and 56% reduction in height, respectively. Escort XP did not control the three species so the treatments were not repeated in 2006.

In 2006, the only significant control recorded for the 2006 study was with Arsenal at rates of 1% v/v and greater on sweet gum. Arsenal (5 and 10% v/v) reduced sweet gum height by 49 and 69%, respectively.

The trees treated in 2005 were smaller and one-year younger than the trees treated in 2006. The results suggested that age and/or stem size may affect the level of control obtained. Using the stems that re-sprouted from the 2005 and 2006 studies, a study was established in 2008 to determine if stem diameter affects control. Stems from the 2005 studies were larger in diameter than the ones from the 2006 study. Stem size did not affect control. Therefore, data for the two stem sizes were pooled for treatment comparisons. The levels of control were similar to those observed in the 2006 experiment. Arsenal (10% v/v) resulted in the greatest reduction in sweet gum height, 51% (Table 3). Arsenal (5 and 10% v/v) and Rodeo (50% v/v) reduced tulip poplar heights by 58, 82, and 87%, respectively. These data suggest that stem diameter itself did not influence control. Rather it appears that the age of the rootstock may dramatically alter the effectiveness of wet-blade herbicide applications.

Summary

Seedling trees were well controlled but trees one year older were not well controlled. Yet, the 2008 data suggest that stem diameter does not affect control. It appears likely that tree age may affect control but more data is needed. Overall, Arsenal (10% v/v) yielded the most consistent results. Garlon 3A was effective on only trees that had been in the field less than one year (these trees being less than two years old from seed). Escort XP did not control sweet gum, tulip poplar, or red maple. Using these results from the first year's study, Arsenal (10% v/v or 0.5 lbs ae/A) and Garlon 3A (50% v/v or 3.75 lbs ae/A) were the herbicides used for the Diamond Wet-Blade and Brown Brush Monitor studies initiated in 2006.

Diamond Wet Blade herbicide application comparisons -- Field Experiments
DWB-applied herbicides - Chatham County Roadside #1

In the 2007 study, Arsenal (0.5 lbs ae/A), Arsenal (0.25 lbs ae/A) plus Garlon 3A (3.75 lbs ae/A), and Garlon 3A (3.75 lbs ae/A) plus Weedar 64 (3.8 lbs ae/A) reduced the amount of stems that re-sprouted by 45, 67, and 56% as compared to the non-treated control, respectively (Table 4). However, there was no reduction in re-growth heights for sweet gum, tulip poplar, or

red maple. Adding Weedar 64 to Arsenal resulted in no reduction in percent stems to re-sprout, suggesting that these treatments are antagonistic which is stated as a possibility on the label. In the 2008 study, Arsenal (0.5 and 0.25 lbs ae/A) and Arsenal (0.25 lbs ae/A) plus Garlon 3A (3.75 lbs ae/A) reduced re-sprouting of all species by 47, 29, and 44%, respectively and 59, 36, and 66% of sweet gum, respectively. Arsenal (0.5 and 0.25 lbs ae/A) reduced sweet gum heights by about 50%. Tulip poplar and red maple heights were not affected by treatments.

DWB applied Garlon 3A and Garlon 3A combinations - Efland

No significant reduction in re-sprouting and re-growth was recorded (Table 5). In contrast, when Arsenal was added to Garlon 3A at the Chatham County Roadside #1 site, stem re-sprouting was reduced both years.

Garlon 3A plus Weedar 64 dose response - Chatham County Roadside #2

A slight re-sprouting reduction of 27% for all species present was recorded using the high rate of Garlon 3A (3.75 lbs ae/A) plus Weedar 64 (3.8 lbs ae/A) (Table 6). No treatments reduced sweet gum re-sprouting or re-growth heights.

DWB applied ester formulations of triclopyr and 2,4-D - Orange County Roadside

Garlon 4 and Patron 170 did not reduce stem re-sprouting or re-growth heights (Table 7). The ester formulations of herbicides were not used in any other studies.

Summary

Control varied from site to site. Some treatments were able to reduce the percentage of stems that re-sprouted; however, the only reduction in sweet gum re-growth heights was recorded using Arsenal applied two years in a row. Tulip poplar and red maple heights were not affected by the herbicide treatments.

Optimal Season of Treatment

In general, summer applications of Garlon 3A through the DWB were more effective than spring or fall treatments. In November 2006, an 82% increase in vegetation control was observed with the summer Garlon 3A treatment compared to the summer mow only (Table 8). November 2007, a 45% reduction in sweet gum re-growth height with the summer treatment was recorded; however, the data was so variable that this differential was not statistically significant. Red maple heights were reduced by 33 and 50% for the spring and summer treatments, respectively; however, the data was so variable that the differential was not statistically significant. Flooding at the site prevented the fall and winter treatments; however, a field equipment comparison study was established the previous fall in an adjacent field. In November 2007, a reduction of 19 and 16% was recorded for fall Garlon 3A treatment on sweet gum and red maple re-growth heights, respectively.

The results at Wilson's Mills were similar to the Greenville results. In June 2009, a 42% height reduction in sweet gum re-growth height was recorded with the summer 2008 Garlon 3A treatment compared to a summer mow only (Table 8). The spring and fall treatments reduced sweet gum re-growth heights by 7 and 23%, respectively

The two Red Oak studies were set-up as an equipment comparison study; however, the sites are on the same property with a similar stand of sweet gum enabling a comparison between tests. A 90% reduction in sweet gum stem re-sprouting was recorded with the summer Diamond

Wet-Blade/Garlon 3A treatment as compared to only a 57% reduction with the fall treatment (Table 13). Also a 58% reduction in sweet gum re-growth height was recorded with the summer treatment compared to only a 22% reduction with the fall treatment.

