The Influence of Timing and Herbicide Treatment for Chinese Privet Control (*Ligustrum sinense* Lour.)

by

Sarah Elizabeth O'Sullivan

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Approved by

Stephen Enloe, Chair, Associate Professor, Agronomy and Soils
Nancy Loewenstein, Research Fellow IV, Forestry and Wildlife
J. Scott McElroy, Associate Professor, Agronomy and Soils
Becky Barlow, Associate Professor, Forestry and Wildlife

Abstract

Cut stump and basal bark studies for Chinese privet (*Ligustrum sinense* Lour.) control were conducted in Auburn, AL. Treatments for the cut stump application consisted of: 1) 25% vol/vol of an amine formulation of triclopyr (Garlon 3A) at 90 g/L, 2) 25% vol/vol of glyphosate (Accord Concentrate) at 120 g/L, and 3) cutting only with no herbicide (the control) and basal bark treatments consisted of 1) untreated control, 2) Pathfinder II (90 g/L), 3) Garlon 4 at 5% (24 g/L), 4) Garlon 4 at 10% (48 g/L), and 5) Garlon 4 at 20% (96 g/L vol/vol). For the cut stump treatment, both herbicides were effective at controlling Chinese privet with < 12% of the stumps exhibiting any sprouting. For the basal bark application, all herbicide treatments were effective, averaging one new sprout per privet clump with a mean percent defoliation of $\geq$ 97%.

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Table of Contents

List of Tables

List of Figures

Cut Stump Application

LITERATURE REVIEW

Invasive Plants: A Brief Overview

An invasive plant species is a non-native plant whose presence could potentially cause harm to the environment, economy, or to human health (Andersen et al., 2004; USDA, 2011). It is estimated that 25,000 non-native, or exotic, plants have been brought into the United States (Pimentel et al., 2005). Exotic plants can be imported either intentionally or unintentionally; however, most introductions have deliberately been brought in for use as food or as ornamentals for landscaping (Pimentel et al., 2005). Just because a plant species is non-native does not mean that it is harmful (Williamson, 1997). For example, the majority of plant species used for crops in the United States are not native, yet provide food for human consumption (Pimentel et al., 2001) and very few escape cultivation. However, exotic species can become a problem when 1) they are plentiful and widespread due to their method of dispersal (e.g., plant parts lodged on equipment or seed that is dispersed by wind, birds, or other animals), 2) are located near disturbed landscapes that provide a suitable environment for establishment, and 3) are located near fragmented natural areas with an increased amount of edge making those areas more vulnerable to the establishment of invasive species (Davies and Sheley, 2007; Mortensen et al., 2009; Gavier-Pizarro et al., 2010; Quinn et al., 2011). Given the large number of non-native plant species currently in the US, even if a small percentage became invasive, natural habitats and human health could be seriously degraded (Pimentel et al., 2005).

The lack of natural control agents (eg., predators and pathogens) can provide exotic species with an advantage over native plants (Huang et al., 2012). Invasive plants may also have an additional competitive edge through increased early, vigorous growth, more efficient use of natural resources, and the ability to tolerate a wide variety of conditions such as flooding and shading (Urgenson, 2006; Saltonstall et al., 2010; Van Riper et al., 2010; Godara et al., 2011). In addition, invasive plants typically have multiple reproductive advantages such as strong asexual reproduction, a shortened juvenile stage allowing earlier sexual reproduction, the production of copious amounts of seed, multiple dispersal mechanisms, and high seed viability and longevity in the soil seed bank (Harrison et al., 2007; Otfinowski et al., 2008; Goddard et al., 2009; Saltonstall et al., 2010). Seed banks are a source for both dormant and germinable seeds. Since seed germination can decline with time (Figueroa et al., 2007; Riar et al., 2012), it is to a plant's advantage to produce copious amounts of seed that is viable for long periods of time, therefore, increasing the chances of germination (Harrison et al., 2007). Not all of these traits are found in every invasive plant species but even a few of these traits can give invasive species the competitive edge to dominate an area and displace native vegetation.

If left uncontrolled, many invasive species will eventually form monotypic stands, also known as monocultures, excluding the establishment of other plants (Webster et al., 2006; Ingham and Borman, 2010). The invasibility of an area is a function of how easily non-native species establish in an area (Milbau and Nijs, 2004) and certain components of forests such as gaps, edges, and disturbed areas may make forests more susceptible to invasion (Milbau and Nijs, 2004; Pimentel et al., 2005; Wilcox and Beck, 2007; Mortensen et al., 2009; Gavier-Pizarro et al., 2010; Miller et al., 2010b). Once established, invasive species can have multiple impacts on ecosystem structure and function including impacts on nutrient cycles, fire frequency and intensity, hydrology, soil biota, stand regeneration, and biodiversity in general (Merriam and Feil, 2002; Urgenson, 2006; Bryson et al., 2007; Brantley, 2008; Corbin and D'Antonio, 2012). Hybridization between invasive and native species may also result in genetic differences between exotic species in the introduced areas versus their native range (DeWalt et al., 2011) leading to new genetic traits and possibly more competitive advantages.

All of these changes to the ecosystem can threaten some native species to the point of local extinction (Pimentel et al., 2001). In the continental US, habitat loss or degradation has impacted 90% of plants that are categorized as imperiled by the Nature Conservancy or as threatened or endangered by the US Fish and Wildlife and 30% of these were affected directly by the presence of non-native species (Wilcove et al., 1998). Habitat loss or degradation and competition with non-native species are the top two threats to imperiled, threatened, and endangered species (Wilcove et al., 1998).

Loss of the diversity of native plants and increased competition for light and nutrients can lead to reduced growth and a decrease in forest productivity (Webster et al., 2007; Brantley, 2008) resulting in lost revenue. Other industries such as farming and livestock production are also impacted by invasive species. It is estimated that non-native plants cost the U.S. $27 billion a year in lost crop yields, $1 billion a year through less productive grazing land, and $500 million in control costs (Pimentel et al., 2005). In total, invasive species costs in the United States are approximately $120 billion a year. However, this estimate would be higher if loss of biodiversity and species extinction could be better economically quantified (Pimentel et al., 2005).

Preventive Strategies

Forest management operations, such as site preparation, thinning, harvesting, road construction, and baling pine straw, can introduce and spread invasive species into an area (Evans et al., 2006; Mortensen et al., 2009). Once an invasive species is well established, the probability of eradication is greatly reduced (Pimentel et al., 2001) so the best control method is prevention. Recognizing invasive species found in the region, reducing and monitoring the amount of recently disturbed soil, cleaning equipment before leaving infested sites, and predicting how invasive species will respond to various management operations (Anderson, 1996) are some examples of preventive control methods that can be done on the local level (Evans et al., 2006). Preventive control methods can also be conducted at the state and national level through the formation of laws, such as the Federal Noxious Weed Act of 1974 (Anderson, 1996). Also, the formation of coalitions, such as the National Invasive Species Council (NISC), can increase awareness and influence policy change (Andersen et al., 2004). Invasive species prevention efforts can even occur globally by the formation of groups, such as the Convention on Biological Diversity (CBD) (Andersen et al., 2004). Also important are risk assessments formulated to determine the invasiveness of a species, methods of introduction, identification of vulnerable areas, and identifying the consequences of the spread of the species (Pheloung et al., 1999; Andersen et al., 2004; Wang et al., 2012).

Since occupation and place of residence can influence how people classify species as invasive, risk assessments can provide an objective analysis on the invasive nature of particular species (Pheloung et al., 1999).

Invasive species do not stop at property lines or state boundaries (Wang et al., 2012) so cooperative weed management areas (CWMAs) and cooperative invasive species management areas (CISMA) have been created to address this issue. The purpose of a CWMA or CISMA is to encourage collaboration and coordination for invasive species management, to provide a network across jurisdictional lines, and a means to compile resources for the benefit of the entire community (Midwest Invasive Plant Network, 2006). A CWMA is organized at the local level, has a formal agreement establishing a long-term working relationship between the parties involved, and is guided by a steering committee (Midwest Invasive Plant Network, 2006).

Despite the best attempts at prevention, invasive species can still infiltrate an area. The first phase of invasion is the entry phase or the initial introduction during which the invasive species first appears in an area (Andersen et al., 2004; Webster et al., 2006). If undetected or uncontrolled, the invasive species could become established, the second phase. During this establishment phase plants within one or more populations begins to reproduce, reducing the danger of local extinction (Andersen et al., 2004). This leads to the third phase, the expansion phase, where the invasive species begins to spread from its point of introduction and invade nearby areas (Andersen et al., 2004; Webster et al., 2006). The last stage, the impact or saturation stage, is where the invasive species occupies its ecological niche usually at the expense of the native species (Andersen et al., 2004; Webster et al., 2006). While many species may escape cultivation and naturalize, few actually reach the impact phase (Andersen et al., 2004). For example, thousands of non-native plants have become naturalized in the U.S. but only 14% of those are currently considered invasive (Wirth et al., 2004). A general rule, the tens rule, suggests that only 10% of introduced species escape and become established, 10% of the escaped species become naturalized and spread, and only 10% of the naturalized species become problematic and achieve the invasive species status (Williamson, 1997). Even though relatively few introduced species become invasive, the longer a problematic species goes unmanaged, the harder it will be to control and eradicate.

To prioritize invasive species, state invasive plant organizations have developed guidelines placing invasive species into multiple categories or watch lists. Different states have different criteria as to what constitutes a placement in specific categories. For example, in Florida an invasive plant is considered Category I if it displaces or hybridizes with native flora, therefore, altering the structure of natural plant communities (Florida Exotic Pest Plant Council, 2011). An invasive species in Category II has increased in number but has not yet altered the native plants in that area (Florida Exotic Pest Plant Council, 2011). In Alabama, an invasive species is a Category I if 1) the plant is not native to Alabama, 2) displays rapid growth, has a large amount of seed production and dispersal, and can become established in natural areas, 3) can negatively impact plant diversity by outcompeting the native plants, 4) persists in Alabama without further cultivation, 5) is found in at least two physiographic regions, and 6) can create monocultures and numerous infestations (Alabama Invasive Plant Council, 2007). Category II plants in Alabama meet points 1-4 as previously mentioned but also have at least one cultural use, is found in one or two of the physiographic regions, and mainly occur as scattered individuals (Alabama Invasive Plant Council, 2007). In Georgia, an invasive plant is classified as Category I if it widely invades natural areas and displaces the native flora, therefore, causing a serious problem (Georgia Exotic Pest Plant Council, 2006). Category II plants displace native species but at a lower level, thereby only causing a moderate level of damage (Georgia Exotic Pest Plant Council, 2006). All three states have different rules for categorizing invasive species but the themes of non-native status, aggressive spread, and impact on native plant diversity permeate all three state lists.

Invasive Plant Control Methods

Invasive plants can be controlled or eradicated but both are scale dependent. The term control means that the invasive species is reduced to an acceptable level but not completely eliminated from the area (Anderson, 1996). Eradication of the invasive plant, on the other hand, is the complete removal, including seed from both the plant and the seed bank, along with any plant parts capable of vegetative reproduction, from the particular area (Anderson, 1996). Although eradication is the ideal, it is not practical for large, wide-spread infestations or for species with long-lived seed due to the cost involved and difficulty depleting the seed bank (Anderson, 1996). Since control is more realistic than eradication, the following section will focus on invasive plant management from a control perspective.

Controlling incipient, small infestations is more effective and financially efficient than attempting to control large, well-established populations (Evans et al., 2006; Wang et al., 2012). Targeting areas with a low density of invasive species can reduce future seed production, potentially help restore native vegetation, and reduce negative impacts on wildlife (Delanoy and Archibold, 2007). Since areas with a low concentration of invasive species have higher growth rates compared to high-density areas, control methods can reduce the growth rate of the invasive species (Delanoy and Archibold, 2007) and help restore native vegetation. Treating small patches of invasive species has a lower cost per acre basis but can actually have a higher cost per stem basis since the stems may be widely distributed compared to monocultures (Delanoy and Archibold, 2007). Despite the higher cost per stem basis, treating small infestations is still more economical since generally it would require less follow-up treatments and fewer years to treat. The number of follow-up treatments and the number of years necessary for control can also impact the cost of controlling an invasive species. The number of follow-up treatments is dependent on the species, its ability to replace native species and the control method selected (Solecki, 1997). If the seed bank for native species has been depleted, then reseeding after the removal of the invasive species is an option (Solecki, 1997) but will be an additional cost.

Considerations when deciding which control method to implement include site characteristics, effectiveness of the control method for the particular invasive species of concern (Corbin and D'Antonio, 2012), and the resources available. Control methods can be categorized into cultural, physical, chemical, and biological (Anderson, 1996; Corbin and D'Antonio, 2012). Examples of cultural control methods include flooding and prescribed burning (Miller et al., 2010a). Flooding can be used to control some terrestrial species through intentionally submerging the roots and possibly the shoots in water. Flooding can effectively displace the air in the soil, limiting the plant's ability to absorb oxygen, which can shut down root respiration. However, the use of flooding is limited by soil type and water availability.

Prescribed burns, on the other hand, use a low intensity fire to intentionally kill the above ground portion of the plants. However, the use of off-site equipment and the soil disturbance necessary to create the firebreaks used to contain the fire could favor the establishment of invasive species into the area. This along with other effects of a prescribed burn such as removal of aboveground biomass, increased nutrients, light, and bare soil could leave an area vulnerable for invasion. Additionally, prescribed burns can result in sprouting of many species (DiTomaso et al., 2006), so monitoring of the controlled areas and follow-up treatments may be needed after a prescribed burn. Despite the disadvantages, repeated prescribed burns have been used to successfully eradicate some species such as common buckthorn (*Rhamnus cathartica* L.) (Delanoy and Archibold, 2007; Beasley and Pijut, 2010).

Physical, also known as mechanical, control can be implemented using several different approaches. One method is hand pulling where seedlings and saplings are pulled from the soil by hand. Hand pulling is labor intensive so it is only effective for small areas and is not applicable for large plants. However, hand pulling has been used effectively on seedlings of some invasive species such as Japanese knotweed (*Fallopia japonica* Sieb. & Zucc.) and autumn olive (*Elaeagnus umbellata* Thunb.) (Miller et al., 2010a). Other mechanical control methods include mowing, girdling, and stem cutting. Mowing is used to reduce aboveground biomass and seed production and can effectively control some species such as Japanese Stiltgrass (*Microstegium vimineum* (Trin.) A. Camus) if done repeatedly (Flory and Lewis, 2009). Mowing can be effective for areas where the terrain allows for safe operation of mowing equipment but can be difficult and very costly on steep, uneven, rocky, or wooded areas (Beasley and Pijut, 2010). Also, since mowing does not remove the root system, asexual sprouting could occur for many species (Beasley and Pijut, 2010).

Girdling, which entails cutting the phloem and preventing translocation of assimilates to the roots, can be done any time of year but is more effective in warmer months especially late spring or early summer (Solecki, 1997). Girdling can kill the original tree but may lead to vigorous root sprouting (Solecki, 1997) in many species such as the Siberian elm (*Ulmus pumila* L.) (Beasley and Pijut, 2010). In other species, such as common buckthorn and glossy buckthorn (*Frangula alnus* P. Mill.), girdling is an effective control method (Solecki, 1997).

Stem cutting is a control method where trees, shrubs or vines are cut at ground level. Repeated stem cuttings can deplete the food reserves of the plant but this may take several years (Solecki, 1997). Despite this, frequent cuttings have been used to diminish shoot growth in species such as glossy buckthorn and Canada thistle [*Cirsium arvense* (L.) Scop.] (Beasley and Pijut, 2010). However, just as with mowing and girdling, cutting can actually intensify the problem by promoting sprouting in many species. For example, 79% of tree-of-heaven [*Ailanthus altissima* (P. Mill.) Swingle] stumps sprouted when cut and no herbicide was applied, with an average of 1.6 new sprouts for every cut stump (Burch and Zedaker, 2003). Cutting without herbicide has also been shown to cause sprouting in Amur maple (*Acer ginnala* Maxim.) and autumn olive (Beasley and Pijut, 2010).

For most invasive species, especially those that reproduce vegetatively, mechanical control methods can curtail the rate of spread but will not eradicate the species from the area. In these cases, a successful control method must kill the stem and the roots so that sprouting is prevented (Burch and Zedaker, 2003). This can be achieved through chemical control, which uses an herbicide to kill both the shoot and the roots so sprouting is prevented (Burch and Zedaker, 2003; Miller et al., 2010a). Chemical controls can be applied to the stump (cut stump treatments), bark (basal bark applications), leaves (foliar applications), or directly into the cambium (hack and squirt treatment). Additionally, certain herbicides may be applied directly to the soil to control invasive plants. Instructions on the herbicide label and local, state and federal regulations must be followed when any herbicide is applied. Appropriate safety clothing varies based on the herbicide being applied but usually consists of eye protection, long sleeve shirt and pants, rubber boots, rubber gloves, and a hat.

