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AN EVALUATION OF APPLICATION TIMING AND HERBICIDES TO CONTROL AILANTHUS ALTISSIMA

A Thesis in

Horticulture

by

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ABSTRACT

Ailanthus (*Ailanthus altissima* [Mill.] Swingle) has become naturalized across the continental United States. Along roadside right-of-ways it can be a visual hindrance and road hazard if left untreated. When mechanically cut by roadside crews this plant sprouts quickly and aggressively from the stump and root system adding to routine maintenance costs. Previous research has indicated that treating cut stumps with herbicide limits sprouting and that treatment timing may further enhance sprout control. The focus of my research was to study the control of this tree species by evaluating (1) cut stump and herbicide treatment timing, (2) a series of herbicide modes of action on cut stumps, and (3) basal bark herbicide application timing. Measurements of surviving growth including root and stump sprouts were used to determine levels of control. All timing and herbicide treatments were effective in controlling the emerging stump sprouts with cut surface treatments. Herbicide-treated stumps showed 84 to 99% stump mortality compared to 41 to 52% for cut but untreated stumps. Root sprout numbers far exceeded the number of originally cut trees for all herbicide and timing treatments. Basal bark treatment, which is much more economical to perform, provided 100 percent control of treated stems, but resulted in root sprout numbers greater than the number of originally treated trees. This work increases our understanding on the role of application timing, treatment methods, and herbicide selection on the sprouting response of Ailanthus.

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Chapter 1

Introduction

Ailanthus (*Ailanthus altissima* [Mill.] Swingle) has several common names including tree-of-heaven, Chinese sumac, stinking sumac, and Brooklyn palm. *Ailanthus altissima* is native to eastern China but the genus consists of several species and varieties native to other areas including: Central and Southern Asia, North Australia, China, and the East Indies (Fry, 2010). Figure 1-1 shows the native range of *Ailanthus altissima* (Mill.) Swingle var. altissima covering most of eastern China and related variety *Ailanthus altissima* (Mill.) Swingle var. sutchuenensis (Dode) Rehder & E.H. Wilson.

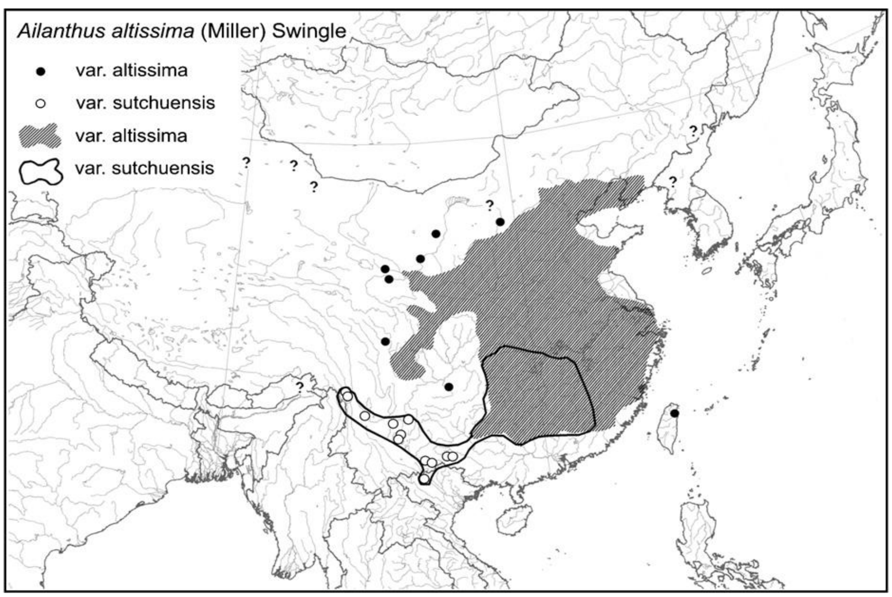

Figure 1-1. Native range of *Ailanthus altissima* (Mill.) Swingle var. altissima and *Ailanthus altissima* (Mill.) Swingle var. sutchuenensis (Dode) Rehder & E.H. Wilson in China and North Vietnam (Kowarik and Säumel, 2007).

Ailanthus was deliberately brought to other parts of the world and now includes a secondary range (Figure 1-2) (Kowarik and Säumel, 2007; Fry, 2010). The species was introduced first to Europe in the 1750s and then expanded its range worldwide (Fry, 2010).

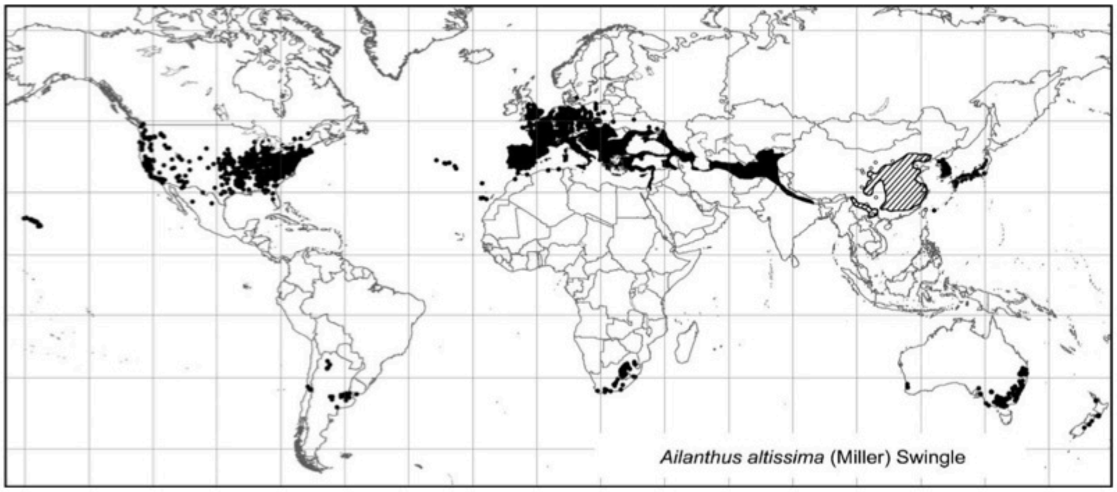

Figure 1-2 Native and secondary range of *Ailanthus altissima*. Native range is indicated by hash marks and found in Eastern China. Black areas indicate the species naturalized range worldwide (Kowarik and Säumel, 2007).

In 1751, Father D'Incarville, a missionary, brought or sent Ailanthus seed from China to London after mistaking the tree for the Chinese lacquer tree (*Toxicodendron vernicifluum* [Stokes] F.A. Barkley) (Feret, 1985; Hu, 1979). Popularity for the tree grew. It was cultivated and quickly spread throughout Europe and continues to be sold and used in urban landscape settings as a street tree. A gardener from Philadelphia, William Hamilton, introduced this species to America in 1784 (Feret, 1985; Hu, 1979). During the 1800's this species was cultivated and used extensively for this purpose throughout urban settings, like Baltimore and Washington D.C. Later Chinese immigrants introduced the plant to California. Currently Ailanthus can be found throughout the Americas extending east to west from Massachusetts to Oregon and north to south from Toronto, Canada to Tucuman, Argentina (Hu, 1979). Populations of Ailanthus can presently be found in 42 of the 50 states in the United States (Figure 1-3).

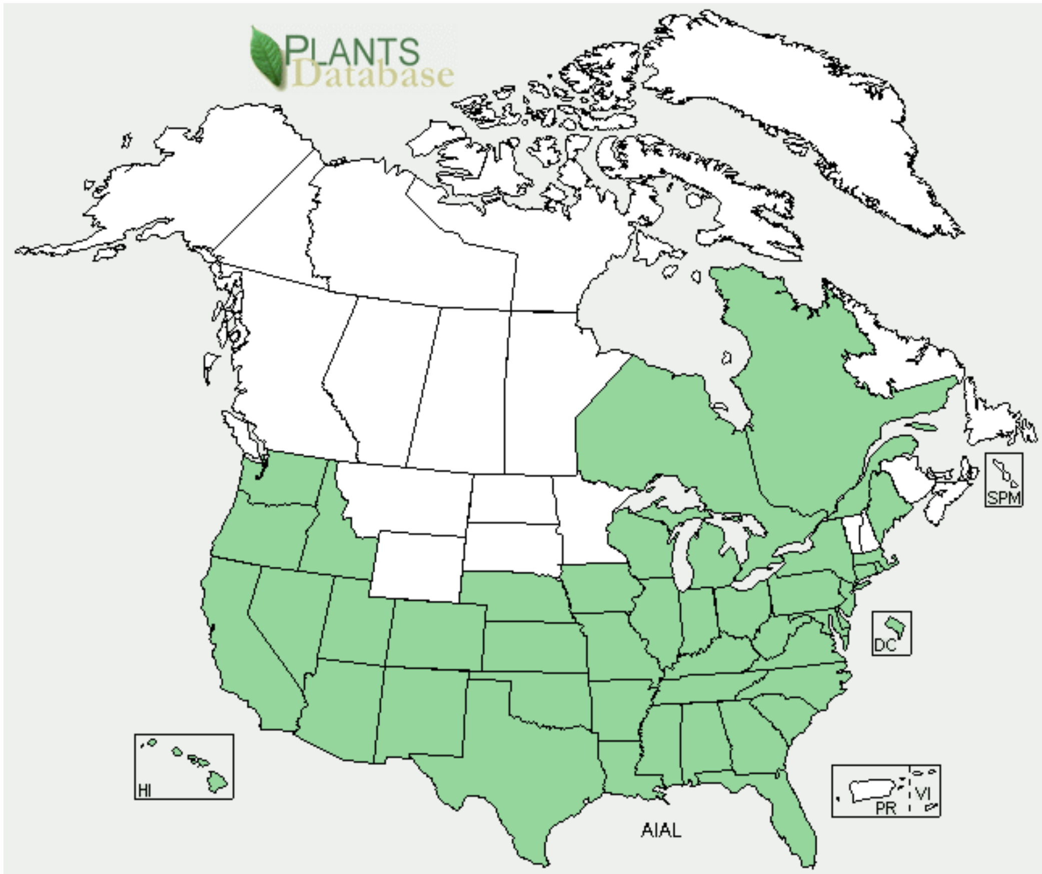

Figure 1-3. U. S. distribution of Ailanthus altissima (Mill.) Swingle. http://plants.usda.gov

Identification

Mature Ailanthus leaves are large and pinnately compound from 20 to 60 cm in length with 4 to 35 leaflets (Hu, 1979). The margins of the leaflets are smooth except for 2 to 4 glandular teeth located near the base (Hu, 1979) (Figure 1-4). Leaves are similar in appearance, and often confused with species like black walnut (*Juglans nigra* L.), staghorn sumac (*Rhus typhina* L.), and butternut (*Juglans cinerea* L.). Ailanthus has several other distinguishing characteristics: branch arrangement is alternate on the stem, bark is gray with light colored lengthwise streaks; branches are stout and yellowish to reddish-brown and smooth or velvety; large leaf scars; small yellowish-green flowers in large panicles; and clusters of samaras (Dirr 2009; Hu 1979). The male flowers and bruised leaves give off a strong odor that some find unpleasant (Peigler, 1993; Hu, 1979).

Figure 1-4: Closeup of a pinnately compound leaf of Ailanthus showing the smooth margins and 2 to 4 glandular teeth at base of each leaflet.

Ailanthus is dioecious, meaning staminate (male) and pistillate (female) flowers are borne on separate trees. While both produce flowers only the female plants bear fruit. Mature samaras develop and vary in color. Hu (1979) notes that Boston has two forms of the species, specifically *A. altissima f altissima* with greenish-yellow and *A. altissima f erythrocarpa* with reddish-yellow samaras.

Growth Characteristics

Ailanthus is dense shade intolerant (Davies, 1944; Feret, 1985; Knapp and Canham, 2000; Kowarik, 1995) thriving in full sun to partial shade. In forested settings it is most often found in disturbed sites where the forest canopy has been removed or reduced through clearing or timber harvesting (Kowarik and Säumel, 2007; Fry, 2010). Ailanthus is a colonizing species that develops over time into large clonal patches through root sprouting (Kowarik and Säumel, 2007) (Figure 1-5). A few native tree species with similar clonal growth habits include quaking aspen (*Populus tremuloides* Michx.), black locust (*Robinia pseudoacacia* L.), and sassafras (*Sassafras albidium* [Nutt.] Nees) (Burns and Honkala, 1990). The species can grow to heights of 17 to 27 m (Davies, 1941; Miller, 1990). As a colonizing species, Ailanthus can also be found invading agricultural production areas where regular disturbance occurs through annual cultivation (e.g., row crops-Figure 1-6) and tree harvesting (e.g., Christmas tree farms). In both of these full sun sites colonies of Ailanthus can be found developing as seedlings of windblown seed or through vegetative propagation of root fragments during tillage and digging operations.

Figure 1-5: Ailanthus stand along SR 220 near Bellefonte, PA illustrating the clonal nature of Ailanthus.

Figure 1-6: Ailanthus invading a cornfield near Newport, PA in early September 2005, illustrates the aggressive nature of this plant with one season of growth.

Ailanthus is amazing in its ability to establish in disturbed, often stressful, habitats like pavement cracks and crevices, landfills, or mine spoils (Kowarik and Säumel, 2007). Ailanthus appears to tolerate a wide range of soil conditions growing in soils ranging from shaley and marginal for tree growth to highly fertile, deep loam agricultural soils (Figures 1-5 and 1-6) (Davies, 1941; Davies, 1944). In contrast, Feret (1985) mentions that Ailanthus may establish in poor gravely and dry sites although it did not thrive or rapidly grow under those conditions. The rapid adoption and spread of Ailanthus as an urban street tree in Europe and the United States was in part due to its tolerance to a wide range of soil conditions, drought resistance, and to its high tolerance to pollution (Davies 1941; Davies, 1944; Peigler, 1993).