Summary

Treatments applied during the summer were more effective in reducing the number of sweet gum stems that re-sprout and reducing sweet gum re-growth heights compared to treatments applied in the spring and fall.

Equipment Field Comparison

DWB vs BBM vs Standard Treatments - Greenville

The only treatment to provided significant control was a spring foliar application of Garlon 3A (Table 9). The Diamond Wet-Blade and Brown Brush Monitor treatments did not vary from the mow-only treatment.

DWB vs BBM vs Standard Treatments - Goldsboro

The Brown Brush Monitor Garlon 3A treatments provided excellent control; however, rates exceeded label rates so results can not be used. At nine months after treatment, the stump application of Garlon 3A and the Brown Brush Monitor with Arsenal provided greater than 80% reduction in heights of both sweet gum and tulip poplar (Table 10). The Diamond Wet-Blade with Garlon 3A plus Arsenal reduced sweet gum and tulip poplar heights by 44 and 32% at nine months after treatment, respectively. At 24 months after treatment, the stump treatment was the only treatment to reduce both sweet gum and tulip poplar heights. The Diamond Wet-Blade with Garlon 3A plus Arsenal and Brown Brush Monitor with Arsenal reduced sweet gum heights 37 and 58%, respectively.

DWB vs BBM vs Foliar Treatment - Beaufort County

Due to rough terrain, the tractor operator of the Brown Brush Monitor slowed down applying more Garlon 3A than what is allowed by the label. The Diamond Wet-Blade treatments did not vary compared to the mow only (Table 11). The poor control from the foliar application was probably due to other vegetation growing around the trees resulting in poor herbicide coverage.

DWB vs BBM - Greensboro

All treatments, except Milestone and Round-up Pro, significantly reduced the number of sweet gum stems to re-sprout (Table 12). Garlon 3A plus Arsenal and the Diamond Wet-Blade with Arsenal reduced sweet gum re-sprouts by 70% or greater. All treatments, except Milestone only, Round-up Pro, and the Brown Brush Monitor with Arsenal, significantly reduced the number of all species to re-sprout. The Diamond Wet-Blade with Arsenal and the Brown Brush Monitor with Garlon 3A plus Arsenal reduced total stem re-sprouting by 56 and 58%, respectively. All other treatments reduced re-sprouting by less than 50%. Only the Diamond Wet-Blade with Arsenal reduced sweet gum re-growth heights by more than 50%. The Garlon 3A plus Milestone treatments reduced tulip poplar re-growth heights by greater than 63%. All treatments, except the Brown Brush Monitor with Milestone and the Diamond Wet-Blade with Round-up Pro, reduced sycamore re-growth heights. The Arsenal, Garlon 3A plus Arsenal, and Garlon 3A plus Weedar 64 treatments reduced sycamore heights by greater than 50%.

DWB vs BBM vs Tiger - Red Oak

All treatments reduced the number of stems that re-sprouted and re-growth in both studies (Table 13). In both studies, the Diamond Wet-Blade and the Brown Brush Monitor performed equally. Both pieces of equipment slightly outperformed the Tiger Flail Mower in the summer study. The Diamond Wet-Blade and the Brown Brush Monitor both performed better in the summer study than in the fall study. In the fall treatment, the Diamond Wet-Blade with Arsenal greatly reduced re-growth height; however, increased in height by over 2.5 times in the final two months of the study where as the other treatments only increased slightly.

The added fall foliar applications reduced stem re-sprouting by 85% at seven months after treatment (Data not presented). In the additional BBM field, the Garlon 3A reduced stem re-sprouting by 61% at 10 months after treatment and at 13 months after treatment a 43% reduction in sweet gum re-growth height was recorded (Data not presented). The trees at the additional BBM field were larger in size which can explain the decrease in stem morality as compared to the BBM treatment in the summer field comparison study.

Summary

Results varied from site to site and varied by tree species. The Greensboro and summer Red Oak study had more positive results than any other studies. Applications for these studies were made during the summer months. The trees at Red Oak were much smaller and younger than at any other site which can explain why control was greater. Where results were available, data showed that both the Diamond Wet-Blade and the Brown Brush Monitor performed equally. The standard treatments of stump and foliar applications provided better control versus the mow/spray equipment.

Objective 2:

Herbicide movement in plants after application

The movement of triclopyr within a plant after cut stem application was assessed using red maples grown in containers and sweetgum growing in the field. Triclopyr was applied to the container grown plants using hand-held pruning shears, and to the field grown plants using a Diamond Wet Blade or a Brown Brush Monitor. Treated plants were divided into sections, and samples were extracted and triclopyr levels analyzed using gas chromatography – mass spectroscopy (GC-MS).

The results of this analysis are not conclusive, but demonstrate evidence for movement of triclopyr within woody plant tissue after application to the cut stem (Table 14 and 15). All of the container-grown and field-grown plants had measurable levels of triclopyr in the different plant sections. It is important to note that the untreated control samples from the container-grown and field grown plants also had detectable levels of triclopyr. The presence of triclopyr in the untreated plants suggests cross-contamination in the field or laboratory.

