CHEMICAL CONTROL OF CHINESE PRIVET (*LIGUSTRUM SINENSE*)

by

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(Under the Direction of Barry Shiver)

ABSTRACT

At a bottomland hardwood forest near Athens, GA, two non-soil-active herbicides (glyphosate and triclopyr) were tested at various rates (0, 1.5, 3.0, 4.5, and 6.0 lbs. a.e. per acre), and timings (April, June, August, October, and December 2000), to identify cost-effective methods for controlling Chinese privet (*Ligustrum sinense* Lour.) A second study tested different formulations (Accord®SP vs. Roundup®Pro Dry for glyphosate and Garlon®3A in water vs. Garlon®4 in JLB®improved plus oil for triclopyr). A third study tested for the effects of trenching to separate root linkages on herbicide efficacy on privet. Immediately prior to and approximately one year following each treatment, privet cover (%) was estimated visually in each plot. The data from each study were subjected to analysis of covariance with pre-treatment cover as a covariate. Multiple comparisons of covariate-adjusted means (α=0.05) were performed.

The first year results from the study testing herbicides, rates and timing showed that timing and herbicide interaction was significant. For glyphosate, October and December timings were more effective. For triclopyr, the December treatment was as effective as glyphosate. Glyphosate was more effective than triclopyr at all timings. In December, glyphosate reduced the privet cover as low as 0% in some replications.

triclopyr was almost as effective as glyphosate in December when it reduced the privet cover to about 2%. The interaction occurred because glyphosate was much better in all months of application other then December. The different rates were not significantly different suggesting that lower rates were as effective as higher rates, which is an important finding from an economic perspective. Neither the formulation study nor the trenching study showed any significant differences.

INDEX WORDS: *Ligustrum sinense*, Privet, glyphosate, triclopyr, trenching, rate, timing, formulation.

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A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2003

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December 2003

DEDICATION

I dedicate this to my parents and my family. Specially my father Mr. Harilal Ahuja.

ACKNOWLEDGEMENTS

I am thankful to Dr. Timothy B. Harrington and Dr. Barry Shiver. I also thank my committee members Dr. Boyd Edwards and Dr. Rodney Will. In addition I appreciate all my friends in Athens and my friends at Warnell School of Forest resources.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

Introduction

Chinese privet (*Ligustrum sinense* Lour.) is an exotic weed in the United States. It was introduced to the United States from China in 1852(Dirr, 1983) as an ornamental plant because of its abundant white flowers (Wyman, 1973). Privet can grow up to a height of 83 feet (AFA, 1996). It escaped cultivation in the early 1930’s and eventually spread all over the eastern United States stretching from Florida to the southern parts of New England, but mostly concentrated in the southeast. The species was successful in establishing itself in the southeast partially due to the hot, humid climate, which is very similar to the tropical climate of its native Asia. Its native range in Asia mainly includes mixed forests in valleys and streamsides at a wide range of elevations between 200 to 2700 meters (Wu and Raven, 1996).

Privet can grow in wide range of environmental conditions. It grows in a wide variety of habitats and can tolerate a wide range of light, temperature, and soil conditions. It is tolerant to shade and drought, and it can withstand cold and wet climatic conditions though it originated in the tropics. Privet generally shows a good shade tolerance and can grow well in wide range of shade levels (Brown and Pezeshki, 2000). It grows well in poor soils ranging from nearly saturated to almost dry soil conditions (Flint, 1993;Corley *et.al*, 1997). It also well in acidic and neutral soils (Flint, 1993), but it grows best in mesic soil (Bailey and Bailey, 1976).

Privet is a member of Oleaceae family. It is a semi-evergreen shrub, with long leafy branches. Stems are opposite and branched and the branching increases upward. Twigs are long and slender projecting out at a right angle. Leaves are opposite in arrangement, dull green in color and are arranged in two rows at right angles to the stem. Leaves are ovate to elliptical in shape and semi-evergreen in nature. Flowering takes place from April to June. Flowers are white in color and scented and are produced in large numbers. Fruits are drupe and ovoid in shape and are produced from October to February. Initially the fruits are green but as the plant matures they become purple or black in color. Each fruit contains one to four seeds. Each individual plant of privet can produce up to 3000 drupes per stem and a mature tree of privet can produce up to a million seeds per year (Mowatt, 1998). These drupes are eaten by birds and mammals and the seeds are dispersed in various types of habitat (Mazia et.al, 1996;Stromayer, 1996). The seeds of privet have vigorous reproductive biology and almost 100% of privet seeds are viable (Mowatt, 1998). They germinate in temperatures ranging from 15^0 C to 25^0 C (Mowatt, 1998). Chinese privet also reproduces vegetatively by means of root suckers and stem.

Privet is present in almost all the states of the southeastern United States. Today it is established from Texas through Virginia, up to Massachusetts in the north and down to Florida in the south (U.S.D.A, 1998). It is a very aggressive species forming dense thickets, particularly in bottomland forests.

Privet dominates the understory of the mesic forest, where it invades quickly (Godfrey, 1988) and establishes itself rapidly. It invades fencerows, roadsides, streams and margins of forests very quickly. The biggest threat posed by this species is ecosystem alteration. It has the capability to cause large-scale ecosystem modification by displacing the native vegetation, and once established it is difficult to eradicate privet because of its high reproductive capacity.

Privet forms pure stands in the understory of hardwood forests and much of the native vegetation occupying this niche is eliminated (Tennessee Exotic Pest Plant Council, 1996;U.S.D.A, 1998). It has already invaded thousands of acres of land and there is little possibility of eliminating privet from its North American range (Randall and Marinelli, 1996). While long-term effects are positive for some species and negative for others, the displacement of native species is cause of concern for forest health. In some cases privet has changed the composition and structure of invaded forests (Dascanio et.al, 1994). In other cases the invasion by this species has caused endanger to rare native species such as Schweinitz's Sunflower in North Carolina (U.S. Fish and Wildlife Service, 1993). In Florida it has invaded undisturbed relict slope hammock habitat, threatening to displace Miccosukee gooseberry (*Ribes echinellum*). Miccosukee gooseberry is listed as endangered in Florida (Florida Fish and Wildlife Conservation Commission, 1997.) Studies have shown that invasion of privet also reduces the reproductive success of native trees during regeneration of the forest (Ward, 2002). Besides forests, it also invades non-forest areas such as abandoned agricultural fields and pastures (Ward, 2002). The threat posed to native vegetation by privet has led to its being ranked among the top ten most troublesome exotic pest plants of Georgia (Georgia Exotic Pest Plant Council, 1999).

In addition, privet is potentially harmful for human and animal health. Its fruits are toxic containing chemicals such as ligstrin, listron, syringin and syringopicrin which may cause nausea, headache, vomiting, abdominal pain, diarrhea, low blood pressure and clammy skin if ingested (Westbrooks and Preacher, 1986). The pollen and scent from privet flowers may cause allergies such as hay fever and asthma, though this has not been clinically proven. Privet can found to be fatal in animals like cows when they eat its leaves (Kerr and Kelch, 1999). Effects on native vegetation, ecosystem and potential human and animal health problems make it imperative to find effective methods of controlling privet. Some work has been done screening chemicals for use on privet, but there are still questions about the herbicide choice, rates and timing, formulations and potential problems with root connectivity in controlling this species.

