Evaluating Vegetation Management Practices for Woody and Herbaceous Vegetation

Prepared by:

Davey Resource Group,
a division of The Davey Tree Expert Company

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16. Abstract
To determine vegetation management practices, ODOT Districts can implement to increase efficiency and cost-effectiveness that contribute to worker safety and foster safe highway use by the traveling public. ODOT would benefit from a Roadside Integrated Vegetation Management (RIVM) program that is innovative and adaptive while placing safety and environmental stewardship first.

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Project Background

Ohio Department of Transportation (ODOT) is challenged with managing vegetation along over 43,000 lane miles of roads throughout Ohio's diverse landscapes. Due to the complexity of management requirements and the magnitude of land that ODOT maintains, the task of managing the rights-of-way is complicated and difficult. Among the primary challenges are rising demands for all road and roadside maintenance services, increased operational costs, reduced staff, regulatory restrictions, and public perception. Current vegetation management practices employ primarily mechanical methods utilizing limited equipment resources, with limited use of herbicides and plant growth regulators (PGR) to control unwanted vegetation and turf height.

ODOT Districts know their mission and responsibilities related to vegetation management on state and interstate right-of-way. Across the state, managers and staff perform a variety of vegetation management tasks to facilitate safe passage on roadways. However, ODOT Districts often encounter obstacles, including equipment and staff challenges that hinder their efforts to proactively respond to vegetation management needs. The major challenges found during Phase I and Phase II are: decentralized and disproportionate distribution of vegetation management equipment; lack of trained/experienced staff; lack of readily available technical resources in the Districts; lack of up to date and specific vegetation management guidance; and limited staff and budget resources, which must be prioritized and allocated to roadway (not roadside) maintenance and safety projects. Because of this last challenge, vegetation management has become a lower priority and largely deferred for many years to address other roadway maintenance work.

The overall purpose of the research project was to identify and evaluate vegetation management practices ODOT Districts can implement to increase efficiency and cost-effectiveness of roadside maintenance activities that improve worker safety, foster safe highway use by the traveling public, and improve roadside aesthetics. ODOT needs a Roadside Integrated Vegetation Management (RIVM) program that places safety and environmental stewardship first while also being more innovative and adaptive.

Davey Resource Group, a division of The Davey Tree Expert Company (Davey Resource Group), was selected by ODOT to conduct this research project. This project consisted of two phases. Phase I included investigating ODOT's current vegetation management practices and researching other tools and techniques that would result in greater efficiencies, increased safety, and improved aesthetics. Phase II included field testing selected chemical and mechanical vegetation management methods.

Our research in Phase I determined that a lack of use of industry-specific, innovative tools and techniques by ODOT could be causing operational inefficiencies that increase the labor costs or time needed to perform roadside vegetation maintenance tasks, as well as the number of maintenance cycles needed for each growing season. These operational inefficiencies over time increase ODOT's cost to manage vegetation along Ohio's state right-of-way.

Our research also determined that other DOTs and private companies have developed a number of industry-specific, innovative vegetation management programs that result in greater efficiencies, increased safety, and improved aesthetics. Therefore, it was proposed that if ODOT made significant changes in its herbicide use program, trained staff to more quickly identify problems and issues, and utilized equipment more effectively and properly, major gains in efficiency and effectiveness would be realized, and costs reduced in both the short and long term.

Based on the results of Phase I research findings, field testing was recommended to thoroughly analyze which techniques would gain ODOT the greatest efficiencies and overall return on investment. The best vegetation management practices as determined in Phase I research and consultation from ODOT's

Technical Advisory Panel for the project moved forward into Phase II field testing. Phase I results were summarized in matrices and are provided in Appendix A.

For Phase II, the following areas were targeted to improve existing ODOT vegetation management operations:

- *Chemical Applications:* Increase broadcast herbicide and plant growth regulator use and utilize a targeted application and follow-up treatment schedule to control noxious and invasive weeds, decrease the frequency of turf mowing, brush maintenance and removal, tree trimming and removal, and maintain bare ground where needed.
- *Mechanical Solutions:* Purchase new equipment and more efficiently use existing equipment to perform vegetation maintenance tasks more quickly and safely.
- *Training and Communication:* Provide training to vegetation management personnel on plant identification, herbicide selection, rates and timing, and encourage communication among counties and districts to streamline operations regarding vegetation management practices across the state.

Through this testing, sufficient information was gathered and analyzed to make recommendations for implementation to improve ODOT's vegetation management program.

Research Context

In Phase II, Davey Resource Group field tested, measured, and monitored new and alternative mechanical and chemical vegetation management methods, and compared them to ODOT's standard vegetation management operating procedures to identify processes and practices for immediate and future use that would increase operational efficiency and reduce costs for various vegetation management objectives, including bare ground, turf management, noxious and invasive weed control, brush control, and tree trimming and removal.

Goals and Objectives

The overarching goal of this project was to evaluate alternative vegetation management processes and practices to increase efficiency, effectiveness, and reduce costs. Further goals included:

- Improving safety for workers and roadway users
- Improving environmental stewardship by use of targeted environmentally responsible herbicides to control prohibited and invasive plants and decreasing mechanical maintenance, thereby reducing use of fossil fuels and resulting air pollutant emissions.
- Evaluating new mechanical methods for vegetation management
- Evaluating use new chemical methods for vegetation management
- Improving the abilities of workers to properly utilize equipment and herbicides
- Decreasing the amount of noxious weeds and invasive plants on the ROW
- Extending maintenance cycles for herbaceous and woody vegetation

Project Tasks

Phase II of the project included the following four tasks:

1. Holding nine field days throughout the state (three in each testing area) to educate ODOT staff about the project's goals, field testing, and successes.
2. Creating an integrated vegetation management guide for identification and control of prohibited noxious and some invasive weeds and shrubs in Ohio for maintenance staff as a resource and reference to help them achieve better results in managing vegetation.
3. Conducting field testing of mechanical and chemical methods of vegetation management utilizing ODOT staff, existing equipment, and recommended equipment. Testing involved coordination with local garage management regarding each test, test site assessment, study design, training on new equipment when provided by the vendor, practice with the new technique or equipment, and field testing. Field testing included the application of herbicide and use of mechanical equipment, measurement during the test of the labor involved, vegetation assessments at designated intervals to assess herbicide performance and vegetation response to treatments, and analysis of all the data collected.
4. Maintaining regular project communication with ODOT garages, and keeping the Technical Advisory Panel apprised of progress. Analyzing data and preparing written reports were the final and critical elements to completing and relaying the findings of the project.