In addition, Ailanthus has few serious pest problems that make it an attractive plant for use in urban landscapes (Peigler, 1993; Dirr 2009). Insect pests known to feed on Ailanthus include ailanthus webworm (*Atteva punctella*), Cynthia moth (*Samia cynthia*), and Asiatic garden beetle (*Maladera castanea*) (Miller 1990). Noted diseases that infect it are Verticillum wilt (*Verticillium albo-atrum*), shoestring root rot (*Armillaria mellea*), leaf spots, twig blight, and cankers (Dirr, 2009; Miller, 1990). *Verticillium* wilt appears to be the greatest threat to the species (Dirr, 2009; Miller, 1990). Herbivory by deer (*Odocoileus virginianus*) has been observed but typically they prefer other species (Kowarik and Säumel, 2007).

Sexual and Asexual Reproduction

Once established, a parent plant spreads by both seed and roots. Seeds are often dispersed by wind and wind is considered the primary means of dispersal of this plant along major transportation corridors. Linear wind currents created by traffic along paved roads disperse seed and expand the size and scope of infestations (Kowarik and Säumel, 2007). Seed deposited in close proximity to the parent plant contributes to the density of an infestation, but spread by roots from the parent plant plays a major role in expanding the boundaries of these clonal populations (Pan and Bassuk, 1986).

Female trees can produce up to 325,000 seeds per year (Kowarik and Säumel, 2008) contributing greatly to the spread of this species. Flowering maturity is reached within 3 to 5 years, but the greatest seed production occurs between 12 and 20 years of age (Kowarik and Säumel, 2007). The samaras hang on the tree in large clusters. Seed clusters often overwinter on the branches before dropping from the tree. Seeds can be dispersed by wind up to 100 m from the parent tree (Landenberger et al., 2007; Aldrich et al., 2010; Kowarik and Säumel, 2007).

Once on the ground, seeds rapidly germinate resulting in first year seedling growth of 1 to 2 m (Hu, 1979). Ailanthus seed is viable for at least one year with variable germination rates (Kowarik and Säumel, 2007). Germination does not require stratification but increases with stratification and increasing light intensity (Kowarik and Säumel, 2007). Germination rates have been demonstrated to vary with soil type from 55 to 71 percent when comparing sand, rubble, and peat substrates (Kowarik and Säumel, 2007). At constant temperatures of 25°C germination rates reach 98% and short 3-day imbibition of seeds in water increased germination to 87% (Kowarik and Säumel, 2007).

Establishment rates are high for seedlings introduced to disturbed open sites. According to DenUyl (1962), 74% of seedlings survived the first growing season on 11 different plantings on Indiana strip mine sites. The percentage decreased to 58% following the first winter demonstrating that environmental factors can inhibit development (DenUyl, 1962). This observation also suggests that heavy seed load production by Ailanthus is a strategy to assure survival and establishment in inhospitable sites. Mitich (1999) suggests that plants can use high seed production and high germination rates as a mechanism to displace native flora.

The shade intolerance of Ailanthus plays an obvious role in the reproductive success. Davies (1944) observed that seedlings of Ailanthus were very sensitive to crowding and constant shade. Feret (1985) also observed very high mortality rates in attempts to establish Ailanthus from seed and proposed that Ailanthus sprouts from root systems account for a large percentage of new plants. Kowarik (1995) confirmed Feret's supposition by reporting that root sprouts were able to survive for several years under forest canopies while demonstrating minimal growth rates. In support of this observation, Knapp and Canham (2000) observed that in old growth forests, Ailanthus tended to take advantage of gaps in forest communities and rapidly grow to fill the void.

Small plants from root sprouts appear to develop beyond the extent of the canopy of the primary tree allowing the colony to enlarge (Pan and Bassuk, 1986). As the tree matures an extensive, but fairly shallow root system develops (Miller, 1990). It is a common survival mechanism when competing for nutrients to allocate increased biomass to the roots to be more competitive for those resources (Aerts et al., 1991). These exploring roots give rise to sprouts that develop into mature trees if enough available light and other environmental conditions allow. With the support of the parent plant and without the inhibiting effects of shade these sprouts quickly develop into new trees. Once established 0.9 m to 1.5 m of growth per season is typical for an average growing season as observed in Denver, Colorado (Peigler, 1993).

The species can spread through the movement of root fragments by excavation, tillage, or water. Kowarik and Säumel (2008) demonstrated that water-dispersed, root fragments are a viable pathway for movement. Once a root piece has been displaced and carried to a new site, a new plant can develop from this single fragment (Kowarik and Säumel, 2008). Additionally, cutting trees results in prolific stump and root sprouts. A mechanical operation meant to eliminate the population often only encourages the vegetative propagation and expansion of the plant's footprint.

Allelopathic Characteristics

Ailanthus is a fierce competitor in the landscape. This tree species contains one or more compounds that inhibit plant growth (Heisey, 1990). Four quassinoids (ailanthone, amarolide, acetyl amarolide, and 2-dihydroailanthone) have been identified in Ailanthus (Heisey, 1990). Inhibitors were discovered within roots, bark, leaflets, and wood in order from greatest to least activity. Seeds also contain inhibitors (Heisey, 1990). Ailanthone was shown to have herbicidal effects (Heisey, 1997). It is uncertain though whether these chemicals are meant to eliminate plant competition or defend against herbivores or disease pests (Heisey, 1997).

Invasive Issues

Ailanthus is a troublesome species on the right-of-way for several reasons: 1) rapid growth, 2) displaces desired or native vegetation, 3) creates safety issues, and 4) resists common control measures.

Rapid vertical growth combined with horizontal spread through root growth and root sprouting to colonize an area make Ailanthus an aggressive competitor in the unmanaged and managed landscape and aid in overwhelming native plant communities. The tree typically grows quickly to an age of 20 years under favorable conditions (Kowarik and Säumel, 2007). In fact, Ailanthus is possibly the fastest growing tree in the northeastern United States (Kowarik and Säumel, 2007; Knapp and Canham, 2000). Ailanthus can grow 17 to 27 m high with rapid growth occurring early in the life of the tree and diminishing to less than 8 cm per year after age 20 or 25 (Miller, 1990; Feret, 1985).

As the stand continues to mature it spreads further by roots and its ability to produce and disperse seeds multiplies and expands as the number of clonal trees increase and grow in the colony. One stand in a roadside setting was observed to have extended to a length of 120 m (Kowarik and Säumel, 2007).

Ailanthus spreads into openings and edge habitats (Pan and Bassuk, 1986). Monotypic stands form and create a negative impact on natural resources and native species (Fry, 2010). In several states Ailanthus is listed as noxious (Vermont), invasive (Conneticut, New Hampshire), or prohibited (Massachusetts) (USDA, NRCS, 2011).

Individual stems are usually short-lived, surviving for only 30 to 50 years (Miller, 1990); but clones produced from the root system offer a nearly limitless lifespan (Kowarik and Säumel, 2007). As the tree reaches maturity (beyond 30 years) the wood becomes brittle, potentially breaking in strong winds, and creating safety concerns along the right-of-way (Hu, 1979).

Wind and soil disturbance along major transportation corridors have already helped to spread this plant. Roadways have provided an opportunity for Ailanthus to move from the urban areas as road networks expanded and new corridors were cleared. The colonizing nature of Ailanthus appears highly resilient and adapted to traditional mechanical control methods and standard roadside construction and management. Site surveys along roadsides and interstates in Virginia and North Carolina have documented the presence and expansion of Ailanthus along transit corridors (Merriam, 2003; Stipes and Witt, 1995).

In a standard pest management system there are several control methods that can be deployed alone or in combination. These control methods include: biological, cultural, mechanical, and chemical. With a species like Ailanthus each method must be considered in developing a successful management plan and the advantages and disadvantages should be considered in developing that plan.

Ailanthus Control Methods

The control methods being actively deployed against Ailanthus are: 1) establishing and maintaining competitive ground covers (e.g., creeping red fescue (*Festuca rubra* L.)), 2) developing biological control systems (e.g., *Verticillium albo-atrum* and *V. dahlia*), 2) using mechanical control systems (e.g., tree removal), and chemical control (e.g., broadleaf herbicides like triclopyr applied foliarly or to cut surfaces). The unique growth rate and clonal nature of Ailanthus creates some additional challenges to success with each system and working experience suggests that a combination of approaches are necessary to control and revegetate an invaded area with an acceptable and manageable ground cover especially along roadside edges.

Cultural Control

Practices such as fertilization, herbicide applications, or mowing that are used to maintain a healthy desirable groundcover while at the same time discouraging unwanted plants are standard cultural approaches along the roadside. Groundcovers serve an important purpose along our roadways by stabilizing the soil and forming dense, competitive stands that crowd out unwanted plant species. As vegetation managers encourage alternate groundcovers fewer undesirable plants have the ability to get a foothold, including Ailanthus (Gover et al., 2006).

Biological Control

Biological controls use living organisms to deter establishment and kill undesirable species. Organisms such as insects, fungi, bacteria, viruses, vertebrates, or even other plants can fall into this category. Ailanthus has no known naturally occurring insect or disease problems in the United States that threaten its survival. There are several insect and disease organisms that cause damage. Two species of *Verticillium* have been investigated as potential biological control agents against Ailanthus including *Verticillium albo-atrum* and *V. dahliae* with promising results (Schall, 2008). Trials evaluating effects on non-target species in naturally occurring stands are underway and have not been reported in the literature (Schall and Davis, 2009).

Investigations have also been performed using fungal pathogens to control stump sprouts on woody species. Some concerns arise when using naturally occurring fungi like *Chondrostereum purpureum*, known as silverleaf disease. Gosselin et al. (1999) reported deploying strains of this fungi showed no adverse risk to other forest trees as naturally occurring strains were the main source for infection.

There is promise of using naturally occurring biocontrol agents for Ailanthus control. However, much work is needed to ensure that non-target plants are not susceptible to the introduced agent. Continued investigation will help to provide a sound risk assessment prior to the adoption of these biocontrol agents in control of Ailanthus (Schall and Davis, 2009).

Mechanical Control

Mechanical control refers to cutting or physical removal of existing plants. Whereas this option is acceptable for some plant species, once Ailanthus becomes established this method alone is not effective. Hand pulling small seedlings can be useful in eliminating plants from confined landscapes such as ornamental beds. Care must be taken to prevent root parts from breaking off and remaining in the soil where they can regenerate from remnant fragments.

Cutting or clipping off the aboveground portion of an established plant has been found to stimulate sprouting and increases stand density. Burch and Zedaker (2003) observed that manual cutting resulted in 79% of stumps sprouting with an average 1.6 sprouts per stump. The time of year of cutting has been shown to significantly impact sprouting. Dumas et al. (1997) observed the number of *Populus* stumps with sprouts varied significantly with the time of cutting. A late September cutting resulted in the greatest number of stumps to sprout while late August cutting produced the least.

Removing the aboveground portions of plants during periods of low carbohydrate reserves may result in increased mortality and reduced sprouting. In the case of perennial, woody deciduous species this would occur from full canopy development to flowering. This provides a window from May to July in Pennsylvania as Dirr (2009) reports flowering occurs mid-June.

Once flowering has occurred carbohydrate reserves begin to accumulate in the roots (Figure 1-7). This process provides the roots with greater energy reserves and further potential to generate sprouts and would explain the observations by Dumas et al. (1997).

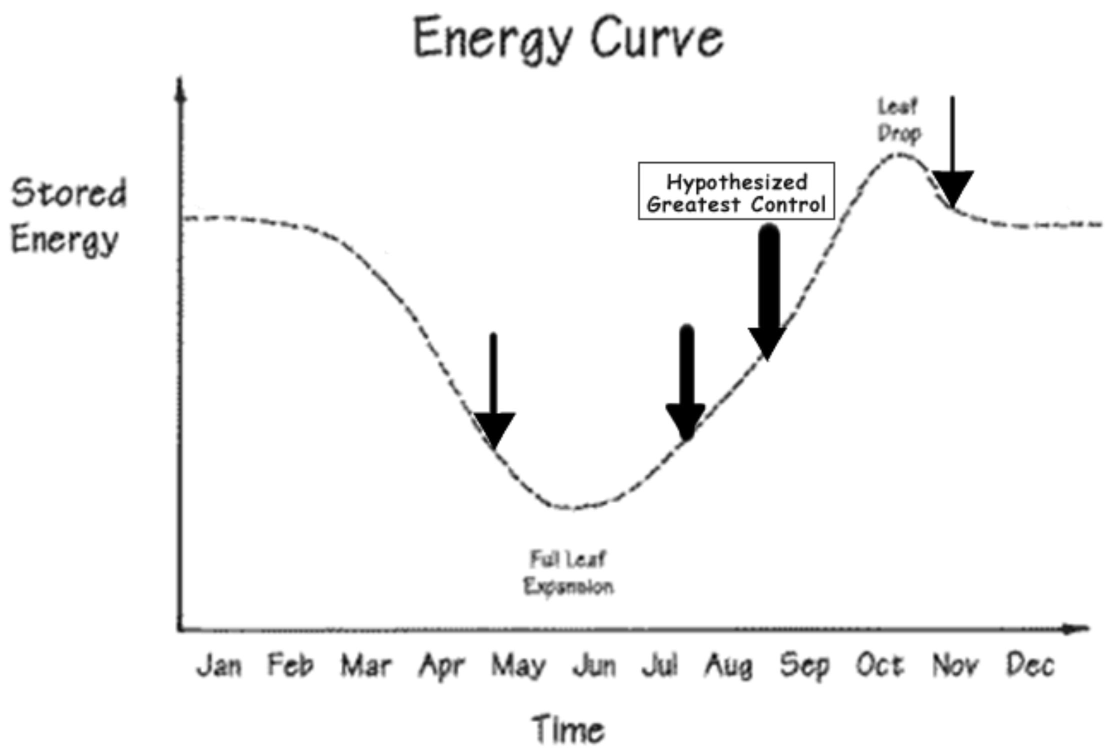

Figure 1-7: Stored energy curve. This conceptualized graph illustrates movement of carbohydrates from the root system to full leaf expansion followed by movement to the roots through leaf drop. Courtesy David Stephenson, “A systems approach to tree care” (Wisconsin Urban & Forestry Newsletter – vol. 1 Spring, 1993). Arrows depict the targeted treatment timings and anticipated best to worst control of root sprouts based on projected phloem movement occurring during those times. Widest arrow predicts greatest control, intermediate widths lesser control, and narrowest the least control.