A study was established in 2000 to evaluate different methods of privet control. Specific objectives were :

1 To evaluate cost-effective methods for controlling privet by foliar application of two herbicides, glyphosate and triclopyr, at different rates and times of application.

2 To evaluate the effect of different formulations of each herbicide for privet control.

3 To evaluate the importance of below ground root linkages of privet clumps in affecting herbicide efficacy.

Earlier studies indicated activity of both glyphosate and triclopyr on privet (James and Mortimer, 1982). Basic information on these two herbicides is presented in Appendix A.

Chapter 2

Literature Review

The main categories of weed control used in forestry are mechanical, chemical and biological weed control.

Mechanical Weed Control:

Mechanical weed control involves methods such as mowing, hand pulling, hoeing, water management, burning, and machine tillage. Attempts have been made to control privet using mechanical methods. In small areas hand removal is effective. Young seedlings are pulled out by hand along with roots (USGS, 1997). Hand removal is only effective in the early stages of invasion when privet plants are young and small. Digging tools, such as a mattock, can be used to remove the underground parts of privet to facilitate its control. Once the privet is established it is difficult to control it and hand removal is almost impossible if privet plants are large (Randall and Marinelli, 1996). In large natural areas, heavy equipment can be used to remove privet plants, but this may disturb the soil leading to soil erosion and making the area more susceptible to subsequent invasions. Bartlow (1997) showed that repeated mowing and cutting can be used to control privet, but since privet sprouts readily this method is not good for eradicating privet completely.

Mowatt (1981) used various cutting treatments to control privet. These included cutting the stem above ground, cutting the stem above the ground followed by covering the top parts by black plastic, removal of the main stem followed by cutting of lateral roots, and cutting the main stem and propping the ends of lateral roots in a vertical position. Results indicated that mechanical methods were not very effective. Only treatments where the cut parts were covered with black plastic showed some chlorotic shoots for some time.

Brown and Pezeshki (2000) used flooding as a tool to eradicate privet. They subjected privet plants to various flooding and shading conditions in a green house to see if flooding and shading have any effect in controlling privet. Results showed that short term flooding did not control or eradicate privet. The study proved that privet plants are capable of withstanding both short term flooding and shading conditions.

Faulkner (1989) showed that fire could be used as a pretreatment for using herbicide. His study showed that when foliar application of glyphosate was applied in spring following fall or winter burns, the majority of Chinese privet plants were killed or at least damaged. However, there was no significant difference between the privet count of burned and unburned plots.

In summary, mechanical methods can be used to eradicate or control privet, but success depends on the degree and level of infestation and also on the area covered and age of the privet. Mechanical methods can be used where herbicides cannot be used or where non-target species are sensitive to herbicides and repeated treatment will almost always be required to achieve long term control.

Chemical Weed Control:

Chemical control involves using various herbicides to control weeds. Herbicide should only be used after considering their effects on non-target species. Kline and

Duquesnel (1996) pointed out that the use of herbicides is not appropriate for all sites because some herbicides may harm non-target species.

Herbicides have been studied to control privet. Little (1982) used “Tordon 50D” to control privet. This herbicide, a mixture of picloram and the amine formulation of 2, 4-D were used as a cut surface treatment. The results indicated that 97% of treated plants died within 3 to 6 months, but application was on each individual plant separately.

In another study, James and Mortimer (1982) used a wide range of herbicides and different types of application methods to control privet. The chemicals used were 2, 4-D, picloram, triclopyr, hexazinone, tebuthiuron, amitrole T, and glyphosate. Methods used to apply herbicides included cut and paint, soil injection and foliar spray. Visual assessment of privet after application of chemicals indicated that cut stump painting with 2,4-D and pilcoram or triclopyr and picloram were effective for privet control. Cut stump applications of glyphosate were also effective in Spring. Results also indicated that hexzinone resulted in more than 50% privet mortality. They also applied glyphosate at two different timings. In spring glyphosate was applied at concentrations of 0.36/0.5 (glyphosate/X-45) and 0.72/0.5 (glyphosate/X-45) ai % weight/volume with an X-45 emulsifier to increase herbicidal activity. In different trials they found that privet mortality ranged from 37% to 100%. The autumn applications of glyphosate at concentrations of 0.49 and 0.72 ai % weight/volume resulted in privet mortality ranging from 15 to 20 %. In the same way triclopyr was applied along with picloram at two different timings and different rates. In spring, triclopyr and picolram were applied at concentrations of 0.2/0.05 (triclopyr/picloram) and 0.4/0.1 (triclopyr/picloram) ai % weight/volume and privet mortality ranged from 8 to 30%. Also in autumn, triclopyr and picloram were applied in three different concentrations and combinations. The first two included the combination of triclopyr and picloram and the concentration of 0.27/0.07 (triclopyr/picloram) and 0.4/0.1 (triclopyr/picloram) ai % weight/volume and a third combination included triclopyr, picloram, and X-45 (emulsifier) in the concentration of 0.27/0.07/0.5 ai % weight/volume resulting in percent mortality of privet ranging from 35 to 38 %. Their results on treatment timings indicated that autumn applications were better than spring applications. They found that an increased rate of herbicide did not significantly improve privet control.

Mowatt (1981) used hexazinone, glyphosate, triclopyr and dicamba to eradicate privet. He used injection to apply the herbicide into mature privet stems. Results showed good control of privet treated with the triclopyr and hexazinone, but variable control with glyphosate.

In another study, Miller (1998) used a range of herbicide treatments to control privet. The main objective of the study was to screen available herbicides for privet control. He used glyphosate, imazapyr, metsulfuron, triclopyr, sulfometuron, dicamba, picloram and clopyralid. Highest recommended rates of all these herbicides were applied in August and September. Results demonstrated that glyphosate, metsulfuron and imazapyr showed good activity on controlling privet. He used Accord (glyphosate) at a rate of 1.5 gallons per acre in August and September and found that the privet control was more than 90% at both times. In the case of Garlon 4 (triclopyr) sprayed at a rate of 1.5 gallons per acre for both timings, the control of privet was found to be 64%.

Randall and Marinelli (1996) showed that chemical control of privet with glyphosate is effective. According to them foliage treatment is best for actively growing plants and cut stump treatment is good for freshly cut wood.

Biological Weed control:

Biological control has not been a very good option for the control of privet. However, a foliage-feeding insect, *Macrophya bunctunalbum*, that is native to Europe is a pest to privet. Bartlow et al. (1997) reported that privet is susceptible to fungal leaf spots, *Pcuedocercospora ligustri,* and a common root crown bacteria, *Agrobacterium tumefaciens.* So, there is potential research to explore in the field of biological control of privet.