Cut stump herbicide applications, in which cutting woody species is followed by an immediate herbicide application, are effective on multiple invasive species such as Callery pear (*Pyrus calleryana* Dcne.), glossy buckthorn, mimosa (*Albizia julibrissin* Durazz.), and tree-of-heaven (Miller et al., 2010a). Spraying or directly wiping the targeted stump with either glyphosate or triclopyr has been proven to be effective on Japanese knotweed, black locust, and buckthorns and prevented sprouting in invasive species such as Amur maple and autumn olive (Solecki, 1997; Beasley and Pijut, 2010). Glyphosate at 20% vol/vol is reported to be effective on Chinese privet (*Ligustrum sinense* Lour.) and autumn olive (Miller et al., 2010a). Cut stump treatments are typically most effective at the end of the growing season (July to September) but can be conducted in the dormant season as well (Solecki, 1997).

In basal bark applications the herbicide is mixed with either diesel fuel or another oil based carrier instead of water and is sprayed directly on the lower 30-38 cm (12-15 in) of each trunk and on existing sprouts (Solecki, 1997). Basal bark applications have been used on tree-of-heaven, glossy buckthorn, and autumn olive (Miller et al., 2010a). A basal bark application of triclopyr applied during the dormant season is effective on common buckthorn and glossy buckthorn with a diameter at breast height (DBH) less than 15 cm (6 in) (Solecki, 1997). Basal treatments on tree-of-heaven sprayed with either Garlon 4 (Dow AgroSciences, Indianapolis, IN 46268) at 20% vol/vol or Garlon 4 at 20% vol/vol mixed with either Stalker (BASF, Florham Park, NJ 07932) at 1-9% vol/vol or Tordon K (Dow AgroSciences, Indianapolis, IN 46268) at 5% vol/vol resulted in a minimum of 79% of the treated trees dying (Burch and Zedaker, 2003). Basal bark applications can be done in cold temperatures (–15 C or 5 F) on common buckthorn but any contamination of the herbicide with water, whether it is by mixing or frost, can increase survival rates (Delanoy and Archibold, 2007). Another version of basal bark treatments is thin-line basal bark applications where a thin line of herbicide is applied around the tree trunk 15-30 cm (6-12 in) above the ground (Solecki, 1997). Thin-line basal treatments using triclopyr have also been used effectively on black locust among other species (Solecki, 1997).

During foliar treatments, herbicide is applied directly to the leaves of the plant. Complete coverage is generally required for optimal control. Foliar applications of herbicide are effective control methods for glossy buckthorn, tree-of-heaven saplings, autumn olive, and black locust (Solecki, 1997; Miller et al., 2010a).

An invasive species' natural enemies can also be used to reduce population numbers through a control method called biological control (Moore et al., 2010). The biotic agent, either an insect or a pathogen, is carefully screened for possible unintentional hosts before introduction. If safe to import, this biotic agent is used to impact the invasive species directly by causing physical damage or indirectly by reducing vigor and competitive ability. Selecting the proper biotic agent is very important. The biotic agent must come from a climate similar to where it will be introduced. Also if several biotic agents are available for a particular invasive species, selecting several agents with different methods of attack is most effective. Biological control is a tool that can be used alone or can be combined with some of the other control methods previously mentioned. Currently, there are few approved biological agents available for most invasive plants in the southeastern U.S.

Privet: An Overview

Privets are found in the Oleaceae family and the *Ligustrum* genus, which contains 40 species (Maddox et al., 2010). Privets are either shrubs or small trees and are prone to having multiple stems. The leaves are simple and opposite with entire leaf margins. Privet flowers are white and arranged in panicles on the end of branches. The fruit is a dark blue to black drupe when ripe and contains up to four seeds per drupe. The native range of privet can be found throughout Europe, Asia, Northern Africa, and even into the northern portion of Australia (Maddox et al., 2010). In the late 1700's and early to mid

1800's at least nine different privet species were imported into the United States mainly for ornamental purposes (Maddox et al., 2010) and some of them can still be bought today. Unfortunately, many of them have escaped cultivation and have invaded natural areas (Godfrey, 1988; Brown and Pezeshki, 2000; Maddox et al., 2010). Some examples of these privet species included glossy privet (*Ligustrum lucidum* W.T. Aiton**),** Japanese privet (*Ligustrum japonicum* Thunb.), European privet (*Ligustrum vulgare* L.), and Chinese privet (*Ligustrum sinense* Lour.).

Glossy privet was introduced into the U.S. in the late 1700's from China. Of the non-native privets glossy privet has the largest leaves, with a length of 5 to 15.2 cm (3 to 6 in) and a width of 5 to 10.2 cm (2 to 4 in). The flowers are arranged in 12.7 to 20 cm (5 to 8 in) long panicles and appear in the late summer. The drupes are 1.3 cm long (0.5 in).

Japanese privet, a species that is often confused with glossy privet, was introduced into the U.S. in the mid-1800's from Japan and Korea. The leaves of Japanese privet are 5.1 cm (2 in) long with slightly rolled leaf margins. Flowering occurs in the spring and the summer and the drupes are 0.5 cm (0.2 in). Japanese and glossy privet can be distinguished apart by looking at the length of the leaf (Japanese privet has shorter leaves) and the thickness of the leaf (glossy privet and has thicker leaves). Glossy privet is also is semi-evergreen and Japanese privet is evergreen.

European privet, which is sometimes confused with Chinese privet, is native to Europe. The leaves of European privet are 2.5 to 6 cm (1 to 2.4 in) long and 0.5 to 1.5 cm (0.2-0.6 in) wide and are deciduous. Flowers appear from April to June. The drupes are 1 to 1.3 cm (0.3–0.05 in) long and persist through the winter. Chinese privet will be discussed in the next section and is the focus of this thesis.

Chinese Privet: A key invader in the Southeastern United States

Chinese privet was first introduced into the southeastern United States from China in 1852 for ornamental purposes (University of Florida, 2011). Since then Chinese privet has become naturalized throughout the southeast (Maddox et al., 2010). In Florida and Georgia, Chinese privet is a Category I weed of natural areas (Georgia Exotic Pest Plant Council, 2006; University of Florida, 2011), and is ranked predominately as a Category I weed in Alabama (Alabama Invasive Plant Council, 2007).

Chinese privet is in the Oleaceae family and the *Ligustrum* genus, which contains about 40 species (Maddox et al., 2010) and is composed of evergreen and deciduous shrubs or small trees. Chinese privet is typically semi-evergreen to evergreen, but is deciduous in the northern part of its US range (Maddox et al., 2010). It can grow as a shrub or a small tree 6-10 meters (19.7-32.8 ft) tall and is prone to form multi-stemmed clumps (Godfrey, 1988; Brown and Pezeshki, 2000). Chinese privet has thin, smooth, grey bark that has pale lenticels. The half-moon shaped leaf scars are raised and contain one vascular bundle scar. Chinese privet has simple, opposite leaves that are 1.25-3.5 cm (0.5-1.4 in) in length, 1-3 cm (0.4- 1.2 in) wide and have entire leaf margins and short petioles. The small white flowers that appear between April and June are bisexual, radially symmetrical, and are clustered together in panicles located at the end of the branches. Chinese privet can sexually reproduce as early as the age of four (Klock, 2009). Fruiting on Chinese privet was observed on plants as short as 1 to 1.5 m (3.3 to 4.9 ft) tall and in saplings that were less than 3 cm (1.2 in) in diameter (Kittell, 2001; Grove and Clarkson, 2005). The fruit appears around July in dense clusters of 4 to 5 mm (0.15 to 0.2

in) globose drupes, with each drupe containing 1-4 viable seeds (Maddox et al., 2010). When first produced, the drupes are green but then ripen to a dark blue or black color. Overwintering fruit provides a food source for birds and bird-dispersal is a significant method of long distance seed dispersal. Chinese privet has a low germination rate with reports ranging from 5-25% germination (Grove and Clarkson, 2005; Klock, 2009; Maddox et al., 2010). The seed bank is short-lived, as most seeds remain viable for only 6 to 12 months (Grove and Clarkson, 2005). However, Chinese privet produces a large amount of seed, often with 172- 6,879 seeds per plant depending on the size of the Chinese privet plant (Kittell, 2001; Klock, 2009). Chinese privet can also reproduce vegetatively by buds on the root collar and by lateral root sprouts.

Privet can be found in disturbed areas, along right-of-ways and fencerows, on forest edges, and under forest canopy (Maddox et al., 2010). Privet can also tolerate a wide range of soil moisture and fertility conditions (Wilcox and Beck, 2007). Chinese privet seedlings can invade both disturbed and undisturbed sites but grow faster in disturbed, open areas with high light environments (Grove and Clarkson, 2005). However, Chinese privet can grow in a wide range of light conditions from areas with a PAR (photosynthetic active radiation) of 5 to 10% to areas with full sun (Brown and Pezeshki, 2000; Merriam and Feil, 2002; Wilcox and Beck, 2007), and seedlings can establish under forest canopy conditions (Harrington and Miller, 2005). Although seedling growth is reduced under shade, the growth rate is still fast enough to allow privet to displace native plants and populate the area (Grove and Clarkson, 2005; Wilcox and Beck, 2007). At sites located in Georgia, low levels of Chinese privet (1 to 2 privet stems per 1 m^2) were negatively correlated with species richness, and higher concentrations of

Chinese privet, exhibited by a dense shrub layer, were correlated with a 40% reduction in plant richness (Loewenstein and Loewenstein, 2005; Brantley, 2008). At sites located in Georgia, an understory composed of just 40% Chinese privet will suppress native plant regeneration to below 50% (Brantley, 2008). This may gradually exhaust the native seed bank (Merriam and Feil, 2002).

Chinese privet seedlings can prevail under a Chinese privet overstory whereas most native species cannot (Grove and Clarkson, 2005). However, Chinese privet growing under a privet canopy produces smaller fruit than Chinese privet growing under a canopy composed of native trees (Grove and Clarkson, 2005). Sites located in North Carolina that were infested with privet had 33% to 42% fewer herbaceous species and 25% to 50% fewer tree species than non-infested areas, depending on the season of measurement (Merriam and Feil, 2002). Repeated depletion of the native seed bank combined with the competitive nature of Chinese privet can lead to near monotypic stands in less than 15 years after a disturbance (Grove and Clarkson, 2005) with only vines and Chinese privet root sprouts persisting under mature Chinese privet (Merriam and Feil, 2002).

When native plants are lacking in the forest understory, many insects will be missing as well (Ulyshen et al., 2010). In Georgia, fewer insect species were found in areas with Chinese privet than areas where Chinese privet had been removed (Ulyshen et al., 2010). Removal of Chinese privet in a Georgia forest increased beetle diversity at ground level but had no effect on beetle diversity in the forest canopy 15 meters (49.2 ft) above the ground (Ulyshen et al., 2010). Also, since Chinese privet is prone to forming dense thickets (Maddox et al., 2010) that may harbor deer ticks (*Ixodes scapularis* Say), Lyme disease could become a problem and cause increased human health problems (Goddard, 1992).

Chinese privet can be utilized by some wildlife species. For example, the white-footed mouse (*Peromyscus leucopus* Rafinesque), golden mouse (*Ochrotomys nuttalli* Harlan), and the short-tailed shrew (*Blarina brevicauda* Say) use Chinese privet for either forage, cover, or nesting sites and more small mammals were seen in forested areas with a large amount of Chinese privet compared to forested areas with little to no privet (Kittell, 2001). However, Chinese privet berries composed only a small component of the diet for the white-footed mouse and the golden mouse (O'Malley et al., 2003). White-tailed deer (*Odocoileus virginianus* Zimmermann) use Chinese privet as a food source in years when acorn consumption is low, with 11-13% of the deer's diet composed of Chinese privet leaves and fruit (Stromayer et al., 1998). Browsing on Chinese privet provides enough crude protein for white-tailed deer to survive the winter and, since Chinese privet tends to grow in thickets, privet reduces forage time (Stromayer et al., 1998). Browsing by white-tailed deer can actually stimulate growth of Chinese privet. Chinese privet that was heavily browsed (≥ 60%) in winter had 4-6 times more regrowth in the spring than plants that were not browsed (Stromayer et al., 1998). Carolina wrens (*Thryothorus ludovicianus* Latham), eastern towhees (*Pipilo erythrophthalmus* Linnaeus), and woodcock (*Scolopax minor* Gmelin) have been reported to inhabit Chinese privet thickets (Kittell, 2001) and Chinese privet provides nesting habitat and security for songbirds migrating in the fall (Wilcox and Beck, 2007). However, in one study conducted in Decatur, Georgia, privet density did not influence the number of bird species nor the total amount visiting the area except in the winter where more birds were found in heavily infested areas, possibly for foraging reasons (Wilcox and Beck, 2007). Even though utilized by bird populations, Chinese privet was not needed to retain songbird populations and removal should be considered since bird populations can spread seed to uninfested areas (Wilcox and Beck, 2007). Despite these examples of wildlife uses, Chinese privet causes an overall decrease in wildlife habitat and biodiversity (Merriam and Feil, 2002; Loewenstein and Loewenstein, 2005; Brantley, 2008) potentially harming more species than are benefited.

Preventive control methods include educating the public about the problems caused by Chinese privet and refraining from selling and planting it (Maddox et al., 2010). For instance in Florida, one of the states where Chinese privet is naturalized and considered a Category I weed, only 8.8% of the nurseries surveyed sold Chinese privet and it comprised less than 1% of the industry’s estimated total sales (Wirth et al., 2004), indicating that a reduction in Chinese privet sales would not be a large financial burden to the industry.

Currently there are no biological agents for Chinese privet control (Maddox et al., 2010). However, *Leptoypha hospita* Drake et Poor, an insect from China, has shown promise as a possible biological control agent (Zhang et al., 2011). Also, the Emerald ash borer (*Agrilus planipennis* Fairmaire) was found to eat Chinese privet in laboratory experiments but currently there is no evidence to suggest that this is occurring in the wild (Anulewicz et al., 2006). Furthermore, the negative impact of the Emerald ash borer on native *Fraxinus* spp. in the US would far outweigh any benefit from damage to Chinese privet.

Several other control methods, such as mechanical control, can be used on Chinese privet. For example, privet seedlings can be hand-pulled (Maddox et al., 2010). Prescribed burns can kill stems if there is sufficient fuel to carry a fire. However, this can lead to prolific sprouting which requires follow-up foliar treatments of 3% glyphosate for good control (Faulkner et al., 1989; Miller et al., 2010a). Also, fire has difficulty spreading in dense privet thickets and the thicket itself acts as an “umbrella," preventing a fuel litter layer from neighboring trees to become established under the privet thicket (Faulkner et al., 1989).

Privet thickets can be mechanically removed through mulching; however, mulching was ineffective at preventing the formation of a privet understory through privet seedlings and sprouts (Hanula et al., 2009). Also, privet seeds can germinate in wet mulch so birds could possibly reestablish privet into the area (Maddox et al., 2010). Flooding of Chinese privet for short periods of time resulted in reduced root and shoot biomass, increased development of the aerenchyma tissue in the roots, formation of lenticels on the stem, and greater formation of adventitious roots than plants that were not flooded, however, provided ineffective control (Brown and Pezeshki, 2000). When Chinese privet seeds were flooded, 64% of the seeds in shallow water and 89% of the seeds in deep water survived for over 81 days (Brown and Pezeshki, 2000).

Chemical control through the use of herbicides is also effective on Chinese privet. Control options include cut stump treatments, basal applications, and foliar applications (Hanula et al., 2009). Cut stump treatments resulted in more non-privet cover than untreated areas and resulted in the establishment of native plant communities (Hanula et al., 2009). With foliar treatments, a wide array of rates of glyphosate or triclopyr can be used without influencing effectiveness of control (Harrington and Miller, 2005). However, timing of foliar applications was important, with spring applications being more effective than fall or summer applications (Harrington and Miller, 2005).

While cut stump and basal treatments are recognized methods to effectively control Chinese privet (Miller et al., 2010a), both methods need to be refined to determine the most effective rates and timings of herbicide application. For example, little is known about stump diameter size in relation to herbicide efficacy. Will larger stumps require several follow-up treatments? Are glyphosate and triclopyr equally effective? Also, since timing was important with foliar applications (Harrington and Miller, 2005), does timing influence the efficacy of cut stump and basal bark treatment methods? Lastly, Harrington and Miller (2005) showed that a range of herbicide rates is effective for foliar applications. Is this also the case for basal applications? Can a lower herbicide rate be as effective as the higher rate and does a ready-to-use herbicide product reduce the herbicide efficacy? These questions will be explored in subsequent chapters.

Research Questions

This thesis focuses on two control methods (cut stump and basal bark applications) commonly used to control Chinese privet. The cut stump chapter aims to answer the questions: 1) Does stem size influence herbicide efficacy; 2) Does season of treatment influence herbicide efficacy; and 3) Is there differential performance between two commonly prescribed herbicides (glyphosate and triclopyr)? With the basal bark chapter, the following questions were answered: 1) Is there a difference in efficacy between Garlon 4 at 20% vol/vol and Pathfinder II; 2) Can lower rates of triclopyr provide effective Chinese privet control; 3) Does application time impact herbicide efficacy; and 4) Do basal bark applications provide effective Chinese privet control across a wide range of root collar diameters?