Chemical Control

Chemical control of Ailanthus typically relies on four application methods: 1) soil active granular herbicides, 2) foliar, 3) cut stump, or 4) basal bark treatments. Timing of the treatment may also have a tremendous influence on control, especially of the root system. While mechanical treatments are encouraged during periods of low carbohydrate levels in the roots (May-July, Figure 1-7), the movement of carbohydrates to the roots post-flowering may provide the best opportunities for foliar and stem chemical applications. Many herbicides are phloem mobile (Devine and Hall, 1990). This movement of herbicides with the flow of carbohydrates could provide an opportunity to assist them in reaching the roots and providing greater control (Figure 1-7).

Granular Method

Granular treatments are conducted by spreading soil active herbicides in pelletized form within proximity of unwanted vegetation. After solubilizing in the soil, the herbicide is taken up by the plant root system. Because granular herbicides are applied to soil and taken up by roots they are somewhat indiscriminate in controlling vegetation. There are granular herbicides that selectively control monocots or dicots; however, those currently used for control of Ailanthus are typically non-selective.

The active ingredient tebuthiuron is effective at controlling Ailanthus infestations (Gangstad, 1989). It is manufactured in a pelletized form, but caution must be observed with its use. Desirable plants will also readily absorb this active ingredient. This includes other tree species as well as forbs (Gangstad, 1989). The application requires soil moisture for movement into the roots but should not be applied to frozen or saturated ground (Gangstad, 1989). The product is persistent in the environment with an average half-life of 360 days in soil (Cornell, 2011). Concerns for leaching and groundwater contamination are high for this product due to its persistence and solubility (Cornell, 2011).

Foliar Methods

Foliar treatments can be further classified into high or low volume spray applications. High volume relies on a hydraulic pump and tank with a large capacity. Spray volumes of 900 to 3700 L/ha are typical with this approach (Dow, 2011a). It is an effective method for reaching higher and further into the canopy and allows the applicator to better penetrate the understory. Equipped with a length of hose and spray gun, an applicator can significantly reduce the number of smaller trees within the understory of Ailanthus infestations. This allows for greater access to follow up on uncontrolled larger trees during subsequent visits to the site.

Low volume foliar treatments are those with carrier volumes less than 900 L/ha (Dow, 2011a). Backpack or handheld sprayers are among the equipment used to make low volume foliar treatments. Lower carrier volumes require increasing herbicide concentrations. Liu et al. (1996) observed increased absorption and movement of glyphosate with increasing herbicide concentrations over a range of droplet size and droplet number. This suggests that by decreasing carrier volume an applicator can still be effective if proper herbicide amounts are contacting the plant. The low volume and pressure produced from this equipment prevent the spray pattern from reaching more than 3 to 4.8 m high. Similarly by carrying backpack-mounted sprays and using low volumes, applicators can travel long distances through rugged terrain to reach isolated or small infestations of Ailanthus where high volume spray units cannot reach. Low volume spray applications also reduce the potential for off target damage, protect desirable understory plants, and can be used to treat colonies missed by high volume applications.

In managing forest vegetation there is no single herbicide mixture that provides the best control in all situations (Nespeca et al., 1998). A sample of the many active ingredients commonly suggested for general brush control treatments are glyphosate, imazapyr, triclopyr, picloram, dicamba, and metsulfuron methyl. A glyphosate plus imazapyr mix has proven to be effective in controlling Ailanthus stands in large-scale demonstrations performed by the author encompassing up to 23 linear kilometers of right-of-way. Nespeca et al. (1998) also found that a combination of glyphosate and imazapyr appeared to control additional species like black cherry (*Prunus serotina* Ehrh.) and winged elm (*Ulmus alata* Michx.)

Triclopyr is another active ingredient labeled for general brush control using foliar treatments. Triclopyr is available in either an amine (Garlon® 3A) (Dow AgroSciences LLC, Indianapolis, IN) or ester (Garlon®4) (Dow AgroSciences LLC, Indianapolis, IN) formulation. Uptake and transport appear to be similar for either the amine or ester formulation (Bovey et al., 1983). Triclopyr is selective and does not control grasses, which may be attributed to the rate of metabolism within the plant. Lewer and Owen (1990) observed faster metabolism of the triclopyr acid using the ester formulation when applied to the cereals wheat (*Triticum aestivum*, cv Norman) and barley (*Hordeum vulgare*, cv Igri) compared to chickweed (*Stellaria media*).

Triclopyr ester (Garlon® 4) was commercially formulated with kerosene as a carrier. Work done by Zedaker et al., (1995) has shown that vegetable-based solvents can provide equal or enhanced control when mixed with triclopyr ester, compared to kerosene, when applied to the adaxial surface of the leaf while also improving environmental safety. More recently DowAgro Sciences (Indianapolis, IN) has replaced the kerosene contained in Garlon® 4 with a methylated seed oil solvent (Garlon® Ultra).

Triclopyr has little to no soil activity at typical use rates. This provides a margin of safety against non-target damage. The herbicide has been shown to have a half-life ranging from 10 to 138 days in the soil depending upon environmental conditions (Ahrens, 1994; Johnson et al., 1995; Norris et al., 1987; and Stephenson et al., 1990). Triclopyr is degraded more rapidly with increased temperatures (Johnson et al., 1995) and exposure to sunlight (Crosby and Tutgrass, 1966; McCall and Gavit, 1986). Where desirable vegetation exists in the proximity of the treatment area triclopyr may be the proper choice.

Once within the plant triclopyr can readily translocate to all parts of the plant with higher concentrations observed in the phloem compared to xylem (Bovey et al., 1983). The ester formulation has been found to be both phloem and xylem mobile within the plant (Lewer and Owen, 1990). Triclopyr moves more easily in the symplast than in the apoplast (Bovey et al., 1983; Radosevich and Bayer, 1979). Because the product is phloem mobile it moves with carbohydrates to areas where they are needed or stored (sinks). Foliar applications of triclopyr amine on purple loosestrife (*Lythrum salicaria* L.) demonstrated that apical portions of treated stems are stronger sinks than roots and crowns (Katovich et al., 1996). Additionally, an accumulation of the ester formulation has been observed in the upper leaves and main stems of some species (Lewer and Owen, 1990).

Environmental conditions can play an important role in controlling vegetation with foliar applications. Stress within the plant from external influences can result in poor control (Seiler et al., 1993). Growth regulator herbicides such as 2,4-D, picloram, and triclopyr or even the amino acid synthesis inhibitor, glyphosate, are influenced by moisture stress (Seiler et al., 1993). Foliar applied herbicides continue to be absorbed under dryer conditions; however, translocation within the plant is reduced (Seiler et al., 1993).

Cut Surface Method

Cut stump herbicide treatments are applied to the entire stump after the tree is cut down (Figure 1-8). The outer edge or cambium is treated with an herbicide during cut stump treatments. The sides of the stump should also be treated to ground level to prevent sprouting from these areas. This method is widely used to prevent adventitious and epicormic sprouts from developing from the stump. Adventitious and epicormic buds arising from the remaining above ground portion of the tree have the benefit of an extensive root system from which to pull resources for rapid growth in the absence of apical dominance (Schier et al., 1985). Stump sprouts of Ailanthus are particularly aggressive and can grow to heights of 1.8 m in a single growing season (Feret, 1985).

Figure 1-8: Image shows coverage of treated stump (blue-green). Herbicide mixture (including dye indicator) applied to the cut surface and sides of stump to soil line immediately after cutting using a squirt bottle.

Triclopyr, imazapyr, or glyphosate are commonly used in this type of application. Glyphosate, triclopyr ester, and triclopyr amine diluted to make one-third herbicide, two-thirds distilled water all provided excellent control of eucalyptus (*Eucalyptus camaldulensis* Dehnh.) stump sprouts (Cudney et al., 1987). Imazapyr and triclopyr have been reported to be as effective at equivalent or lesser rates compared to glyphosate on ash (*Fraxinus excelsior* L.), sycamore (*Acer pseudoplatanus* L.), and birch (*Betula* L. spp.) (Willoughby, 1999). Cut stump applications with undiluted triclopyr ester has shown improved control compared to the amine formulation on glorybush (*Tibouchina urvilleana* (DC.) Cogn. in DC.) and strawberry guava (*Psidium cattleianum* Sabine) (Santos et al., 1988; Santos et al., 1989).

Timing of cut stump application has been observed to affect the successful control of some woody tree species with spring considered a less effective time for treatment. One potential reason for this is that spring represents increased sap flow upward from the roots that may dilute or wash away the newly applied herbicide to the stump of the tree as the sap emerges from the cut surface. Warren (1976) reported that application of triclopyr amine was less effective in controlling tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehder) in the spring while good control was recorded with fall (October) applications. *Betula* sprouts were better controlled with fall cut stump applications of glyphosate versus spring (February-May) (Lund-Hoie and Rognstad, 1990).

Winter-time cut stump treatments are slightly less effective than growing season treatments as a general rule for woody species (Williamson and Miller, 1988). Lewis et al. (1984) found summertime (June-August) treatments provided better control than winter (February-April) for a range of herbicides and species. In contrast, Darrall (1984) found undiluted triclopyr, dicamba, glyphosate and fosamine ammonium all provided effective control when applied to cut stumps in late winter (January-February) on a range of species.

Herbicide treatments made to the stump are typically effective at controlling sprouts originating from the stump. The herbicide is directly applied to areas that contain adventitious buds. However, root-sprouting species like Ailanthus require movement of the herbicide to the root system for complete control. The question remains whether herbicides are effectively translocated to the roots with this treatment. The disruption of vascular tissue caused by the cutting operation would likely prevent herbicides from freely moving to below ground portions of the tree.

Cut surfaces should be treated immediately after cutting for two reasons: (1) callus tissue may prevent entry of herbicide and (2) stumps will not be overlooked or missed. Willoughby (1999) found that a one-week delay in herbicide application after cutting did not reduce control of sprouts; however, he also suggests that treatments not be delayed beyond one week of cutting.

Basal Bark Method

Basal bark herbicide treatment is an alternative approach for controlling unwanted trees. It first became widely accepted and used by right-of-way vegetation managers in the 1950's (Schneider et al., 1990). This method has several advantages over others: (1) it is selective, resulting in less collateral damage to non-target vegetation; (2) brown out of vegetation is eliminated when applied during the dormant season; (3) can be applied any time of year; (4) this technique offers better control of some species; (5) and the possibility for herbicide drift is less with this method (Schneider et al., 1990).

Herbicide applications are made to the lower 31 to 46 cm of the trunk to the soil line and completely surrounding the stem to assure girdling by the herbicide (Figure 1-9).

Figure 1-9: Basal bark treatment. Shows application of herbicide mixed in basal oil to lower 31 to 46 cm of stem.

The herbicide is diluted in an oil-based solvent that allows the material to penetrate the bark. The solvent or diluent constitutes the remainder of the mix, or the part that is not herbicide (e.g., a mix having 25% v/v herbicide would contain 75% v/v diluent). Tree size is a factor in choosing this application method over cut stump. Commonly trees with a diameter breast height (DBH) of 15 cm or less are often targeted with this application method and effective control has been observed (Gover et al., 2000; Williams and Yeiser, 1995). Larger dead trees would present possible hazards if left standing. In addition, the bark of mature trees proves more difficult for the herbicide to penetrate.

Timing the application of herbicide treatment is also critical for optimum control (Miller and Bishop, 1989). Lyman (1994) investigated the movement of bark-applied treatments using C14 radiolabeled triclopyr at three timings (September, November, and March). Second year seedlings of green ash (*Fraxinus pennsylvanica* Marsh.) were treated each of the three times and a highly significant difference in application time, region of movement in the plant, and interaction of region by time was observed. September treatment resulted in the greatest movement and most accumulation occurred in the stems compared to roots. It is unknown whether the amounts translocated were sufficient to produce herbicidal effects. There was little movement of triclopyr from the treated area with November or March treatments to green ash or black birch (*Betula lenta* L.).

As suggested by Devine and Hall (1990), the translocation of phloem-mobile herbicides may be dependent upon the production and movement of photosynthates. Timing of the treatment would be critical for herbicides to enter the phloem and be translocated to the roots. According to Stephenson (1993) the greatest flow of photosynthates to the roots would occur post-flowering until leaf drop when the plant is actively storing sugars within its root system as reserves for the following season.

Miller and Bishop (1989) suggested that basal bark treatments are most effective when applied from late January through early March or late May through October. Gover et al., (2002) treated an Ailanthus stand in June 1999 using basal bark treatments of several mixes including Garlon® 4 (triclopyr ester) in basal oil. No root sprouts were observed by the September evaluation for any of the treatments. Other studies have shown improved control with dormant season (January, February) applications compared to growing season (May, June) treatments (Rhodenbaugh and Yeiser, 1994; Williams and Yeiser, 1995). Rhodenbaugh and Yeiser (1994) and Williams and Yeiser (1995) results were complicated due to the test plants undergoing drought stress in the summer months during the year of treatment. However, clear control was observed in both trials. Basal bark and cut surface treatments made during periods of drought were found to be much less effective (Johnson and Back, 1981).

Triclopyr is labeled for basal bark application and has resulted in effective control of Ailanthus (Gover et al., 1990). The triclopyr ester (Garlon® 4) label recommends from 20 to 30 percent of product diluted in oil for basal bark applications. Burch et al. (1987) reported that decreasing the rate of triclopyr applied reduced control in streamline basal applications. Streamline basal applications are explained as a narrow band of treatment made to only 1 or 2 sides of the stem rather than the entire circumference and in this case at or near the root collar (Burch et al., 1987).