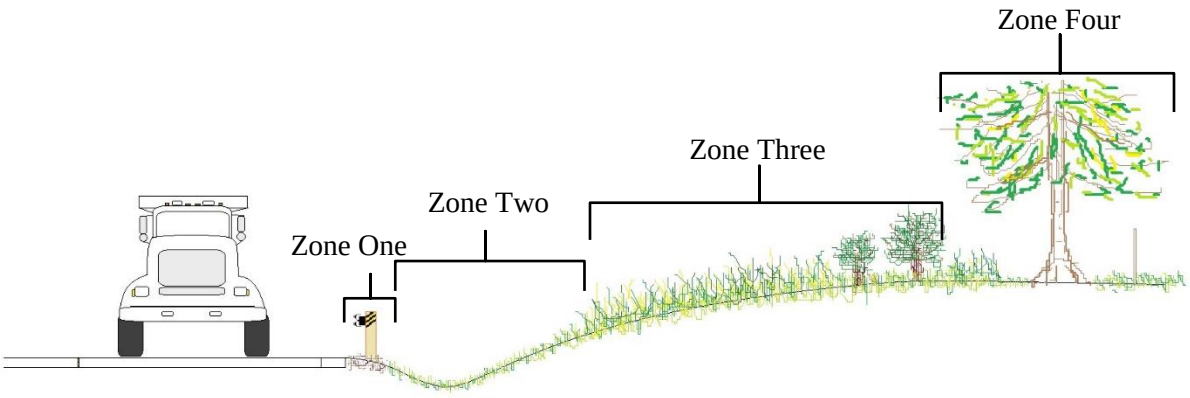
Research Approach

ODOT manages the 7th largest highway system in the U.S. (http://www2.dot.state.oh.us/interstate50/OhioInterstateHistoryTimeline.htm). This highway system or right-of-way (ROW) is largely occupied by paved two-lane state and U.S. routes, and multi-lane interstate highways. The ROW is also largely occupied by vegetated land present in wide center medians, and extends from the road edges to the outer boundaries of the ROW. The ODOT ROW is divided into the following four management zones (Ohio Maintenance Operations Manual, 803):

- Zone One: Vegetation Free Zone
- Zone Two: Operational Zone
- Zone Three: Transition Zone
- Zone Four: Undisturbed Zone

These management zones are depicted in Figure 1 (Diagram of ODOT's Roadside Management Zones). These zones encompass many safety designs, vegetation types, sight distance requirements, and other parameters for which they are managed (ODOT Location and Design Manual Volume 1, Sections 900 Roadside Safety Landscaping Guidelines, 201 Sight Distance, 600.2 Clear Zone, and Ohio Maintenance Operations Manual, 803).

Figure 1: Diagram of ODOT's Roadside Management Zones



Testing Overview

Twenty-five separate field tests were conducted in this project and were grouped in the four management zones. A few of the field tests were repeated on more than one test site in order to test under different conditions (e.g., cable rail versus guardrail, turf versus denser weedier vegetation) or due to site disturbances (e.g., contractor inadvertently applying herbicides in the test site, equipment malfunctions). In these cases, field tests were moved to new locations and started again. At each test site, each treatment method was replicated three times. In all but one test (the species-specific Tree Maintenance: Chemical Control of Lateral Limbs test) the randomization occurred in a complete block design. Under this method, each treatment was repeated one time per replication, and the treatments were randomized within each replication. In the species-specific Tree Maintenance: Chemical Control of Lateral Limbs test, it was necessary to use a different design to ensure that each tree species being treated was tested nine times (three times by each treatment). The design of these plots was completely random to ensure the necessary replications by species. Fact Sheets of each test with study design details are included in Appendix B.

Each test site was chosen with the assistance of local ODOT management to ensure test sites fit the objective of each test, had little chance of outside disturbance, and were similar throughout the replications in general vegetation composition, slope, and accessibility. Through discussions with the ODOT Technical Advisory Panel, purchase of equipment and materials was determined for testing. The local ODOT management determined the Standard Operating Procedure (SOP) against which alternative equipment and materials were tested. All materials, equipment, and labor for each test were provided by ODOT. When equipment with new technology was purchased, the equipment vendor led ODOT maintenance staff and mechanics in a training session.

Prior to testing, a baseline vegetation assessment of each plot was completed to minimize plot variation. If necessary, a different site with less variation was chosen. The baseline vegetation assessment was used as part of the analysis of treatment methods. During testing, labor and equipment timing were tracked and later used to conduct a cost analysis per treatment. At standardized intervals, vegetation assessments were completed to see how the vegetation was progressing.

A water sample was taken from each garage that was the source of water for herbicide mixes to determine the water hardness and pH. Hardness and pH can impact the effectiveness of herbicides and should always be measured and adjusted if appropriate. Although the Montgomery and Stark County garages were found to have extremely hard water, adjustments were not made to the water used from these garages during testing. This decision should be made on a case by case basis with herbicide labeling recommendations going forward.

Davey Resource Group directed practice using all new equipment to give the operators some familiarity with the equipment, but in many cases the test day was the first time the equipment was operated. For herbicide tests, Davey Resource Group directed the applicators on the proper herbicide rates, mixing, and application techniques and assisted the applicators with calibration of equipment. Specific equipment brand manufacturer names used in this report are not an endorsement of said brand names. Other equipment from other manufacturers with the same specifications could be used in their place.