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CUT STUMP APPLICATION

Abstract

Since its introduction to the United States in 1852 for ornamental purposes, Chinese privet (*Ligustrum sinense* Lour.) has spread throughout the Southeast, invading roadsides, rights of ways, and forest edges and interiors. Manual control by cutting is one of the most common strategies many landowners initially employ. However, rapid sprouting from the root collar and some lateral roots results in treatment failure. Cutting followed by either a glyphosate or triclopyr application to the stumps is reported to be effective. However, the efficacy of these herbicides in relation to treatment timing and privet size has not been explored. The goal of this experiment was to determine the effectiveness of glyphosate and triclopyr cut stump treatments compared to cutting alone at spring (April) and fall (November) timings across a range of privet size classes. A completely randomized experiment with approximately 50 privet stems per treatment was conducted in Auburn, Alabama at two sites heavily infested with privet. Treatments were an untreated cut stump control, cut stump + glyphosate (120 g/L), or cut stump + triclopyr (90 g/L); root collar diameter was recorded for each stem, stems were cut 2.5 cm above the ground, and herbicide treatments were applied within 30 seconds of cutting. Treatment efficacy and Chinese privet sprouting were quantified 6, 12 and 18 months after treatment (MAT). Both herbicides and timings were effective, however, glyphosate provided slightly better results than triclopyr and the fall timing had a lower percentage

of sprouting plantsthan the spring timing. Root collar diameter was significantly correlated with lateral sprout length only at 18 MAT for the spring timing and did not have an effect on the November timing.

Introduction

Chinese privet is an invasive shrub infesting roadsides, rights of ways, wild lands, and forested areas throughout the southeastern United States (Maddox et al., 2010). Native to China, Chinese privet was first introduced into the southeastern region of the United States in 1852 for ornamental purposes (Dirr, 1998). Its growth form and its semi-evergreen to evergreen nature made it conducive for hedgerowing and other ornamental purposes. Over time Chinese privet escaped cultivation and began to spread to nearby natural areas, with animals, especially birds, consuming the drupes and dispersing the seed through excrement. Once established, Chinese privet can also spread vegetatively by lateral root sprouts, although this has not been well studied. If left unchecked, Chinese privet can dominate the forest understory, inhibiting woody native plant regeneration (Loewenstein & Loewenstein, 2005; Brantley, 2008) and the formation of an herbaceous layer (Merriam and Feil, 2002; Greene and Blossey, 2012), thereby reducing native plant diversity. While the long-term dynamics of Chinese privet invasion are still unclear, loss of native woody plant recruitment along with reduced light to the herbaceous layer, could convert many riparian areas to a Chinese privet shrub-dominated system over time.

To address the privet problem, many homeowners and land managers alike have opted to aggressively manage Chinese privet with multiple physical methods (e.g., hand pulling of seedlings, mulching, or cutting) providing immediate removal. However, physical methods can be costly, labor intensive, (Smith et al., 1997) and ineffective for long-term control due to stump and root sprouting. Klepac et al. (2007) calculated that a mechanical treatment utilizing a 110-horsepower-engine mulching machine cost around $317 per acre. Batcher (2000) commented that cutting and mowing could control a small population of Chinese privet but would not eradicate it and would need to be repeated on an annual basis.

Sprouting in woody plants usually from suppressed buds immediately below the point of damage on the stem or roots, is typically a response to injury and results in the production of secondary trunks (Del Tredici, 2001). Sprouting has been observed on many woody invasive plants such as tree-of-heaven [*Ailanthus altissima* (P. Mill.) Swingle] where cutting alone resulted in over 5,000 stems per acre and greatly increased stand density (Burch and Zedaker, 2003). Cutting alone may not be an adequate method of control for species with the ability to sprout and may actually lead to an increase in the number of stems (Burch and Zedaker, 2003; Sands and Abrams, 2009).

Del Tredici, (2001) likened a tree's ability to sprout as an insurance policy where the tree invests resources in a manner that improves survival after disturbance. A plant's ability to survive a cutting through sprouting is supported in the literature (Burch and Zedaker, 2003; DiTomaso and Kyser, 2007; Mwavu and Witkowski, 2008; Sands and Abrams, 2009). Factors of the stump, such as stump height and stump diameter, can influence the number and vigor of the sprouts produced (Mwavu and Witkowski, 2008; Sands and Abrams, 2009). For example, stumps with a diameter between 5 and 15 cm (2-6 in) produced vigorous sprouts while stumps as large as 25-30 cm (10-12 in) also produced vigorous sprouts but in lesser amounts (Del Tredici, 2001; Mwavu and

Witkowski, 2008; Sands and Abrams, 2009). The increase in sprouts for stumps between 5-15 cm (2-6 in) could be attributed to the benefits of a large, established root system associated with full grown trees without the reduction in vigor found in trees with larger diameters (Kays and Canham, 1991) while the decline in sprouts at 25-30 cm (10-12 in) could be attributed to the thicker bark associated with mature trees, negatively impacting the tree's ability to sprout (Smith et al., 1997). Regardless, the published literature clearly supports a correlation between stump size and number of sprouts for many species.

When dealing with species that can sprout, both the stems and roots must be killed for successful control (Burch and Zedaker, 2003). A year after cutting without an herbicide application resulted in Chinese privet sprouts large enough to be treated by a foliar spray (Harrington and Miller, 2005). A foliar application after cutting is a viable control option for the present sprouts, however, it may not prevent future sprouting from cut stumps (De Steven et al., 2006). Cutting followed by an immediate application of herbicide to the stump (also known as cut stump treatment or a cut and treat application), can prevent future sprouting in many woody and invasive species (Hartman and McCarthy, 2004; Miller, 2007). While the cut stump application technique is a recommended method of control for Chinese privet (Miller, 2007), its effectiveness on Chinese privet has not been well studied.

Herbicide mode of action and formulation may affect the efficacy of cut stump applications. For example, Gale (2000) noted that European buckthorn (*Rhamnus cathartica* L.) stumps sprayed with triclopyr had less regrowth than stumps sprayed with glyphosate. Triclopyr and glyphosate can also be used in cut stump applications on Chinese privet (Miller, 2007). Triclopyr mimics auxin, a hormone responsible for controlling plant growth, resulting in unrestrained growth and eventual plant death. Triclopyr has two formulations, a triethyamine salt and a butoxyethyl ester formulation, that differ in factors such as water solubility and volatilization and thus behave differently, possibly influencing control results. Garlon 3A (Dow AgroSciences, Indianapolis, IN 46268), a herbicide with triclopyr as the active ingredient, is used in right of ways and forested areas for either cut stump or foliar applications (Evans et al., 2006). Glyphosate is non-selective and hinders the production of proteins by affecting 5-enolpyruvylshikimate-3-phosphate (EPSP) synthase, an enzyme needed for the production of three aromatic amino acids. Preventing the formation of aromatic amino acids prevents protein synthesis, thereby halting plant growth and causing tissue decay. At sites located near Athens, Georgia, Harrington and Miller (2005) found that glyphosate was more effective than triclopyr when applied as a foliar spray to Chinese privet, suggesting the possibility that the type of herbicide could influence control for cut stump applications as well.

The season of cutting can also influence sprout growth for up to 2 years after cutting (Kays and Canham, 1991). When the herbicide is applied, also known as the timing of application, can also impact the effectiveness of control. At plots located in Virginia, Roth and Hepting (1969) noticed an increase in sprout number and vigor from 30.5 cm (12 in) oak stumps cut during the dormant season. In contrast, Delanoy and Archibold (2007) stated that the best time to treat European buckthorn was in the fall. Evans et al. (2006) also tended to favor a fall application, suggesting cut stump treatments with triclopyr should be avoided in the spring during sap flow. These examples show that timing can affect control but provide conflicting information as to the best time for herbicide application.

This experiment aims to answer the following questions regarding cut stump treatments for Chinese privet control: 1) Does root collar diameter influence herbicide efficacy; 2) Does season of treatment influence herbicide efficacy; and 3) Is there differential performance between two commonly prescribed herbicides (glyphosate and triclopyr)? Answering these questions would greatly benefit land managers who are using cut stump herbicide treatments for Chinese privet control, fill a void in research in this area, and provide valuable insight into the importance of herbicide application, especially for large diameter privet shrubs.

Materials and Methods

The study was conducted at two locations on Auburn University property in Auburn, Alabama. The first site is a hardwood forest located at Auburn University's Swine Unit Research and Education facility (32° 35' 1.32" N, 85° 30' 12.61" W). The forest is adjacent to a pasture and is predominately composed of Chinese privet (*Ligustrum sinense* Lour.) trees approximately 6 m (20ft) tall. Other tree species present include hackberry (*Celtis laevigata* Willd.), mockernut hickory [*Carya tomentosa* (Lam.) Nutt] and blackjack oak (*Quercus marilandica* Münchh.). Other non-native species found on the property include nandina (*Nandina domestica* Thunb.), Chinaberry *(Melia azedarach* L.), and Chinese tallowtree [*Triadica sebifera* (L.) Small]. The soil series is a mixture of Pacolet sandy loam with a 6 to 10% slope and Marvyn loamy sand with 1 to 6 % slope. This site will be referred to as the SWU site.

The second site is a forest located next to Auburn University's intramural fields (32° 35' 46.06" N, 85° 29' 44.23" W) with a small stream along two of the boundaries. This forest has a water oak (*Quercus nigra* L.) and loblolly pine (*Pinus taeda* L.) overstory with sweetgum (*Liquidambar styraciflua* L.), eastern red cedar (*Juniperus virginiana* L.), mimosa (*Albizia julibrissin* Durazz.), and Chinaberry as other overstory components. The midstory was dominated by Chinese privet approximately 6 m (20 ft.) tall and other invasive species including kudzu [*Pueraria montana var. lobata* (Willd.) Maesen & S. Almeida], nandina, and English ivy (*Hedera helix* L.) were found in the understory. Carolina laurel cherry (*Prunus caroliniana* Aiton) was also present in the midstory. The soil series is a Kinston silt loam with a 0 to 1% slope. This site will be referred to as the IMF site.

A completely randomized experimental design (CRD) was used with individual Chinese privet stumps as experimental units. A wood caliper was used to measure the root collar diameter of each Chinese privet shrub. The stem was then cut using a chainsaw (Husqvarna 123HD60, Husqvarna, Charlotte, NC 28269) leaving a flat 2.5 cm (1 in) high stump. Treatments were applied within 30 seconds using an Echo MS-4 backpack sprayer for the April timing and a 1.5L Garden Plus pressurized hand sprayer with an adjustable cone nozzle for the November timing. To ensure adequate coverage, the entire surface of each stump was sprayed to wet but not to the point of runoff. The amount of herbicide applied was dependent on the size of the stump.

The treatment design was a 3 x 2 x 2 x 3 factorial of treatment by timing (April and November) by site (IMF and SWU) by month after treatment (MAT = 6, 12, 18). There was a minimum of 50 replicates (stumps) per treatment by site by timing combination.

Treatments were randomly assigned to stumps and consisted of glyphosate (Accord Concentrate, Dow AgroSciences, Indianapolis, IN 46268) at 25% vol/vol, an amine formulation of triclopyr (Garlon 3A, Dow AgroSciences, Indianapolis, IN 46268) at 25% vol/vol, and an untreated control. The acid equivalent for glyphosate was 120 g L^{-1} (1 lb gal^{-1}). The acid equivalent for triclopyr was 90 g L^{-1} (0.75 lb gal^{-1}). Both herbicides were mixed with water and a non-ionic surfactant (Timberland 90, Loveland Products, Loveland, CO 80538) was added to each herbicide at 0.5% vol/vol. Separate backpack sprayers and separate spray bottles were used for each herbicide treatment.

Stems at the SWU site were cut and sprayed on April 16, 2008 and the IMF site was cut and sprayed on April 10, 2008. Temperatures for April 16 ranged from a low of 3 C (37 F) to a high of 22 C (72 F) (Table 1). Temperatures for April 10 ranged from a low of 16 C (61 F) to a high of 26 C (79 F). The average high temperature for April 2008 was 23 C (74 F) and the average low was 12 C (53 F). The second treatment timing at the SWU site was carried out on November 19, and November 21, 2008 and the IMF site was treated on November 18 and 19, 2008. The high temperatures for these dates were 11 C (52 F), 8 C (46 F), and 8 C (46 F) respectively. The lows were -2 C (28 F), -2 C (28 F), and 1 C (30 F) respectively. The average high temperature for November 2008 was 18 C (64 F) and the average low was 6 C (42 F). Detailed monthly temperature and precipitation information is shown in Table 1.

According to US Climate Data, average monthly highs in Auburn range from 12.8 C (55 F) in January to 32.2 C (90 F) in July with an average annual high temperature of 23.3 C (74 F). The average low temperature ranges from 1.1 C (34 F) in January to 21.1 C (70 F) in July with an annual average low of 11.6 C (52.8 F) and an overall average annual temperature of 17.4 C (63.4 F). Average monthly precipitation varies, ranging from 69 mm (2.72 in) in October to 165 mm (6.5 in) in March with average annual precipitation of 1336 mm (52.6 in).

The total number and height of stump sprouts, lateral root sprouts within 30 cm of a treated stump, and a combined total were recorded 6, 12, and 18 months after treatment (MAT). Height of stump and lateral root sprouts were summed separately for a total length for each sprout type. The total stump sprout length and the total lateral root sprout length were also combined to calculate a total sprout length for each stump.

Response data (length of stump and lateral sprouts, and the combined total sprouting length at 6, 12, and 18 MAT) were analyzed using linear mixed model methodology as implemented in SAS® PROC GLIMMIX. Site, treatment, timing, MAT, and their respective interactions were considered fixed effects. The sole random effect was stumps within site by treatment by timing.

Based on the biology of this invasive species we anticipated that the root-collar diameter would influence the response to treatments, expecting that larger plants would be able to mobilize greater reserves for regrowth after treatment. Univariate analysis indicated that root-collar diameter values were right-skewed and best modeled using log-transformed values. Hence log-transformed root-collar diameter was used as a covariate in the analysis of stump data. The best-fitting covariate model had separate slopes for each site by timing by MAT combination, somewhat complicating treatment comparisons. Unlike the case for a single covariate slope or parallel slopes, treatment differences in the unequal slope situation depend on the value of the covariate. Based on the suggestion by Littell et al. (2002) we compared treatment means at the mean of the covariate using the AT MEANS option within the LSMEANS command in PROC GLIMMIX.

Even before statistical analysis, it was clear that both herbicide treatments (glyphosate and triclopyr) were highly effective compared to cutting alone (control). Greater than 80% of the herbicide treated stumps had no regrowth compared to the control treatment where fewer than 27% of stumps had no regrowth. Thus non-homogeneous treatment variances were a concern. The initial overall analysis as conducted using the group option in SAS PROC GLIMMIX created separate variance groups for treated and control treatments.

Additionally, separate analyses were conducted for the controls and for the treated stumps (glyphosate or triclopyr). For the controls the effect of site, timing, MAT, and their interactions was analyzed. For each set of data, lateral sprout length, stump sprout length, and the total sprouting length (stump and lateral combined) were analyzed. Because the experiment has a repeated nature (i.e., measurements were taken 6, 12, and 18 MAT on the same experimental unit, the stump, over a period of 18 months) the residual variance structure was modeled to arrive at a reasonable covariance relationship (R-side modeling in SAS parlance). The criteria used for selection of an appropriate covariance structure were a low value for the corrected Akaike's information criterion (AICC) and a reasonable standard error for calculated means.

The best fitting model for the control's total sprouting length was one where the GROUP = timing option was used to account for the heterogeneity of the G matrix and an ARH (1) structure for the residual covariance. For stump length the G matrix was also by timing but an AR (1) residual covariance provided the best fit. For lateral sprouting length the best fit was a G matrix grouped by site and AR (1) residual variance structure.

For the treated stumps, the treatment (glyphosate or triclopyr) and its interaction with other fixed effects were additional sources of variation. For all three response variables the best fitting model included experimental error grouped by site x treatment. The best residual structures were CS for total and lateral sprouting length, whereas AR (1) provided the best fit for stump regrowth.

In this experiment there was an a priori assumption that interactions should be an important source of variation; hence we considered interactions important when $P \leq 0.10$. Interaction least squares means were generated and simple effects means compared using the SLICEDIFF option of the LSMEANS statement of PROC GLIMMIX. The simulation option ($\alpha = 0.10$) was used to adjust the Type 1 error rate for multiple comparisons.

It is also important to consider the number of plants that sprout, or the sprouting frequency, since a sprouted plant, regardless of sprout length, has the ability to develop into a fully mature plant, whereas a dead stump does not. The number of stumps that produced sprouts (either stump, lateral root sprouts, or both) was divided by the total number of treated stumps in that treatment x site x timing x MAT combination and displayed as a percentage (sprouting frequency). Data were analyzed using generalized linear model methodology implemented in SAS® PROC GLIMMIX with a binary distribution function and logit as the natural link function. Because the residual has no inherent meaning for the binary distribution function, R-side modeling as done for normally distributed data is not possible. The covariance structure for the repeated portion of the model was modeled on the design side (G-side).