Basal bark treatments require dilution of herbicide in a carrier in order to penetrate the bark. Burch et al. (1987) has observed effective control (72 to 98 percent) for a wide range of hardwood species even with streamline basal applications using 3 to 5 mL of herbicide mixture per stem with 20 percent triclopyr ester (Garlon® 4); 10 percent crop oil surfactant (Cidekick) (JLB International, Inc., Vero Beach, FL); and 70 percent diesel fuel. Treatments were made during various seasons throughout 1984 to 1986 in three southern states. Among the species demonstrating control were red oak (*Quercus rubra* L.), white oak (*Quercus alba* L.), hickory (*Carya* Nutt. spp.), sweetgum (*Liquidambar styraciflua* L.), and red maple (*Acer rubrum* L.) (Burch et al., 1987). In more recent years, diesel fuel has been replaced with more user-friendly petroleum or vegetable-based diluents. Many of these products have demonstrated utility in basal bark applications (Gover et al., 1997; Burch et al., 1987). A petroleum-based basal diluent containing lecithin and kerosene (Arborchem Basal Oil, Arborchem Products, Mechanicsburg, PA) showed similar control to diesel for control of hardwoods using streamline basal applications (Burch et al., 1987).

When effectively applied at ground level, basal bark treatments prevent shoots from forming at the root collar and typically control everything above that point. Non-root sprouting species do not have the ability to form adventitious buds on below ground portions of the plant, so no root sprouts form and the plant is ultimately controlled. Del Tredici (1995) reports many native tree species do not sprout from the roots. Therefore, they do not present the challenge faced with Ailanthus. This same treatment on root sprouting species, like Ailanthus, can cause a tremendous flush of sprouting from the roots. This sprouting is much more pronounced when the tree has suffered stress from cutting, chemical treatment, or some natural decline (Johnson, personal observation).

Determining a more effective approach to control Ailanthus is needed. Two separate trials were conducted to investigate the role of application timing and compare herbicides using cut surface application. The influence of treatment timing using the basal bark application technique was investigated. Altogether, three different studies were conducted investigating Ailanthus control:

(1) The cut surface timing trial investigates the importance of treatment timing to control root and stump sprouts of this species using the cut surface method and triclopyr ester (Garlon® 4, Dow AgroSciences, Indianapolis, IN) herbicide. Treatment applications were coordinated with leaf bud swell (late April), full leaf expansion (mid July), post seed development (late August), and plant dormancy based on post leaf senescence (mid November). Greater amounts of carbohydrate are moving toward the roots following the production of leaves and reproductive parts. It is anticipated that the post seed development (late August) timing will offer the best opportunity for movement of the phloem-mobile herbicide, triclopyr, to the roots and control of root sprouts during this period.

(2) The herbicide screening study was conducted to confirm previous findings that triclopyr ester (Garlon® 4) plus picloram (Tordon K, Dow AgroSciences, Indianapolis, IN) or imazapyr (Stalker, BASF Corporation, Research Triangle Park, NC) limit sprouting on Ailanthus with cut surface treatments and to explore the effectiveness of glyphosate (Glypro, Dow AgroSciences, Indianapolis, IN), fosamine (Krenite S, E.I. du Pont de Nemours and Company, Wilmington, DE), and metsulfuron (Escort, E.I. du Pont de Nemours and Company, Wilmington, DE) herbicides in controlling stumps sprouts and reducing root sprouting. A treatment date was

targeted to correspond with the best opportunity for herbicide movement to the roots (mid August).

(3) The basal bark timing study investigates the role of treatment timing on reduction of stump and root sprouts of Ailanthus using triclopyr ester (Garlon® 4) herbicide. Applications to intact stems may aid in the uptake and movement of this material to provide an overall reduction in sprouts. Treatments were applied in April, July, September, and November 2001. These four timings correspond to the annual phenological indicators for plant growth and development beginning in the early spring with leaf bud swell, followed by full leaf expansion, post-seed development and dormancy. It is predicted that the post seed development (September) timing will allow for the greatest movement of this phloem-mobile herbicide to the roots and best control of root sprouts.

Chapter 2

EFFECT OF CUT SURFACE APPLICATION TIMING ON SUPPRESSION OF AILANTHUS RESPROUTS

ABSTRACT

Cutting down Ailanthus stems will lead to substantial root and stump sprouting. It is suspected that movement of triclopyr might occur within the plant following bark-applied treatments and timing may play a role in controlling sprouts. This study investigated the importance of treatment timing to control root and stump sprouts of Ailanthus using the cut surface removal method combined with triclopyr herbicide treatment. Trees were cut during leaf bud swell (April 24), full leaf expansion (July 5-10), post seed development (August 30), and post leaf senescence (November 15-19), 2001 and herbicide applied to the surface and sides of each stump immediately following the cutting with a chain saw. Trees were also cut and left untreated (no herbicide) at each time for comparison. Applying herbicide prevented stump sprouts, regardless of application time. Forty-one percent of trees cut but not treated with herbicide produced no stump sprouts with no difference in treatment timing. All treatments regardless of application time with or without herbicide resulted in root sprout densities greater than 42,400 stems/ha the year following treatment. Timing did not affect sprout numbers the following year. We found no evidence that applications made during the growing season will reduce root sprouts with cut surface treatments of triclopyr ester alone. Future investigations should evaluate product combinations that include soil active chemistry to assist in control of this clonal root system. Perhaps timing of the cut surface application to enhance uptake of soil active products will promote delivery and control of the roots. Additionally, timings outside the window investigated here and within a period of low carbohydrate reserves should be tested.

INTRODUCTION

Ailanthus has become naturalized across much of the continental United States (Miller, 1990; Aldrich et al., 2010). The tree commonly colonizes highway systems (Burch and Zedaker, 2003; Merriam, 2003; Aldrich et al., 2010; Kowarik and Säumel 2007). The shallow, extensive root system allows it to survive and expand along roadsides. Generally, roots are located within the upper 46 cm of soil (Miller, 1990). Roots were found to extend three to four times further than roots of Norway maple (*Acer platanoides*) or sweetgum (*Liquidambar styraciflua*) in two year-old seedlings (Pan and Bassuk, 1986). The roots can develop many sprouts that grow to heights of 3 to 4 m per year (Miller, 1990) (Figure 2-1).

Figure 2-1: Ailanthus root system. This photo shows the shallow lateral root system and sprout development following a basal bark application to the main stem.

The clonal root system that allows for the aggressive spread of this plant also makes control challenging. Cutting Ailanthus results in considerable root and stump sprouting (Kowarik and Säumel, 2007; Burch and Zedaker, 2003). Burch and Zedaker (2003) found that cutting followed by applications of triclopyr and picloram to the stump reduced stems per hectare from 13,900 (cutting alone) to 200 (cut and treat).

Trees often have to be cut and removed from the right-of-way (Figure 2-2) and this work is frequently performed during the dormant season when the canopy is absent.

Figure 2-2: Ailanthus stand demonstrating the potential for infestation along highway corridors. Photo was taken August 2001 along southbound I-81 near Mechanicsburg, PA.

Ideally the remaining stumps are treated with an herbicide to limit sprouts. Clearly, cutting followed by an herbicide treatment to the stump causes disruption to the vascular system and may confound movement of herbicide. However, quick uptake offered by the open wound and active movement of carbohydrates during certain times of the year may offer opportunity for the herbicide to effectively enter the roots using this tactic. Previous evidence suggests that movement of triclopyr occurs within the phloem (Bovey et al., 1983). Peak times for carbohydrate movement downward within the plant may offer greater opportunity for triclopyr to enter the roots. Seasonal differences in control have been observed with bark-applied treatments of triclopyr (Gover et al., 2001).

During leaf bud swell and full leaf expansion, stored energy reserves (carbohydrates) from the root system are utilized to develop the canopy and reproductive organs of the plant. Much of the carbohydrate movement within the phloem is upward during this time. Once the canopy and seeds have fully developed, the plant begins to restore carbohydrates to the root system. During post seed development; carbohydrates manufactured within the leaves (source) begin downward movement through the phloem to the roots (sink). The dormant timing is a period of little movement within the phloem; leaves have fallen and the large exchange of nutrients within the plant is no longer needed. The movement of carbohydrates toward the roots, from full leaf out until leaf drop, leads to the prediction that the herbicide would be more readily translocated via the phloem to the roots during this timing. This study investigated the effect of cut surface application timing with and without herbicide on Ailanthus sprouting. It is hypothesized that post seed development (August) timing will provide the greatest control of root sprouts using triclopyr ester.

MATERIALS AND METHODS

The study was conducted within a mature stand of Ailanthus (up to 24 years of age) located on an embankment with an average width of 46 m and 0.4 km in length. The site was situated along the shoulder at the exit ramp for the interchange of state road (SR) 114 and interstate (I)-81 south bound near Mechanicsburg, PA (GPS coordinates: 40.272093,-77.03609). Treatments were applied at four treatment timings based on observed annual phenological indicators of plant growth and development during 2001. Treatment applications were coordinated with leaf bud swell (April 24), full leaf expansion (July 5-10), post seed development (August 30), and plant dormancy based on post leaf senescence (November, 15-19).

Each treatment time period included both an herbicide-treated and untreated plot. This resulted in a total of 24 plots (4 timings x treated versus untreated x 3 replications). Plots were 6 m by 6 m with a 3 m wide buffer area around each plot arranged in a randomized complete block design (RCBD) with three replications. The entire plot and buffer area was treated but data was collected only within the plot. Johansson (1988) and Burch and Zedaker (2003) used similar plot sizes of 5 x 5 m to discern root-sprouting differences on European aspen (*Populus tremula*) and Ailanthus (*Ailanthus altissima*) following herbicide treatments. The herbicide mix used at all timings in the trial was a 1:3 mixture of 479 g triclopyr acid/L, as the butoxylethyl ester (Garlon® 4, Dow AgroSciences, Indianapolis, IN) diluted in basal oil (Arborchem Basal Oil, Arborchem Products Co., Mechanicsburg, PA), plus a dye indicator. Trees were cut using a chain saw. The cut surface and sides of the stump to the soil line were sprayed immediately following cutting using a squirt bottle to provide thorough coverage but not to the point of runoff (Figure 2-3). A fresh herbicide mixture was created for each timing.

Figure 2-3: A treated stump (blue-green) showing the coverage pattern. Herbicide mixture (including dye indicator) applied to the cut surface and sides of stump to soil line immediately after cutting using a squirt bottle.

The entire trial area was delineated prior to the initial (April 24) treatment and leaf out. During a visit to the site on May 14, 2001 it was noticed that a number of trees had not developed leaves in plots not yet treated (Figure 2-4). A decision was made during subsequent treatments to replace and relocate five plots adjacent to the study due to the reduction in living stems (Figure 2-5). All data collected in these replacement plots was recorded and analyzed in lieu of the originally defined plots.

Figure 2-4: Shows apparent symptoms on Ailanthus stand on standing tall growing trees within trial area. Picture taken July 10, 2001.

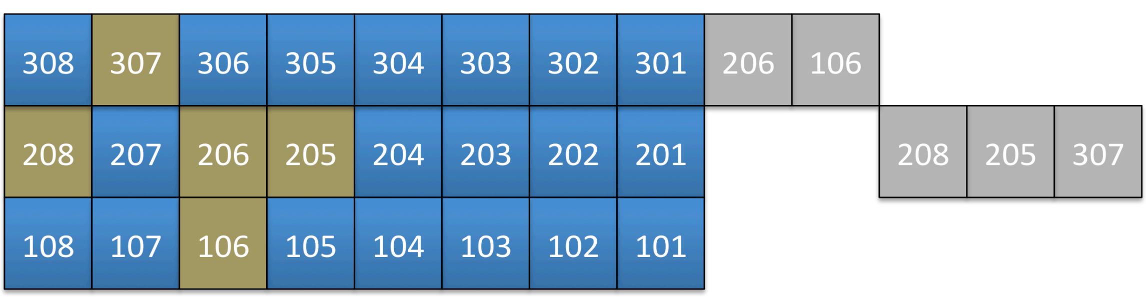

Figure 2-5: Layout of study area showing original plots in blue, abandoned plots in brown, and replacement plots in gray.

Identification and measurement of all treatment trees were collected and included both a stem count and tree diameter measurement. Original stem caliper measurements were taken 15 cm above soil line. Stem number and caliper were used to calculate original stem numbers and original basal area (πr^2). The year following treatment root sprouts and stump sprouts were harvested over a period of time from August 15 through September 14, 2002. Measurements of sprout height and caliper at 8 cm above soil line or at the point of attachment to the stump was collected at harvest. The number and caliper of stumps that had at least one sprout was also recorded. These were considered to be surviving stumps.

Reference is made throughout this text to both root sprouts and stump sprouts. Root sprouts are defined as sprouts originating from the soil and primarily arise from roots, but may include some seedlings. Stump sprouts are sprouts originating from the stump.

The data collected were used to calculate the following descriptive statistics.

1. original stem number (no./ha) – count of stems cut within the plot.
2. stump sprout number (no./ha) – total count of sprouts originating from the stumps within the plot. These were further classified as produced in 2001 or 2002 as determined by developmental characteristics.
3. root sprout number (no./ha)– total count of sprouts originating from the roots within the plot. These were further classified as produced in 2001 or 2002 as determined by developmental characteristics.
4. percent cut stem mortality - represents the percentage of stems at harvest that did not sprout.
5. average stump sprouts per stem - the average number of sprouts arising from surviving stumps for each treatment.
6. average stump sprout height (cm) - average height of sprouts originating from the stump.
7. average root sprout height (cm) - average height of sprouts originating from the root.

8. original basal area (cm^2/ha) – the basal area (πr^2) of stems originally cut within the plot.

9. total sprout basal area (cm^2/ha)- the basal area (πr^2) of both root sprouts and stump sprouts.

The data were subjected to analysis of variance using SAS 9.1 (SAS Institute, 2004). When there was a significant interaction ($P \leq 0.05$) between herbicide and application time, the analysis was conducted for application time by herbicide (n=3) using Fisher's Protected LSD.