All herbicide mixes and applications were made in accordance with product label requirements. Adjuvants such as a surfactant, drift control, anti-foamer, and dye were added to the mixes in accordance with labeling instructions when needed. Specific product names used in this report are not endorsements of said brand names. Generic products with the same active and inactive ingredients could be used in their place.

Data Analyses

Repeated measurement design was used in all longitudinal studies. This design is recommended when several measurements are taken on the same experimental unit, and thus the measurements tend to correlate with each other. In this case, the measurements are thought of as responses to levels of experimental factors: *time, response,* and a *correlation between response and time* can be taken into account by performing a repeated measures analysis of variance (ANOVA). In such cases, multiple comparisons between the measures of the different treatment methods at each sampling time were conducted using the Least Squares Means (LS Means) option in the General Linear Model procedure of SAS®. When data were collected as part of a longitudinal study, the analysis was conducted also using General Linear Model procedure of SAS®.

Homogeneity testing was conducted when the response variable was the frequency (count) of an event. In such cases, data were displayed in the form of two-way contingency tables. To compute the expected frequencies for each cell, the total frequency in the corresponding row was multiplied by the total frequency in the corresponding column and divided by the total of observations. Corresponding chi-square tests were conducted to determine whether or not the frequency distribution was uniform among treatments.

Outputs for both the repeated measures ANOVA and homogeneity test analyses were represented as calculated LS Means and their calculated statistical significance (P-value). The P-value is a probability used to assess the level of statistical significance of an observation and the confidence in the conclusion about the null hypothesis (hypothesis of no difference). In other words, the P-value provides evidence to reject or fail to reject the null hypothesis, allowing statistical conclusions to be drawn about the alternative hypothesis relative to the real world experiment. P-values represented in text are associated with the term "significant," which refers to a P-value that represents a probability equal to or less than 5% (or $p \leq 0.05$) of the null hypothesis being correct. A P-value less than 0.05 indicates strong evidence against the null hypothesis and supports the notion that the patterns observed in the collected data are a result of a real effect and are not a result of environmental or experimental bias or random chance.

Graphical representations of ANOVA and homogeneity tests have been included for each test. The graphs are included for multiple metrics of data (e.g., grass coverage, broadleaf coverage, and woody coverage) that are important to the type of test that was performed. All the graphs use the LS Means values from each assessment date. The assessment date is included as the x-axis, and the LS Means is included as the y-axis. Accompanying the LS Means values are the standard error associated with the LS Means. The standard error is represented as error bars. These error bars are calculated through the ANOVA and homogeneity test and convey the range of values that were used to calculate the LS Means. Wide error bars indicate that the data recorded in testing showed large amounts of variation between replications. Sources of variation between replications include different vegetation response, data sampling error, and possible error by applicators (missed application). The use of three replications in the experimental design often resulted in large variation between the replications, which could have potentially confounded the statistical analysis and hidden significant relationships or responses. The issue of large variation affected many of the tests and may have masked the statistical significance of the results, constraining the discussion to observed responses taking place.

Cost Analyses

Cost analyses were calculated for each test, method, and treatment. The cost analyses included labor to perform the treatment and follow-up labor during the testing phase. When applicable to tests, the purchase price of herbicides was compared. Finally, the purchase price for new and/or specialty pieces of equipment was used along with labor costs to determine the return on investment (ROI).

Data for the labor analyses were recorded by timing the operations during field testing (e.g., timing of a mowing operation to complete each test plot). These calculations also represent any reductions in time (to accomplish field testing) through successive years of chemical and mechanical treatments. An arithmetic mean of field testing data was then used to calculate the labor hours and labor costs. Labor hours and labor costs were utilized to calculate per mile and per acre costs to determine production rates. Further computation was used to analyze the labor cost based on an average direct wage for ODOT Highway Technicians (HT 1, 2, and 3). Labor comparisons were summarized by evaluating maintenance activity occurrences per year of the field operations to give a clear picture of how the labor hours may be affected by the field operations in a particular test.

For all tests using herbicides there is a cost comparison of the herbicides for each treatment. Herbicide cost per container was used with application rates to calculate ounces used per acre and cost per acre and per mile (Appendix C). These costs were then multiplied by the applications occurrences per year to obtain the total herbicide cost per treatment per acre per year and total cost per mile per year.

The operational cost of equipment used in testing was obtained from ODOT's Equipment and Inventory Management System (EIMS) but was ultimately not used as part of the calculations as it could not assist in the analysis performed. The EIMS data presented large variations in age of equipment, equipment maintenance costs, and similar pieces of equipment with different operational costs. Additionally, it was found that calculating the operational costs of tests was effected by which pieces of equipment ODOT supplied on the day of testing. For example, the crew could show up on site with a 1/2-ton pickup equipped as a spray truck one day, and a modified sweeper truck equipped as a spray truck the next day. Both pieces of equipment would perform the same task but with different operational costs. The intricacies of the EIMS system and the calculations for operational costs provided inconsistent figures when looking at a comparison between tests. Therefore, the EIMS data was not used in comparisons between tests.

The purchase price of new equipment (Appendix C) was used to determine the ROI. Production rates established during testing along with purchase price were used to perform a basic ROI analysis on the purchase price of new equipment in terms of labor savings. In this analysis, similar testing activities were grouped together within vegetation management zones, and comparisons were made using labor cost and production rates with respect to purchase price of new equipment. The standard operating procedure or slowest method was used as a baseline for labor cost and production rate per mile or per acre. The baseline is typically the method that requires the largest amount of total labor hours and has the greatest cost per mile or per acre. For each recommended improved method, cost savings were demonstrated in per acre or mile labor reduction when compared to the baseline method. The cost savings per acre or mile was then divided by the purchase price to determine how many miles or acres each improved method would need to be used to realize a ROI. To determine how many hours it would take to achieve a ROI, the total acres or miles required to realize a ROI was divided by per-acre or per-mile production rates established during testing. The result is the number of hours required to achieve a ROI per improved method based on purchase cost, labor savings, and production rates. ROI was calculated in separate tables by zone for each piece of equipment. ROI will be realized even faster than expressed in these tables when equipment is used in multiple operations and zones (e.g., skid sprayer used in both Zone One and Zone Two, or Bandit 1850 chipper used for performing tree maintenance and removal clean-up for on-road and off-road scenarios).