Results

A higher percentage of the control stumps produced sprouts than either the glyphosate or triclopyr treated stumps (Table 2). For the herbicide treatments, the highest percentage of sprouting plants (16%) was observed at 18 MAT for triclopyr at the IMF site, whereas the lowest total sprouting percentage for the untreated control plants was 74% at 12 MAT at the SWU location.

The percentage of herbicide-treated stumps that produced stump sprouts was minimal throughout the 18-month measurement period, with a maximum of 4% of glyphosate-treated stumps sprouting at 12 MAT at the IMF site (Table 2). In fact, initiation of new stump sprouts on glyphosate-treated plants was observed only at the IMF site on plants treated in April. The triclopyr treatment almost completely eliminated stump sprouts as only 1 plant out of 50 (2%) had stump sprouts 18 MAT at the IMF site and no stumps sprouted at the SWU unit.

Shallow lateral roots of herbicide treated plants, however, sprouted more frequently than the stumps. Eight out of 50 (16%) of stumps treated with triclopyr in April at the IMF site had sprouts 18 MAT. Looking at the 18 MAT data overall, a higher percentage (2-8% more) of triclopyr treated stumps had lateral root sprouts than glyphosate-treated stumps.

There was no overlap in the sprouting length when control and herbicide treated plants were compared, with the minimum observed control response was always at least twice the maximum response observed for the herbicide treatments (Table 3). The minimum value of total sprouting length (88 cm or 34.6 in) of the controls was well above the maximum total sprouting length for either glyphosate or triclopyr treated plants (14 cm (5.5 in) and 23 cm (9 in) respectively). Since the herbicide treatments were extremely effective regardless of timing or type of herbicide used, controls were analyzed separately from treated stumps.

Cutting without an herbicide treatment is utilized frequently in vegetation control through cutting along roadsides, utility right of ways, and in forested areas. It is therefore of interest how root collar size, timing, location, and time since cutting (MAT) might affect sprouting without subsequent herbicide treatment. A univariate analysis of initial diameter indicated that the values followed a lognormal rather than a normal distribution; hence log-transformed diameter was used as a covariate in the analysis.

The regression for the covariate showed that initial root collar diameter had a significant effect on stump, lateral, and total sprout length for the control stumps ($P \leq 0.0001$). ANCOVA regression estimates using log (initial root collar diameter) as a covariate showed that initial root collar diameter significantly affected total and stump sprout length at all Site x Timing x MAT combinations except for 6 MAT stumps cut in November (Table 4). Results for lateral root sprouting were not quite as clear-cut. In addition to non-significant *P*-values for 6 MAT for the November timing, as was the case with the total and stump sprouts, the lateral sprouts also exhibited non-significant *P*-values for 6 and 12 MAT measured at the SWU site for the April timing. Nonetheless, the slope estimates for lateral sprouts measured 18 MAT were always significant ($P < 0.06$) showing that root collar diameter had a significant effect on lateral sprout length at 18 MAT at all sites and timings, with larger stumps producing longer sprouts.

There were clear trends in slope estimates for total and stump sprout lengths. With increasing MAT the covariate effect became more pronounced implying that stumps with a larger initial root collar diameter will have more growth over time than stumps with a smaller diameter. Again, the situation for sprouting from laterals was not quite as clear-cut but it fits the general trend of a positive relationship between the covariate effect and MAT.

Since root collar diameter could influence sprout length (Kays and Canham, 1991; Mwavu and Witkowski, 2008), treatment means were compared at the mean of the covariate (mean initial diameter of 4.1 cm or 1.6 in) using the AT MEANS option within the LSMEANS command in PROC GLIMMIX (Littell et al., 2002). The interaction between site and MAT for cut stump controls at a mean root collar diameter of 4.1 cm (1.6 in) was significant for stump ($P = 0.043$) and total ($P = 0.076$) sprout lengths but not for lateral sprout length ($P = 0.204$). As expected, the average sprout length increased with increasing MAT (Table 5). Pairwise comparisons among MAT indicated that each additional 6 months after treatment increased stump and lateral sprout length significantly ($P \leq 0.0432$) except for lateral sprouts at the IMF site between 12 and 18 MAT. The information gleaned from the site and MAT interaction clearly demonstrates the impact of time elapsed since plants were cut on sprout growth at both sites.

Generally, initial root collar diameter had little effect on the sprout length of herbicide-treated stumps (Table 6); exceptions were lateral sprouting 18 MAT for the April treatment timing at the IMF site and 12 and 18 MAT at the SWU site. Different trends for the effect of initial root collar diameter were seen based on the type of sprout (stump or lateral) and MAT regardless of timing. The total and lateral sprout length followed the same pattern as the controls with the covariate effect (initial root collar diameter) becoming more pronounced with increasing MAT except for a sharp decrease for the 18 month data collected for stumps treated in November at the SWU site. Generally there was no change in the covariate effect for the stump sprouts.

Since in some cases the initial root collar diameter did impact sprout length, the interaction between treatment and MAT was analyzed at a mean initial stump diameter of 4.4 cm or 1.7 in. (Table 7). In general, triclopyr-treated stumps had longer lateral sprouts than glyphosate-treated stumps with the difference becoming larger with increasing MAT. For example, for lateral sprouts at 18 MAT, sprouts originating from triclopyr-treated stumps were 20 times longer than glyphosate-treated stumps. However, as indicated earlier, both glyphosate and triclopyr treated stumps had much shorter sprouts than the controls. Time after treatment (MAT) did not impact the length of stump sprouts since no significant differences were found when the two herbicides (glyphosate and triclopyr) were compared. In general, the average sprout length was more dependent on origin of the sprout (stump or lateral root) rather than on the MAT. In contrast, the sprout length of untreated controls increased with MAT.

In terms of control, the percentage of plants exhibiting sprouts (Fig.1) can be just as concerning as the average sprout length. There was no significant difference between the two herbicides in the percentage of stumps that sprouted when the plants were cut and sprayed in April but there was a significant difference between herbicides for plants that were cut and sprayed in November, with triclopyr having a higher percentage of stumps with lateral root sprouts. Also, more stumps sprouted after the April timing than the November timing.

For herbicide-treated stumps, the percentage of plants sprouting per measurement period (MAT) was analyzed to reveal that MAT was significant for both total and lateral sprouts with an increase in the percentage of stumps sprouting as MAT increased (Fig. 2). The difference in the percentage of herbicide-treated stumps that sprouted at 6 MAT and those that sprouted at 18 MAT was also found to be significant for both the total and lateral root sprouts. This shows the impact of time after treatment on the percentage of sprouting stumps.

Of the herbicide-treated stumps measured at 18 MAT, a total of 42 plants out of 400 (10.5%) had measurable sprouting, mostly from lateral roots (Fig. 3). About 50% had a total sprout length ≤ 50 cm (19.7 in) and about 10% had a total sprout length > 250 cm (98.4in). Analysis of sprout length based solely on the stumps that had sprouted revealed that none of the treatment factors and their interactions were significant ($P > 0.2311$; data not shown). There also was no relationship with initial root collar diameter.

Discussion

Stem size did not affect herbicide efficacy for control of stump sprouts but did significantly influence lateral sprout length at 18 MAT for the April timing. Since stump sprout length contributed minimally or not at all to the total sprout length, the root collar's influence is attributed to the lateral root sprouts rather than stump sprouts. To see the affect root collar diameter has on herbicide efficacy it is important to compare the response of the herbicide-treated stumps to that of the controls to see what would have happened if herbicide had not been applied. For the untreated controls, a significant positive correlation between stem size and stump, lateral root, and total sprout length was observed. When comparing total sprout length, the covariate (root collar diameter) effect on the controls increased at a much higher rate (at least 61 times greater) as MAT increased than the treated stumps. Without herbicide, larger stumps produce more growth. The difference between treated and untreated stems demonstrates what a large impact the herbicide treatments had on effectively controlling sprouting.

Similar to reports of Del Tredici (2001) and the findings of Sands and Abrams (2009), the untreated controls responded to cutting by initiating vigorous stump sprouts. Our findings that larger stumps produce more growth supports ideas by Del Tredici (2001) and Mwavu and Witkowski (2008) that stump size influences the number and vigor of the sprouts produced. The sprout growth in this experiment was attributed to longer sprout lengths rather than numerous short sprouts, supporting Del Tredici's (2001) idea that large stumps produced vigorous sprouts but in smaller amounts. Mwavu and Witkowski (2008) also showed that stumps with fewer sprouts would produce longer total length than stumps with numerous sprouts.

Regardless of length or number, if left uncontrolled, these sprouts would likely re-infest the treated area. Though little research is available on cut stump applications for Chinese privet, this control method has been studied for multiple other invasive species such as tree-of-heaven, princesstree [*Paulownia tomentosa* (Thunb.) Sieb. & Zucc. ex Steud.], Chinese tallowtree, autumn-olive [*Elaeagnus umbellata* Thunb.], Oriental bittersweet (*Celastrus orbiculatus* Thunb.), European buckthorn, and Japanese honeysuckle (*Lonicera japonica* Thunb.) (Evans et al., 2006; Delanoy and Archibold, 2007). When dealing with species that reproduce vegetatively, one strategy for preventing re-infestation is to control new sprouts following the initial control method

(Bowker and Stringer, 2011), which requires the death of the roots (Burch and Zedaker, 2003). The need to prevent sprouting through herbicide usage or another method of killing the roots was demonstrated by the high number of sprouts from the untreated controls in this experiment. Similarly, in a study with tree-of-heaven and cutting alone, 79% of the stumps sprouted, resulting in an increase of 1.6 new sprouts for every stem cut (Burch and Zedaker, 2003). In this experiment, the untreated controls averaged 8.7 new sprouts per stump 18 months after cutting. Sprouting of both Chinese privet in this experiment and sprouting in tree-of-heaven (Meloche and Murphy, 2006) was greatly reduced when an herbicide was applied to the cut stumps.

Sprouting can be a problem for both native and non-native species since vigorous stump sprouts that were allowed to persist can eventually grow into the canopy (Kleim et al., 2006). The mere act of cutting can stimulate the formation of root sprouts in species such as American beech (*Fagus grandifolia* Ehrh.) (Kochenderfer et al., 2006) and Oriental bittersweet (Dreyer, 1994). Stimulated sprouting, combined with the effect of root collar diameter on sprout length, supports the findings of Burch and Zedaker (2003) and Sands and Abrams (2009) that cutting alone is not an adequate form of control. Cut stump treatment on American beech using a 54% solution of glyphosate, resulted in no stump sprouts and a large decrease in the number of beech root sprouts, especially as stump diameter increased (Kochenderfer et al., 2006).

Due to the initiation of new sprouts over time, visual checks of privet should be conducted for at least 1.5 years following herbicide application to ensure the effectiveness of control. Land managers should check for stump sprouts and also carefully check for lateral sprouts that may be overlooked. These sprouts have the potential to become separate plants with time. Follow-up treatments increase the effectiveness of control (Delanoy and Archibold, 2007) and should be applied to existing sprouts and emerging seedlings in the form of foliar treatments for at least 1.5 years after initial treatment. However, if cutting alone was the initial control method (e.g., untreated controls) then 1.5 years is too long to wait for a follow-up application due to the copious numbers of long sprouts making foliar applications more difficult. In this case, foliar treatments to sprouts and emerging seedlings should be applied between 6 and 12 months after cutting.

Effect of stem size on sprout length for the untreated control was significant regardless of when the stumps were cut (spring vs. fall). For the herbicide-treated stumps, however, stem size of stumps treated in November was not significantly correlated with lateral root sprout length, but stem size was significantly correlated with the length of lateral root sprouts at 18 months after the April treatment. Seasonal differences for the treated stumps were also seen in the percentage of sprouting plants, with more of those treated in the spring (April) sprouting than those treated in the fall (November). Depleted root starch concentrations that could possibly occur during a fall timing, cannot be replenished by newly-formed sprouts (Kays and Canham, 1991). This, combined with herbicide, could explain the higher sprouting percentage for the April cutting. Both timings, however, in this study were effective in controlling Chinese privet.

A factor to consider when comparing the spring vs. fall timings is that the three 6-month measurement periods and the growing periods (the time in between the measurement periods) were on different months and seasons of the year depending on the timing. Therefore, sprouts experienced different monthly temperatures and precipitation depending on the timing of treatment (Table 1). For example, the stumps treated in April had two growing periods (the first and third) that coincided with spring and summer months while the stumps sprayed in November experienced only one growing period (the second) during the spring and summer months. If the stumps treated in November had experienced one more spring and summer growing season, it is possible that stem size may have been significantly correlated with sprout length in the November timing as was seen at the18 MAT for the April timing.

The literature has been unclear on the best timing for cut stump applications. For example, Delanoy and Archibold (2007) found a fall cut stump application for European buckthorn was an effective control method but Boudreau and Willson (1992) showed both fall and summer timing for European buckthorn were equally effective, resulting in 100% mortality. Opinions in the literature favoring a spring timing for cut stump applications also exist. According to Kochenderfer et al. (2006) the best time to apply glyphosate is when the plant is actively growing, however, control of root sprouts could also be achieved if herbicide was applied past the growing season. But Kochenderfer et al. (2006) also noted that herbicide efficacy for beech root sprouts is less consistent when herbicide is applied to stumps in the spring. Love and Anderson (2009) suggested that fewer sprouts occurred when Morrow's honeysuckle (*Lonicera morrowii* Gray) was cut in the spring because of low carbohydrate reserves in the roots. Despite the mixed information on timing, all of the above mentioned papers agree that regardless of when applied, an herbicide application is more effective than no herbicide at all. This was also confirmed in my experiment where the spraying of Chinese privet stumps controlled Chinese privet better than no herbicide at all regardless of the timing of the application.

When controlling Chinese privet, land managers also want to use the most effective herbicide. Both glyphosate and triclopyr were effective compared to the untreated controls. The majority of the control stumps sprouted while ≤ 16% of the treated stumps sprouted. When the two herbicides were compared, no significant differences in total sprout length were observed until 18 MAT. Stumps sprayed with triclopyr in the fall (November) had significantly more lateral root and total sprouts than stumps sprayed with glyphosate. However, there was no significant difference between the two herbicides in the percentage of stumps that sprouted for the spring (April) timing. Depending on site and timing, 2 to 12% of the stumps treated with glyphosate exhibited some form of sprouting (stump or lateral) at 18 MAT while 8 to 16% of the stumps treated with triclopyr exhibited sprouting 18 MAT. Glyphosate yielded a slightly better performance than triclopyr, with fewer and smaller sprouts following treatment with glyphosate.

The differences between glyphosate and triclopyr on cut stump applications of Chinese privet may be considered negligible from a managerial standpoint. Therefore, other factors such as selectivity and safety of the two herbicides could be considered. Glyphosate, a non-selective herbicide, is effective for managing different types of weeds such as grasses, broadleaf, or woody plants. Triclopyr, on the other hand, is a selective herbicide used mainly on broadleaf and woody plants. Triclopyr would be beneficial when limited damage to grasses is desired. Regardless of which herbicide is chosen, care must be implemented to reduce the chance of herbicide drift or splash to nearby vegetation when treating stumps. In regards to safety, both herbicides are non-carcinogenic and relatively low in toxicity towards humans. Eye irritation is a possibility with both herbicides; however, some formulations of triclopyr have the potential to damage the eyes so protective eyewear should be worn during the application process. The herbicide label should be read and followed regarding specific safety concerns and the application process.

Cut stump applications using either glyphosate or triclopyr are effective on other invasive species as well. Sprouting in tree-of-heaven was greatly reduced when glyphosate was applied by cut stump treatments (Meloche and Murphy, 2006). Glyphosate can also be applied to bush honeysuckle (*Lonicera spp)* stumps *(*Hovis, 2009) and triclopyr can be used on Oriental bittersweet **(**Dreyer, 1994). Both triclopyr (Boudreau and Willson, 1992) and glyphosate (Delanoy and Archibold, 2007) can be used for cut stump applications on European buckthorn. However, Gale (2000) noted that spraying European buckthorn stumps with triclopyr provided more control than spraying with glyphosate even at a 30-50% glyphosate concentration.

Time since treatment (MAT) is a hidden and often overlooked factor that can have an important influence on the perceived impact of stem size, sprout length, and percent of sprouting plants. The covariate effect (root collar diameter) generally became more pronounced as MAT increased in both the controls and the treated stumps. The difference between the 6, 12, and 18 MATs was also found to be significant for most of the controls and for the percent of herbicide-treated stumps that sprouted. For the treated stumps, there appears to be a linear trend where the percent of plants sprouting increased as MAT increased, suggesting survival of apparently inactive stumps even at 18 MAT. If the time period for collecting measurements in this experiment had been extended and this trend continued then it could possibly yield a higher percent of plants sprouting. Without herbicide, oak stumps can persist (Roth and Hepting, 1969) and the number of beech root sprouts can increase to two times the pre-treatment amount two years after a cutting only treatment (Kochenderfer et al., 2006). Although the percent of herbicide-treated stumps with sprouts was low even at 18 MAT, these sprouting plants pose a threat to control especially since some of the stumps produced sprouts with lengths exceeding 250 cm (98.4in) when measured 18 MAT.