RESULTS AND DISCUSSION

Trees in the study area showed symptoms of obvious decline even in untreated plots throughout the 2001 season. The study was initiated in April prior to leaf-out. Given the absence of foliage at the onset of the trial, it was not obvious that many trees were dead or dying throughout a portion of the trial area. Leaf and stem samples were collected and submitted to the Penn State plant disease lab for diagnosis. No causal organisms were identified for the symptoms. While the cause of the initial decline is unknown the substitution of five plots in an adjacent area were thought to constitute a fair evaluation of the treatment. Any indication of decline did not impact the vitality of trees within the study area. Sprouting throughout the trial area was robust for all plots (Figure 2-6). The lowest average root sprout numbers recorded for any treatment was 42,400/ha for July herbicide treated plots. This far exceeded those reported by Burch and Zedaker (2003) following manual cutting at 13,900 stems/ha.

Figure 2-6: Density of stump sprouts and root sprouts demonstrating the potential for regrowth of this species by end of second season following cutting.

The original number of trees cut within all plots averaged from 8,900 to 19,500 stems on a per hectare basis. Little difference occurred in the total number of stump sprouts comparing time of cut without herbicides (untreated, Table 2-1). Cutting trees in April resulted in an average of 18,100 stump sprouts/ha the first season in the untreated, but produced only 5,900/ha additional sprouts in 2002. The July, August, and November timing produced 28,900; 23,200; and 21,600 sprouts/ha, respectively, during second growing season. The only significant difference for untreated (no herbicide) plots resulted from the abundance of sprouts produced from the April cutting. The sprout counts may have been confounded by not harvesting sprouts exactly one year from each treatment date. Though first and second year sprouts could be discerned at harvest in August and September of 2002, the April treatments had sixteen months lapse between treatment and evaluation, November treatments had nine months, and July and August had eleven and twelve months, respectively. Plots cut in July and August without herbicide treatment delayed development of stump sprouts until the following growing season. Though not statistically different, July cut and untreated plots showed a trend and produced more stump sprouts on average and among the fewest root sprouts (Tables 2-1, 2-2). Perhaps, the diminished stored carbohydrate reserve within the root system was a factor in this response.

Treating stems with herbicide after cutting clearly prevented the development of stump sprouts (Table 2-1). The only herbicide treated plots to produce stump sprouts were two of those treated in August (Table 2-1). Five stumps survived out of 98 originally cut and sprayed for that treatment within the 37 m^2 plots and developed a total of nine sprouts in 2002 (i.e., average 800 sprouts/ha, Table 2-1). Several possible explanations exist for sprouting from these five stumps. It is possible the stumps were overlooked and received no herbicide; the herbicide was not applied thoroughly to ground line missing adventitious buds; or insufficient coverage did not provide enough herbicide for control. The cut trees producing these sprouts were smaller with diameters ranging from 17 to 45 mm measured at 15 cm above ground line. It is unlikely these stumps had greater stored energy reserves to develop sprouts than other stumps within the treated area based on size; however, given the rhizomatous growth habit of this species, a particularly large root system could have fueled growth. Burch and Zedaker (2003) observed complete control of stump sprouts following herbicide treatments to the stump.

Table 2-1: Summary of average stump sprouts produced in 2001 and 2002 and combined total for both seasons. Treatments were conducted April 24, July 5-10, August 30, and November 15-19, 2001. Sprouts were tallied from August 15 to September 14, 2002. The 'n' indicates the number of observations used in determining each value. An '---' indicates that a significance level was not determined because there were no sprouts to analyze variance. Differences between means were considered statistically significant at p ≤ 0.05. ns = not significant. All values are the mean of three replications.

Application Timing		Average Stump Sprouts Produced 2001 (no./ha)		Average Stump Sprouts Produced 2002 (no./ha)		Average Total Stump Sprouts Produced (no./ha)	
		Untreated	Treated	Untreated	Treated	Untreated	Treated
Apr	(n=3)	18,100	0	5900	0	23,800	0
Jul	(n=3)	0	0	28,900	0	28,900	0
Aug	(n=3)	0	0	23,200	800	23,200	800
Nov	(n=3)	-	0	21,600	0	21,900	0
Herbicide x Time (p) (n=6)		0.0060		0.087		0.86	
Time		0.027	---	0.026	0.12	0.61	0.12
LSD (p=0.05)		12,400	---	13,200	ns	ns	ns

A large number of root sprouts developed regardless of herbicide treatment or timing (Table 2-2). Similar to stump sprouts, the April timing resulted in a flush of 53,500 root sprouts/ha the first season. Even within herbicide treated plots an average of 34,600 root sprouts/ha were counted. The interaction of herbicide x time was not significant for root sprouts produced in 2001, 2002 and total (p=0.93, 0.49, 0.75). The average number of root sprouts produced in 2001, 2002, and total is included to demonstrate overall treatment effects (Table 2-2). LSD values could not be determined without significant interaction. The August cut and untreated plots averaged 94,100 total root sprouts per hectare and was the highest number recorded among the timings. Treating the stumps with herbicide did cause a reduction in root sprouts with the August timing producing an average of 45,900 total root sprouts per hectare. A buildup of stored carbohydrates in the root system may be contributing to the delayed but observable increase in root sprouts with the August cutting. While the herbicide treatment decreased root sprout numbers for this timing it was not the lowest compared to July (Table 2-2).

A comparison of treated (herbicide) versus untreated (no herbicide) and effect of timing were not significant producing an average of 56,500 to 66,500 and 48,400 to 70,800 total root sprouts per hectare, respectively.

Table 2-2: Summary of average root sprouts produced in 2001 and 2002 and combined total for both seasons. Treatments were conducted April 24, July 5-10, August 30, and November 15-19, 2001. Root sprouts were tallied from August 15 to September 14, 2002. The 'n' indicates the number of observations used in determining each value. Differences between means were considered statistically significant at $p \leq 0.05$. ns = not significant. All values are the mean of three replications.

Application Timing		Average Root Sprouts Produced 2001		Average Root Sprouts Produced 2002		Average Total Root Sprouts Produced	
		(no./ha)		(no./ha)		(no./ha)	
		Untreated	Treated	Untreated	Treated	Untreated	Treated
Apr	(n=3)	53,500	34,600	14,100	39,500	67,600	74,100
Jul	(n=3)	2,200	500	52,200	41,900	54,300	42,400
Aug	(n=3)	1,100	300	93,200	45,700	94,100	45,900
Nov	(n=3)	500	300	49,700	63,500	50,300	63,500
Herbicide x Time (p) (n=6)		0.93		0.49		0.75	
Time (p)		0.32	0.24	0.39	0.80	0.77	0.84
LSD (p=0.05)		ns	ns	ns	ns	ns	ns
Untreated	(n=12)	14,300		52,200		66,500	
Treated	(n=12)	8,900		47,600		56,500	
Herbicide							
Sign. Level (p=0.05)		0.65		0.79		0.64	
LSD (p=0.05)		ns		ns		ns	
Apr	(n=6)	44,100		26,800		70,800	
Jul	(n=6)	1,400		47,000		48,400	
Aug	(n=6)	500		69,500		70,000	
Nov	(n=6)	500		56,500		57,000	
Time							
Sign. Level (p=0.05)		0.05		0.40		0.86	
LSD (p=0.05)		35,400		ns		ns	

Comparison of treated versus untreated for all timings (n=12) was significant (i.e., p=0.0001) and revealed 99 percent of the treated stumps did not sprout (i.e., cut stem mortality) while 41 percent of the untreated stumps had no sprouts. The surviving untreated stumps yielded an average of 3 sprouts per stump (Table 2-3). Treating stumps significantly increased the mortality and prevented the development of adventitious buds from the stump and root collar, similar to observations by Burch and Zedaker (2003).

Table 2-3: Summary of average original stem number, average percent cut stem mortality, and average stump sprouts per stem across all timing treatments. 'Average percent cut stem mortality' is the number of stumps that did not sprout divided by the number of original stems multiplied by 100. The 'average stump sprout per stem' indicates the average number of stump sprouts per surviving stump. The 'n' indicates the number of observations used in determining each value. All values are the mean of three replications.

	Average Original Stem	Average Cut Stem Mortality	Average Stump Sprout per Stem
	(no./ha)	(%)	(no.)
Untreated (n=12)	15,900	41	3
Treated (n=12)	11,600	99	0.3
Herbicide			
Significance Level (p=0.05)	---	0.0001	0.0001

Basal area (πr^2) was used to compare the volume of trees prior to and after imposing treatments (Table 2-4). Originally, basal area ranged from 148,600 to 417,600 cm^2/ha for all treatments. This is an average of all stems present and cut at the time of treatment. Total sprout basal area includes the basal area of all stump sprouts and root sprouts found within the treatment area during the collection of data in August and September 2002. The interaction (herbicide x time) was not significant (p=0.26). Therefore, significance levels for cut and treated or cut and untreated plots could not be determined. Total sprout basal area ranged from 27,000 to 110,800 cm^2/ha for cut and untreated plots, while cut and treated plots averaged 8,400 to 37,800 cm^2/ha.

A decrease in basal area occurred with cutting. The use of herbicides and subsequent reduction in stump sprouts caused even further reduction in basal area compared to cut and untreated plots.

Table 2-4: Summary of average original and average total sprout basal area. Average original basal area includes stems present and cut within the plot at the time of treatment. Average total sprout basal area includes both stump sprouts and root sprouts found within the plot at harvest in August and September 2002. Means are shown on a cm^2 per hectare basis and correlate to the area determined per plot. Original basal area was used as a covariate to derive other data and was not significant. Therefore, no significance levels were determined for 'original basal area'. An '---' indicates that a significance level was not determined because the interaction was not significant. The 'n' indicates the number of observations used in determining each value. Differences between means were considered statistically significant at $p \leq 0.05$. All values are the mean of three replications.

Application Timing		Average Original Basal Area (cm^2/ha)		Average Total Sprout Basal Area (cm^2/ha)	
		Untreated	Treated	Untreated	Treated
Apr	(n=3)	347,000	281,100	110,800	37,800
Jul	(n=3)	417,600	148,600	68,100	8,400
Aug	(n=3)	255,100	307,000	40,800	26,800
Nov	(n=3)	389,500	248,400	27,000	23,000
Herbicide x Time (p) (n=6)		---		0.26	
Significance Level (p=0.05)		---		ns	

Average stump sprout height in untreated plots observed in August and September 2002 decreased from April 2001 to November 2001 cuttings (Table 2-5). This is likely due to the difference in the time that elapsed between treatment and evaluation. Stump sprouts for April cuttings had 16 months to develop and July, August, and November had only 13, 12, and 9 months, respectively. Stump sprout heights were significantly taller for stumps that received no herbicide treatment. Untreated stumps produced sprouts that averaged 109 cm while the few stump sprouts in the herbicide treated areas averaged only 18 cm in height (Table 2-5). No significant difference was observed in average stump sprout height associated with time of cut (herbicide and control combined). Average stump sprout height ranged from 38 to 76 cm by August/September 2002 for all timings.

Average root sprout height resulted in a significant interaction between timing and herbicide treatment ($p=0.019$, LSD=20). The April timing resulted in taller root sprouts for the cut and herbicide treated plots than the July and November timings with heights of 61, 30, and 38 cm, respectively (Table 2-5). Root sprouts from the August cut and herbicide treated plots averaged 51 cm in height. Two possible explanations for this difference are that the April timing had more time to develop larger root sprouts, and secondly there would have been a greater buildup of carbohydrates in the roots which fueled the growth of root sprouts compared to other timings. Average root sprout height within cut plots using no herbicide ranged from 25 to 86 cm for all timings with no significant differences.

Table 2-5: Summary of average stump sprout and average root sprout height. 'Average stump sprout height' is the average height of those sprouts originating from the stump and found within the plot at harvest in August and September 2002. The 'average root sprout height' is the average height of all root sprouts. Original basal area was used as a covariate to derive other data and was not significant. Therefore, no significance levels were determined for 'original basal area'. A '---' indicates that a significance level was not determined because the interaction was not significant. 'Average root sprout height' had a significant interaction, therefore LSD values were calculated. Each value is the mean of three replications.

Application Timing		Average Stump Sprout Ht. (cm)		Average Root Sprout Ht. (cm)	
		Untreated	Treated	Untreated	Treated
Apr	(n=3)	152	0	66	61
Jul	(n=3)	124	0	86	30
Aug	(n=3)	84	66	41	51
Nov	(n=3)	76	0	25	38
LSD (p=0.05)		ns	ns	n.s.	20
Interaction (Herbicide x Time)					
Significance Level (p)		0.067		0.019	
Untreated	(n=12)	109		53	
Treated	(n=12)	18		46	
Herbicide					
Significance Level (p)		0.0001		0.23	
Apr 24	(n=6)	76		64	
Jul 5	(n=6)	64		58	
Aug 30	(n=6)	76		46	
Nov 15	(n=6)	38		33	
Time					
Significance Level (p)		0.41		0.042	

CONCLUSIONS

This trial demonstrates that regardless of timing, treating stumps with triclopyr will eliminate stump sprouts. However, herbicide treatments made to the stump did not prevent the proliferation of root sprouts at any timing. The lowest average root sprout count of any treatment resulted in densities of 42,400 stems/ha for July by the end of the following growing season. The number of stump and root sprouts was not affected by treatment timing with cut only treatments either (i.e., no herbicide applied). Both stump and root sprout yields were extremely high and averaged 21,900 to 28,900 stump sprouts/ha and 50,300 to 94,100 root sprouts/ha among timings with no herbicide treatment.

This study does not substantiate that applications made during post seed development (August) or other periods tested within the growing season will reduce root sprouting with cut surface treatments of triclopyr alone. Work done by Burch and Zedaker (2003) did demonstrate a reduction in stem densities following treatment with this product and method on Ailanthus. The greatest activity was reported with combinations of triclopyr and picloram. However, collection of data occurred at unequal intervals for the various treatment timings in the study reported here and may have confounded the interpretation of treatment effects. Later investigations should involve collecting data at equivalent days after treatment for all timings (e.g., one year after treatment). Future work should evaluate alternative herbicides and combinations that include soil active chemistry to assist control of this clonal root system. Timing of the application during the growing season and within a period of low carbohydrate reserves may enhance uptake of the products, promote delivery and control of the roots, and take advantage of a carbohydrate-starved root system.