Aesthetic Feedback

Public complaints regarding ROW aesthetics were generally related to sight distance, visual and sound buffers from the roadway, and quality of work. Most of the complaints that were forwarded from ODOT's Public Information Officers and County Managers were related to sight distance problems around intersections or driveway entrances. Additionally, County Managers relayed general complaints they repeatedly received from neighboring commercial properties wanting increased clearance for prospective customers to be able to see their business from the highway. Conversely, complaints were received from residential property owners when clearance was increased in front of their property, and their sound and visual buffer from the highway was reduced or removed.

Complaints from motorists about the quality of work were focused on tree maintenance. Flail mowers, rotary mowers, and forestry mulchers do not properly trim trees. They leave ragged cuts that cannot be properly sealed by the tree. All-terrain tree trimmers (e.g., Sky Trim or Jaraff) do not prune trees to International Society of Arboriculture (ISA) and American National Standards Institute (ANSI) pruning standards. The stub cuts left by all-terrain tree trimmers cannot be properly sealed by the trees. When trees are left as spiked totem poles by this equipment (considered removed from the managers' perspective), the trees are considered eyesores and receive many complaints. Many of these 'removed' trees have been found prolifically resprouting.

Due to the wide variation in complaints from various parties, no consistent measurement or evaluation method could be developed; therefore, aesthetics were not included in the testing evaluation and measurement.

Safety Evaluation

During testing, there were 0 reported safety incidents at any of the testing sites. While the testing sites were free of safety incidents, there were incidents occurring throughout the state in the maintenance department. The Davey Resource Group research team became aware of lacerations from chainsaws and mowers hit by passing vehicles. Staff also witnessed maintenance crews using string trimmers to cut back poison hemlock which could have led to blisters on the skin due to the toxic nature of poison hemlock.

Reducing the frequency and length of time staff spend maintaining the ROW will reduce exposure to potential safety hazards. Controlling toxic plants by using spray equipment rather than coming into contact with toxic plants through manual cutting methods will reduce exposure. Putting maintenance workers in vehicles to perform maintenance work with appropriate maintenance of traffic procedures enables them to be better protected and more visible than working on the side of the road using more manual methods such as string trimming. The use of the chippers is notoriously dangerous in work. Per the Centers for Disease Control and Prevention (2004), from 1992-2001, there were 31 deaths from mobile chippers and 2,042 injuries from mobile and stationary wood chippers nationwide. Minimizing use of chippers and manual feeding of chippers will greatly reduce exposure to the risks of using them. Maintaining the ROW on a routine maintenance cycle to prevent unwanted vegetation reduces the cost, equipment, and labor needed to reclaim an area that has been allowed to grow into mature trees. Routine maintenance cycles and reduced mowing through the prudent use of herbicides reduces the frequency of maintenance along the ROW and for the most part, utilizes equipment that uses less fossil fuels and emits less carbon emissions thereby having a smaller environmental footprint. Allocating areas for pollinator habitat will further increase the benefit of reduced mowing in designated areas.

The Bureau of Labor Statistics tracks annual rates and the number of work-related injuries, illnesses, and fatal injuries, and how these statistics vary by incident, industry, geography, occupation, and other characteristics. These reports are very beneficial in helping companies and industries benchmark and help to provide a focus on a safety culture to decrease injuries. These statistics are grouped by broad industry categories and employment size. Narrowing in on specific sectors of an industry or incidents caused by a certain type of equipment is not feasible. Worker safety and safety of the traveling public were evaluated qualitatively only, due to the lack of comparable quantitative industry standards and data. Observations regarding safety of the public or workers, when applicable, are included in the zone overview and recommendations where relevant.

Research Findings and Conclusions

The research project determined that ODOT is currently using reactive maintenance practices with limited use of RIVM methods. The research and observations from the project found that overall, ODOT lacks tools and techniques commonly used in cutting-edge ROW vegetation management programs. These deficiencies cause inefficiencies and increase program costs. Vegetation management strategies that can decrease crew and equipment hours by increasing the period between manual and mechanical treatments have not been implemented. Statewide, mechanical methods that could increase vegetation management efficiency are absent. District and County level knowledge of chemical methods, such as herbicides and plant growth regulators, is lacking. District and County staff do not have the tools necessary to manage noxious weeds in the ROW.

Throughout the project, Davey Resource Group was able to observe ODOT's equipment, processes, training, and expertise for managing ROW vegetation. There is a disproportionate availability of sufficient equipment, as well as relevant knowledge and experience between counties and districts. Some of the areas in need of improvement include vegetation identification, herbicide use, and experience with equipment related to vegetation management.

Specific findings and conclusions of each of the 25 tests are included in Appendix D, which is organized by Management Zone. Each section describes the zone location, goal, current maintenance practices, safety concerns, and testing objectives. Then, for each test conducted in that zone, an explanation of the particular test objective, methods, and treatments tested, results (vegetation response, costs of labor, materials, and equipment), and recommendations are provided. After presenting each test, a summary of zone recommendations, which includes a ROI for new pieces of equipment, are provided.

Labor costs for each method have been calculated based on timed maintenance activities at the test sites over the course of the testing period. Several factors influence labor costs such as variations in methods, equipment efficiency, number of staff, and occurrences per year. Tables provided in Appendix E summarize the cost to manage the ROW based on all of the RIVM methods used throughout Phase II and the labor cost to treat one acre or one mile for each method. These tables can be used to compare different methods between all tests performed in Phase II.

Vegetation Identification

Identification of vegetation is important to understand how best to manage undesirable plants and trees and to be able to distinguish from vegetation that has desirable characteristics (e.g., pollinator habitat). Being able to identify and transfer information about problematic plant colonies to trained applicators and managers is important for devising an RIVM plan. Many of the maintenance staff have not been trained to identify vegetation that causes sight distance issues and, therefore, increased maintenance. ODOT maintenance staff spend a great deal of time maintaining undesirable weeds by mowing them several times per year. These fast and tall-growing weeds cause sight distance issues that prompt mow efforts. Once identified and communicated to staff knowledgeable in vegetation management, long-term RIVM solutions can be devised and employed to control undesired vegetation.