When triclopyr was found in the plant tissue, it was not consistently located in the same segments (Table 14). Triclopyr was most consistently found in the main roots (12 of 13 samples), and least consistently in the fine roots (9 of 13). The concentration of triclopyr found in the different samples also varied, ranging from 0 to 9.6 µg/g dry weight. Though this is a broad range, the average amount of triclopyr (µg/g dry weight) in the different plant sections was similar (Table 15). However, when the biomass was taken into account, the majority of the

triclopyr accumulated in the fine roots, accounting for 40 to 47% of the total triclopyr recovered (Table 15).

Summary

Because of the limited data collected, conclusions about triclopyr movement within plants after application to a cut stem surface should be conservative. However, detectible levels of triclopyr were found in all of the plants sampled, and in all of the sections analyzed, is strong evidence for movement of the herbicide after application.

Though there is evidence for herbicide movement after a cut stem application, the importance of movement in herbicide efficacy is not understood. The results from the field trials noted "variable efficacy" with any of the cut stem application methods. The variable or limited herbicide movement in woody tissue after application may explain the variable efficacy in the field. Further studies would be needed to better define the role of herbicide movement within the plant and herbicide efficacy in the field. The data from this study sampled all tissue in a relatively uniform manner, and did not distinguish between accumulation in meristematic or structural plant tissue. Because vegetation management with herbicides would require accumulation of the chemicals in the meristems, it will be important to understand the accumulation in different tissues with greater precision. It will be very important to obtain consistent results in field studies in order to correlate the herbicide efficacy with the movement and accumulation within plant.

Objective 3:

Biological Control of Stem Resprouting with *Chondrostereum purpureum* (Chontrol™)

Chondrostereum purpureum (Chontrol™) did not provide control any of the weedy species in any of these experiments (data not presented).

OVERALL SUMMARY

In November 2005, plantation grown sweet gums, tulip poplars, and red maples were treated with commonly used woody vegetation herbicides by using the wet-blade technique with hand-held pruners. Data indicated that Garlon 3A at 50% v/v and Arsenal at concentrations of 1% v/v or greater provided the greatest control of the tree species. In November 2006, the hand-held lopper experiment was repeated with poor results. Only sweet gum was controlled using Arsenal at rates of 1% v/v or greater. This data suggest that tree age can have an affect on tree control as the trees were one year older in 2006.

Using data from the 2005 hand lopper study, a field experiment was initiated in August 2007 to test these treatments along with Weedar 64 using the Diamond Wet-Blade mower. Arsenal (0.5 lbs ae/A or 10% v/v), Arsenal (0.25 lbs ae/A) plus Garlon 3A (3.75 lbs ae/A or 50% v/v), and Garlon 3A (3.75 lbs ae/A) plus Weedar 64 (3.8 lbs ae/A or 40% v/v) significantly increased stem mortality as compared to mowing only. However, no treatments reduced tree heights of surviving stems. A second field experiment was established in the spring 2008 looking at Garlon 3A and Garlon 3A combinations. No reduction in stem density or re-growth heights was recorded.

Using primarily results from the August 2007 study, two studies were established to test Garlon plus 2,4-D combinations. Stem re-sprouting and re-growth heights were not significantly reduced at these sites.

Two studies were established to test if there is a seasonal effect on a Garlon 3A application using the Diamond Wet-Blade. Data from these studies and other studies that were performed, summer wet-blade applications are general more effective than spring and fall applications, but control was mostly less than 50%.

Six field studies were established to compare the Diamond Wet-Blade Mower (DWB) and the Brown Brush Monitor (BBM). In the first three studies, the only mower applied treatment to provide any control was Garlon 3A (3.75 lbs ae/A) plus Arsenal (0.05 lbs ae/A) at one site and control was less than a 45% reduction in re-growth height. In the fourth study, three treatments resulting in greater than 70% sweet gum stem mortality: DWB and BBM with Garlon 3A (3.75 lbs ae/A) plus Arsenal (0.5 lbs ae/A) and DWB with Arsenal (0.5 lbs ae/A). All treatments significantly increased stem mortality over mow alone, but mortality was generally less than 50%. Reduction in re-growth height varied by tree species and by herbicide treatment. Arsenal provided the greatest reduction in sweet gum height, Garlon 3A plus Milestone provided the greatest tulip poplar control and Arsenal, Garlon 3A plus Arsenal, and Garlon 3A plus Weedar 64 reduced sycamore heights. The fifth and sixth studies looked at the treatment of Garlon 3A (6 lbs ae/A) using the DWB and BBM. In both studies, both mowers significantly reduced stem re-sprouting and re-growth heights; however, the study established in summer provided greater control than the one established in the fall.

The research also demonstrated good evidence for herbicide movement after application to the cut stem. The distribution, though not uniform, did seem similar in both field and container grown plants. Herbicide movement was also similar after application via the hand operated or mechanical implements. However, understanding the relationship between herbicide movement and field efficacy will require further study.

Herbicide treatments using these pieces of equipment can reduce the number of stems that re-sprout when applied during the summer, but generally the reduction was no greater than 50%. Re-growth height reduction was generally less than 50% and varied depending on tree species, site, timing, and treatment. Arsenal provided the most consistent and greatest control. Adding Garlon 3A to Arsenal rarely had an additive effect. Summer applications of herbicides were generally more effective than spring or fall treatments.