MANAGEMENT IMPLICATIONS

Cut surface treatments should be applied immediately following a clearing operation. Timing seems to be less critical with this application method on Ailanthus since translocation to the roots has been minimal, at best. Herbicide treatments applied to the surface and sides of the stump will prevent vigorous stump sprouts from developing. Follow up foliar herbicide treatments should be made after one full growing season. This will ensure that the canopy is still at a height that can be treated with relative ease. Annual visits to address further root sprouts should also be incorporated into the management plan. Further investigation is needed to develop a strategy that is more effective and less labor intensive.

Chapter 3

EVALUATION OF HERBICIDES FOR CONTROL OF AILANTHUS USING CUT SURFACE APPLICATIONS

ABSTRACT

Ailanthus has become well established along many roadway corridors and other open areas in the United States. Previous research has reported that herbicides applied to the cut surface of newly cut tree stumps reduced stump and root sprouts of Ailanthus. This study was conducted to confirm those findings and to contrast the effectiveness of glyphosate, fosamine, and metsulfuron herbicides in controlling stumps sprouts and reducing root sprouting. Trees were cut in August 2001 and directed spray treatments were applied to the cut surface and sides of each stump immediately following the cutting operation. One year after treatment (September 5 to October 27, 2002) mortality, stump and root sprout numbers, sprout diameters, and sprout heights were recorded for each treatment. All herbicide treatments prevented stump and root sprouts equally. Though not statistically different, mixes of triclopyr at 96 g ae/L plus picloram at 12.0 g ae/L or metsulfuron at 10.6 g ai/L plus 5% water diluted in basal oil provided the best performance in nearly all categories evaluated among those herbicides tested. These two treatments resulted in 96 percent stem mortality and an average of 95,900 or fewer total root sprouts per hectare. This experiment did confirm the effectiveness of triclopyr plus picloram in reducing stump and root sprouts though not to the extent observed in other research. Metsulfuron demonstrated a potential for use in Ailanthus control and requires further testing and re-evaluation of the labeled maximum rate of application. Future work should also investigate basal

bark as a treatment method. Timing of the application during the growing season and within a period of carbohydrate movement toward the roots may enhance uptake and control.

INTRODUCTION

Ailanthus is a non-native invasive tree species which rapidly establishes in disturbed sites along right-of-way corridors and in canopy gaps of tracts of land cleared during timber harvest operations (Stipes and Witt, 1995; Landenberger et al., 2007). It can quickly colonize an area, outcompeting desirable vegetation, with its rapid growth and ability to spread by root sprouts and seed. Ailanthus can grow 17 to 27 m high with rapid growth occurring early in the life of the tree and diminishing to less than 7.6 cm per year after age 20 or 25. (Miller, 1990; Feret, 1985). As the tree reaches maturity after 30 years, the wood becomes brittle and can break in strong winds creating safety concerns along the right-of-way (Hu, 1979).

A standard integrated vegetation management strategy employed by roadside vegetation managers is the complete harvest of Ailanthus trees followed by an herbicide application to the cut surface and sides of the stump. The key to controlling Ailanthus is to kill the roots. Ailanthus response to being cut down is to release stump and root sprouts (Gover et al., 2004). Stump sprouts are defined as sprouts originating from meristematic tissue on the stump. Root sprouts originate from adventitious buds found within the periderm of the root (Kormanik and Brown, 1967). Adventitious buds in the roots develop into sprouts, especially in response to injury or cutting (Schier et al., 1985). Sprout development is inhibited by auxins from upper portions of the tree. Once the tree is cut the tree is released from apical dominance and sprouts begin to grow (Schier et al., 1985). One challenge to an integrated vegetation management approach to Ailanthus control is defining the appropriate combination of treatment timing, herbicide selection, and rate of application to reduce root sprouts.

Previous research employing basal bark herbicide applications during the dormant season resulted in abundant root sprout release on treated trees of Ailanthus (Gover et al., 2002). Basal bark applications consist of treating the lower 30 to 46 cm of trunk with herbicide in an effort to chemically control the target tree. The root system is rapidly replenished with carbohydrates once full-size mature leaves develop and flowering and seed production is complete (Wilson et al., 1975). Schier et al. (1973) observed that carbohydrate reserves within another clonal species, aspen (*Populus tremuloides* Michx.), fluctuate throughout the year with low amounts in spring and early summer, increasing in late summer, and decreasing again into fall. In theory, a late summer treatment should present phloem mobile herbicides the greatest opportunity to move into the roots.

Burch and Zedaker (2003) established manual cutting trials on Ailanthus evaluating several herbicide combinations in June 1997. Among the herbicide treatments were triclopyr ester at 96.0 g ae/L alone, or combined with imazapyr at 2.4 or 7.2 g ae/L, or picloram at 12.0 g ae/L; triclopyr ester at 72.0 g ae/L plus imazapyr at 7.2 g ae/L; and imazapyr at 21.6 g ae/L alone. All treatments provided 98 to 100 percent mortality of treated stems, except triclopyr ester at 72.0 g ae/L plus imazapyr at 7.2 g ae/L (80 percent). It was observed at two years after treatment the mixes containing picloram were more effective at reducing the resurgence of root sprouts.

The selection of herbicides, mixes, and rates used in this trial are based upon previous work or label suggestions for control of this species. The goal of this experiment was to evaluate cut surface treatments of recommended and previously tested herbicides alone and in combination for control of stump and root sprouts in Ailanthus with an August treatment.

MATERIALS AND METHODS

This experiment was established in a stand of *Ailanthus altissima* on a cut slope along SR 81S, near Harrisburg, PA, (GPS coordinates: 40.272363, -77.025436) on the following dates: August 8, 10, 14, and 15, 2001. The diameter of treated stems ranged from 1 mm to 361 mm measured at 15 cm above the ground. There were eight treatments including triclopyr ester at 96.0 g ae/L (Garlon® 4, Dow AgroSciences, Indianapolis, IN) alone or in combination with imazapyr at 4.8 g ae/L (Stalker, BASF Corporation, Research Triangle Park, NC) or picloram at 12.0 g ae/L (Tordon K, Dow AgroSciences, Indianapolis, IN), diluted in 80%, 78% or 75% v/v basal oil (Arborchem Basal Oil, Arborchem Products Co., Mechanicsburg, PA), respectively; glyphosate at 480 g ae/L (GlyPro, Dow AgroSciences, Indianapolis, IN); glyphosate at 240 g ae/L plus imazapyr at 4.8 g ae/L in water; fosamine at 240 g ai/L (Krenite S, E.I. du Pont de Nemours and Company, Wilmington, DE) plus imazpyr at 4.8 g ae/L in water; and metsulfuron at 10.6 g ai/L (Escort, E.I. du Pont de Nemours and Company, Wilmington, DE) diluted in 5% v/v water and 95% v/v basal oil; and an untreated check. Trees were cut down using chain saws and debris removed from the site. Immediately following cutting, the cut surface and sides of each stump were treated using a squirt bottle labeled with the herbicide treatment combination. The study was arranged in a randomized complete block design with three replications. The first and second replications were contiguous while the third replication was located approximately 0.4 km away. Plot size was 6.1 m wide by 18-24 m deep.

Figure 3-1. Herbicide screening trial. Shows third replication after the cutting and herbicide treatment of the site.

The caliper and number of all cut stems were measured and recorded prior or during cutting. Measurements were taken approximately 15 cm above the soil line. From the stem size records, basal area was calculated for the entire plot. This information was used to determine the original stem number and basal area (πr^2). One year after treatment (YAT) all stump and root sprouts within each plot were harvested and measured. The data was collected from September 5 to October 27, 2002. Root sprout caliper, height, and number were recorded and all root sprouts were cut at the soil line. Stem calipers were measured at 8 cm above the soil line. Surviving stumps, those having at least one sprout, were also counted and their diameter measured. The number, caliper, and height of each stump sprout were also recorded. Stump sprouts were measured at the point of attachment to the stump.

The root sprout, stump sprout, and stump diameter data was used to calculate original and total sprout basal area. Total sprout basal area figures incorporate both stump and root sprouts. Stem mortality is the percentage of stumps that did not develop stump sprouts by 1 YAT. All data were subjected to analysis of variance and when treatment effect F-tests were significant ($p \leq 0.05$) treatment means were compared using Fisher's Protected LSD.

RESULTS AND DISCUSSION

Prior to cutting, the average number of trees within a plot ranged from 8,600 to 33,800 on a per hectare basis (Table 3-1) while original basal area varied from 407,300 to 951,600 $cm^{2/}$/ha (Table 3-2). Basal areas among plots were not significantly different. Significant differences were found between herbicide treated and non-herbicide treated plots for average number of sprouting stumps, percent stem mortality, and total sprout basal area. Herbicide treatments resulted in an average of 540 to 2,700 sprouting stumps/ha, 84 to 96 percent stem mortality, 78,100 to 153,000 root sprouts/ha, and 30,000 to 62,400 cm^2/ha total sprout basal area (Tables 3-1, 3-2). The data collected 1 YAT showed no statistical differences among herbicide treatments for any of the variables measured. The treatment control (cutting without herbicide application) resulted in an average of 13,800 sprouting stumps/ha, 52 percent stem mortality, 83,000 root sprouts/ha, and 128,600 cm^2/ha of total sprout basal area 1 YAT (Tables 3-1, 3-2).

Table 3-1: Summary of average original stem number, average number of sprouting stumps, average percent stem mortality, and average total root sprouts. Original stem numbers were recorded near the treatment dates of August 8, 10, 14, and 15, 2001. Sprout information was collected one year after treatment (YAT) from September 5 to October 27, 2002. The number of sprouting stumps represents any stump that has, at least, one sprout originating from it. Percent stem mortality is the percentage of stumps that had no sprouts by 1 YAT compared to the original stem count. Total root sprouts represent the number of sprouts emerging away from the treated plants. All values are the mean of three replications.

	Application Dosage	Average Original Stem No.	Average Sprouting Stumps	Average Stem Mortality	Average Total Root Sprouts
		(no./ha)	(no./ha)	(%)	(no./ha)
Untreated	---	29,700	13,800	52	83,000
triclopyr basal oil	96.0 g ae/L 80% v/v	24,300	1,100	94	104,100
triclopyr imazapyr basal oil	96.0 g ae/L 4.8 g ae/L 78% v/v	33,800	1,400	96	108,600
triclopyr picloram basal oil	96.0 g ae/L 12.0 g ae/L 75% v/v	27,600	540	96	78,100
glyphosate	480 g ae/L	24,900	2,200	90	153,000
glyphosate imazapyr water	240 g ae/L 4.8 g ae/L 48% v/v	8,600	1,100	84	117,300
fosamine imazapyr water	240 g ai/L 4.8 g ae/L 48% v/v	22,700	2,700	91	102,700
metsulfuron water basal oil	10.6 g ai/L[1/] 5% v/v 95% v/v	24,600	540	96	95,900
LSD (p=0.05)		ns	6,500	15	ns
Significance Level (p=0.05)		0.28	0.01	0.0003	0.85

[1/] The rate of metsulfuron used in this trial was determined based on a target of 841 g metsulfuron/ha. Similar areas were treated with cut surface applications at volumes of approximately 80 L/ha of total solution. Based on these estimates 21.1 g metsulfuron was mixed in 100 mL of water and added to 1900mL of basal oil.

Table 3-2: Summary of average original basal and average total sprout basal area (BA). The diameter of all stems at 15 cm above soil line was recorded near the treatment dates of August 8, 10, 14, and 15, 2001. The total sprout basal area incorporates both stump and root sprouts. Diameters were measured at point of attachment (stump sprout) or 8 cm above soil line (root sprout). Total sprout data was collected one year after treatment (YAT) from September 5 to October 27, 2002. Basal area was calculated using the formula ($BA = \pi r^2$). All values are the mean of three replications.

Treatment	Application Rate	Average Original Basal Area	Average Total Sprout Basal Area
		(cm^2/ha)	(cm^2/ha)
Untreated	---	473,200	128,600
triclopyr basal oil	96.0 g ae/L 80% v/v	630,000	55,900
triclopyr imazapyr basal oil	96.0 g ae/L 4.8 g ae/L 78% v/v	951,600	45,900
triclpyr picloram basal oil	96.0 g ae/L 12.0 g ae/L 75% v/v	502,700	37,800
glyphosate	480 g ae/L	613,800	55,900
glyphosate imazapyr water	240 g ae/L 4.8 g ae/L 48% v/v	437,000	62,400
fosamine imazapyr water	240 g ai/L 4.8 g ae/L 48% v/v	600,500	33,500
metsulfuron water basal oil	10.6 g ai/L[1/] 5% v/v 95% v/v	407,300	30,000
LSD (p=0.05)		n.s.	50,500
Significance Level (p=0.05)		0.45	0.022

[1/ /] The rate of metsulfuron used in this trial was determined based on a target of 841 g metsulfuron/ha. Similar areas were treated with cut surface applications at volumes of approximately 80 L/ha of total solution. Based on these estimates 21.1 g metsulfuron was mixed in 100 mL of water and added to 1900mL of basal oil.

No significant difference was found in the average total root sprout numbers recorded between herbicide treated and non-herbicide treated plots from 78,100 to 153,000/ha compared to 83,000/ha, respectively (Table 3-1). In contrast, Burch and Zedaker (2003) observed a reduction in sprouts following herbicide treatment to cut stumps with a June application. Similar treatments included triclopyr ester at 96 g ae/L alone, or combined with imazapyr at either 2.4 or 12.0 g ae/L or picloram at 12.0 g ae/L.