Herbicide Use

Many counties or even districts do not have an adequate spray system available for applying herbicides. Some counties do not have licensed applicators to make herbicide applications. Many of the licensed applicators need support and further training to be more effective at controlling undesirable vegetation. The topics for further training include: setting up and being familiar with the different parts of an herbicide spray system, understanding the control panel to measure output, calibrating equipment, understanding herbicide labels, rates and mixing instructions, and reviewing application techniques.

Materials should be stored in accordance with the labels to protect from heat or freezing per label requirements.

Equipment Use

Maintenance staff are involved in numerous tasks throughout the year. While some tasks do not require high levels of expertise, experience has a significant impact on efficiency. During testing, it was observed that repeatedly using specific equipment or working on a task as a crew increased efficiencies, even on simple tasks such as string trimming. This relationship between experience and efficiency gain was observed in many of the test sites. As crews became more knowledgeable and used equipment more frequently, their work became more efficient. When new operators were put in equipment, especially specialized equipment, crews were slower, experienced difficulty in properly using the equipment, and even damaged the equipment.

Some tasks performed by employees have higher safety risks due to the equipment involved or the assigned task. This is especially true when it comes to tree maintenance and removal. This work

requires planning, organization, training, experience, and expertise. Employees who received training once and only conduct tree maintenance and removal periodically during six months of the year did not obtain sufficient experience to develop the expertise required to perform this task safely and efficiently. Employees who worked together frequently on tree work throughout the season under the direction of an experienced crew leader on the job site were found to be more efficient than crews who had no crew leader, had infrequently performed tree work or infrequently performed work with the specialized tree equipment team. Insufficient experience led to inefficiency, difficulties with using equipment, equipment failures, and created potential safety risks.

Equipment to be stored over the winter should be winterized according to manufacturers' recommendations.

Recommendations for Implementation

To transition from a reactive vegetation maintenance program, it is recommended that ODOT implement a comprehensive, proactive RIVM program based on plant life-cycles to improve safety, effectiveness, and efficiency. Detailed recommendations by zone, and broader educational and management recommendations, are presented below.

Maintenance of Management Zones

A major goal of this research project was to provide results that can be successfully implemented to yield the benefits expected and desired by ODOT. Test-specific recommendations for effective chemical and mechanical control of roadside vegetation are included in Appendix D. The following sections summarize the recommendations for each management zone.

Zone One: Vegetation Free Zone

The goal of vegetation management in Zone One is to maintain bare ground as stated in ODOT's Ohio Operations Manual in Zone One. However, the reality is that there are circumstances (intentional or unintentional) where vegetation is present in this zone. Where environmental factors make it possible, bare ground should be maintained, as it is more economical than maintaining vegetation under guardrail and cable rails. The main safety risk in this zone for maintenance workers is exposure to traffic because it is the zone closest to traffic. Reducing the number of workers present, frequency of maintenance, and amount of time per maintenance activity reduces workers' safety exposure in this zone. Using vehicle-based methods such as spray trucks or guardrail mowers as opposed to worker-based methods such as string trimming increases worker visibility and protection, reduces the number of employees exposed, can reduce the frequency of maintenance (if using herbicides), and reduces the length of time for maintenance activity in this zone, thereby reducing employee exposure.

Equipment Recommendations

- Purchase spray equipment for each county as there is a significant ROI due to the savings in reduced mow occurrences per year. With the spray equipment purchased and tested in Zone 1, the ROI is realized after 13 miles of use.
- Skid sprayers with boomless nozzles and a control panel such as purchased for this project or another spray system of at least equal abilities should be specified.
- Purchase spray nozzles that match the treatment area width for bare ground goals.
- If mechanical vegetation maintenance is necessary, purchase a U.S. Ditcher, Inc. GRM-60 Spider Guardrail Mower or equivalent equipment instead of string trimmers. The ROI for a guardrail mower head and tractor is achieved after only 256 miles of use. This is a good investment at the district level that could be shared by counties that maintain vegetation under rails. The unit requires a trained, experienced, and consistent operator to optimize equipment performance.

Achieve Bare Ground

- Apply herbicides using a skid sprayer with boomless nozzles and control panel or another spray system of at least equal abilities.
- If material costs are the major concern, three applications per year of Rodeo® (64 oz./acre) is the most cost-effective herbicide treatment method.
- Vegetation can be effectively controlled all season with one application per year of either a Rodeo® (64 oz./acre), Perspective® (7 oz./acre), and Esplanade® 200 SC (7 oz./acre) mixture, or a Rodeo® (64 oz./acre), Oust® (8 oz./acre), and Esplanade® 200 SC (7 oz./acre) mixture.

Trim Vegetation Under Guardrails or Cable Rails

- Utilize the U.S. Ditcher, Inc. GRM-60 Spider Guardrail Mower, or equivalent to achieve a more cost-effective, efficient, and safer means of maintaining vegetation under guardrails or cable rails compared to string trimmers.

Zone Two: Operational Zone

The goals of vegetation management in Zone Two are to provide sight distance, maintain visible ditches, manage turf height and prevent cover while controlling tall weeds and maintaining visual quality. Sloped areas provide additional challenges. Zone Two requires a large amount of labor and equipment resources if maintained only by mechanical methods. The following recommendations address turf height and weed coverage as the most significant factors in reducing labor and mowing occurrences in Zone Two, and also address sloped areas.