RECOMMENDATIONS AND TECHNOLOGY IMPLEMENTATION

Although there were demonstrable reductions in stem counts and the heights of re-growth in several experiments, more often no control of woody vegetation was achieved with the herbicides applied through the mower-applicator systems evaluated. Based upon this research, we would not recommend the purchase of these pieces of equipment for herbicide application on woody weeds. Results from research in other regions of the United States suggest that such mower/applicator systems may have utility for herbaceous vegetation control.

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Appendix

Table 1. Treatments, active ingredients, rates, and date of application for the field comparison site near Greensboro.

#	Equipment	Treatment	Active Ingredient	Rate lbs ae/A	Date of Application
1	DWB	Mow only			7/3/2008
2	DWB	Garlon 3A	triclopyr	3.75	7/8/2008
3	BBM	Garlon 3A	triclopyr	6	7/2/2008
4	DWB	Garlon 3A	triclopyr	6	7/3/2008
5	BBM	Garlon 3A	triclopyr	3.75	7/1/2008
6	DWB	Garlon 3A + Milestone	triclopyr + aminopyralid	3.75 + 0.22	7/9/2008
7	BBM	Garlon 3A + Milestone	triclopyr + aminopyralid	3.75 + 0.22	7/2/2008
8	DWB	Milestone	aminopyralid	0.22	7/8/2008
9	BBM	Milestone	aminopyralid	0.22	7/2/2008
10	DWB	Arsenal	imazapyr	0.5	7/9/2008
11	BBM	Arsenal	imazapyr	0.5	7/1/2008
12	DWB	Arsenal + Garlon 3A	imazapyr + triclopyr	0.5 +3.75	7/9/2008
13	BBM	Arsenal + Garlon 3A	imazapyr + triclopyr	0.5 +3.75	7/1/2008
14	DWB	Garlon 3A + Weedar 64	triclopyr + 2,4-D	3.75 + 3.8	7/9/2008
15	BBM	Garlon 3A + Weedar 65	triclopyr + 2,4-D	3.75 + 3.8	7/2/2008
16	DWB	Roundup Pro	glyphosate	3	7/9/2008

DWB, Diamond Wet-Blade. BBM, Brown Brush Monitor. lbs ae/A, pounds of acid equivalent per acre.

Table 2. Herbicide dose comparison using hand-held loppers for the control of sweet gum, tulip poplar, and red maple.

		2005			2006		
		Sweet Gum Height inches	Tulip Poplar Height inches	Red Maple Height inches	Sweet Gum Height inches	Tulip Poplar Height inches	Red Maple Height inches
Treatment	Rate	12 MAT	12 MAT	12 MAT	12 MAT	12 MAT	12 MAT
Untreated		55.9 ab	68.8 ab	35.0 abc	47.6 ab	61.1 a	41.4 a
Garlon 3A	50% v/v	0.0 e	31.3 defg	8.8 efg	47.5 ab	66.6 a	37.0 a
Garlon 3A	25% v/v	9.8 e	33.0 defg	25.6 bcde	43.2 abc	51.4 a	31.9 a
Garlon 3A	10% v/v	35.8 cd	32.4 defg	21.0 cdef	50.9 a	55.3 a	38.3 a
Garlon 3A	5% v/v	38.8 bcd	51.6 abcd	48.1 a	47.6 ab	40.3 a	36.6 a
Garlon 3A	1% v/v	53.1 abc	45.1 bcdef	44.4 a	54.1 a	45.9 a	39.4 a
Rodeo	50% v/v	52.0 abcd	14.1 gf	15.4 defg	45.9 abc	29.2 a	30.6 a
Rodeo	25% v/v	50.4 abcd	50.3 abcde	20.4 cdef	51.0 a	49.4 a	32.8 a
Rodeo	10% v/v	48.9 abcd	9.5 g	29.6 abcd	48.7 ab	55.2 a	44.6 a
Rodeo	5% v/v	34.6 d	32.4 defg	13.7 defg	45.1 abc	63.6 a	36.0 a
Rodeo	1% v/v	55.4 ab	32.4 defg	44.5 a	44.8 abc	71.7 a	28.3 a
Arsenal	10% v/v	0.0 e	1.8 g	0.0 g	14.8 e	31.1 a	22.1 a
Arsenal	5% v/v	13.8 e	14.5 fg	6.4 fg	24.2 de	36.1 a	10.0 a
Arsenal	2.5% v/v	12.6 e	7.8 g	0.0 g	37.1 bc	53.6 a	29.3 a
Arsenal	1% v/v	7.3 e	17.1 efg	0.0 g	34.8 cd	50.8 a	26.0 a
Arsenal	0.5% v/v	41.7 abcd	34.1 cdefg	4.1 fg	50.3 a	63.5 a	15.6 a
Escort XP	2.25 g/gal	49.4 abcd	49.5 abcde	44.4 a	-	-	-
Escort XP	1.13 g/gal	48.9 abcd	61.5 abcd	46.6 a	-	-	-
Escort XP	0.45 g/gal	53.1 abc	72.5 ab	43.4 ab	-	-	-
Escort XP	0.23 g/gal	57.4 a	81.4 a	40.8 ab	-	-	-
Escort XP	0.04 g/gal	58.8 a	72.5 ab	31.3 abcd	-	-	-
Garlon + Arsenal	50 + 1% v/v	-	-	-	44.3 abc	65.2 a	42.1 a
Garlon + Arsenal	25 + 1% v/v	-	-	-	42.8 abc	52.7 a	16.4 a
Garlon + Rodeo	50 + 10% v/v	-	-	-	42.1 abc	57.6 a	29.6 a
Garlon + Rodeo	25 + 25% v/v	-	-	-	46.6 abc	52.2 a	44.5 a

Means within a column followed by the same letters are not significantly different according to Student-Newman-Keuls LSD P=0.05.
MAT, months after treatment. v/v, volume to volume. g/gal, grams per gallon.