Linkage Literature:

There are several studies that show that linkages between plants of same species help them in increasing their survivorship. A study conducted by Raphael and Nobel (1986), showed that parent and ramet connection for a species named *Agave deserti*, a common perennial, greatly increased ramet growth and survivorship as compared to its seedlings. They also showed that ramets severed from their parents showed decreased survivorship with death of 27% of severed ramets, while all unsevered ramets remained alive. In another study, Alpert and Mooney (1985) studied a herbaceous perennial, *Fragaria chiloensis*. They showed that rosettes of this plant share water and photosynthate. The connection between two established rosettes prevented their death by drought and shade, even when neither of the rosettes could have survived singly. These results indicate the physiological integration of connected rosettes may increase total growth of clones of *F.chiloensis* through sharing of resources among ramets.

Ashmun et al. (1982) studied the translocation of photoassimilates between the sister ramets in two species called *Clintonia borealis* and *Aster accuminatus*. They found that in *C.borealis*, there was small but consistent translocation of photoassimilate between sister ramets. They also observed that any disturbance of unexposed sister ramets by defoliation or shading increased the flow of photoassimilates to the disturbed part of *C.borealis*. This shows that connected ramets of *C.borealis* are physiologically integrated. No sharing was observed in *A. accuminatus.*

Physiological integration of ramets in *Salidago canadensis* was studied by Harhett and Bazzaz (1983). They observed that ramets severed from their parental clone in the field experienced reduction in growth, suvivorship and flowering, relative to their intact counterparts. While there have not been similar studies for privet, its propensity to reproduce through sprouting indicates that it could share resources between plants connected underground.

Chapter 3

Materials and Methods

The study site is situated on the outskirts of Athens, GA, near McNutts creek (Location: 33.93 N, 83.35 W.). It is about three-acres in size and is the property of The Georgia Department of Transportation. The site has mainly Madison -Louisa (Fine, kaolinitic, thermic, Typic, Kanhapludults) sandy clay loam soil. These are well drained to excessively drained soil. The site is dominated by bottomland hardwood forest where the most common species are *Acer negundo* (boxelder), *Acer rubrum* (red maple), *Betula nigra* (river birch), *Fraxinus pennslvanica* (green ash) and *Platanus occidentalis* (sycamore). The understory of the forest is primarily privet. Before the start of the project the privet was cut once by the Department of Transportation in Spring 1999.

Plot layout, Treatments and Experimental Design:

Three separate studies were designed to meet the three objectives. The design, treatments, and plot layout of the three studies will be discussed separately.

Objective 1. To identify cost-effective methods for controlling privet by foliar application of two herbicides, gyphosate and triclopyr, at different rates and times of application. To meet this objective a grid of plots was established in March 2000, each with dimensions of 10 ft x 20 ft. The formulations of the herbicides were Accord SP for glyphosate and Garlon 3A in water for triclopyr for all rates and timings. Treatments consisted of five timings and five different rates of two herbicides, glyphosate and triclopyr. Timings were April, June, August, October and December. Rates were 0, 1.5, 3.0, 4.5, and 6.0 lbs a.e. per acre of each herbicide. There were four replications of each rate and timing combination except control. The same 0 lbs a.e. rate plot was used for both herbicides and all timings, but there was a separate 0 rate plot established for each replication. Therefore there were 2 herbicides x 5 timings x 4 rates x 4 replications plus 4 0 rate plots for each replication for a total of 164 plots used to test the hypothesis for this objective. Plots were arranged in a randomized complete block design. All plots were marked using 1.5 meter long PVC pipes with an aluminum tag containing a plot identification number.

Objective 2. To evaluate the effect of different formulations of both herbicides on privet control. There are different formulations of herbicides that might result in better privet control than the standard ones used in Objective 1. This portion of the study was designed to determine if there were differences in formulation. To meet this objective, 2 additional formulations, one each for glyphosate and triclopyr were evaluated. The additional formulations were Roundup Pro Dry for glyphosate and Garlon 4 in oil for triclopyr. Only one timing, August, was used in this study, but the same rates as were used on plots to satisfy Objective 1 were used in this formulation study. Therefore there were 4 rates x 2 new herbicide formulations x 4 replications to sum to 32 new plots. In addition, the 32 corresponding plots for the Accord SP formulation of glyphosate and the Garlon 3A formulation of triclopyr for the original study were used plus the 4 zero rate plots for the 4 replications for a total of 68 plots used to satisfy this objective. Plot size, layout, and identification were identical to those described for Objective 1. These additional plots for the formulation study were randomly incorporated in the larger set of plots, which were established for Objective 1.

Objective 3. To evaluate the importance of below ground root linkages of privet clumps in affecting herbicide efficacy, hereinafter called the trenching study. This objective was included in the study because there has been some concern that the underground root linkages of a shrub species like privet might inhibit control of privet in sprayed areas. In other words, the privet outside the sprayed area might be able to reduce efficacy of herbicides on sprayed privet by providing resources through root linkages. The study consisted of three sub-lethal rates of glyphosate in the Accord SP formulation with three replications of each rate. The rates were 0, 0.4, and 0.8 lb a.e. per acre applied at the August timing. Each of the rates was applied to a plot that had a trench dug around its perimeter to insure root isolation of treated plants from untreated plants outside the plot. In addition, plots were established for each rate and replication that were not trenched. So a total of 18 plots were established completely independently of those established for objectives 1 and 2 (3 rates x 3 replications x trenched or not). Plots were arranged in a randomized complete block design.

Evaluation of privet control was the same for all three objectives. Before spraying, three 1 (10.24 sq. ft) meter square sub plots (quadrat) were established systematically down the center of each rectangular plot at a distance of 1 (3.2 ft), 3 (6.4 ft), and 5 (16 ft) meters. Plots were marked by pin flags to facilitate relocation. Within each quadrat, an ocular estimate of privet cover was made. One year after treatment (1YAT) for each timing quadrats were reestablished and a post-treatment ocular estimate of privet cover was made.

Herbicides were applied at the appropriate timings on each plot using a CO_2 sprayer with an 8002VS spray nozzle calibrated for 20 gallons of solution per acre at a pressure of 30 lb per sq in. Each spray swath was 6 ft wide down the center of the rectangular plot. The analysis was done on post treatment percent of privet cover taking the pretreatment percent of privet cover as a covariate.

Statistical Analysis:

The statistical software package SAS (SAS Institute 1989) was used to analyze the data. The privet cover data was subjected to analysis of covariance with pretreatment cover as a covariate. A square root arc sin transformation was made on the percentage data before analysis was performed to homogenize the variance of the data. Multiple comparisons of covariate adjusted means were performed at alpha= 0.05.

Chapter 4

Results

Herbicide Rate and Timing Study Results:

When the analysis of covariance for the herbicide rate and timing study was performed on average percent privet cover one year after treatment (1 YAT) with the zero rate included in the model it indicated that herbicide, rate, timing, and all two-way interactions were significant (Table 1). An examination of the means plotted in Figure 1 indicated that many of the interactions were only significant because of the inclusion of the check plots in the analysis. When the analysis of covariance was conducted excluding the zero rate, the p- value indicated (Table 2) that herbicide, timing, and timing*herbicide were the only significant factors. With few exceptions, there was a little difference in response across rates for different treatment timings except for the difference between zero and 1.5 lbs a.e per acre (Figure 1). The Analysis of covariance with check plots excluded reveals the same trends as the plotted means in Figure 1. The significant sources of variation are discussed separately.