The rate of triclopyr ester at 96 g ae/L used in this trial falls within the range of 96 g ae/L to 144 g ae/L recommended on the label (Dow, 2011a). Triclopyr ester at 96 g ae/L plus the addition of imazapyr at 4.8 g ae/L or picloram at 12.0 g ae/L are within the range or correspond with rates documented to control stump sprouts on Ailanthus (Burch and Zedaker, 2003). Treatments of triclopyr ester at 96 g ae/L plus picloram at 12.0 g ae/L and metsulfuron alone did show a trend and were numerically among the best performing herbicides in nearly all categories measured, although no significant differences were detected. The average number of sprouting stumps was 540/ha for these two herbicide treatments versus 1,100 to 2,700/ha for the others. Average stem mortality was 96 percent compared to 84 to 96, and total sprout basal area 37,800 and 30,000 cm^2/ha, respectively versus 33,500 to 62,400 cm^2/ha (Tables 3-1, 3-2). This trend corresponds with the results of triclopyr ester at 96 g ae/L plus picloram at 12.0 g ae/L reported by Burch and Zedaker (2003).

Glyphosate is labeled for cut stump treatments at use rates of 240 g ae/L in water or undiluted. The glyphosate label cautions movement of this herbicide into roots of desirable trees when roots are grafted to the treated stump (Dow, 2011b). Potential movement through the root system is desirable in control of this species. Fosamine is also applied at 240 g ae/L in water or undiluted. Ailanthus is listed on the fosamine label within the 'plants controlled' section (E.I. du Pont, 2011a). These products were evaluated using undiluted glyphosate, glyphosate at 240 g ae/L plus imazapyr at 4.8 g ae/L, or fosamine at 240 g ae/L plus imazapyr at 4.8 g ae/L. All demonstrated improved control from the cut-untreated plots for average number of sprouting stumps from 1,100 to 2,700/ha versus 13,800/ha, average percent stem mortality was 84 to 91 versus 52, and average total sprout basal area was 33,500 to 62,400 cm2/ha versus 128,600 cm^2/ha (Tables 3-1, 3-2). Nonetheless, the treatments did not prohibit sprouting from the roots. Average root sprout numbers ranged from 102,700 to 153,000/ha for these herbicide treatments compared to 83,000/ha for cut-untreated (Table 3-1).

The cut and untreated plots showed a marked difference in sprout production and stem mortality between this trial and that observed by Burch and Zedaker (2003). This trial produced an average of 83,000 sprouts/ha with an average stem mortality of 52 percent (Table 3-1). Burch and Zedaker (2003) reported 13,900 sprouts/ha and stem mortality of 21 percent. Time of cutting alone did not result in differences in control within the previous cut surface timing trial reported. A possible explanation for the reported differences in sprout numbers observed by Burch and Zedaker (2003) and this trial may be attributed to decreased levels of stored carbohydrate reserves within the roots in June when they applied compared to August. Decreased carbohydrate levels may inhibit sprout production. Schier and Zasada (1973) did not observe differences in sprout numbers for aspen (*Populus tremuloides* Michx.) with varying amounts of carbohydrate but suggested levels outside the range tested may play a role. A second potential cause is variation among clones in the ability to produce sprouts (Schier et al., 1985). Genetic variation may also explain differences in stem mortality. One clone may promote or have a greater number of adventitious buds within the roots, while another sprouts more aggressively from the stump.

CONCLUSIONS

Herbicide selection seems to be less critical with this application method. There was value shown in treating stumps with herbicide. The number of stumps that produced sprouts was significantly reduced by all herbicide treatments compared to cut-untreated. The volume of Ailanthus returning to the site is delayed with the use of herbicide evaluated in this trial as seen by the reduction in total sprout basal area. However, root sprouts have not been effectively controlled with any of the treatments tested.

Although there were no statistical differences between herbicide treatments, there was a trend. The triclopyr ester plus picloram combination and metsulfuron alone were among the best treatments for all of the variables measured. Burch and Zedaker (2003) recommended the triclopyr ester plus picloram at rates evaluated in this trial. It should be noted that picloram carries a restricted label (Dow, 2011c). Caution, use, and notification requirements must be adhered to when using this product and may limit the effective use of this product in our area.

Metsulfuron is not labeled for this application method (E.I. du Pont, 2011b). Additionally, treating Ailanthus stands often corresponds to high stem densities. The rate of metsulfuron tested in this trial will potentially exceed maximum label rates when treating populations of this species. The maximum label rate for metsulfuron is 168 g/ha/year (E.I. du Pont, 2011b). Based on volumes used in similar areas it was estimated that 841 g metsulfuron/ha would be applied if an entire hectare were treated. Further work is necessary to evaluate reduced rates for effectiveness in control of this species. Use of this product for cut surface treatments would require the addition of this application method on the product label in the future.

Future work should also investigate basal bark as a treatment method. Basal bark applications would keep the stem intact. The herbicide may have greater potential to move upward and downward through the plant with the phloem serving as a conduit. Timing of the application during the growing season and within a period of carbohydrate movement toward the roots may enhance uptake of the products and promote delivery and control of the roots.

MANAGEMENT IMPLICATIONS

To achieve the most desirable results, cut surface herbicide treatments should be applied immediately following a clearing operation. Herbicide treatments applied to the surface and sides of the stump will help prevent vigorous stump sprouts from developing. Follow up foliar herbicide treatments should be made after one full growing season. This will ensure that the canopy is still at a height that can be treated with relative ease. Future visits to treat further root sprouts should also be incorporated into the management plan.

Chapter 4

EFFECT OF BASAL BARK APPLICATION TIMING ON SUPPRESSION OF AILANTHUS SPROUTS

ABSTRACT

The control of Ailanthus along roadway corridors is often necessary to limit the continued spread of this tree. In chapters 2 and 3 cut stump combined with herbicide applications to remove trees and prevent root and stump sprouting was tested. From an operational and cost saving approach basal bark applications when appropriate may provide similar results with less labor. This experiment was conducted to evaluate timing of basal bark herbicide application. Trees were treated April 20, July 12, September 13, or November 20, 2001. By August 2002, all treated stems were controlled and subsequent first and second year root sprouts were measured and counted. The average total number of root sprouts ranged from 53,200 to 131,600 stems/ha for the treated plots. This represents an average overall increase in stems of 1.37 to 3.24 fold from the original count. A reduction in biomass was demonstrated by a decrease in basal area from 4.1 to 17.6 percent of basal area originally present for the herbicide treatments. Basal area increased by 3.2 percent for the untreated plots and does not include the living, original stems. Sprout height varied from 27 to 46 cm for the treatments. There were no statistical differences found between any of the treatment dates for any of the data collected. No effect of application timing was found on reduction of root sprouts using basal bark treatments on Ailanthus. Future work might investigate a timing window when carbohydrate reserves are depleted or alternative chemistry to reduce sprouts.

INTRODUCTION

The cutting and removal of Ailanthus has resulted in a significant number of root sprouts following cut surface herbicide treatments. Burch and Zedaker (2003) observed complete control of stump sprouts and reduction of root sprouts using several herbicide combinations on Ailanthus with cut surface treatments applied in June. Attempts to define the best herbicide and application timing resulted in significant root sprout numbers following cut surface treatments discussed in earlier chapters.

Basal bark treatments may provide an option to control Ailanthus infestations where trees are less than 15 cm in diameter, as stipulated on the Garlon® 4 label, and left standing pose no threat to the right-of-way (Dow, 2011a). This treatment method requires less cost than cutting and treating stumps. In a typical roadside situation a 5-man crew plus 2 trucks and chipper cost $162 per hour for cutting and removal of trees. This work leads to lane closures and increased safety risk. Two men are designated for traffic control operations. The others are devoted to cutting, chipping, and treating stumps. Average daily production may cover a distance of 800 linear feet of right-of-way. Basal bark treatments do not require lane closures or added personnel. A typical cost for this application is $106 per hour for a two-man crew and spray truck plus $27 per gallon for herbicide. Average daily production is likely 8000 linear feet for this application. There are many variables to these estimates but production is much greater and overall costs lower for basal bark treatments when compared to cutting and removal of trees (Mike Maurer, PennDOT Roadside Vegetation Manager, personal communication, October 19, 2011).

Basal bark treatments have demonstrated effective results. Applications to Ailanthus in June have provided 95 to 100 percent control of treated stems and fewer than 1,900 root sprouts/ha following basal bark applications (Gover et. al., 2002). The disruption of the vascular system using cut surface treatments may interfere with the movement of herbicides to the roots.

Alternatively, basal bark treatments leave the stem intact and provide a conduit for movement of herbicide through the vascular system, mainly the phloem. The active ingredient triclopyr is reportedly transported via the phloem (Bromilow et al., 1990). However, triclopyr, was shown to have minimal downward movement during September, November, and March with basal bark treatments using C14 radiolabeled triclopyr applied to ash (*Fraxinus pennsylvanica* Marsh) or black birch (*Betula lenta* L., Nov and March only) (Lyman, 1994).

The movement of carbohydrate occurs within the phloem. In perennial species, the direction of carbohydrate movement varies throughout the year (Schier and Zasada, 1973). In the spring and early summer carbohydrates within the root are utilized to develop the canopy of leaves and shoots. Once the leaves are developed and canopy expanded, carbohydrates are manufactured and the root system begins to be replenished (Schier and Zasada, 1973). The dormant season offers little movement of carbohydrates. The greater movement of carbohydrates toward the roots, from full leaf out until leaf drop, would indicate that the herbicide would be readily translocated via the phloem to the roots during this timing. This study investigated the effect of basal bark application timing on the reduction of Ailanthus sprouts. It is hypothesized that the post seed development (September) timing will provide the greatest control of root sprouts using triclopyr ester.

MATERIALS AND METHODS

The study site was located along the shoulder at the exit ramp for the interchange of state road (SR) 114 and interstate (I)-81 southbound near Mechanicsburg, PA (GPS coordinates: 40.27211, -77.0343717). The study area was a south facing cut slope with a large, established stand of Ailanthus. Diameter of the treated trees ranged from 1 mm to 356 mm measured at 15 cm above soil line. Treatments were applied on April 20, July 12, September 13, and November

20, 2001. These four timings correspond to the annual phenological indicators for plant growth and development beginning in the early spring with leaf bud swell, followed by full leaf expansion, post-seed development and dormancy. The herbicide mixture used in the trial was triclopyr ester at 120 g ae/L (Garlon® 4, Dow AgroSciences, Indianapolis, IN) and 75% v/v basal oil (Arborchem Basal Oil, Arborchem Products, Mechanicsburg, PA), plus a dye indicator. The treatments were applied to completely cover the lower 31 cm of each stem. The average volume applied per treatment ranged from 209 to 303 L/ha. Application equipment included backpack sprayers equipped with a Spraying Systems #5500 Adjustable ConeJet nozzle with a Y-2 tip. Plots were 6 m by 6 m with a 3 m wide buffer area around each plot arranged in a randomized complete block design (RCBD) with three replications. The entire plot and buffer area was treated but data was collected only within the plot.

Initial stem counts and tree diameters were taken at the time of treatment. The initial data for the untreated plots was recorded on October 18, 2001. Tree diameters were measured at approximately 15 cm above the soil surface and used to calculate original basal area (πr^2) while stem counts provided original stem numbers. An evaluation of percent control of treated trees and information on root sprouts was collected between August 1 and 5, 2002 for all treatments. Data included number, caliper, and height of all root sprouts. The number of sprouts that developed in 2001 versus 2002 was also determined. These measurements were used to calculate the number of root sprouts produced in 2001, 2002, and total; percent change in stem numbers compared to original; root sprout basal area (πr^2); percent change in basal area; and root sprout height.

All data were subjected to analysis of variance, and when treatment effect F-tests were significant ($p \leq 0.05$), treatment means were compared using Fisher's Protected LSD. The untreated check was not included in the statistical analysis.

RESULTS AND DISCUSSION

Prior to treatment the plots averaged from 31,600 to 50,800 stems/ha (Table 4-1). The herbicide treatments controlled all treated trees. The average number of root sprouts within each plot ranged from 53,200 to 131,600 stems/ha by the following season (August 2002, Table 4-1). This flush of new stems represents a 1.37 to 3.24 fold increase from the original count. Few root sprouts were produced in 2001 as determined by the presence of nodes on the stem indicating second year growth. An average of less than 1,600 root sprouts/ha developed for the herbicide treated and 5,700/ha within the untreated plots (Table 4-1). Root sprout development in 2002 was dramatically higher with average sprout numbers from 51,900 to 130,300/ha (Table 4-1). This was a marked difference from that observed by Gover et. al. (2002). June-applied basal treatments using triclopyr ester at 72 g ae/L alone, combined with imazapyr at 7.2 g ae/L, or triclopyr ester at 4.8 g ae/L plus imazapyr at 7.2 g ae/L resulted in greater than 95 percent control of treated Ailanthus trees and root sprout numbers were fewer than originally treated stems (Gover et. al., 2002). Perhaps there exists a better window of timing that falls outside this trials investigation. It appears that specifically using phenological indicators may not be the best approach but rather consider the pattern of stored carbohydrates within the roots. Gover et. al., (2002) results suggest that prior to full leaf expansion may be better than targeting downward carbohydrate movement in the phloem. Early June may offer both an opportunity for herbicide movement (leaves are nearly expanded) and a significant depletion of stored carbohydrates within the roots.

Table 4-1: Summary of average original stem number, average root sprouts produced in 2001 and 2002, and average total root sprouts produced. Basal bark applications of triclopyr ester at 120 g ae/L in basal oil were made to Ailanthus on April 20, July 12, September 13, or November 20, 2001. Original stem numbers were tallied at time of treatment. Root sprout numbers were recorded between August 1 and 5, 2002. Data was collected within a 37 m^2 plot for each treatment and averages transformed to a per hectare basis. The number in parentheses next to total root sprouts produced indicates the average fold-increase in stem number from the original. Each value is the mean of three replications.

Timing	Average Original Stem No.	Average Roots Sprouts Produced 2001	Average Root Sprouts Produced 2002	Average Total Root Sprouts Produced
	(no./ha)	(no./ha)	(no./ha)	(no./ha)
untreated[a]	31,600	5700	58,100	63,500 (1.67)
Apr 20	42,400	1600	51,900	53,200 (1.37)
Jul 12	43,200	0	73,000	73,000 (2.26)
Sep 13	50,800	270	79,500	79,700 (2.17)
Nov 20	42,400	1,100	130,300	131,600 (3.24)
LSD (p=0.05)	---	ns	ns	ns (ns)
Sign. Level (p=0.05)		0.32	0.46	0.47 (0.70)

[a]The untreated check was not included in the statistical analysis.