Since the percentage of stumps sprouting increased with MAT, stumps should be monitored to ensure that the stumps exhibiting no sprouts are truly dead and not merely delayed. Sprouting percentage for herbicide treated stumps was minimal (10.5% of treated stumps) even at 18 MAT but not tending to these plants provides a way for Chinese privet to become re-established. As shown in Fig. 3, sprouts can grow 250 cm (98.4in.) in 18 months. Land managers should also be aware that Chinese privet sprouted differently with and without herbicide. Without herbicide, plants exhibited more stump sprouts while herbicide-treated stumps exhibited more lateral root sprouts. Controlling the two types of sprouts can be similar, but this information would help land managers locate sprouts.

A decrease in cover after a cut stump treatment leads to an increase in open area (Kochenderfer et al., 2006) and light penetrating to the forest floor. This could release Chinese privet seedlings since physical control applications do not always destroy seedlings in the area (Hanula et al., 2009). Even though Chinese privet has a relatively low germination rate of 5- 25% (Maddox et al., 2010), seed production is high, resulting in a large amount of viable seed that could regenerate the area. Re-invasion could also occur from birds dispersing seed from nearby privet infestations (Maddox et al. 2010).

Furthermore, even if Chinese privet is permanently removed from the area other unwanted plants could occur. As Luken et al. (1997) and Hulme and Bremner (2006) mentioned, the removal of some invasive species might actually lead to an increase in different alien or native weedy species, thereby replacing one problem species with another. This was the case at both of our sites as English ivy, kudzu, and pokeweed (*Phytolacca americana* L.) became prevalent at the IMF site and pokeweed at the SWU site. Pokeweed, a weedy native and early successional plant, was also seen when Chinese privet was removed from Hanula and Horn's (2011) Georgia sites. Burch and Zedaker (2003) found that removal of tree-of-heaven increased native diversity even though garlic mustard [*Alliaria petiolata* (Bieb.) Cavara & Grande], another invasive species, was present prior to herbicide application. However, Delanoy and Archibold (2007) stated that removing invasive species from the understory will not always ensure an increase in native plants. The recruitment of unwanted species demonstrates that to fully rehabilitate an area, vegetation control may not be enough and additional tactics need to be implemented.

Deer browse on Chinese privet foliage and drupes. Studies show that privet composed 11.1-13.3% of the deer's diet with more browsing occurring in the winter than in the fall when acorns are available (Stromayer et al., 1998). Evidence of deer browsing on Chinese privet was found at both sites for both the April and November timings in the current study and included browsed shoots and the presence of scat. The damage caused by deer browsing did not likely impact the results greatly since evidence was found at both timings and sites. Furthermore, since the controls were such prolific and vigorous sprouters any foliage lost to deer browsing would be marginal. Also, deer browsing could possibly stimulate growth. Stromayer et al., (1998) found that Chinese privet twigs that were subjected to a browsing intensity of over 60% were able to quickly regrow in the spring at 4-6 times its original rate. Browsing by deer tends to have more of an impact on native plants than alien plants but deer browsing can negatively impact the cover of woody plants in general (Rossell et al., 2007).

In conclusion, stem size plays a significant role in sprouting. However, the influence of root collar diameter can be counteracted if glyphosate or triclopyr herbicide is directly applied to the stump within 30 seconds of cutting. The impact that stem size and timing had on lateral sprouts suggests that it would be slightly more effective to treat large Chinese privet in the fall to decrease the chance of stump and lateral sprouting off of the large stumps. Both glyphosate and triclopyr were effective at controlling Chinese privet. However, glyphosate provided slightly better results than triclopyr. Regardless of what timing or herbicide is chosen, a follow-up treatment will be needed to ensure complete control and to monitor the species that are re-colonizing the area.

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Table 1. Monthly precipitation and mean high and low temperatures for Auburn, AL for the duration of the study, April 2008-May 2010[ab]

	Treatment applied in April							Treatment applied in November						
Timeline	Month	Avg. High		Avg. Low		TTL Precip.		Month	Avg. High		Avg. Low		TTL Precip.	
		-C-	-F-	-C-	-F-	-mm-	-in-		-C-	-F-	-C-	-F-	-mm-	-in-
Treatment applied	Apr	23	74	12	53	80	3.1	Nov	18	64	6	42	73	2.9
GP1-1M	May	28	82	16	61	85	3.3	Dec	16	61	6	43	82	3.2
GP1-2M	Jun	33	91	21	69	39	1.5	Jan	14	57	3	37	73	2.9
GP1-3M	Jul	33	92	21	70	58	2.3	Feb	16	60	3	38	96	3.8
GP1-4M	Aug	31	87	21	70	189	7.4	Mar	19	67	9	48	178	7.0
GP1-5M	Sep	29	84	18	65	31	1.2	Apr	23	73	11	52	147	5.8
6 MAT	Oct	23	73	12	53	99	3.9	May	26	79	17	63	194	7.6
GP2- 1M	Nov	18	64	6	42	73	2.9	Jun	32	89	21	70	122	4.8
GP2- 2M	Dec	16	61	6	43	82	3.2	Jul	31	88	21	69	91	3.6
GP2-3M	Jan	14	57	3	37	73	2.9	Aug	31	88	21	70	76	3.0
GP2-4M	Feb	16	60	3	38	96	3.8	Sep	29	84	20	68	125	4.9
GP2-5M	Mar	19	67	9	48	178	7.0	Oct	22	72	13	55	173	6.8
12 MAT	Apr	23	73	11	52	147	5.8	Nov	18	65	7	44	118	4.6
GP3-1M	May	26	79	17	63	194	7.6	Dec	12	54	3	37	260	10.2
GP3-2M	Jun	32	89	21	70	122	4.8	Jan	11	52	0	32	148	5.8
GP3-3M	Jul	31	88	21	69	91	3.6	Feb	11	51	1	32	141	5.5
GP3-4M	Aug	31	88	21	70	76	3.0	Mar	17	62	6	42	130	5.1
GP3-5M	Sep	29	84	20	68	125	4.9	Apr	26	79	13	55	32	1.2
18 MAT	Oct	22	72	13	55	173	6.8	May	28	83	18	64	97	3.8

[a] GP = growing period between sampling dates at 6, 12, and 18 months after treatment.
[b] Data accessed at http://www.wunderground.com/history.

Table 2. Frequency of sprouted Chinese privet plants at 6, 12, and 18 months after treatment arranged by treatment, timing and location.

	Untreated control				Glyphosate				Triclopyr			
	IMF		SWU		IMF		SWU		IMF		SWU	
MAT	APR	NOV	APR	NOV	APR	NOV	APR	NOV	APR	NOV	APR	NOV
	---------- % sprouted plants ----------											
	Stump											
6	90	92	85	73	2	0	0	0	0	0	0	0
12	92	84	72	73	4	0	0	0	0	0	0	0
18	92	84	70	67	2	0	0	0	2	2	0	0
	Laterals											
6	37	40	32	42	4	0	4	0	2	0	2	4
12	51	69	57	69	0	0	8	4	7	2	10	8
18	47	74	68	73	10	2	12	4	16	6	14	12
	Total											
6	94	92	85	77	4	0	4	0	2	0	2	4
12	94	90	74	79	4	0	8	4	7	2	10	8
18	94	88	79	81	12	2	12	4	16	8	14	12

Table 3. Maximum and minimum estimates for sprouting length calculated from four-way treatment x site x timing x months after treatment interaction means.

	Laterals		Stump		Total	
Treatment	Max	Min	Max	Min	Max	Min
	---------------------------- cm ------------------------------					
Control	372	40	740	45	1020	88
Glyphosate	14	0	1	0	14	0
Triclopyr	18	0	5	0	23	0

Table 4. Regression estimates for the cut controls for each site x timing x MAT combination.

		APR			NOV		
Site	MAT	Estimate	StdErr	Probt	Estimate	StdErr	Probt
Total							
IMF	6	507	122.8	<0.0001	141	114.4	0.2191
IMF	12	510	100.1	<0.0001	429	86.9	<0.0001
IMF	18	570	123.5	<0.0001	480	117.3	<0.0001
SWU	6	399	147.9	0.0072	99	113.7	0.3863
SWU	12	501	121.1	<0.0001	805	86.2	<0.0001
SWU	18	960	151.1	<0.0001	845	115.2	<0.0001
Stump							
IMF	6	440	86.5	<0.0001	115	62.5	0.0654
IMF	12	405	86.2	<0.0001	266	62.6	<0.0001
IMF	18	439	86.2	<0.0001	348	62.5	<0.0001
SWU	6	356	89.1	0.0001	35	49.1	0.4713
SWU	12	427	89.0	<0.0001	435	49.0	<0.0001
SWU	18	630	89.8	<0.0001	424	49.1	<0.0001
Laterals							
IMF	6	79	42.2	0.0627	23	44.2	0.5967
IMF	12	119	41.7	0.0046	159	44.4	<0.0001
IMF	18	150	41.7	0.0004	123	44.2	0.0059
SWU	6	46	64.3	0.4754	50	55.9	0.3750
SWU	12	79	64.2	0.2224	367	55.8	<0.0001
SWU	18	335	65.2	<0.0001	390	55.9	<0.0001

Table 5. Site x MAT interaction means for sprouting length of the cut controls estimated at a mean initial diameter of 4.1 cm.

	IMF				SWU			
			P-value vs.				*P*-value vs.	
MAT	Estimate	SE	12 MAT	18 MAT	Estimate	SE	12 MAT	18 MAT
	------- cm -------				--------- cm ---------			
Total								
6	479	75.3	<0.0001	<0.0001	256	76.6	<0.0001	<0.0001
12	731	59.5		0.2613	592	60.8		<0.0001
18	804	75.8			852	78.2		
Stump								
6	417	48.3	0.0003	<0.0001	205	40.9	<0.0001	<0.0001
12	537	48.2		0.0432	385	40.9		0.0003
18	606	48.1			495	41.0		
Laterals								
6	68	27.4	<0.0001	0.0002	46	35.3	<0.0001	<0.0001
12	201	27.2		0.9334	204	35.4		<0.0001
18	211	27.1			346	35.4		

Table 6. Regression estimates from ANCOVA for herbicide treatments using the log-transformed root collar diameter as a covariate.

		APR			NOV		
Site	MAT	Estimate	StdErr	Probt	Estimate	StdErr	Probt
Total							
IMF	6	0.9	3.89	0.8091	0.0	2.96	0.9998
IMF	12	3.1	3.86	0.4244	0.2	2.95	0.9453
IMF	18	8.6	3.86	0.0258	1.8	2.99	0.5457
SWU	6	2.6	5.04	0.6063	1.3	3.51	0.7036
SWU	12	8.2	5.05	0.1066	5.0	3.51	0.1585
SWU	18	11.8	5.11	0.0206	-4.6	3.52	0.1937
Stump							
IMF	6	0.0	1.31	0.9737	0.0	0.84	1.0000
IMF	12	0.4	1.30	0.7356	0.0	0.84	1.0000
IMF	18	-1.7	1.30	0.1955	0.0	0.85	0.9732
SWU	6	0.0	0.97	1.0000	0.0	0.98	1.0000
SWU	12	0.0	0.97	1.0000	0.0	0.98	1.0000
SWU	18	0.0	0.99	1.0000	0.0	0.98	1.0000
Laterals							
IMF	6	0.9	3.21	0.7767	0.0	2.49	1.0000
IMF	12	2.6	3.19	0.4080	0.2	2.48	0.9350
IMF	18	10.3	3.19	0.0014	1.8	2.52	0.4790
SWU	6	2.6	4.88	0.5999	1.3	3.31	0.6866
SWU	12	8.1	4.90	0.0981	5.0	3.31	0.1352
SWU	18	11.8	4.94	0.0177	-4.6	3.32	0.1683

Table 7. The treatment means, standard error (SE), and *P*-values were calculated for the treatment x MAT interaction. Means were estimated at a mean root collar diameter of 4.4 cm.

	Glyphosate		Triclopyr		
MAT	Estimate	SE	Estimate	SE	P (gly vs. tric)
	-------- cm --------		------- cm -------		
Total					
6	1.2	2.30	0.9	2.29	0.9296
12	1.0	2.30	5.9	2.28	0.1356
18	6.2	2.31	14.4	2.29	0.0121
Stump					
6	0.1	0.63	0.0	0.61	0.8789
12	0.0	0.62	0.0	0.63	0.6788
18	0.4	0.63	1.3	0.61	0.1416
Laterals					
6	1.0	2.08	5.9	2.07	0.9553
12	0.9	2.08	6.1	2.09	0.0705
18	0.6	2.08	13.1	2.07	0.0196

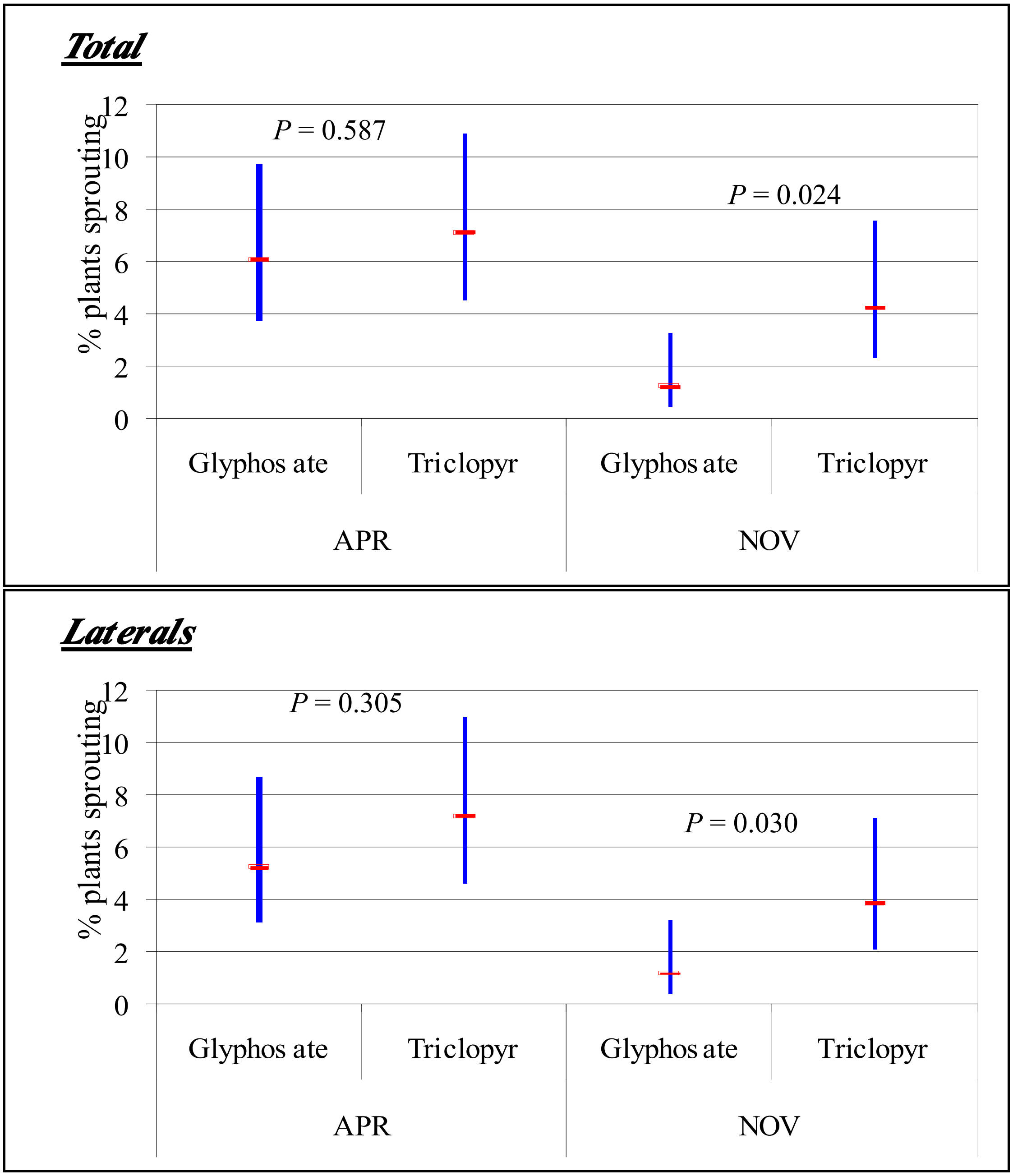

Fig. 1. Effect of herbicide treatment and application timing on percent of Chinese privet plants that sprouted after a cut stump treatment. Since very few sprouts originated off of treated stumps, only the lateral and total sprout information is displayed.