Timing * Herbicide Interactions:

Timing* herbicide interaction was significant. Since rate was not significant, average percent privet cover (1 YAT) was averaged across rates for different timings and plotted in Figure 2 for Accord SP and in Figure 3 for Garlon 3A. An examination of Figures 2 and 3 lead to the conclusion that Accord SP always results in lower percent cover of privet after treatment than Garlon 3A at a given timing. Note the different scales in Figures 2 and 3. The average post-treatment privet cover for Accord SP treated plots was between 0% and 6.3 % over different months whereas for Garlon it was between 1.4% and 20.1 % (Tables 3 and 4). Interestingly, both the herbicides had low post-treatment privet cover for December applications, which suggests that the december is a good time to achieve effective control with either herbicide. The probable cause of the significant interaction of timing*herbicide is that there were larger differences in herbicide efficacy in all months except December.

When the analysis of herbicide efficacy for both herbicide is done for various months separately the results (Table 5) indicate that Accord SP and Garlon 3A are significantly different from each other at all timings including the month of December. When post treatment privet cover of both the herbicides at various months is compared, it shows that Accord SP is always better then Garlon 3A at all timings (Tables 3 and 4).

Both gylphosate and triclopyr reduced privet cover to low levels: 0.09% (glyphosate) and 1.4 % (triclopyr). A better case for efficacy can me made if pretreatment privet cover of treated plots is known so control across different rates and timing can be made. The average pretreatment cover of privet for various timings, rates and herbicide is shown in Tables 6, 7 and 8. The analysis of variance of pretreatment privet cover showed that the pretreatment privet cover does not differ significantly to plots assigned to different herbicide and rates, but it did differed significantly across timing (Table 9). The multiple comparison of the pretreatment privet cover showed that it was only the August timing, which differed significantly from all other timings. This analysis of variance result of pretreatment privet cover is important because it indicates that there were not large differences in pretreatment conditions for the treatments.

Herbicide Formulation Study Results:

Glyphosate:

The herbicide rate and timing study indicated that there was a significant herbicide*timing interaction. Further analysis suggested that Accord SP resulted in lower privet cover 1 YAT than Garlon 3A in all months except December. A similar analysis was conducted to see if different herbicide formulations might yield differing results. The Round up Pro formulation of glyphosate has a different surfactant than that of Accord SP that may help it move into the plant better. Table 10 details the Analysis of covariance that tests for difference in formulation and rate with the zero rate included. Figure 4 indicates that as with the herbicide rate and timing study, rate is only significant because the zero rate was included in the analysis. Table 11 presents results of the analysis of covariance with the zero rate excluded. There are no significant differences in either glyphosate formulation or rate.

Triclopyr:

The ester formulation (Garlon 4) is considered to be better then the amine formulation of Garlon 3A at cutting through the waxy surface on leaves and moving triclopyr into the plant. Table 12 indicates that there was no significant difference in triclopyr formulations and rates even with nonzero rates plots included. Figure 4 suggests that though Garlon 3A is more variable across rates than Garlon 4, it would be difficult to choose between them, The Analysis of covariance was also conducted without the zero rate plots (Table 13). Neither formulation nor rate is significant.

Trenching Study Result:

The trenching study analysis was conducted with and without the zero rates included. Figure 5 indicates that there are no real differences except at the zero rate. Therefore the analysis with zero rate plots (Table 14) was replaced with the analysis without zero rate plots included (Table 15). Neither trenching, rate, nor the interactions are significant. This means that trenching has no effect on herbicide efficacy. The average percent privet cover values one year after treatment (1 YAT) for trenched and untrenched plots are shown in Figure 5.There are very small difference in treatment values involving rate or trenching other than the random variation in the zero rate plots.

Chapter 5

Discussion and Conclusion

The first year results indicate that glyphosate treatments dramatically reduce privet cover at all timings. Another herbicide, triclopyr, also reduced the privet cover, but was not as effective as glyphosate. In both herbicides the June treatment was not as effective as other timings. The reason for lower effectiveness for the June treatment may be reduced herbicide efficacy due to drought (Table 16) In addition, glyphosate absorption and translocation are lower at lower humidity (Gottrup *et.al*, 1976). Another possible reason may be that herbicides do not work as well during the period of active privet growth (from April to August). Figure 2 indicates that both herbicides work best during the dormant period of October to December. The December time, in particular, showed the best results with privet cover getting as low as 0% and 2 % in case of glyphosate and triclopyr respectively (Tables 3 and 4).

When the difference between the average pretreatment privet cover and post treatment privet cover for both herbicides is calculated, it is clear that the glyphosate is better then triclopyr (Tables 3 and 4), When the privet control is calculated on the scale of 100, glyphosate controls 88 to 100% and triclopyr controls 56 to 96% of privet cover.

If we compare these results with the results of the study conducted by James Miller (1998), privet was reduced by 90% for glyphosate and 64% for triclopyr in

Miller's study. In his study he used rate of 1.5 gallons per acre for both glyphosate and triclopyr.

The comparison of different rates indicated that they did not differ significantly from each other. This finding is of high practical importance. It means lower rates will be as effective as higher rates at obtaining privet control. These are similar to results found by James and Mortimer (1982). In their study they found that higher than normal rates did not have any additional effect on privet control. These results have extreme importance from an economic point of view.

If cost is calculated for applying the two herbicides at different rates, glyphosate (Accord SP) costs are $35, $45, $55, and $65 for rates of 1.5, 3.0, 4.5 and 6.0 lbs a.e. per acre respectively. This assumes a price of Accord SP @ $ 20 per gallon and $ 25 as application rate per acre. Costs for triclopyr (Garlon 3A) are $ 55, $85, $115, and $145 respectively for rates of 1.5, 3.0, 4.5,and 6.0 lbs a.e/acre respectively. This assumes a price of Garlon 3A @ $60 per gallon and $25 as application rate per acre). It is clear that landowners can save money by applying lower rates to achieve similar control of privet instead of using for higher rates.

The effectiveness of low rates was evident for all three studies, even for the very low 0.4 and 0.8 lbs a.e. rates of glyphosate used in the trenching study. This provides additional evidence that landowners can save money treating privet by using low rates and dormant season applications. More landowners may be willing to attempt privet control if spraying is less expensive.

There was a significant Herbicide*Timing interaction and Accord had lower post-treatment privet cover than Garlon 3A at all timings. The only timing at which Garlon 3A approached the efficacy level of Accord SP was December and this is likely the reason for the interaction. For all other timings, Accord SP was always a superior herbicide compared to Garlon 3A for privet control. Again this is a good finding economically because Accord SP costs less then Garlon 3A (Appendix A).

The effectiveness of Garlon 3A in December could be useful in some situations. Glyphosate is a broad-spectrum herbicide, which kills grasses. Therefore, it should not be used in situations where grass plants need protection. In such situations Garlon 3A could be a better choice in December because it provides effective privet control and will not kill grass.