Table 2 cont. Herbicide dose comparison using hand-held loppers for the control of sweet gum, tulip poplar, and red maple.

Treatment	Rate	Sweet Gum 12 MAT	Tulip Poplar 12 MAT	Red Maple 12 MAT
ANOVA				
Year		***	***	***
Herbicide		***	*	***
Dose		***	**	N/S
Year*Herbicide		***	N/S	N/S
Herbicide*Dose		***	N/S	N/S
Year*Dose		N/S	N/S	*
Year*Herbicide*Dose		N/S	N/S	N/S

ANOVA: N/S, not significant. *,P<0.05. **,P<0.01. ***P<0.001.

Table 3. Herbicide dose comparison using hand-held loppers for the control of one-year regrowth vs. two-year regrowth sweet gum, and tulip poplar.

Treatment	Rate	Sweet Gum Height inches 6 MAT		Tulip Poplar Height inches 6 MAT	
Untreated		58.1	ab	73	a
Garlon 3A	50% v/v	57.2	ab	46	cde
Garlon 3A	25% v/v	61.7	a	39.8	de
Garlon 3A	10% v/v	59.8	ab	53.8	abcd
Garlon 3A	5% v/v	56.5	ab	49.7	bcd
Garlon 3A	1% v/v	55.2	ab	53.5	abcd
Rodeo	50% v/v	51	abc	9	f
Rodeo	25% v/v	60.2	ab	27.5	ef
Rodeo	10% v/v	56.3	ab	40.5	de
Rodeo	5% v/v	60	ab	60.7	abc
Rodeo	1% v/v	61.9	a	68.8	ab
Arsenal	10% v/v	28.4	d	12.8	f
Arsenal	5% v/v	41.2	cd	35.7	de
Arsenal	2.5% v/v	48.5	bc	40	de
Arsenal	1% v/v	53.1	abc	48.7	cd
Arsenal	0.5% v/v	50	abc	64	abc
ANOVA					
1 Year vs. 2 Year		N/S		N/S	
Herbicide		***		***	
Year*Herbicide		N/S		N/S	

Means within a column followed by the same letters are not significantly different according to Student-Newman-Keuls LSD P=0.05.

ANOVA: N/S, not significant. *,P<0.05. **,P<0.01. ***P<0.001.

MAT, months after treatment. v/v, volume to volume. Treatment by stem size interaction (p>0.05) was not significant so data was pooled.

Table 4. Diamond Wet-Blade and herbicide efficacy for woody vegetation control along a roadside in Chatham County, NC treated in 2007 and then retreated in 2008.

		All Species Resprout % 9 MAT	Sweet Gum Height inches 12 MAT	Tulip Poplar Height inches 12 MAT	Red Maple Height inches 12 MAT	Sweet Gum Resprout % 9 MAT	All Species Resprout % 9 MAT	Sweet Gum Height inches 10 MAT	Tulip Poplar Height inches 10 MAT	Red Maple Height inches 10 MAT
Treatment	Rate (lbs ae/A)	2007	2007	2007	2007	2008	2008	2008	2008	2008
Mow Only		80 a	47.7 a	49.7 a	50.3 a	94 a	95 a	41.4 a	47.5 a	33.8 a
Arsenal	0.5	44 b	33.7 a	51.9 a	33.3 a	39 cd	51 b	19.8 b	41.0 a	32.3 a
Arsenal	0.25	54 ab	41.1 a	65.0 a	26.5 a	60 bc	67 b	19.0 b	53.1 a	33.8 a
Arsenal + Garlon 3A	0.25 + 3.75	26 b	49.3 a	58.9 a	32.6 a	32 d	53 b	23.5 ab	50.5 a	46.2 a
Garlon 3A + Weedar 64	3.75 + 3.8	35 b	44.2 a	56.5 a	59.3 a	81 ab	87 a	40.0 a	56.6 a	52.8 a
Weedar 64 + Arsenal	3.8 + 0.25	85 a	37.3 a	41.7 a	68.9 a					

Means within a column followed by the same letters are not significantly different according to Student-Newman-Keuls LSD P=0.05.
MAT, months after treatment. lb ae/A, pounds of acid equivalent per acre.
Height measurements were made by measuring the ten tallest sweet gums, five tallest tulip poplars and three tallest red maples per plot.

Table 5. Diamond Wet-Blade and herbicide efficacy for woody vegetation control under a power distribution line in Efland, NC.