Original basal area ranged from 170,800 to 365,900 cm^2/ha (Table 4-2). Basal area decreased for all treated plots regardless of timing. Since all treated trees were controlled only first and second year root sprouts were measured. Basal area ranged from 11,600 to 24,900 cm^2/ha for the treated plots (Table 4-2). This represents 4.1 to 17.6 percent of the original basal area. The root sprout basal area for the untreated check is reported as percent increase due to sprouting and does not include the basal area of the living, original stems. Resprout height varied from 27 to 46 cm for the treatments (Table 4-2). There were no statistical differences found between any of the treatment dates for any of the data collected.

Table 4-2: Summary of average original basal area, average root sprout basal area, and average root sprout height. Basal bark applications of triclopyr ester at 120 g ae/L in basal oil were made to Ailanthus on April 20, July 12, September 13, or November 20, 2001. Original basal area measurements were recorded at time of treatment. Root sprout diameter (used to calculate basal area) and height were recorded between August 1 and 5, 2002. Data was collected within a 37 m^2 plot for each treatment and averages transformed to a per hectare basis. The number in parentheses following the root sprout basal area represents the percent of root sprout basal area compared to the original basal area present for that treatment. Each value is the mean of three replications.

Application Timing	Average Original Basal Area	Average Root Sprout Basal Area	Average Root Sprout Height
	(cm^2/ha)	(cm^2/ha)	(cm)
untreated[a]	287,600	7000 (3.2%)	19
Apr 20	310,500	20,000 (8.0%)	46
Jul 12	365,900	17,000 (5.6%)	27
Sep 13	271,400	11,600 (4.1%)	29
Nov 20	170,800	24,900 (17.6%)	27
LSD (p=0.05)	ns	ns (ns)	ns
Sign. Level (p=0.05)		0.64 (0.29)	0.79

[a]The untreated check was not included in the statistical analysis.

CONCLUSIONS

Previous work had suggested that there was a correlation between basal bark application timing and the production of root sprouts on Ailanthus. This study does not prove that applications made during post seed development (September) or other periods tested within the growing season will reduce root sprouting with basal bark treatments of triclopyr ester alone. None of the timings chosen in the experiment demonstrated enhanced control of root sprouts. Basal bark applications made to Ailanthus serve to reduce the basal area by controlling the large treated stems. Future work should incorporate a treatment timing during the expansion of leaves or evaluate alternative herbicides and combinations to assist in control of this clonal root system. A June timing along with other timings used in this trial will help validate these results.

MANAGEMENT IMPLICATIONS

Basal bark treatment is a cost-effective tool for controlling Ailanthus trees but root sprouts will develop. This application is regarded as one option, as a first step, to managing an Ailanthus stand. Basal bark treatments limit the size of stem that can be treated. Trees up to 15 cm in diameter are treated using this method. In a mature stand of Ailanthus not all trees may be addressed with this treatment. Some may have to be cut and removed or treated with a hack and squirt method. Hack and squirt is an injection treatment not previously discussed in this paper. This treatment utilizes a hatchet and squirt bottle filled with herbicide. Downward cuts are made at spaced intervals around the stem and the herbicide is applied within these wounds. Like basal bark, it might provide an opportunity for herbicide movement toward the roots if an opportune window is found. It is a little more labor intensive but is an option for selectively treating larger trees within the stand. These may later need removal once control is achieved to prevent possible falling hazards.

There will always be a need for follow-up foliar herbicide treatments. The basal bark application, when applied correctly to the root collar, will prevent vigorous sprouts from developing on the trunk of the tree. Root sprouts do not grow as rapidly as sprouts that develop from the base of the tree. Most sprouts that develop from this approach will be root sprouts and much easier to target with a foliar follow-up treatment due to their reduced size.

Chapter 5

Summary and Recommendations

Overview

Three trials were conducted to determine the significance of application timing and herbicide selection on controlling the root system of *Ailanthus altissima* using cut surface and basal bark treatment methods. The four timings did not significantly impact the resurgence of root sprouts with either treatment method. Herbicide selection did demonstrate a trend in reducing root sprout numbers with two product mixes tested, triclopyr ester plus picloram and metsulfuron alone, using the cut surface method.

Clonal issues

Ailanthus offers a tremendous challenge for research and investigation in control of the species. The long, extensive root system that ensures its survival makes control with conventional herbicide treatments difficult. Attempting to reduce sprouts with this species using herbicides applied to stems or cut surfaces typically result in a flush of root sprouts. The loss of apical dominance caused by cutting or injury will spur new growth by decreasing auxin levels to roots from leaves. These treatments appear to elicit that response. The active ingredients evaluated did not demonstrate movement in sufficient quantity to control the roots with cut surface or bark-applied treatments.

Herbicides

Triclopyr ester plus picloram and metsulfuron alone appeared to enhance control of the root system compared to other herbicides tested using cut surface treatments. Both picloram and metsulfuron have soil activity. Uptake from the root system is a plausible explanation for the added control observed with those treatments. The results of this work did not demonstrate a significant reduction in sprouts using triclopyr ester plus picloram observed in other cut surface trials (Burch and Zedaker, 2003). The triclopyr ester plus picloram combination should be further investigated to confirm the results. Metsulfuron did show potential for cut surface application. Metsulfuron is not currently labeled for this treatment method. The maximum label rate for metsulfuron is 168 g/ha/year. Cut surface treatments made to an Ailanthus stand with a high stem density could quickly surpass that amount. In evaluating herbicides the estimated application rate was 841 g metsulfuron/ha if an entire hectare were treated at similar stem densities. Future investigation with reduced amounts to ensure maximum label rates are not exceeded should be tested.

Gover et.al. (2002) used combinations that included triclopyr ester at 72 g ae/L alone or with imazapyr at 7.2 g ae/L and triclopyr ester at 4.8 g ae/L plus imazapyr at 7.2 g ae/L for basal bark treatment with excellent results following a June application. Fewer than 1,900 sprouts/ha were found at 70 weeks after treatment (WAT). A wide range of herbicides and rates were not evaluated for basal bark treatments within the scope of the work discussed. Further work with existing chemistry, various rates, and combinations may offer greater movement and enhanced control of the roots.

New chemistry should be investigated. Active ingredients such as aminocyclopyrachlor recently released by E.I. du Pont de Nemours and Company, Wilmington, DE, may provide control of this species. It is effective on brush and currently formulated and undergoing tests for cut surface and basal bark application.

Study design

Two lessons were learned regarding the layout of these trials. First, an area designated for the trial should be established in advance and any potential concerns of the site determined prior to initiating the study. The cut surface timing trial had to be modified midway through the study to accommodate natural decline observed within the Ailanthus stand. Designating and observing the site the previous year while foliage was present would have provided an opportunity to identify this potential issue and find a better-suited location. Secondly, the extensive root system of Ailanthus creates questions on what constitutes a plot size that will avoid confounding influences from adjacent treatments. In a New York urban setting the root system of Ailanthus was documented to extend up to 2 m (Pan and Bassuk, 1986). Although these trials were laid out in accordance with others performing similar work and given a wide berth, lack of control could be skewed by living roots originating outside the plot boundaries. Future work should incorporate whole clones as an experimental unit. The entire clone treated with a single treatment does bring into question clonal variation, but eliminates the potential confounding factor of a shared root system. Through repetition factors involving clonal differences may be teased out.

Alternatively, controlled experiments that utilize areas with lower stem densities and where root systems can be more closely examined. This would require small isolated stands either located in natural settings or the pre-planned establishment of Ailanthus plots. In these settings the roots and sprouts could be harvested and studied.

Evaluation

The timing studies presented some unique challenges related to the collection of data. Treatments were applied over a range of dates throughout 2001 and data were collected in late summer of 2002. Therefore, the data did not represent the same span of time for the four timings evaluated. When recording data the difference between one-year and two-year old sprouts was determined. This allowed for a fairer assessment of the effect of application timing. A better approach would be to collect data at similar intervals following treatment (e.g., one year after treatment) for all timings.

Carbohydrate reserves

All three studies may have missed a critical but short window to take advantage of the point of lowest carbohydrate reserves within the roots. These tests were focused on the period of greatest carbohydrate movement toward the roots. Successful reduction in Ailanthus root sprouts following cut surface and basal bark applications made in June have been documented (Burch and Zedaker, 2003; Gover et al., 2002). This timing falls between bud swell and early full leaf expansion. Roots have exhausted carbohydrate reserves and herbicide treatments that controlled aboveground portions may have limited the ability of the plant to produce new growth. This narrow window of time deserves further investigation to determine whether carbohydrate depletion may assist in limiting root sprouts after controlling the stem.

Carbohydrate movement

It does not seem that carbohydrate movement toward roots effect the transfer of the phloem mobile compounds tested in this work. The movement of other products, foliar applied or injected herbicides might be more significant. The pathway offers an opportunity for control of the species if the proper material or entry into the vascular system is found.

Further Investigation

The trials should be repeated to clearly validate these results. A single trial that examines each aspect of timing or herbicide selection may not be representative. Existing chemistry that includes triclopyr ester plus picloram, metsulfuron or additional rates and combinations of other products should be investigated. New chemistry such as aminocyclopyrachlor warrants research for control of Ailanthus with these application methods at various treatment timings. Could an auxin be identified that mimics that naturally occurring in Ailanthus? If so, could exogenous applications to the cut surface or bark alone or in conjunction with herbicides effectively control the roots? Tests using a combination of practices (e.g., foliar sprays followed by basal bark or cut surface) to reduce sprouts and the spread of this plant could be investigated.

Other approaches beside herbicide treatments are offering promise in management of this species. The introduction of fungal pathogens to existing stands of Ailanthus is showing positive results. Ongoing investigations with *Verticillium albo-atrum* and *Verticillium dahlia* may provide a biological control option in future years.

Practical Application

The cut surface and basal bark treatments have nearly eliminated stump sprouts with all timings and herbicides tested. These two application methods provide an opportunity used in conjunction with other treatment methods to control Ailanthus stands. According to A.E. Gover (Penn State Univ., Research Support Assoc., personal communication, October 2011) anecdotal evidence exists that properly timed basal bark treatments (full leaf expansion to leaf drop) on full stands of Ailanthus will discourage root sprouts. While not confirmed with these tests, it may offer an advantage to treat during that interval using the basal bark method. Evidence does not exist to confirm that timing plays a role in reduction of root sprouts with cut surface treatments. However, if the site allows (e.g., there are no desirable trees in the vicinity of the treatment area), the addition of picloram may enhance control with this method.

Treating the stand first with foliar applications to control the vast majority of stems followed by either cut surface or basal bark treatments on remaining trees is a valid approach. Root sprouts will have to be addressed with future herbicide treatments to the stem or foliage using basal bark or foliar applications. This will offer selectivity by ensuring placement of the herbicide is focused on the treated stem. Groundcovers whether existing or introduced should be encouraged to compete against the Ailanthus and provide protection to soil.

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Appendix A

Rain Data (Harrisburg INTL/Middletown)

Month/Year	Actual Precipitation (inch)	Avg. Monthly Precipitation (inch)
January 2000	2.01	2.84
February 2000	2.33	3.04
March 2000	6.06	3.28
April 2000	2.63	3.24
May 2000	4.01	4.26
June 2000	4.09	3.85
July 2000	2.83	3.59
August 2000	4.13	3.31
September 200	8.61	3.51
October 2000	0.47	2.93
November 2000	1.55	3.52
December 2000	3.61	3.24
Total=	**42.33**	**40.61**
January 2001	2.30	2.84
February 2002	1.36	2.93
March 2002	4.19	3.28
April 2002	1.72	3.24
May 2002	1.66	4.26
June 2002	2.01	3.85
July 2002	1.91	3.59
August 2002	3.79	3.31
September 2002	2.18	3.51
October 2002	1.01	2.93
November 2002	1.51	3.52
December 2002	1.87	3.24
Total=	**25.51**	**40.50**
January 2002	2.45	2.84
February 2002	0.39	2.93
March 2002	5.05	3.28
April 2002	3.84	3.24
May 2002	4.31	4.26
June 2002	2.38	3.85
July 2002	1.27	3.59
August 2002	2.69	3.31
September 2002	3.68	3.51
October 2002	6.37	2.93
November 2002	3.77	3.52
December 2002	4.61	3.24
Total=	**40.81**	**40.50**

Appendix B

Rain Data (Harrisburg)

Month/Year	Actual Precipitation (inches)	Average Monthly Precipitation (inches)
January 2000	1.93	3.18
February 2000	2.40	2.99
March 2000	6.16	3.58
April 2000	4.10	3.31
May 2000	4.12	4.60
June 2000	5.29	3.99
July 2000	2.55	3.21
August 2000	3.14	3.24
September 2000	4.60	3.65
October 2000	0.69	3.06
November 2000	1.53	3.53
December 2000	3.21	3.22
Total=	**39.72**	**41.56**
January 2001	2.07	3.18
February 2001	1.34	2.88
March 2001	3.75	3.58
April 2001	1.99	3.31
May 2001	2.17	4.60
June 2001	2.68	3.99
July 2001	1.49	3.21
August 2001	3.05	3.24
September 2001	3.07	3.65
October 2001	0.90	3.06
November 2001	1.33	3.53
December 2001	1.86	3.22
Total=	**25.70**	**41.45**
January 2002	2.20	3.18
February 2002	0.41	2.88
March 2002	4.87	3.58
April 2002	3.16	3.31
May 2002	3.93	4.60
June 2002	2.75	3.99
July 2002	1.49	3.21
August 2002	2.02	3.24
September 2002	3.90	3.65
October 2002	6.27	3.06
November 2002	3.39	3.53
December 2002	4.18	3.22
Total=	**38.57**	**41.45**