The comparison between the different formulations of both herbicides showed that they were not significantly different. This indicates that different formulations will have the same effectiveness to control privet. Our hypothesis was that different formulations might have different efficacies and their effect on privet control might be different. There is no evidence from this study to support that hypothesis. Since there is no difference in formulations, the formulation which is cheaper and which is easier to handle should be used to get effective control of privet. These formulation results also have economic importance. For example in the case of triclopyr, the Garlon 3A is cheaper ($60 per gallon) as compared to the Garlon 4 ($82 per gallon). So, landowners can buy the cheaper formulation and achieve the same amount of privet control.

There was no difference between the trenched and untrenched treatments. The assumption was that trenching cuts off the root linkages between the privet plants, which could help in increase privet control. Results of the study, however, indicated though there may be underground root linkages in privet communities, they are not important in impacting herbicide efficacy.

Finally, it should be noted that although low rates of glyphosate reduced privet cover to less than 1 % at some timings (Table 3), no rate or timing reduced the privet cover to zero. This means eliminating this exotic plant will require at least one follow up treatment. Landowners should not expect a single treatment to completely eliminate privet, even at higher rates. As is the case with attempts to completely eliminate other exotics such as kudzu, multiple treatments will be required to eliminate privet.

Table 1**.** Analysis of covariance table of average (%) privet cover one year after treatment for herbicide rate and timing study (with zero rate plots included).

Source	df	Sum of Squares	Mean Square	p
Timing[1] (T)	4	0.5195	0.1298	<0.0001
Herbicide[2] (H)	1	1.6342	1.6342	<0.0001
Rate[3] (R)	4	3.4155	0.8538	<0.0001
T* H	4	0.1427	0.0356	0.0190
R* T	16	0.3999	0.0249	0.0097
R* H	4	0.4295	0.1078	<0.0001
R*T*H	16	0.1341	0.0083	0.7731

[1]Timing= Different months of treatment.

[2]Herbicide= Different Herbicides (Accord SP and Garlon 3A).

[3]Rate = different treatment rates applied.

Table 2. Analysis of covariance table of average (%) privet cover one year after treatment for herbicide rate and timing study (with zero rate plots excluded).

Source	df	Sum of Squares	Mean Square	p
Timing[1] (T)	4	0.6845	0.1711	<0.0001
Herbicide[2] (H)	1	0.0740	2.0740	<0.0001
Rate[3] (R)	3	0.0341	0.0113	0.4298
T* H	4	0.2012	0.0503	0.0038
R* T	12	0.1366	0.0113	0.5207
R* H	3	0.0071	0.0023	0.8992
R*T*H	12	0.0974	0.0081	0.7834

[1]Timing= Different months of treatment.

[2]Herbicide= Different Herbicides. (Accord SP and Garlon 3A).

[3]Rate = different treatment rates applied.

Table 3. Average post-treatment (%) privet cover one year after treatment for Accord SP (glyphosate) treated plots.

	Rate (a.e. lbs. per acre)				
Time (Month)	0.0	1.5	3.0	4.5	6.0
April	24.35	0.17	1.07	0.52	0.09
June	25.77	1.40	6.34	3.10	1.76
August	18.58	2.23	1.05	1.01	1.34
October	29.14	0.00	0.00	0.16	0.00
December	25.44	0.13	0.26	0.00	0.40

Table 4. Average post-treatment (%) privet cover one year after treatment for Garlon 3A(triclopyr) treated plots.

	Rate (a.e. lbs. per acre)				
Time (Month)	0.0	1.5	3.0	4.5	6.0
April	24.35	9.88	11.06	12.36	9.98
June	25.77	7.09	22.01	16.32	20.08
August	18.58	8.09	13.67	15.46	7.07
October	29.14	13.44	7.63	10.95	5.51
December	25.44	2.57	1.39	2.20	2.03

Table 5. p-values for herbicide and timing comparison.

	ACC (4)	G3A (4)	ACC (6)	G3A (6)	ACC (8)	G3A (8)	ACC (10)	G3A (10)	ACC (12)	G3A (12)
ACC (4)	-	-	-	-	-	-	-	-	-	-
G3A (4)	**<0.0001**	-	-	-	-	-	-	-	-	-
ACC (6)	0.2297	<.0001	-	-	-	-	-	-	-	-
G3A (6)	<.0001	0.7544	**<.0001**	-	-	-	-	-	-	-
ACC (8)	0.8705	<.0001	0.1667	<.0001	-	-	-	-	-	-
G3A (8)	0.0246	<.0001	0.2830	<.0001	**0.0145**	-	-	-	-	-
ACC (10)	0.0040	0.0003	0.0185	0.0008	0.0021	0.5002	-	-	-	-
G3A (10)	<.0001	0.0765	<.0001	0.0435	<.0001	<.0001	**<.0001**	-	-	-
ACC (12)	0.6330	<.0001	0.0895	<.0001	0.7491	0.0059	0.0007	<.0001	-	-
G3A (12)	<.0001	0.7493	<.0001	0.9966	<.0001	<.0001	0.0012	0.0406	**<.0001**	-

ACC: Accord SP (glyphosate).
G3A: Garlon 3A (triclopyr).
Labels refer to herbicide in parentheses month number e.g. ACC (4) is Accord SP in April.

Table 6. Average pre treatment (%) privet cover of plots for various timings.

Time	Privet Cover (%)
April	54.33
June	52.48
August	45.92
October	55.50
December	50.58

Table 7. Average pre treatment (%) privet cover of plots for various rates (zero rate excluded).

Rate (a.e. lbs. per acre)	Privet cover (%)
1.5	54.29
3.0	49.40
4.5	51.65
6.0	51.63

Table 8. Average pre treatment (%) privet cover of plots for two herbicides.

Herbicide	Privet cover (%)
Accord SP	50.89
Garlon 3A	52.55

Table 9. Analysis of covariance table of average (%) privet cover before treatment for herbicide rate and timing study (with zero rate plots excluded).

Source	df	Sum of Squares	Mean Square	p
Timing[1] (T)	4	0. 1896	0.0474	0.0033
Herbicide[2] (H)	1	0. 0163	0.0163	0.2308
Rate[3] (R)	3	0. 0585	0.0195	0.1648
T* H	4	0. 0993	0.0248	0.0732
R* T	12	0. 1415	0.0117	0.4126
R* H	3	0.0380	0.0126	0.3423
R*T*H	12	0.1589	0.0132	0.3097

[1]Timing= Different months of treatment.

[2]Herbicide= Different Herbicides. (Accord SP and Garlon 3A)

[3]Rate = different treatment rates applied.

Table 10. Analysis of covariance table of average (%) privet cover one year after treatment with different rates and formulations of glyphosate (with zero rate plots included).

Source	df	Sum of Squares	Mean Square	p
Formulation[1](F)	1	0.0067	0.0067	0.0245
Rate[2] (R)	4	0.0199	0.0049	0.0246
F* R	4	0.3461	0.0029	0.0668

[1]Formulation= Different formulations of glyphosate (Accord SP or Roundup Pro)

[2]Rate = Different treatment rates applied.

Table 11. Analysis of covariance table of average (%) privet cover one year after treatment with different rates and formulations of glyphosate (with zero rate plots excluded).