		Sw. Gum Stem Resprout %	All Species Stem Resprout %	Sw. Gum Height inches	Sycamore Height inches
Treatment	Rate lbs ae/A	5 MAT	5 MAT	12 MAT	12 MAT
Mow Only		98 a	98 a	37.8 a	58.4 a
Garlon 3A	3.75	84 a	83 a	36.8 a	36.0 a
Garlon 3A + Arsenal	3.75 + 0.25	82 a	84 a	29.3 a	50.7 a
Garlon 3A + Weedar 64	3.75 + 3.8	74 a	76 a	34.2 a	44.3 a

Means within a column followed by the same letters are not significantly different according to Student-Newman-Keuls LSD P=0.05.
MAT, months after treatment. lb ae/A, pounds of acid equivalent per acre.
Height measurements were made by measuring the ten tallest sweet gums and three tallest sycamores.

Table 6. Diamond Wet-Blade and Garlon 3A plus Weedar 64 efficacy for woody vegetation control along a roadside in Chatham County, NC.

Treatment	Rate lbs ae/A	Sw. Gum Stem Resprout % 5 MAT 2009	All Species Stem Resprout % 5 MAT 2009	Sw. Gum Height inches 12 MAT 2009
Mow Only		97 a	99 a	42.1 a
Garlon 3A + Weedar 64	3.75 + 3.8	83 a	72 c	43.4 a
Garlon 3A + Weedar 64	1.87 + 3.8	95 a	91 ab	50.9 a
Garlon 3A + Weedar 64	1.87 + 1.9	99 a	97 a	48.4 a
Garlon 3A + Weedar 64	3.75 + 1.9	90 a	86 b	40.1 a

Means within a column followed by the same letters are not significantly different according to Student-Newman-Keuls LSD P=0.05.
MAT, months after treatment. lb ae/A, pounds of acid equivalent per acre.
Height measurements were made by measuring the ten tallest sweet gums.

Table 7. Diamond Wet-Blade and Garlon 4 plus Patron 170 efficacy for woody vegetation control along a roadside in Orange County, NC.

Treatment	Rate lbs ae/A	Sw. Gum Stem Resprout % 5 MAT	All Species Stem Resprout % 5 MAT	Sw. Gum Height inches 12 MAT
Mow Only		98 a	98 a	45.6 a
Garlon 4	3	100 a	92 a	40.5 a
Patron 170	1.29	100 a	100 a	54.0 a
Garlon 4 + Patron 170	3 + 1.29	98 a	95 a	43.6 a

Means within a column followed by the same letters are not significantly different according to Student-Newman-Keuls LSD P=0.05.
MAT, months after treatment. lb ae/A, pounds of acid equivalent per acre.
Height measurements were made by measuring the ten tallest sweet gums.

Table 8. Seasonal treatments of the Diamond Wet-Blade with Garlon 3A for woody vegetation control at Greenville and Wilson's Mills, NC test sites.

Treatment	Rate lbs ae/A	All Species % Control Greenville Nov. 06	Sw. Gum Height inches Greenville Nov. 07	Sw. Gum Height % Reduction Greenville Nov. 07	R. Maple Height inches Greenville Nov. 07	R. Maple Height % Reduction Greenville Nov. 07	Sw. Gum Height inches W. Mills 9-Jun	Sw. Gum Height % Reduction W. Mills 9-Jun
Mow Only - Spring		24 a	37 a		45 a		72.4 a	
DWB - Garlon 3A - Spring	3.75	26 a	51 a	0	30 a	33	67.3 a	7
Mow Only - Summer		22 a	47 a		38 a		27.4 b	
DWB - Garlon 3A - Summer	3.75	86 b	26 a	45	19 a	50	16 c	42
Mow Only - Fall		0	79		63		29.6 b	
DWB - Garlon 3A - Fall	3.75	18	64	19	53	15	22.7 bc	23
ANOVA								
Season			***		***		***	
Garlon 3A			N/S		**		***	
Season*Garlon 3A			***		N/S		N/S	

Means within a column followed by the same letters are not significantly different according to Student-Newman-Keuls LSD P=0.05.

ANOVA: N/S, not significant. *,P<0.05. **,P<0.01. ***P<0.001.

MAT, months after treatment. DWB, Diamond Wet-Blade. lb ae/A, pounds of acid equivalent per acre.

Percent control based on visual estimates of vegetation control on 0-100% scale (0=no control, 100=complete control).

The Fall Greenville data was carried over from the Greenville field comparison study which was located in an adjacent field.

Height measurements were made by measuring the five tallest sweet gums and three tallest red maples per plot at Greenville and the ten tallest sweet gums at Wilson's Mills.

Table 9. Field comparison of the Diamond Wet-Blade and Brown Brush Monitor for woody vegetation control in a test field in Greenville, NC.

Treatment	Rate lbs ae/A	All Species % Control 12 MAT	All Species % Control 21 MAT	Sw. Gum Height inches 24 MAT	R. Maple Height inches 24 MAT
Mow Only		0 b	0 b	78.8 a	62.8 a
Mow - Spring Foliar w/Garlon 3A	6	88 a	65 a	33.6 b	18.9 b
Mow - Broadcast w/Garlon 3A	6	25 b	3 b	71.7 a	69.0 a
DWB - Garlon 3A	3.75	18 b	13 b	63.7 ab	53.4 a
BBM - Garlon 3A	3.75	35 b	28 b	52.1 ab	57.8 a

Means within a column followed by the same letters are not significantly different according to Student-Newman-Keuls LSD P=0.05.
MAT, months after treatment. lb ae/A, pounds of acid equivalent per acre.
DWB, Diamond Wet-Blade. BBM, Brown Brush Monitor.
Height measurements were made by measuring ten tallest sweet gums and five tallest red maples present in each plot.
Percent control based on visual estimates of woody vegetation control 0-100% scale (0=no control, 100=complete control).