Equipment Recommendations

- Purchase spray equipment for each county as there is a significant ROI due to the savings in reduced mow occurrences per year.
- Skid sprayers with boomless nozzles and a control panel as well as hose reel and spray gun such as purchased for this project or another spray system of at least equal abilities should be specified.
- Purchase spray nozzles that match the treatment area width for mowing and maintaining low-growing grass.
- For areas not reachable with a spray truck that are mowable, purchase a Diamond WetBlade™ batwing mower or similar equipment to simultaneously mow and apply herbicide to save on the cost of separate applications. The WetBlade™ unit requires a trained, experienced, and consistent operator and guidance from a licensed applicator who can calibrate the unit and adjust the controls necessary to get the desired herbicide rate dispensed and optimize equipment performance.
- If mechanical maintenance of slopes too steep for traditional mowers is necessary, the Kut Kwick or similar equipment should be used for turf mowing on slopes up to 40 degrees and the Alamo Traxx™ RF or similar equipment should be used for thick weed mowing on slopes up to 60 degrees.

Turf Height Control

- In areas that require frequent mowing, apply PGR to established turf stands in spring every other year to reduce one mow occurrence each year.
- Plateau® (4 oz./acre) is the recommended PGR.
- PGR could also be used selectively in directed applications around areas that require significant amounts of yearly mechanical labor such as near intersections, signs, and guardrails or cable rails.

Broadleaf Weed Control

- Apply broadleaf selective herbicide every year to reduce mowing occurrences per year. The ideal timing is in late spring-early summer. The alternate timing is early fall for most weeds. It is best to apply PGR in spring for slow turf growth and for weedy areas, follow with broadleaf herbicide applications a few weeks to one month later after most weeds have germinated.

Milestone® (7 oz./acre) or Perspective® (5 oz./acre) are the recommended broadleaf herbicides as their soil active properties control a broad spectrum of broadleaf weeds. Milestone® and Perspective® are comparable in price and effectiveness.

- Perspective® may be desired in some situations for its ability to suppress turf height and seed head formation. However, Perspective® can also cause slight browning of the turf for a few weeks.
- In areas where a batwing mower is used, especially areas that a spray truck cannot reach (e.g., mow back areas) the Diamond WetBlade™ Batwing Mower or similar equipment can simultaneously accomplish mowing and herbicide application.

Slope Maintenance

- Maintain slopes by applying broadcast herbicide applications annually in late spring or early summer to control problematic broadleaf and woody weeds, as these are prominent vegetation on slopes. This method is more effective and less expensive than mowing.
- If the entire slope cannot be reached with the spray system's boomless nozzles, the unit's spray gun should be used.
- Milestone® (7 oz./acre) or Perspective® (5 oz./acre) are the recommended herbicides that should be annually alternated.
- Milestone® is the recommended herbicide for steep slopes as Milestone® allows grass seed heads to develop. This is important because slopes are often gravelly, void of nutrients, and may be sparse in grass coverage.
- In the rare circumstance where mechanical mowing may be preferred to exclusively completing an annual herbicide application, vegetation type will guide the decision on which slope mower is the best option. If the area to be mowed is primarily grass, then the Kut Kwick or similar equipment will cover the acreage faster due to its larger deck size. If the area is overgrown with primarily weeds and needs reclaiming, the Alamo Traxx™ RF or similar equipment should be used.

Zone Three: Transition Zone

The goal of vegetation management in Zone Three is to selectively control brush, shrubs, small-diameter trees, and noxious or invasive plants. The SOP for mechanical vegetation control is mowing (with flail mower, rotary mower, batwing mower, or forestry mulcher). Mechanical methods have not been effective at controlling the undesirable vegetation and merely reduce height for a short time. Recommendations for Zone Three are focused on noxious and invasive weed control and control of brush and trees. Herbicide applications are more effective, less labor-intensive, and less costly than mechanical maintenance.

Equipment Recommendations

- Purchase spray equipment for each county as there is a significant ROI due to the savings in reduced mow occurrences per year.
- The spray gun from a skid sprayer is the most effective way to target unwanted noxious and invasive weeds that tend to be sporadic and may be entering the ROW where boomless nozzles may not reach.
- Purchase a Diamond WetBlade™ rotary boom mower or similar equipment to simultaneously mow and apply herbicide. The unit requires a trained, experienced, and consistent operator and guidance from a licensed applicator who can calibrate the unit and adjust the controls as

necessary to get the desired herbicide rate dispensed and optimize equipment performance.

Noxious Weed Control

- Johnsongrass is best controlled midsummer with an application of Outrider® (0.75 oz./acre) when it reaches approximately 18 inches tall. This perennial grass may need to be treated for a few years to control large colonies. Reseed bare patches with desirable seed mix to reduce undesirable vegetation from seeding itself.
- Japanese knotweed is best controlled with Ecomazapyr 2 SL (64 oz./acre) applied once per year in midsummer. Mowing of Japanese knotweed should be avoided unless necessary to improve sight distance, as it encourages knotweed to grow thicker on its present site and cuttings transported on the mower can start colonies at new sites. This perennial weed will need to be treated with herbicide for several years to adequately control its populations.
- Poison hemlock is recommended to be controlled with Perspective® (7 oz./acre) or Milestone® (7 oz./acre) applied in early spring. Mowing alone does not control poison hemlock. Annual applications will need to be made for several years, as the plant is biennial and has a seed bank that can be viable for several years.
- Kudzu is best controlled with Milestone® (7 oz./acre) or Streamline® (9.5 oz./acre) applied in spring-late summer. Repeat annual applications may be necessary if the colony has become large and dense.

Brush Control

- Autumn olive can be controlled with herbicides applied as a foliar application (either instead of or months prior to removal), basal bark, hack-n-squirt, or cut stump treatment. Both mixtures of Milestone® (7 oz./acre) with Triclopyr 4 (256 oz./acre) and Streamline® (9.5 oz./acre) with Triclopyr 4 (256 oz./acre) applied as foliar applications were found to be an effective means of control. Repeat spot treatments with a backpack may be necessary to prevent regrowth.
- Bush honeysuckle can be controlled with herbicides applied as a foliar application (either instead of or months prior to removal), ground application, basal bark, hack-n-squirt, or cut-stump treatment. Tordon® K (64 oz./acre) applied after (flail) mowing as a ground application was found to be an effective means of control. Only use Tordon® K or other restricted use herbicides after consulting with the District Office of Environmental Services.
- Shrubs and small trees in areas where a forestry mulcher is typically used are best controlled with Tordon® K (64 oz./acre) as a ground application after mowing.
- During the dormant season, brush on slopes as frequently seen around bridges are best controlled with a basal bark application. Triclopyr 4 and basal oil at a 1:5 ratio is the recommended herbicide
- Tree-of-heaven is best controlled with a basal bark treatment during the dormant season. Triclopyr 4 and basal oil at a 1:5 ratio is the recommended herbicide. Tree-of-heaven is not controlled by manual removal and manual removal without herbicide use will increase Tree-of-heaven coverage.