Source	df	Sum of Squares	Mean Square	p
Formulation[1](F)	1	0.0069	0.0069	0.1792
Rate[2] (R)	3	0.0186	0.0062	0.2196
F* R	3	0.0117	0.0039	0.3135

[1]Formulation= Different formulations of glyphosate (Accord SP or Roundup Pro)

[2]Rate = Different treatment rates applied

Table 12. Analysis of covariance table of average (%) privet cover one year after treatment with different rates and formulations of triclopyr (with zero rate plots included).

Source	df	Sum of Squares	Mean Square	p
Formulation[1] (F)	1	0.0031	0.0031	0.4074
Rate[2] (R)	4	0.0202	0.0050	0.3643
F* R	4	0.0162	0.0040	0.4617

[1]Formulation = Different formulation of triclopyr (Garlon 3A and Garlon 4).

[2]Rate = Different treatment rates applied

Table 13. Analysis of covariance table of average (%) privet cover one year after treatment with different rates and formulations of triclopyr (with zero rate plots excluded).

Source	df	Sum of Squares	Mean Square	p
Formulation[1] (F)	1	0.0006	0.0006	0.6840
Rate[2] (R)	3	0.0108	0.0036	0.4747
F* R	3	0.0104	0.0034	0.4858

[1]Formulation = Different formulation of triclopyr (Garlon 3A and Garlon 4).

[2]Rate = Different treatment rates applied

Table 14. Analysis of covariance table of average (%) privet cover one year after treatment with and without trenching at different rates of glyphosate for trenching study (with zero rate plots included).

Source	df	Sum of Squares	Mean Square	p
Trenching (T)	1	0.0024	0.0024	0.2643
Rate[1] (R)	2	0.2042	0.1021	<0.0001
Rate*Trenching	2	0.2693	0.1346	0.1346

[1]Rate = Different sub lethal rates applied in trenching study.

Table 15. Analysis of covariance table of average (%) privet cover one year after treatment with and without trenching at different rates of glyphosate for trenching study (with zero rate plots excluded).

Source	df	Sum of Squares	Mean Square	p
Trenching (T)	1	0.0017	0.0017	0.4567
Rate[1] (R)	1	0.0044	0.0044	0.2576
Rate*Trenching	1	0.0002	0.0002	0.7594

[1]Rate = Different sub lethal rates applied in trenching study.

Table 16. Normal average rainfall and year 2000 rainfall of Athens, GA (in inches) [1].

Month	Average Normal Rainfall	Rainfall in 2000
January	4.6	4.9
February	4.4	2.1
March	5.4	3.1
April	3.9	1.7
May	4.3	0.9
June	3.9	1.7
July	4.8	2.2
August	3.7	3.3
September	3.3	3.9
October	3.2	0.2
November	3.6	4.0
December	4.0	3.6

[1] Source: Whitehall Forest, Athens, GA.

Figure 1. Average (%) privet cover resulting from different rates and timings of application of Accord SP (ACC) and Garlon 3A (G3A).

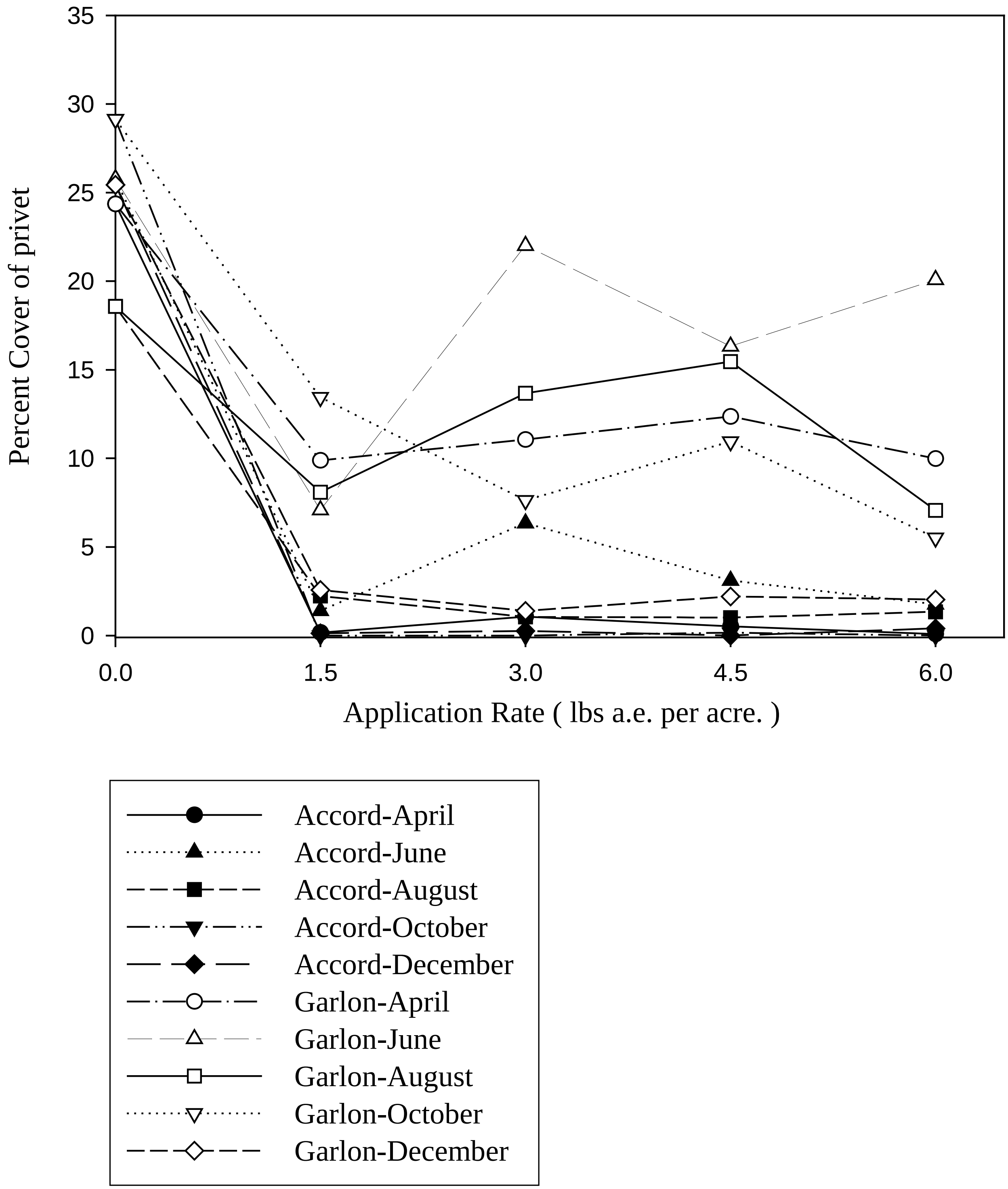


Figure2. Average post treatment (%) privet cover for Accord SP (glyphosate) treated plots averaged across all non-zero rates at different timings.