Table 10. Field comparison of the Diamond Wet-Blade and Brown Brush Monitor for control of sweet gum and tulip poplar in a test field in Goldsboro, NC.

Treatment	Rate lbs ae/A	Sw. Gum Height inches 9 MAT	T. Poplar Height inches 9 MAT	Sw. Gum Height inches 24 MAT	T. Poplar Height inches 24 MAT
Mow Only		47.6 a	60.2 a	76.8 a	100.0 a
Mow - Stump treat w/Garlon 3A	6	0.0 c	1.6 c	3.1 c	2.8 b
DWB - Garlon 3A	3.75	45.7 a	55.1 ab	84.3 a	90.9 a
DWB - Arsenal	0.05	41.7 a	59.8 a	75.6 a	85.0 a
DWB - Garlon 3A + Arsenal	3.75 + 0.05	26.8 b	40.9 b	48.4 b	91.7 a
BBM - Garlon 3A	30	2.8 c	0.0 c	10.6 c	7.9 b
BBM - Arsenal	0.4	5.1 c	11.0 c	31.9 b	58.3 a
BBM - Garlon 3A + Arsenal	30 + 0.4	3.1 c	7.1 c	5.5 c	9.1 b

Means within a column followed by the same letters are not significantly different according to Student-Newman-Keuls LSD P=0.05.
MAT, months after treatment. lb ae/A, pounds of acid equivalent per acre. DWB, Diamond Wet-Blade. BBM, Brown Brush Monitor.
Height measurements were made by measuring all sweet gums and tulip poplars present in each plot.

Table 11. Field comparison of the Diamond Wet-Blade, Brown Brush Monitor and foliar application for woody vegetation control under a power distribution line in Beaufort County, NC.

Treatment	Rate lb ae/A	All Species Control % 8 MAT		Sweet Gum Height inches 12 MAT		Sweet Gum Height inches 20 MAT	
Mow Only		0	b	43.7	ab	65.3	a
Fall Mow Only + Spring Foliar - Garlon 3A	6	.		40.7	ab	.	
DWB - Garlon 3A	3.75	0	b	43.4	ab	68	a
DWB - Garlon 3A + Arsenal	3.75 + 0.05	19	b	46.9	ab	63.5	a
BBM - Garlon 3A	11	75	a	25.5	c	37.3	b
BBM - Garlon 3A + Arsenal	11 + 0.15	73	a	30.8	bc	51.3	a

Means within a column followed by the same letters are not significantly different according to Student-Newman-Keuls LSD P=0.05.
MAT, months after treatment. DWB, Diamond Wet-Blade. BBM, Brown Brush Monitor. lb ae/A, pounds of acid equivalent per acre.
Percent control based on visual estimates of woody vegetation control 0-100% scale (0=no control, 100=complete control).
Height measurements were made by measuring the ten tallest sweet gums per plot.

Table 12. Field comparison of the Diamond Wet-Blade and Brown Brush Monitor for woody vegetation control in a test field near Greensboro, NC.

Treatment	Rate lbs ae/A	Sw. Gum Stem Resprout % 10 MAT	All Species Stem Resprout % 10 MAT	Sw. Gum Height inches 12 MAT	T. Poplar Height inches 12 MAT	Sycamore Height inches 12 MAT
Mow Only		99 a	99 a	41.4 a	33.0 a	39.6 ab
DWB - Garlon 3A	3.75	43 cd	57 cd	22.5 bc	21.3 abc	23.7 cde
BBM - Garlon 3A	3.75	49 cd	62 cd	30.2 ab	27.2 ab	28.0 bcd
DWB - Garlon 3A	6	50 cd	56 cd	26.1 bc	26.2 ab	27.9 bcd
BBM - Garlon 3A	6	39 cd	52 cd	24.8 bc	26.8 ab	27.0 bcd
DWB - Garlon 3A + Milestone	3.75 + 0.22	46 cd	53 cd	24.3 bc	6.7 c	19.9 de
BBM - Garlon 3A + Milestone	3.75 + 0.22	43 cd	51 cd	29.6 ab	12.1 bc	31.8 bcd
DWB - Milestone	0.22	84 ab	89 ab	33.5 ab	20.8 abc	31.7 bcd
BBM - Milestone	0.22	87 ab	89 ab	35.6 ab	23.0 abc	35.3 abc
DWB - Arsenal	0.5	20 d	44 d	14.9 c	25.0 abc	16.6 de
BBM - Arsenal	0.5	69 bc	77 abc	24.6 bc	23.1 abc	18.9 de
DWB - Garlon 3A + Arsenal	3.75 + 0.5	29 d	51 cd	21.0 bc	18.8 abc	9.6 e
BBM - Garlon 3A + Arsenal	3.75 + 0.5	29 d	42 d	23.1 bc	24.3 abc	18.3 de
DWB - Garlon 3A + Weedar 64	3.75 + 3.8	61 c	68 bcd	27.1 bc	25.1 abc	19.1 de
BBM - Garlon 3A + Weedar 64	3.75 + 3.8	46 cd	57 cd	26.6 bc	24.0 abc	17.5 de
DWB - Round-up Pro	3	98 a	98 a	42.2 a	38.4 a	46.3 a
ANOVA						
Mower		N/S	N/S	***	*	**
Herbicide		***	***	***	***	***
Mower*Herbicide		N/S	N/S	**	N/S	N/S

Means within a column followed by the same letters are not significantly different according to Student-Newman-Keuls LSD P=0.05.