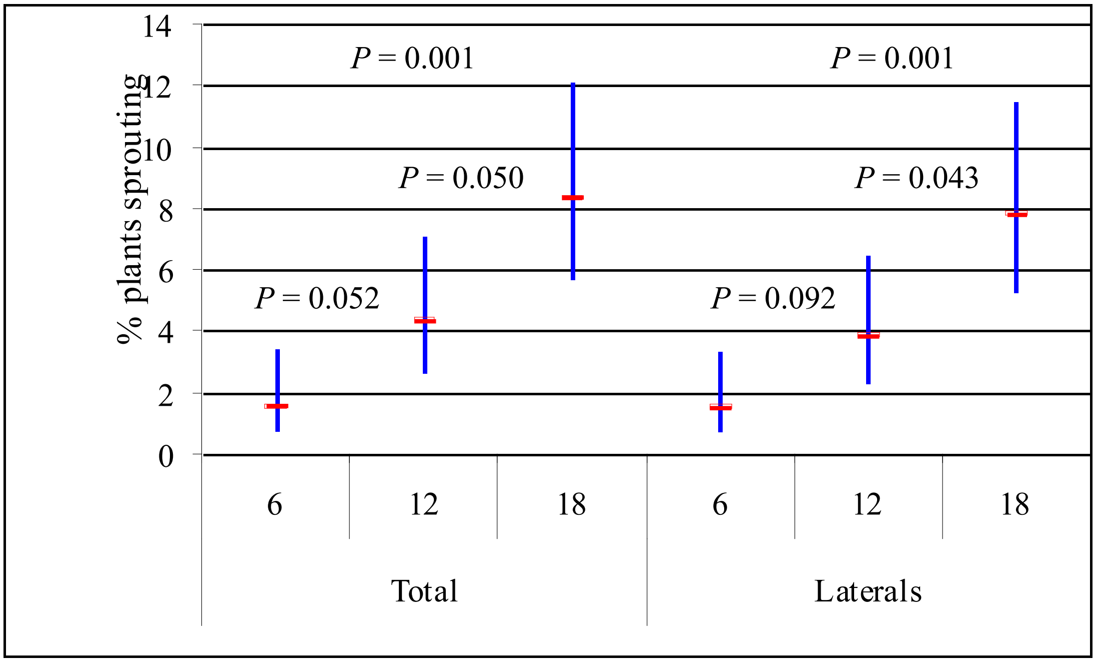

Fig. 2. Effect of time after herbicide treatment (MAT) on sprouting percentage for total (combination of stump and lateral root sprouts) and for lateral root sprouts within 30 cm of a treated Chinese privet stump. Data were analyzed using generalized models procedures with a binomial distribution function. Means were back-transformed to frequencies and converted to percent. The *P*-values at the top are for the 6 vs. 18 contrast.

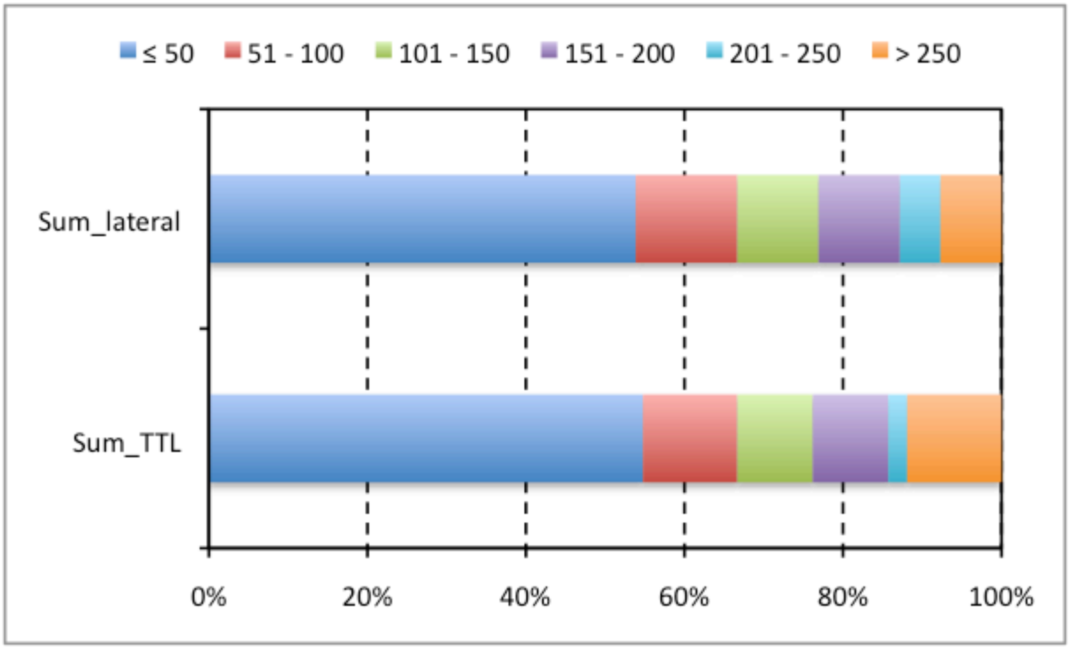

Fig. 3. Only 42 out of the 400 Chinese privet plants treated with herbicide (10.5%) had measurable sprouting 18 MAT. In this figure, the sprouting herbicide-treated stumps (the 10.5%) is color-coded into size classes and arranged by the lateral (lateral root sprouts within 30 cm of a herbicide-treated stump) and the total sprout length (stump and lateral sprout length combined). The x-axis shows a running percentage of the 10.5% that fell into each category.

BASAL BARK APPLICATION

Abstract

Chinese privet (*Ligustrum sinense* Lour.), originally introduced to the U.S. in 1852 for ornamental purposes, grows as a shrub or small tree and is prone to multiple stems. Since its introduction, it has spread throughout the Southeast, invading disturbed areas, roadsides, rights of ways, and forest edges and interiors. If not controlled, Chinese privet can outcompete native species. A basal bark herbicide application is a control method where herbicide is applied to the lower 30-46 cm (12-18 in) of each stem. A basal bark application of Garlon 4 at 20% or Pathfinder II is a recommended control method for Chinese privet. However, there is very little scientific research comparing these two herbicides on Chinese privet. Our objectives for this experiment were to 1) determine if there is differential performance between Garlon 4 at 20% vol/vol and Pathfinder II, 2) determine the effectiveness of lower rates of Garlon 4, and 3) determine the effects of timing and root collar diameter on herbicide efficacy. A completely randomized experiment was conducted at two sites in Lee County, Alabama and at two timings (January and March). Treatments consisted of the ready-to-use triclopyr/oil mixture Pathfinder II (89.96 g/L); triclopyr (Garlon 4) at 5% (24 g/L), 10% (48 g/L), and 20% (96 g/L) vol/vol; and an untreated control**.** Percent defoliation and number and length of new sprouts were recorded 6, 12, and 18 months after treatment (MAT). All herbicide

treatments provided effective control averaging ≥ 97% defoliation and only one new sprout per privet clump. Generally, privet treated with the highest concentration of Garlon 4 (20%) and Pathfinder II had less growth and survival than the lower Garlon 4 concentrations. Garlon 4 at 20% and Pathfinder II were equally effective, with no difference in defoliation or number of new sprouts.

Introduction

Chinese privet is a highly invasive shrub that was first introduced into the southeastern United States from China in 1852 for ornamental purposes (University of Florida, 2011). It has since become naturalized in several southern states (Maddox et al., 2010). It is a semi-evergreen to evergreen multi-stemmed shrub or tree growing 6-9 meters (19.7- 29.5 ft) tall having thin, smooth, grey bark with pale lenticels (Brown and Pezeshki, 2000; Miller et al., 2010). Privet can be found in disturbed areas, on forest edges, and under forest canopies (Maddox et al., 2010). Once established, it can reproduce sexually through copious seed production and vegetatively through basal and shallow lateral root sprouts. Following establishment, Chinese privet tends to form dense thickets that may cause a reduction in the number of stems and species in the understory and midstory for both forbs and tree species (Kittell, 2001; Merriam and Feil, 2002). Possibly more disturbing is its ability to reduce or entirely prevent tree regeneration, which could ultimately have severe impacts on forest dynamics across the southeast. Chinese privet is so competitive that near monotypic stands can form in as little as 15 years after a disturbance (Grove and Clarkson, 2005) with only vines and Chinese privet sprouts growing under mature Chinese privet (Merriam and Feil, 2002). This process can be stopped if integrated control measures, such as herbicides and physical methods are implemented.

As previously discussed, glyphosate (Accord Concentrate, Dow AgroSciences, Indianapolis, IN 46268) at 25% vol/vol or an amine formulation of triclopyr (Garlon 3A, Dow AgroSciences, Indianapolis, IN 46268) at 25% vol/vol were effective for cut-stump treatments with 10.5% of the herbicide-treated stumps sprouting. However, cut stump control is labor intensive (Hillmer and Liedtke, 2003) and leads to the formation of large brush piles. These brush piles may be problematic, especially in areas where burning is prohibited (Cooper et al., 1972) or chipping is not an option. Basal spray, also known as a basal bark application, is another effective control method for Chinese privet (Miller, 2007) where the lower 30-46 cm (12-18 in) of each stem is sprayed with an herbicide mixed with an oil carrier (Smith et al., 1997; Burch and Zedaker, 2003; Nelson et al., 2006). The oil carrier helps the herbicide penetrate the bark and reach the vascular tissue where translocation throughout the plant occurs. The desired result is death of all aboveground tissue, the root crown and all lateral roots. Herbicide induced girdling, which results in a starvation of the roots that depend on photosynthates for energy, may contribute to the process (Smith et al., 1997). The benefits of basal spray reside in not only killing the stem but also preventing sprouting (Smith et al., 1997; Bowker and Stringer, 2011). Other advantages for basal bark applications include application to individual plants allowing selectivity, potential year-round application including during the dormant season, and a low chance of drift or runoff in surface waters (Smith et al., 1997; Nelson, 2006).

While basal bark applications can be made year round, there is conflicting information on the best time of year for basal bark applications. Miller et al. (2010) stated that basal sprays applied between June and September were the most effective. However, Rhodenbaugh and Yeiser (1994) determined that a dormant season (January or February) triclopyr basal bark application to hardwoods in Arkansas was more effective than those applied during the growing season (May or June). At plots located in Oklahoma, Yeiser and Boyd (1989) found a 20% vol/vol triclopyr solution applied to one or two sides of the hardwood stem (a streamline application) resulted in 64.7% defoliation when applied in September compared to 42.4 % defoliation when applied in June. While it is clear that timing can be important, the most effective time period for basal bark applications is yet to be determined and may be species dependent.

In general, basal bark treatments are recommended for trees ≤ 10 cm (4 in) in root collar diameter (Schutzman and Kidd, 1987) or ≤ 20 cm (8 in) in diameter at breast height, a diameter taken 1.37 meters (4.5 ft) above ground level (Miller et al., 2010). However, some invasive species can have even lower diameter limits. For example, basal bark applications on European buckthorn (*Rhamnus cathartica* L.) were less effective on stems larger than 7 cm (2.8 in.) in diameter (Gale, 2000). Others have also reported better control on hardwood trees with small root collar diameters (Yeiser et al., 1989) and smaller stems (Williams et al., 1996). With increasing root collar diameter, basal spray treatments of hardwood species resulting in less defoliation and reduced control (Schutzman and Kidd 1987; Yeiser et al., 1989). Experiments conducted in Arkansas showed a significant reduction in defoliation when the diameter of hardwoods increased by just 2.5 cm or 1 inch (Yeiser et al., 1989; Williams et al., 1996). In Monticello, Arkansas, a root collar diameter of 2.5 cm (1 in) yielded 80% defoliation of hardwoods while a root collar diameter of 5 cm (2 in) yielded only 58% (Yeiser et al., 1989). Reduced herbicide efficacy for larger stems was seen in other experiments as well (Schutzman and Kidd 1987; Yeiser and Reed, 1990; Williams and Yeiser, 1995; Williams et al., 1996) suggesting that larger plants may require additional follow-up treatments to attain complete control.

Selecting the most effective herbicide may reduce the need for follow-up treatments. Garlon 4 (Dow AgroSciences, Indianapolis, IN 46268) at 20% vol/vol and Pathfinder II (Dow AgroSciences, Indianapolis, IN 46268) have been recommended for basal spray applications on several invasive species (Miller et al., 2010). The active ingredient for both of these herbicides is the ester formulation of triclopyr, which mimics the plant growth hormone auxin and causes unrestrained growth and eventual plant death (Tu et al., 2001). Triclopyr is translocated throughout the plant and accumulates in the root collar (Evans et al., 2006). A basal bark application of Garlon 4 at 20% vol/vol or undiluted Pathfinder II is effective on tree-of-heaven [*Ailanthus altissima* (P. Mill.) Swingle], mimosa (*Albizia julibrissin* Durazz.), paulownia [*Paulownia tomentosa* (Thunb.) Sieb. & Zucc. ex. Steud.], Chinese tallow tree [*Triadica sebifera* (L.) Small], autumn olive (*Elaeagnus umbellata* Thunb.), Chinese privet, Oriental bittersweet (*Celastrus orbiculatus* Thunb.), and European buckthorn (*Rhamnus cathartica* L.) (Gale, 2000; Evans et al., 2006; Miller, 2007). The effectiveness of Garlon 4 in basal bark applications is demonstrated with tree-of-heaven, where a 20% vol/vol treatment yielded 100% mortality one year after treatment (Burch and Zedaker, 2003) and a 25% vol/vol rate prevented sprouting in 97% of treated stems (Bowker and Stringer, 2011).

Garlon 4 at 20% vol/vol and Pathfinder II are both recommended for use on Chinese privet (Miller, 2007). Both contain triclopyr but differ in convenience and flexibility. Pathfinder II is a ready-to-use mixture with a fixed concentration of 13.6% triclopyr. Garlon 4, on the other hand, must be mixed with an oil carrier before application. This provides Garlon 4 the flexibility of adjusting the herbicide rate in the final mix but requires the separate purchase of an oil carrier and time to prepare the oil herbicide mixture. Garlon 4 at 20% vol/vol has a slightly higher percentage of triclopyr than Pathfinder II, but experimental tests of differences in efficacy have yet to be conducted.

There is evidence that some species may be susceptible to lower rates of triclopyr than found in Pathfinder II. For example, Garlon 4 at 13% vol/vol provided effective control of European buckthorn (Gale, 2000) and basal bark applications of Garlon 4 at 10% vol/vol resulted in 98.9% defoliation of American beech (*Fagus grandifolia* Ehrh.) trees in West Virginia (Kochenderfer et al., 2004). Kochenderfer et al. (2004) concluded that Garlon 4 rates as low as 5% vol/vol are effective on thin-barked tree species. Since Chinese privet is a thin-barked species (Maddox et al., 2010), it is possible that Garlon 4 at 5% vol/vol may provide some level of control.

Since species that have the ability to vegetatively reproduce are not considered to be effectively controlled unless sprouting is prevented (Bowker and Stringer, 2011), the lower herbicide rates would also need to prevent sprouting. Sprouting is a mechanism used by some plants to replace damaged stems after disturbance (Harcombe and Marks, 1983; Sakai et al., 1995; Bond and Midgley, 2001). Sprouting in Chinese privet can occur from lateral roots in the form of root sprouts or from stems in the form of basal sprouts. Injury-induced root sprouts, originating off of trees that may appear dead, can appear close to or some distance away from the primary stem (Del Tredici, 1995). Since sprouting requires stored starch reserves and living meristems (Bond and Midgley, 2001), the majority of the basal sprouts occur at the root collar where many buds that are suppressed may be present (Del Tredici, 2001). Regardless of where the sprout originates, the presence of a sprout implies that at least some of the original root system still persists (Del Tredici, 2001) and that the tree is not dead. For this reason, a basal bark application is not a complete success unless sprouting is prevented.

This experiment was designed to determine the most effective basal bark application treatments for control for Chinese privet, by answering the following questions: 1) Is there a difference in efficacy between Garlon 4 at 20% vol/vol and Pathfinder II; 2) Can lower rates of triclopyr provide effective Chinese privet control; 3) Does application time impact herbicide efficacy; and 4) Do basal bark applications provide effective Chinese privet control across a wide range of root collar diameters?

Material and Methods

The study was conducted in Lee County, Alabama at two sites. The first site is a hardwood forest located at Auburn University's Swine Unit Research and Education facility (SWU) (32° 35' 4.49" N, 85° 30' 15.52" W) approximately two miles SW of Auburn University's main campus. The hardwood forest is adjacent to a pasture and is predominately composed of Chinese privet shrubs and small trees approximately 7.6 -9.1 meters (25-30 ft.) tall. Tree species present in the overstory include sycamore *(Platanus occidentalis* L.), water oak (*Quercus nigra* L.) mockernut hickory [*Carya tomentosa*

(Lam.) Nutt], sweetgum (*Liquidambar styraciflua* L.), eastern red cedar (*Juniperus virginiana* L.), loblolly pine (*Pinus taeda* L.), and American beech. Other invasive species found on the property include nandina (*Nandina domestica* Thunb.), Chinaberry (*Melia azedarach* L.), and Chinese tallowtree. The soil series is Pacolet sandy loam with a 6-10% slope. This site will be referred to as the SWU site.

The second site, on property owned by the Alabama Forestry Commission (AFC), is located near Opelika, Alabama (32° 34' 2.48" N, 85° 22' 5.92" W). The site is located within an area of unmanaged hardwoods where Chinese privet averaging 6.1- 7.6 meters (20-25 ft.) tall is prevalent. Overstory tree species include sweetgum, sycamore, mimosa, sweetbay magnolia (*Magnolia virginiana* L.), and water oak. The soil series is a Cartecay silt loam with less than 1% slope. This site will be referred to as the AFC site.