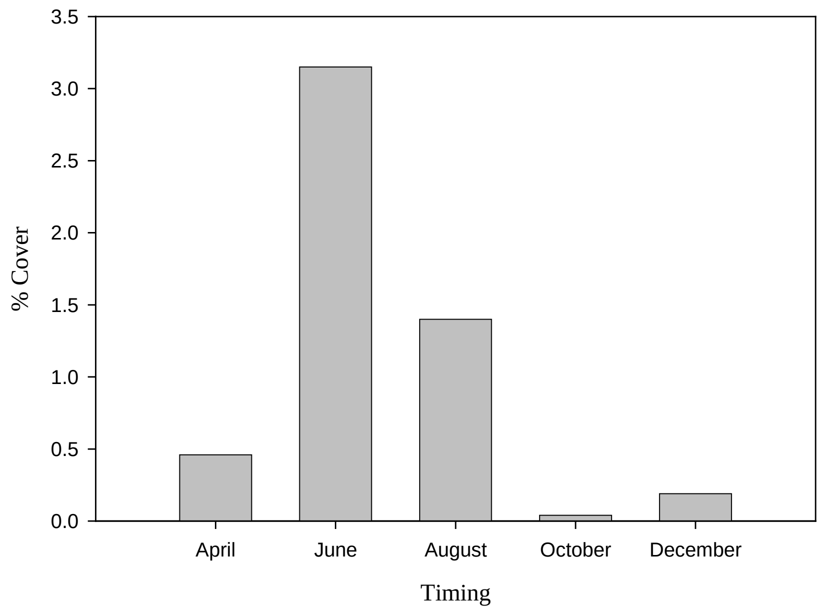


Figure 3. Average post treatment (%) privet cover for Garlon 3A (triclopyr) treated plots averaged across all non-zero rates at different timings.

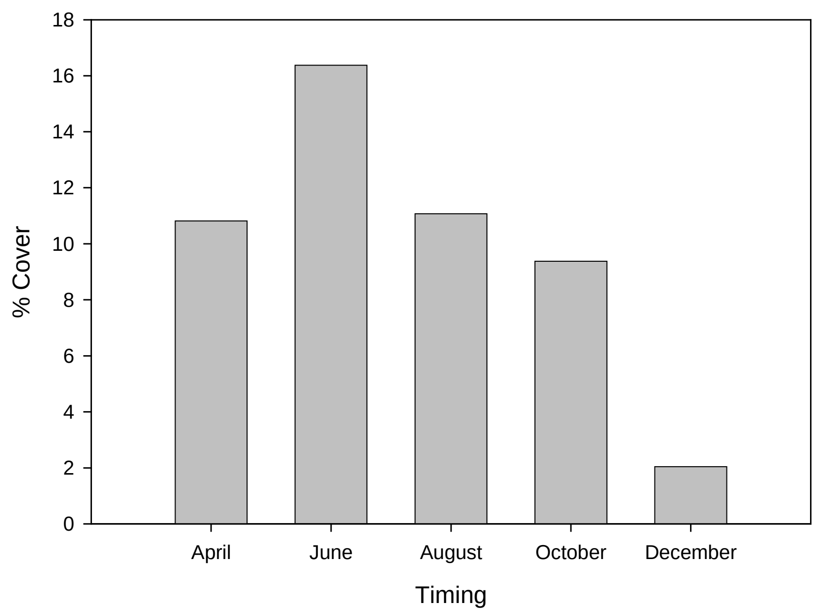


Figure 4. Average (%) privet cover for different formulations of glyphosate and triclopyr applied at five rates in August.

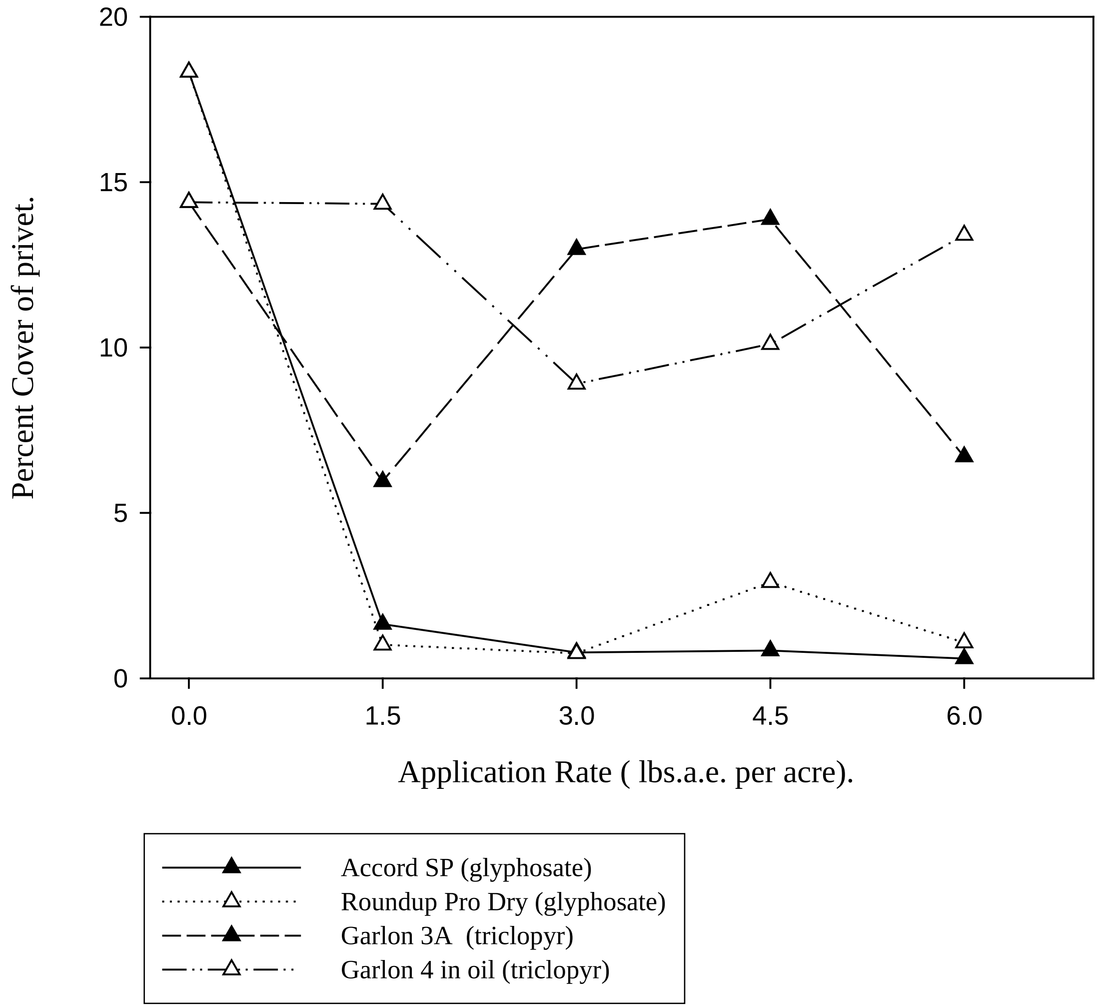
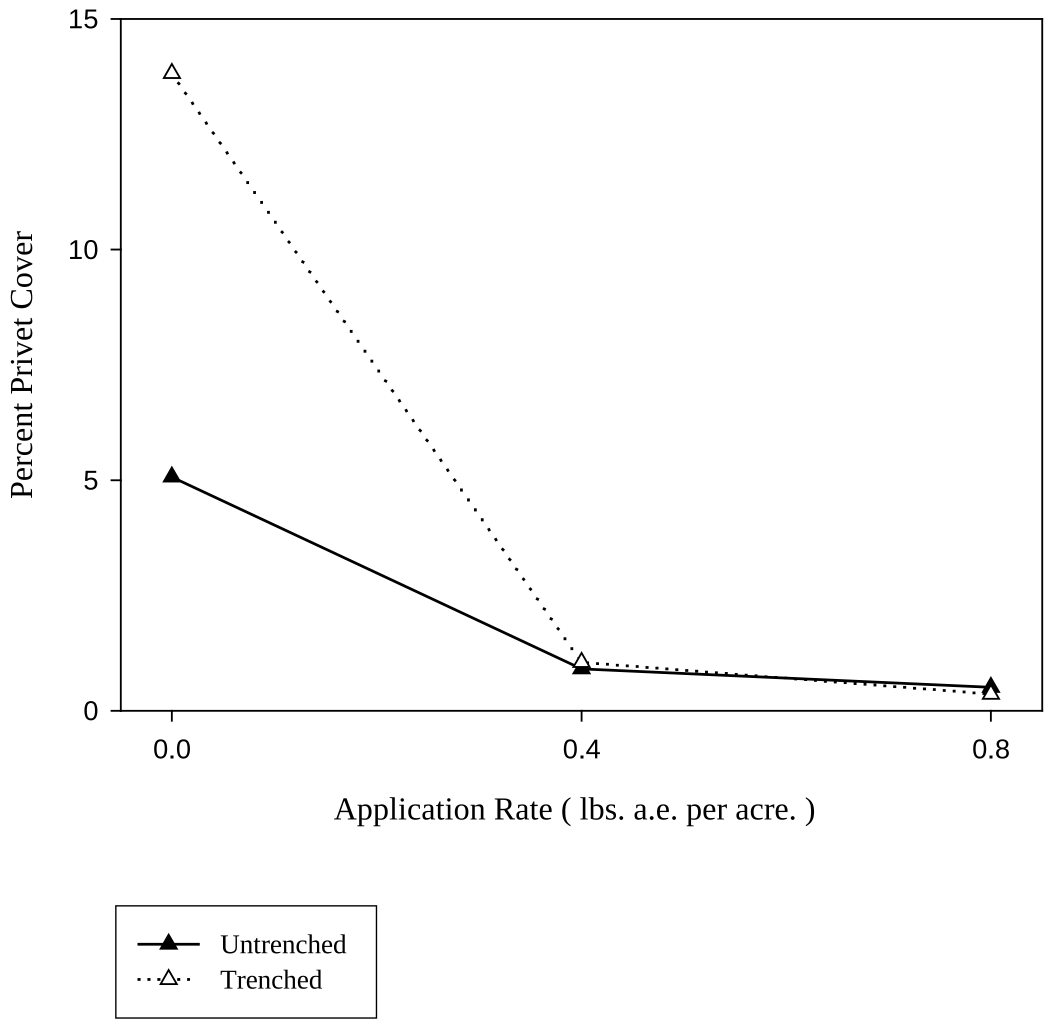