ANOVA: N/S, not significant. *,P<0.05. **,P<0.01. ***P<0.001. Mow only, DWB-Round-up Pro, and DWB,BBM-Arsenal treatments were exclude to balance the data.

MAT, months after treatment. lb ae/A, pounds of acid equivalent per acre. DWB, Diamond Wet-Blade. BBM, Brown Brush Monitor.

Height measurements were made by measuring the ten tallest sweet gums and five tallest tulip poplars and sycamores per plot.

Table 13. Field comparison of the Diamond Wet-Blade, Brown Brush Monitor, and Tiger Flail Mower for woody vegetation control in two test fields near Red Oak, NC.

Treatment	Rate lbs ae/a	All Species Stem Resprout % Summer 10 MAT	Sw. Gum Stem Resprout % Summer 10 MAT	Sw. Gum Height inches Summer 12 MAT	Sw. Gum Stem Resprout % Fall 7 MAT	Sw. Gum Height inches Fall 9 MAT	Sw. Gum Height inches Fall 11 Mat
Mow Only		100 a	100 a	58.1 a	99 a	44.9 a	45.0 a
DWB - Garlon 3A	6	11 c	10 c	24.2 c	43 b	35.1 b	36.6 b
BBM - Garlon 3A	6	17 c	17 c	31.1 bc	55 b	35.1 b	36.9 b
Tiger - Garlon 3A	6	38 b	37 b	35.7 b	.	.	.
DWB - Arsenal	0.5	.	.	.	36 b	4.1 c	11.0 c

Means within a column followed by the same letters are not significantly different according to Student-Newman-Keuls LSD P=0.05.
MAT, months after treatment. lb ae/a, pounds of acid equivalent per acre. DWB, Diamond Wet-Blade. BBM, Brown Brush Monitor.
Height measurements were made by measuring the ten tallest sweet gums per plot.

Table 14. Levels of triclopyr in sections of red maple or sweetgum after application to a cut stem. Red maples were 3 years old grown in containers and triclopyr was applied with pruning shears. Sweetgums were in a natural stand of variable ages and triclopyr was applied with either a Diamond Wet Blade (DWB) or a Brown Brush Monitor (BBM).

Red Maple

Sample	Section[1]	µg/g Triclopyr[2]
RM1	MS	6.4
	SS	0
	MR	1.2
	FR	1.6
RM2	MS	3.6
	SS	3.6
	MR	0
	FR	0
RM3	MS	4.4
	SS	3.2
	MR	5.2
	FR	3.6
RM4	MS	0
	SS	4.8
	MR	5.2
	FR	4.4
RM5	MS	7.6
	SS	6.8
	MR	5.2
	FR	0

Sweetgum

Sample	Section	Treatment Method	µg/g Triclopyr
SG1	MS	DWB	7.2
	SS		4.4
	MR		6
	FR		5.2
SG2	MS	DWB	2.8
	SS		8.8
	MR		4.4
	FR		6
SG3	MS	DWB	0
	SS		5.6
	MR		3.2
	FR		4.4
SG4	MS	DWB	7.2
	SS		0
	MR		4
	FR		0
SG5	MS	BBM	1.2
	SS		6.4
	MR		4.4
	FR		6
SG6	MS	BBM	0
	SS		5.6
	MR		4.4
	FR		3.2
SG7	MS	BBM	3.2
	SS		3.6
	MR		2
	FR		5.6
SG8	MS	BBM	4.8
	SS		4.8
	MR		9.6
	FR		0

[1] Plant sections: MS-stem section directly below the cut; SS-stem section from root connection and above; MR-main root segments attached to stem section; FR-fine roots.
[2] µg/g = triclopyr per gram dry weight plant tissue.

Table 15. Average levels (µg/g dry wt) and standard error of triclopyr in sections of red maple or sweetgum after application to a cut stem. Red maples were 3 years old, grown in containers and triclopyr was applied with pruning shears. Sweetgums were in a natural stand of variable ages and triclopyr was applied with either a Diamond Wet Blade (DWB) or a Brown Brush Monitor (BBM).

Red Maple - Nursery

Plant Section[1.]	Triclopyr µg/g dry wt	Std Error	% of total Triclopyr/ Section[2.]	Std Error
MS	3.6	0.67	25.1	5.0
SS	2.9	0.51	19.1	4.0
MR	2.9	0.66	8.6	1.4
FR	2.4	0.50	47.1	8.6

Sweetgum - Diamond Wet Blade

MS	4.3	0.88	17.2	5.9
SS	4.7	0.91	17.7	3.8
MR	4.4	0.29	26.0	3.7
FR	3.9	0.67	40.2	7.0

Sweetgum - Brown Brush Monitor

MS	2.3	0.53	8.7	2.3
SS	5.1	0.30	17.3	0.2
MR	5.1	0.80	27.2	6.2
FR	3.7	0.69	46.6	7.9

[1] Plant sections: MS-stem section directly below the cut; SS-stem section from root connection and above; MR-main root segments attached to stem section; FR-fine roots.
[2.] The % of total triclopyr found in the different plant sections.