Average monthly high temperatures in Auburn and Opelika range from 12.8 C (55 F) in January to 32.2 C (90 F) in July, with an average annual high temperature for both locations of 23.3 C (74 F). For Auburn, the average low temperature ranges from 1.1 C (34 F) in January to 21.1 C (70 F) in July with an annual average low of 11.7 C (53 F). The average low temperature for Opelika ranges from 0.6 C (33 F) in January to 20 C (68 F) in July with an annual average low of 10 C (50 F). The overall average annual temperature is 17.2 C (63 F) for Auburn and 16.7 C (62 F) for Opelika. The amount of precipitation for Auburn varies throughout the year ranging from 69.1 mm (2.72 in) in October to 165.1 mm (6.5 in) in March with an average annual precipitation of 1,336 mm (52.6 in). For Opelika, average precipitation ranges from 82 mm (3.23 in) in October to 176 mm (6.93 in) in March with average annual precipitation of 1,435.1 mm (56.5 in).

The treatment design was a 5 x 2 x 2 x 3 factorial consisting of five treatments (untreated, Pathfinder II, and three concentrations of Garlon 4, the butoxyethyl ester formulation of triclopyr), two timings (March and January), two sites (SWU and AFC), and three measurement periods (6, 12, and 18 months after treatment). The experimental design was a completely randomized design (CRD) with a minimum of 40 replicates (trees) per treatment x site x timing combination with each Chinese privet tree serving as an experimental unit. Chinese privet trees with multiple stems were considered a single experimental unit.

Prior to initiating treatments, the number of main stems and sprouts were counted and main stems were marked with flagging. A main stem was considered any stem originating from the lower 30 cm (12 in) of the tree with a base diameter of at least 1 cm (0.4 in) at the time of measurement. Stems with a diameter of less than 1 cm (0.4 in) were considered a sprout. Root sprouts within a 30 cm (12 in) radius of the main stem were also counted if it was clear that the sprout originated from the flagged tree.

Using a wooden caliper, the root collar diameter and the diameter at breast height (DBH) of the largest main stem were measured. DBH is a measurement taken at 1.37 m (4.5 ft.) above ground level. Treatments, which were randomly assigned, consisted of Pathfinder II; 20% vol/vol Garlon 4 mixed with Bark Oil Blue (UAP Distribution Inc., Greeley, CO 80634); 10% vol/vol Garlon 4 mixed with Bark Oil Blue; 5% vol/vol Garlon 4 mixed with Bark Oil Blue, and an untreated control**.** Treatments were applied to the lower 30 cm (12 in) of the entire circumference of all main stems and present sprouts using a 1.5 L Garden Plus pressurized hand sprayer with an adjustable cone nozzle. Stems and sprouts were sprayed to wet but not to the point of run off. A separate spray bottle was used for each herbicide treatment. The amount of herbicide applied per tree was dependent on root collar diameter, the number of stems, and the number of sprouts, with an estimate of 6.4 ml of herbicide solution per inch of root collar diameter. The acid equivalent for triclopyr at 5% vol/vol is 24 g L^{-1} (0.2 lb gal^{-1}), at 10% vol/vol it is 48 g L^{-1} (0.4 lb gal^{-1}) and at 20% vol/vol the acid equivalent is 96 g L^{-1} (0.8 lb gal^{-1}). The acid equivalent for Pathfinder II is 89.96 g L^{-1} (0.75 lb gal^{-1}).

For the March timing, fifty privet trees per treatment were sprayed, with a total of 250 trees per site. The SWU site was sprayed March 3-5, 2009 and the AFC site was sprayed March 9-10, 2009. High temperatures for March 3-5 were 10 C (50 F), 12.8 C (55 F), and 18.9 C (66 F), respectively. High temperatures for March 9-10 were 25 C (77 F) and 26.7 C (80 F), respectfully. The lows for March 3-5 were -3.9 C (25 F), 0.6 C (33 F), and 3.9 C (39 F), respectfully and 12.8 C (55 F) and 13.9 C (57 F) for March 9-10. The average high and low temperatures for March 2009 were 19.4 C (67 F) and 8.9 C (48 F), respectively.

The second treatment timing was applied in January 2010. A single basal bark herbicide application was applied to a minimum of 40 trees per treatment, with a total of approximately 200 trees per site. The SWU site was sprayed January 4- 5, 2010 and the AFC site was sprayed January 6-7, 2010. The weather for the January spraying was uncharacteristically cold for the area with highs of 2.8 C (37 F) and 1.1 C (34 F) at the SWU site and 6.1 C (43 F) and 7.2 C (45 F) at the AFC site. Lows were -7.8 C (18 F) for January 5 and 6, -7.2 C (19 F) for January 4, and -5 C (23 F) for January 7. The average high temperature for January 2010 was 11.1 C (52 F) and the average low was 8.9 C (48 F).

For both the January and the March timing, preliminary data were collected 3 months after treatment (MAT) and consisted of a visual estimation of percent defoliation for the entire tree on a scale from 0% (no defoliation) to 100% (total defoliation). Number of sprouts within a 30 cm (12 in) radius of the main stem that showed growth of new leaves was also recorded. The new growth could be in the form of new leaves on existing sprouts or the formation of new sprouts.

Using the same methodology as the preliminary (3 month) data, percent defoliation and total number of sprouts were collected 6, 12, and 18 MAT. For each privet clump, the number of newly formed sprouts (those that appeared after the herbicide application), along with the number of existing sprouts (those present at the time of the herbicide application) exhibiting leaves, were combined to arrive at a total number of live sprouts per privet clump. This variable from now on will be labeled as “total number of sprouts”. Since many of the sprouting herbicide-treated privet exhibited the formation of new sprouts, two other measurements were taken 6, 12, and 18 MAT. The first measurement is called “new sprouts” and is the number of newly formed sprouts (those that formed after the herbicide application) per privet clump. The second measurement, called “sprout length”, is the combined length of all the newly formed sprouts per privet clump. For untreated controls, all living sprouts were measured and summed to reach a total sprout length per privet clump and is reported in the “sprout length” variable.

Response data were analyzed using linear mixed model methodology as implemented in SAS® PROC GLIMMIX. Site, treatment, timing, MAT and their respective interactions were considered fixed effects. The sole random effect was privet trees within site by treatment by timing.

Based on the biology of this invasive species, we anticipated that the root-collar diameter might have an influence on the response to treatments, expecting that larger plants would be able to mobilize greater reserves for regrowth after treatment. Univariate analysis indicated that root-collar diameter values were right-skewed and best modeled using natural log-transformed values. Hence natural log-transformed root-collar diameter was used as a covariate in the analysis. The best-fitting covariate model had separate slopes for each timing. Unlike the case for a single covariate slope or parallel slopes, treatment differences in the unequal slope situation depend on the value of the covariate. Based on the suggestion by Littell et al. (2002), we compared treatment means at the mean of the covariate using the AT MEANS option within the LSMEANS command in PROC GLIMMIX.

Even before statistical analysis, it was clear that herbicide treatments were highly effective compared to no herbicide application (control) since the herbicide-treated privet clumps averaged ≥ 78% defoliation. Untreated controls had a maximum average percent defoliation of 61%. Thus non-homogeneous treatment variances were a concern. The initial overall analysis as conducted using the group option in SAS PROC GLIMMIX created separate variance groups for herbicide-treated and control treatments.

Additionally, separate analyses were conducted for the controls and for the herbicide-treated privet. Because the experiment has a repeated nature, i.e., measurements taken on the same experimental unit (privet tree) over a period of 18 months (3, 6, 12, and 18 MAT or 6, 12, 18 MAT depending on the response variable), the residual variance structure was modeled to arrive at a reasonable covariance relationship (R-side modeling in SAS parlance). The criteria used for selection of an appropriate covariance structure were a low value for the corrected Akaike's information criterion (AICC) and a reasonable standard error for calculated means.

In this experiment there was an apriori assumption that interactions should be an important source of variation; hence we considered interactions important when $P \leq 0.10$. Interaction least squares means were generated and simple effects means compared using the SLICEDIFF option of the LSMEANS statement of PROC GLIMMIX. The simulation option ($\alpha = 0.10$) was used to adjust the Type 1 error rate for multiple comparisons.

Statistical analysis was also conducted on the percent of privet that showed signs of life (% living) 18 MAT. The total number of sprouts data 18 MAT was converted into a binary where 0 represented no living sprouts and 1 equaled living sprouts present 18 MAT. The percent defoliation 18 MAT was also converted into a binary where 0 equaled complete defoliation (100%) and 1 represented < 100% defoliation. These two binaries (the one for the total number of sprouts and the one for percent defoliation) were combined into a single binary. If the sum of the two binaries was 0 then the privet was considered dead and assigned a value of 0. If the sum of the two binaries was ≥ 1 then the privet was alive and was assigned a value of 1. In other words, privet was considered dead if it exhibited 100% defoliation and had no living sprouts. Dead privet was given a value of 0. If the privet had < 100% defoliation and/or exhibited live sprouts then it was considered alive and assigned a value of 1. Next, the ratio of living privet to the total number of plants for each site x timing x treatment combination was calculated. An arcsine square root transformation was conducted on the ratio data and a one-way ANOVA was conducted on the transformed data. The model was then reduced to a single effect and the means and confidence intervals were calculated using the back transformed scale.

Results

An initial analysis of the response variables (percent defoliation, new sprouts, sprout length, and total number of sprouts) revealed no overlap between the untreated controls and any of the herbicide treatments (Table 1). For example, the untreated controls had a maximum average percent defoliation of 61% and the herbicide-treated privet had a minimum average at 78% defoliation. The minimum average for the untreated controls was 2 to 3 times the maximum average for the herbicide treated privet for both the number of new sprouts and for the total number of sprouts. The averages in Table 1 confirm that the control data and the herbicide-treated data were not homogeneous. To remedy this, the control data and the herbicide-treated privet data were analyzed as two separate data sets.

Out of over 2,000 sprout data points measured across all the treatments, sites, timings, and MAT, the newly formed sprouts (new sprouts) and the total number of sprouts (previously existing sprouts plus newly formed sprouts) differed in only 40 instances (data not shown), indicating that the newly formed sprouts encompassed the majority of the sprout total. As a result, the sprout data analysis focused specifically on the new sprouts.

Because we expected plant size to affect the response to the herbicide treatments, root collar diameter was measured on each plant before the treatment application. Graphing the raw data indicated that the root collar diameters were lognormal distributed; hence the $\log_e$ (root collar diameter) was chosen as a covariate. Based on the AICC fit statistic we selected a nested covariate model where a separate line was fitted for the January and March applications. With increasing root collar diameter, the defoliation response decreased while the number of new sprouts and sprout length increased (Table 2). Based on the 95% confidence interval, we could ascertain an affect for the March application but not for the January application date.

All herbicide treatments were highly effective at defoliating Chinese privet, with mean percent defoliation $\geq$ 97% (Table 3). There were significant differences in percent defoliation between the lower (5% and 10% vol/vol of Garlon 4) and the higher herbicide concentrations (20% vol/vol of Garlon 4 and Pathfinder II). However, there was no significant difference in the amount of defoliation between 20% vol/vol of Garlon 4 and Pathfinder II. There was a significant difference in percent defoliation between the two timings at the SWU site but not at the AFC site (Table 4). At the SWU site, mean percent defoliation differed by 5% between the two timings, with 100% defoliation observed for the January application. In general, there was no significant difference in percent defoliation across MAT except between 3 and 18 MAT (Table 5).

For all herbicide treatments and application timings, very few new sprouts were initiated (Table 6). For the March timing, there was a significant difference in the number of new sprouts between the lower concentrations of Garlon 4 (5% and 10% vol/vol) and Pathfinder II. There was also a significant difference in the number of new sprouts between the 10% and 20% vol/vol Garlon 4 treatments for the March timing. The only significant difference in the number of new sprouts for the January timing was between the 5% and 20% vol/vol Garlon 4 treatments. There was no significant difference in the number of new sprouts between the 20% vol/vol of Garlon 4 and the Pathfinder II treatments at either timing.

The effect of MAT on the number of new sprouts was more prominent for the January timing, with a significant difference between 6 and 12 MAT and 6 and 18 MAT (Table 7). For the March timing, a significant difference between the number of new sprouts was only seen between 12 and 18 MAT. The mean number of new sprouts increased steadily with MAT for the January timing, but fell at 12 MAT and then increased at 18 MAT for the March timing.

Timing interactions had an effect for number of new sprouts and sprout length. The effect of site and application timing was significant ($P = 0.005$) for the number of new sprouts with both sites and timings averaging one new sprout per privet clump (Table 8). Timing was also important for sprout length. For the January timing, the only significant treatment difference in sprout length was between the 5% and 20% vol/vol Garlon 4 treatments (Table 9). For the March timing, there were significant differences in sprout length between the lower (5% and 10% vol/vol of Garlon 4) and higher herbicide concentrations (20% vol/vol of Garlon 4 and Pathfinder II). There was no significant difference in sprout length between Garlon 4 at 20% vol/vol and Pathfinder II at either timing.

Significant differences were found in regards to site and timing for sprout length. For example, the difference between average sprout length for the January timing (1.6 cm or 0.6 in) and the March timing (5.2 cm or 2 in) was significant at the SWU site. However, at the AFC site, where average sprout length was 6.6 cm (2.6 in) for the

January timing and 4.5 cm (1.8 in) for the March timing differences were not significant (Table 10).

MAT also influenced sprout length with significant differences found between the earlier measurements (6 MAT) and the later measurements (12 and 18 MAT) for the January timing (Table 11). For the March timing, only the sprout lengths at 12 and 18 MAT were significantly different. Mean sprout length increased with MAT for the January timing. For the March timing, average sprout length decreased between 6 and 12 MAT and then increased between 12 and 18 MAT.

Looking at percent defoliation and the number and length of sprouts is important when selecting the best herbicide treatment and timing. The ultimate goal of most land managers is to efficiently kill as much Chinese privet as possible and to reduce privet recovery (% living). Treatment means for the percent living indicated that the lower herbicide concentrations (5% and 10% vol/vol of Garlon 4) had more signs of survival than the higher concentrations (20% vol/vol of Garlon 4 and Pathfinder II) (Table 12). Significant differences were seen among all treatments except between 20% vol/vol of Garlon 4 and Pathfinder II.

The interaction between timing and treatment was also analyzed for percent living (Table 13). When the January and March timing were compared, the January timing showed the lowest percent living for all treatments except Pathfinder II. For both timings, the 5% vol/vol Garlon 4 treatment averaged the highest percent living (26% for the January timing and 39% for the March timing). The treatment that provided the best level of control (the lowest percent of living privet) varied with the treatment timing. For example, for the January timing, the 10% and 20% vol/vol Garlon 4 treatments were the most effective treatments, with only 12% of the treated privet showing signs of life. For the March timing, Pathfinder II averaged the lowest percent living (10%).

There were significant differences between the treatments for the timing and treatment interaction. For the January timing, significant differences were found between the 5% and 10% vol/vol Garlon 4 treatments ($P = 0.051$) and between the 5% and 20% vol/vol Garlon 4 treatments ($P = 0.046$). For the March timing, significant differences were found between the lower concentrations (5% and 10% vol/vol Garlon 4) and the higher concentrations (20% vol/vol of Garlon 4 and Pathfinder II). There was no significant difference in percent living between Garlon 4 at 20% and Pathfinder II for either timing.

For the percent living, an interaction was seen between herbicide timings and site (Table 14). At the SWU site, the January timing had a lower percent living (8%) than the March timing (29%). However, at the AFC site the March timing showed a lower percent living (19%) than the January timing (27%). At both sites the difference in the timings was significant.

Discussion

Small differences in percent defoliation, number of sprouts, and sprout length had statistical significance. While interesting to know that our large data set was able to tease out these small differences, from an operational standpoint these minute changes would not likely influence the effectiveness of control. For example, all herbicide rates yielded an average percent defoliation of ≥ 95%. Despite such a high amount of defoliation, significant differences were found between the lower (Garlon 4 at 5% and 10%) and the higher (Garlon 4 at 20% and Pathfinder II) concentrations. From a statistical standpoint, these differences are important but from a control standpoint an average of 95-99% defoliation is excellent control. However, if complete control is desired then 100% defoliation would be necessary since any living crown would provide an opportunity for recovery from the herbicide treatment (Nelson et al., 2006). Land managers who are managing for complete control may find the difference between the Garlon 4 concentrations (≤ 99% defoliation) and Pathfinder II (100% defoliation) interesting. However, all of the herbicides treatments were highly effective at defoliating Chinese privet and for most land managers 95-99% control would be sufficient.

Low herbicide concentrations of Garlon 4 have effectively defoliated other species as well. For example**,** high amounts of defoliation (98.9%) were also seen from basal bark applications of Garlon 4 at 10% on American beech (Kochenderfer et al., 2004). However, lower triclopyr concentrations do not always yield high amounts of defoliation. For example, when a modified version of a basal bark application called a streamline basal spray (Miller et al., 2010) was applied on various hardwoods at a 5%, 10%, or 20% triclopyr concentration defoliation was 38%, 78%, and 84% respectfully (Yeiser et al., 1989).