Figure 5. Average (%) privet cover for plots with and without trenches at three application rates of Accord SP (glyphosate) in August.



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APPENDIX A

Description of Herbicides

Accord® Site Prep is an herbicide product of the Monsanto Company formulated as a liquid containing 4 lbs. of the isopropylamine salt of glyphosate (N-phosphonomethyl glycine) per gallon. One gallon of product contains 3 lbs. of the parent carboxylic acid of glyphosate (used in calculations of acid equivalent). Roundup® Pro is another glyphosate herbicide product of the Monsanto Company that is formulated as a dry granule for mixing with water.

Glyphosate is a phosphonalkyl compound that inhibits synthesis of 3 aromatic (cyclic) amino acids (phenylalanine, tyrosine, and tryptophane) which are required for growth and development of plants. Plants susceptible to glyphosate show symptoms of whitening of foliage several weeks after treatment because the mode of action limits chlorophyll formation. The herbicide is absorbed by foliage uptake only. It becomes inactive in soil because it is strongly adsorbed by soil colloids.

In forestry, Accord® Site Prep has been specifically designed for use in site preparation because it controls a broad spectrum of woody and herbaceous plants, including pines. The product contains a surfactant blend to increase spreading of the herbicide and its uptake through the foliage. Species exhibiting some tolerance to the phytotoxic effects of Accord® Site Prep, include hickories, red maple, black cherry, and dogwood.

Accord® Site Prep has a very low mammalian toxicity, with an LD-50 value (lethal dose to kill 50% of a test population of rats) of 5400 mg toxin kg^{-1} of body weight. Its label carries a "caution" signal word because it causes eye and skin irritation. Contact of the product with the eyes and skin should be avoided by wearing rubber gloves, pants, and a long-sleeve shirt. A gallon of Accord Site Prep cost about $ 20 in 2003.

Triclopyr is a herbicide product of the Dow AgroSciences Company with two formulations. Garlon® 4 as a liquid containing the butoxyethyl ester of triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid) per gallon. One gallon of product contains 4 lbs. of the parent carboxylic acid. Product price in 2003 is approximately $81 per gallon.

Garlon®3A is another herbicide product of the Dow AgroSciences Company formulated as a liquid containing the triethylamine salt of triclopyr (3,5,6-trichloro-2-pyridinyloxyacetic acid) per gallon. One gallon of product contains 3 lbs. of the parent carboxylic acid. Product price in 2003 is approximately $60 per gallon.

Triclopyr is a chlorophenoxy compound somewhat similar to 2,4-D and 2,4,5-T that mimics auxin to cause accelerated and unbalanced cell division. Plants susceptible to triclopyr demonstrate symptoms of epinasty (curling of the shoot) within several days after treatment due to differential cell division. Uptake of the herbicide is from foliage only; the herbicide has no soil activity.

Like Accord®, Garlon®4 is used primarily for site preparation in forestry applications because it controls a broad spectrum of woody plants, including pines. It can be dissolved in oil for penetration of thin-barked stems and waxy, evergreen foliage, or it can be dispersed in water with a surfactant for conventional foliage applications. Garlon®3A, which is used in forestry less frequently than Garlon®4, can be dissolved in water for foliage and cut-stem applications, but it will not penetrate bark or waxy foliage. Grasses tolerate the phytotoxic effects of Garlon®4 and Garlon®3A.

Garlon®4 has low mammalian toxicity, with an LD-50 value of 2460 mg toxin kg^{-1} of body weight. Like Accord®, the label of Garlon®4 carries a "caution" signal word because it causes eye and skin irritation. Contact of the product with the eyes and skin should be avoided by wearing rubber gloves, pants, and a long-sleeve shirt. At temperatures above 90°F, Garlon®4 can volatilize and injure nearby seedlings of woody plants.