When evaluating the effectiveness of a basal bark application, both percent defoliation and the number of live sprouts should be monitored since elevated light levels caused by increased defoliation can lead to basal sprouting (Bond and Midgley, 2001; Del Tredici, 2001). Once established, basal and lateral root sprouts have accelerated growth and vigor compared to seedlings, and re-infestation of the treated area is a possibility (Bond and Midgley, 2001). For this reason, the monitoring of sprouts after a basal bark application is important to evaluate the effectiveness of the herbicide treatment. All of the herbicide rates were effective at reducing sprouting. Untreated controls averaged 2.7-5.4 living sprouts per plant compared to 1.1-1.3 new sprouts for herbicide-treated privet. The small difference of ≤ 0.2 sprouts per plant for the lower (Garlon 4 at 5% and 10%) and higher (Garlon 4 at 20% and Pathfinder II) herbicide concentrations were statistically significant depending on the timing analyzed. However, from a land manager's perspective 0.2 sprouts per plant is likely negligible. Also, from a control perspective ≤ 1.3 new sprouts per plant would be considered effective control, especially when compared to the untreated controls that averaged 2.7-5.4 living sprouts per plant depending on site, timing, and MAT. Even with as little as ≤ 1.3 new sprouts per plant, follow-up treatments will be needed to prevent re-infestation (DiTomaso and Kyser, 2007).

Herbicide-treated privet produced shorter sprouts (≤ 11.5 cm or 4.5 in. average length per plant) than the controls, however, the lower herbicide concentrations (Garlon 4 at 5% and 10%) generally averaged somewhat longer sprouts. As seen with the number of sprouts, small differences (≤ 9.1 cm or 3.6 in.) in sprout lengths between the lower (Garlon 4 at 5% and 10%) and higher (Garlon 4 at 20% and Pathfinder II) concentrations were significantly different. However, the differences in sprout length probably wouldn't influence the follow-up control method.

Using lower herbicide concentrations can reduce the initial cost of herbicide applications (Kochenderfer et al., 2004), but potential financial gains may be lost if control is not achieved. To test if the lower herbicide rates provided effective control, the presence of leaves, sprouts, or both (% living) 18 MAT was analyzed. The percent living shows not only the growth that occurred after the herbicide application but can also demonstrate the need for follow-up treatments to obtain complete control. As seen in Table 12, the lower concentration herbicides (Garlon 4 at 5% and 10%) on average had 1.6-2.3 times larger percent living than the higher concentrations (Garlon 4 at 20% and Pathfinder II). This supports the findings of Yeiser et al. (1989) where an increased concentration of triclopyr led to greater herbicide efficacy and less regrowth on hardwoods in Arkansas. However, Kochenderfer et al. (2004) found Garlon 4 at 5% was effective on trees with thin bark. Our findings also suggest that Chinese privet treated with a lower triclopyr rate are prone to higher percent living and will require follow-up treatments consisting of foliar and/or basal spray applications to ensure high levels of defoliation are obtained and new sprouts are killed.

There were no significant difference between Garlon 4 at 20% and Pathfinder II for any of the response variables (percent defoliation, number of sprouts, sprout length, or percent living). Both Garlon 4 at 20% and Pathfinder II were extremely effective at defoliating Chinese privet (99% and 100% respectfully), reducing sprouting (around 1 new sprout per plant), and averaged the same percent living (14%) at 18 MAT. Non-significant differences in sprout length were seen between the two herbicides, however, which herbicide yielded the shorter sprouts was dependent on the timing (Garlon 4 at 20% for the January timing and Pathfinder II for the March timing). The difference in sprout length, however, is not concerning since there was no significant difference between the two herbicides for either timing.

When the herbicide treatments were compared based on timing, generally the herbicide treatments applied during the January timing maintained less percent living than those applied during the March timing (Table 13). Rhodenbaugh and Yeiser (1994) had similar findings where a dormant season (January or February) application of triclopyr on hardwoods in Arkansas produced better control than a growing season (May or June) application. However, an earlier study also conducted in Arkansas by Rhodenbaugh and Yeiser (1992) found basal bark applications of triclopyr on oak and sweetgum resulted in higher defoliation when applied during the growing season (an August spraying yielded 99.1%) than the dormant season (a January spraying yielded 87.4%). Yeiser and Boyd (1989) also reported that a streamline basal bark application of triclopyr applied during the growing season (June or September) provided significantly better control of hardwoods than a dormant season (February) application. In my experiment, both the January and the March timing resulted in good control with ≥ 95% defoliation and only approximately one new sprout per plant.

As with the herbicide concentrations, there were significant statistical differences between results for the two application timings that, from a biological perspective, may not lead to a change in the recommendation for the timing of control. For example, at the SWU site, percent defoliation for the two timings differed by only 5% yet was statistically significant. However, land managers could find the 5% difference important since it reflected the difference between good control (95% for the March timing) and complete defoliation (100% for the January timing). Another example is the sprout length at the SWU site, where a difference of 3.6 cm between the two timings was seen as statistically significant. Since Chinese privet is such a prolific sprouter, 3.6 cm (1.4 in) is not likely a biologically significant difference between the two timings.

The influence of the covariate effect (root collar diameter) on percent defoliation, number of sprouts, and sprout length was also influenced by timing. For example, root collar diameter had no effect on the response variables (percent defoliation, number of sprouts, and sprout length) for the January timing but did for the March timing, with privet with large root collar diameters more likely to produce more and longer sprouts. The negative correlation between diameter and herbicide efficacy as seen in the March timing has been observed in other research as well. For example, trees with a root collar diameter of 2.5 cm (1 in) experienced 80% percent defoliation while those with a root collar diameter of 5.0 cm (2 in) experienced 58% defoliation and those with a root collar diameter of 7.5 cm (3 in) experienced only 43% defoliation (Yeiser et al., 1989) with significant differences in percent defoliation occurring with a 2.5 cm (1 in) increase in diameter (Yeiser et al., 1989; Williams et al., 1996). A possible reason for the negative correlation between root collar diameter and herbicide efficacy could be an inability of large trees to translocate triclopyr throughout the plant (Schutzman and Kidd, 1987). Since a positive correlation between root collar diameter and bark thickness exists (Yeiser et al., 1989), another possible reason is an inability of the herbicide to penetrate the thicker, more mature, bark (Schutzman and Kidd, 1987). The negative correlation between stem kill and both root collar diameter and bark thickness (Yeiser et al., 1989) could support the idea of a thicker bark decreasing herbicide efficacy. However, as evidenced by the January timing, the negative correlation between diameter and herbicide efficacy does not always occur. For example, low volume basal bark applications of triclopyr on hardwoods resulted in ≥ 90% defoliation regardless of the root collar diameter with no significant differences in percent defoliation among the root collar diameters (Williams and Yeiser, 1995). Also, stem diameter did not influence herbicide efficacy on tree-of-heaven where an application of Garlon 4 at 20% resulted in $\geq$ 86% defoliation of the treated plants regardless of the size of the stem (DiTomaso and Kyser, 2007). Our findings of high percent defoliation and the low number of sprouts indicate that control was equally effective for Chinese privet with large root collar diameters.

The results from different sampling times, also known as months after treatment (MAT), were also analyzed. Given that preliminary measures at 3 MAT showed high defoliation (97%), land managers who aren't seeing significant defoliation within the first 6 months should be alerted that something could potentially be wrong with the treatments. As with the response variables, statistically significant differences in results as a function of MAT would not necessarily impact the methods of control. For example, differences in percent defoliation between 3 and 18 MAT were statistically significant ($P = 0.0467$) even though the difference was only 2%. This was also seen for the number of sprouts and for sprout length. For example, there was a significant difference ($P < 0.0001$) between the number of sprouts produced at 6 and 18 MAT for the January timing even though the averages differed by only 0.14 sprouts and by only 3 cm (1.2 in) in length. From a biological perspective, a difference of 0.14 sprouts or 3 cm (1.2 in) in sprout length is negligible.

Even though there was only a small biological difference in the number or length of sprouts between 6 and 18 MAT, the treated area should still be monitored for the growth of new leaves and sprouts to prevent re-infestation. All of the treatments resulted in $\leq$ 32% living, however, none of the herbicide treatments averaged 100% control (0% living). Based on these results, even the most effective treatment and timing combination would require follow-up treatments (foliar treatments to existing sprouts or an additional basal spray) to have complete Chinese privet control.

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Table 1. Maximum and minimum estimates for all response variables following basal bark application to Chinese privet.

Treatment	Defoliation		New sprouts		Sprout length		Total number of sprouts	
	Max	Min	Max	Min	Max	Min	Max	Min
	-----%-----		------- #/ plant -------		---- cm / plant ----		--- # /plant ---	
Control	61	11	5.4	4.1	793	506	5.4	2.7
Garlon 05	100	78	0.9	0.0	49	0	0.9	0.0
Garlon 10	100	81	1.2	0.0	53	0	1.2	0.0
Garlon 20	100	92	0.8	0.0	38	0	0.8	0.0
Pathfinder II	100	91	1.2	0.0	43	0	1.2	0.0

Table 2. Regression estimates from ANCOVA using the natural log-transformed root collar diameter as a covariate for basal bark applications on Chinese privet.

Response Variable/		95% Confidence Interval	
Timing	Estimate	Lower	Upper
% Defoliation			
January	-0.5126	-1.3728	0.3476
March	-1.8663	-2.2523	-1.4803
# of Sprouts			
January	-0.0175	-0.0820	0.0470
March	0.1102	0.0643	0.1562
Sprout Length (cm)			
January	-0.0123	-0.2079	0.1833
March	0.4266	0.2857	0.5675

Table 3. Chinese privet percent defoliation and simulated adjusted *P*-values for herbicide treatments. *P*-values < 0.1 were considered significant.

		95% Confidence Interval		Sim. adj. *P*-vaules vs. Garlon 4 @:		
Treatment	Mean	Lower	Upper	10%	20%	Pathfinder II
	------------------%------------------					
Garlon 4@ 5%	97	94	98	0.9902	0.0065	0.0013
Garlon 4 @ 10%	97	95	98		0.0116	0.0026
Garlon 4 @ 20%	99	98	100			0.8270
Pathfinder II	100	99	100			

Table 4. Percent defoliation means for the site x timing interaction for basal bark herbicide-treated Chinese privet and the *P*-values comparing the timings. *P*-values < 0.1 were considered significant.

Site/ Timing	Mean	95% Confidence Limits Lower	Upper	Contrast Jan vs. March
	-----------------%-----------------			
AFC Site				
January	99	98	100	0.2613
March	98	97	99	
SWU Site				
January	100	99	100	<0.0001
March	95	92	96	

Table 5. Percent defoliation means and simulated adjusted *P*-values for MAT for basal bark herbicide treated privet. *P*-values < 0.1 were considered significant.

		95% Confidence Interval		Sim. adj. *P*-vaules vs.		
MAT	Mean	Lower	Upper	MAT 6	MAT 12	MAT 18
	-------------%-------------					
3	97	96	98	0.5518	0.1282	0.0467
6	98	97	99		0.7591	0.3754
12	99	98	100			0.8983
18	99	98	100			

Table 6. Timing x treatment interaction means for the newly formed sprouts and simulated adjusted *P*-values comparing the herbicide treatments. *P*-values < 0.1 were considered significant.

				Sim. adj. *P*-values vs.		
		95% Confidence limits		Garlon 4 @:		
Month/ Treatment	Mean	Lower	Upper	10%	20%	Pathfinder II
	----------- N $plant^{-1}$	-------------				
January						
Garlon 4@ 5%	1.2	1.15	1.34	0.235	0.017	0.838
Garlon 4 @ 10%	1.1	1.04	1.21		0.712	0.738
Garlon 4 @ 20%	1.1	0.99	1.15			0.155
Pathfinder II	1.2	1.10	1.28			
March						
Garlon 4@ 5%	1.3	1.17	1.34	0.528	0.199	0.086
Garlon 4 @ 10%	1.3	1.25	1.43		0.004	0.001
Garlon 4 @ 20%	1.1	1.07	1.22			0.978
Pathfinder II	1.1	1.05	1.20			

Table 7. Means for the Timing x MAT interaction for newly formed sprouts and simulated adjusted *P*-values comparing MAT. *P*-values < 0.1 were considered significant.

Timing	MAT	Mean	95% Confidence limits Lower	Upper	Sim. adj. *P*-values vs. MAT 12	MAT 18
		----------- N $plant^{-1}$	-------------			
January	6	1.08	1.03	1.13	0.0007	<0.0001
	12	1.16	1.12	1.22		0.2186
	18	1.22	1.15	1.28		
March	6	1.21	1.16	1.26	0.2004	0.2458
	12	1.17	1.13	1.22		0.0065
	18	1.26	1.20	1.32		

Table 8. Site x timing interaction means and the 95% confidence intervals for newly formed sprouts after basal bark application to Chinese privet.

Timing/ Site	Mean	95% Confidence limits Lower	Upper
	----------- N $plant^{-1}$	-------------	
January Timing			
AFC site	1.24	1.18	1.31
SWU site	1.07	1.01	1.13
March Timing			
AFC site	1.22	1.16	1.28
SWU site	1.20	1.15	1.26

Table 9. Sprout length means for the timing x treatment interaction and adjusted *P*-values comparing the herbicide treatments. *P*-values < 0.1 were considered significant.

Timing/		95% Confidence Interval		Sim. adj. *P*-vaules vs. Garlon 4 @:		
Treatment	Mean	Lower	Upper	10%	20%	Pathfinder II
	------------- cm / plant -------------					
January						
Garlon 4 @ 5%	6.5	3.70	11.57	0.1123	0.0063	0.5395
Garlon 4 @ 10%	2.6	1.48	4.64		0.7503	0.8079
Garlon 4 @ 20%	1.7	0.97	3.10			0.2307
Pathfinder II	3.8	2.11	6.82			
March						
Garlon 4 @ 5%	7.3	4.33	12.19	0.6028	0.0431	0.0186
Garlon 4 @ 10%	11.5	6.88	19.24		0.0008	0.0003
Garlon 4 @ 20%	2.7	1.64	4.59			0.9909
Pathfinder II	2.4	1.46	4.10			

Table 10. Sprout length mean response to Chinese privet basal bark application applied either March 2009 or January 2010. Simulated adjusted *P*-values comparing the two timings are also displayed. *P*-values < 0.1 were considered significant.

Site/ Timing	Mean	95% Confidence Limits Lower	Upper	Contrast Jan vs. March
	------------- cm / plant	-------------		
AFC Site				
January	6.6	4.13	10.55	0.2372
March	4.5	2.97	6.89	
SWU Site				
January	1.6	1.13	2.29	< 0.0001
March	5.2	3.86	7.09	

Table 11. Sprout length means and simulated adjusted *P*-values comparing MAT by treatment timing. *P*-values < 0.1 were considered significant.

Timing/		95% Confidence Interval		Sim. adj. *P*-vaules vs.	
MAT	Mean	Lower	Upper	12 MAT	18 MAT
	------------- cm / plant -------------				
January					
6	2.0	1.39	2.76	0.0010	< 0.0001
12	3.6	2.53	4.99		0.2090
18	5.0	3.31	7.49		
March					
6	4.8	3.54	6.52	0.2190	0.2466
12	3.7	2.77	5.06		0.0088
18	6.4	4.46	9.24		

Table 12. Means for percent living Chinese privet following basal bark application and the simulated adjusted *P*-values comparing the herbicide treatments. *P*-values < 0.1 were considered significant.

		95% Confidence limits		Sim. adj. *P*-values vs. Garlon 4 @:		
Treatment	Mean	Lower	Upper	10%	20%	Pathfinder II
	------------------% Living------------------					
Garlon 4@ 5%	32	27	38	0.069	0.003	0.004
Garlon 4 @ 10%	22	17	27		0.086	0.099
Garlon 4 @ 20%	14	10	18			0.999
Pathfinder II	14	10	19			

Table 13. Means and 95% confidence intervals for the treatment and timing interaction for percent living Chinese privet following basal bark application. Also displayed below are the simulated adjusted *P*-values comparing the herbicide treatments. *P*-values < 0.1 were considered significant.

				Sim. adj. *P*-values vs.		
		95% Confidence limits		Garlon 4 @:		
Timing/ Treatment	Mean	Lower	Upper	10%	20%	Pathfinder II
	------------------% Living ------------------					
January						
Garlon 4@ 5%	26	19	34	0.051	0.046	0.361
Garlon 4 @ 10%	12	7	19		1.000	0.417
Garlon 4 @ 20%	12	7	18			0.384
Pathfinder II	18	12	25			
March						
Garlon 4@ 5%	39	31	48	0.716	0.008	0.002
Garlon 4 @ 10%	34	26	42		0.021	0.005
Garlon 4 @ 20%	16	10	23			0.459
Pathfinder II	10	6	16			

Table 14. Means and 95% confidence intervals for the site and timing interaction for percent living Chinese privet following basal bark herbicide application. Also displayed below are the simulated adjusted *P*-values comparing the timings. *P*-values < 0.1 were considered significant.

Site/ Timing	Mean	95% Confidence Limits Lower	Upper	Contrast Jan vs. March
	------------------% Living	------------------		
AFC Site				
January	27	22	33	0.033
March	19	14	24	
SWU Site				
January	8	5	12	≤ 0.001
March	29	23	34	