Zone Four: Undisturbed Zone

The goal of vegetation management in Zone Four is focused on tree maintenance and tree removal in on-road and off-road settings. The SOP for tree maintenance is either a forestry bucket truck or an all-terrain tree trimmer. The SOP for tree removal is a manual chainsaw crew utilizing a brush chipper. All methods for Zone Four tree work require efficient crews that can optimize their working time while staying safe. Recommendations for Zone Four are focused on safety, efficiency, and proper

arboricultural techniques. Herbicide applications can also be utilized in Zone Four to reduce the coverage of woody vegetation and lengthen the control period obtained by mechanical methods.

Equipment Recommendations

- Tree maintenance and removal equipment is specialized and requires trained, experienced, and consistent operators to optimize equipment performance.
- Utilize an excavator to load debris into every chipper to increase safety and efficiency.
- Purchase and test the Tree Commander™ remote control for the Vermeer BC1500. It should be utilized by the excavator operator to further reduce the need for ground crews to manually feed the chipper.
- Purchase a Brown Brontosaurus whole tree mulcher or similar equipment for tree removal.

Tree Maintenance

- Tree maintenance can be performed efficiently with either the Altec 60' Forestry Bucket Truck or the Kershaw SkyTrim 75 G2. Both pieces of equipment were efficient at removing branches but had significant differences in their abilities to perform proper arboricultural cuts. If proper cuts are a concern to ODOT, the Altec 60' Forestry Bucket Truck with a knowledgeable operator should be utilized.
- The Bandit 1850 whole tree chipper utilizes a smaller crew size and is a safer chipper due to the optional grapple for self-feeding. However, if an efficient brush chipper crew is utilized with an excavator feeding the chipper and operating the Tree Commander™ remote control, the Vermeer BC1500 labor costs will be reduced while efficiency and safety is increased. Due to the cost of the Bandit 1850 chipper, it is not the best option for this type of work.
- If trees are responding with excessive sprouting after pruning, chemical control of lateral limbs could be utilized to extend the mechanical maintenance cycle. Chemical control of lateral limbs can also precede mechanical trimming by one or two years to buy time until mechanical pruning can be scheduled. Krenite® S in a 4% solution will provide excellent limb defoliation, while not damaging the tree, and can also be used for spot treatment of limbs near signs.

Tree Removal

- Utilize a Brown Brontosaurus whole tree mulcher or similar equipment for whole tree removal. The whole tree mulcher has a lower purchase price than other pieces of forestry equipment and has a much lower per acre labor cost compared to ODOT's SOP, which makes it a viable option for ODOT uses. The Brontosaurus only requires one operator (plus a second crew member for spotting or falling stumps of large-diameter trees) and mulches trees from the top down to the stump. This is a safe option that eliminates many of the hazards associated with tree removal projects.
- Always follow tree removals with cut-stump treatments of Triclopyr 4 and basal oil in a 1:5 ratio to prevent stumps from re-sprouting.

Training and Educational Programs

ODOT should develop a formalized training program for RIVM staff. This includes creating an annual training schedule for all employees and tracking completion of the training. Documentation of safety training is especially important. Documentation of training for each employee would also help shed light on areas that need improvement and aid in customizing a training program for each employee's current job description and future career path.

A quality training program is essential for keeping staff safe, efficient in their work, and motivated to learn new skills. Reasons for training include new-hire training about ODOT's RIVM programs and operations to introducing new technical concepts, practical techniques, and safety principles to field staff, to bringing in new software applications for district managers and administrative staff.

Training can be provided by a variety of sources already used by ODOT, such as other ODOT divisions and employees, local utility companies, equipment manufacturer representatives, local and regional professional organizations, and qualified consultants. Depending on the topic, training can be offered annually, seasonally, at weekly "tailgate" sessions, or as needed.

Training does more than just educate workers. Training supports professional development and job advancement and positively influences attitudes and morale. It encourages timely and more appropriate decision-making on the local level and can result in fewer accidents and equipment damage and repairs.

Specific training recommendations include providing routine and specialized training and education programs, increasing herbicide use training and equipment at the district level, improving job-site practices and training tree work, and expanding the *Guide for Roadside Integrated Vegetation Management of Prohibited Noxious Weeds in Ohio*. Each of these recommendations is discussed below.

Routine and Specialized Training and Educational Programs

For ODOT RIVM staff, general training is needed given the nature of the resource and the unique, highly visible, and potentially dangerous working conditions associated with an RIVM program. At a minimum, these RIVM topics and procedures should be provided to staff on a regular basis:

- Herbaceous plant and woody plant identification
- ODOT safety and general safety programs (e.g., job-site safety, Occupational Safety and Health Administration compliance, general equipment use, and electrical hazards and awareness)
- Pesticide use and storage

Training is also recommended for select staff so that they can acquire professional credentials that are now the recommended minimum standards in the industry. These include:

- ISA Certified Tree Worker, Certified Arborist, and ISA Tree Risk Assessment Qualification
- Ohio Commercial Pesticide Applicator Training

Herbicide Use Training and Equipment in the Districts

Herbicides are recommended as the primary means to control unwanted vegetation in the ROWs. Therefore, it is critical that every District have properly credentialed and trained staff, prioritize recurring staff training, and have access to the proper equipment. Implementation recommendations are:

- Employ at least one licensed pesticide applicator per county. Ready access to a qualified staff for maintenance crews will improve efficiency and effectiveness.
- Institute a continuing education program for licensed applicators. A licensed applicator needs repeated and continuous training after obtaining their license to maximize the effectiveness of any herbicide control program. This should be a hands-on training with the following topics:
    - Calibration of equipment
    - Herbicides - types and uses
    - Reading labels - sections that apply to roadsides
    - Properly mixing herbicide solutions
    - Using surfactants
    - The importance of testing water quality and how it affects the effectiveness of herbicides
    - Cleaning equipment and disposal of rinsate

Job-Site Practices and Training for Tree Work

Several tests were performed using arboricultural equipment to evaluate better methods of maintaining and removing trees on the state ROW. Given the labor- and equipment-intensive nature of this type of work and the high-risk potential to ODOT staff and the traveling public, the following recommendations are made for staff and job sites where mature trees are being maintained or removed:

- Assign a qualified and experienced foreman to the job site to keep crew members safe and productive with assigned jobs.
- Arrange for hands-on training for tree maintenance subjects such as ANSI A300 tree pruning, maintenance, and protection standards, tree risk assessment, insect and disease diagnosis and management, felling techniques, basic roping, rigging, aerial rescue, and specialized equipment use, calibration, and safety. Provide this training at least annually per county or district.
- Provide the opportunity for ODOT maintenance staff to watch a professional tree crew at work. Observe how a tree maintenance project is a carefully planned team effort where everyone has a specific task, making sure they stay clear of each other when working, and there is very little time where something is not getting accomplished by every crew member.
- Provide regular safety training on topics such as chainsaw drop starts, pinched saws, and kick-backs; how to control the fall of a tree; making notches, hinges, and back cuts; chipper safety; and aerial rescue.

Guide for Roadside IVM of Prohibited Noxious Weeds in Ohio

The Guide for Roadside Integrated Vegetation Management of Prohibited Noxious Weeds in Ohio is a practical field guide for identifying and controlling all of Ohio's prohibited noxious weeds and a few select invasive weeds. There are numerous other invasive and non-native plants that are problematic on the state right-of-way, and these should be added to the Guide. Also, the current Guide is in printed and electronic format only. Creating an application for use on smartphones, field computers, and other electronic devices would facilitate distribution and encourage greater use of this reference resource. Implementation recommendations are:

- Expand the content of the Guide to include problematic weeds/vegetation that are not on the Ohio Prohibited Noxious Weed list. The information on the additional plants should have the same content and be in the same graphic layout as the current Guide.
- Create an electronic application for the Guide which could find target weeds by season, life-cycle time, or flower color for use on smart phones, field computers, and other electronic devices.

Adaptive Management Program

To implement a comprehensive, proactive vegetation management program, ODOT will need to make changes to current reactive management practices. The framework for developing this program should include completing a vegetation inventory to document what vegetation is present, developing a management plan to control undesirable vegetation and promote desirable vegetation, utilization of technology to implement the plan, and identifying the appropriate equipment and staff to complete the work. This adaptive management program should be spearheaded and managed by an individual within ODOT in a state-level operations and planning vegetation program manager position to provide consistent oversight and connectivity. To implement a proactive management program, it is recommended that both roadside vegetation and asset inventories are completed, a written RIVM plan created, GIS-based work planner software is acquired and used, cultural controls are implemented, equipment is purchased and used to improve worker safety, and benefits and use of contractors are maximized.

Roadside Vegetation Inventory

Much like equipment and materials inventories, a computerized vegetation inventory would provide ODOT staff valuable and time-saving access to information about the locations, quantities, and conditions of roadside vegetation. The inventory would capture data in each district and county by management zone on the type of vegetation (e.g., turf, noxious weed, invasive weed, and tree), location (mile markers), size of the vegetation type in square feet, and the condition of the vegetation population. The inventory can also include identification of suburban and urban landscape trees and large-diameter trees along interstates that represent a safety risk and liability.

An inventory of roadside vegetation would help identify trends, schedule and perform regular maintenance, and create long-term management plans and help manage budgets for ODOT's RIVM program. Inventories are also invaluable for recording and tracking work performed and work costs. It is particularly important to have inventory data before creating a vegetation management plan.

Below is an example of where the inventory would be performed and what information would be collected in each zone. Note that most inventory work can actually be accomplished remotely in the office using GIS information.

Zone One

Categorize: as edge of road or center median
Guardrails Road Edge Inventory: Miles of bare ground and maintained turf
Cable Rails Road Edge Inventory: Miles of bare ground and maintained turf

Zone Two

Turf Inventory: Distance from road edge to ditch bottom, lane miles, areas that need to have grass planted
Sign Inventory: Location of sign posts away from the road edge

Zone Three

Incompatible Vegetation Inventory: Polygon inventory of the number of acres of non-desirable vegetation (noxious weeds, brush, young trees)

Zone Four

Risk Tree Inventory: Individual count of risk trees, noxious or invasive weeds present

Rest Stops

Risk Tree Inventory: Individual count of risk trees, noxious or invasive weeds present

Emerald Ash Borer Hazard Ash Tree Inventory

Ash Tree Inventory: Emerald ash borer has spread throughout the state and affects the ROW with miles of imminent hazards. Trees infected with emerald ash borer have lost their structural integrity. They fail more rapidly than typical decaying or dead trees and are more dangerous to remove. Identify all risk trees (those which, when failing, may threaten ODOT workers, contractors, the traveling public, adjacent landowners, and structures and signs). Due to the spread of emerald ash borer, inventories have proven to be valuable for municipalities and utilities to have for planning work that will be required from these failing trees.

Asset Inventory

In conjunction with or independently of the vegetation inventory, conduct a GIS-based inventory for hardscape, mechanical, and structural roadside assets that are impacted by or directly impact RIVM tasks. Similar to the vegetation inventory, the location and initial condition of guardrail, cable rail, signs, lights, and pad mounts would be recorded to facilitate work planning and set priorities.

RIVM Plan for Each District

An RIVM Plan is a tool that can serve as primary guidance for maintenance of roadsides and provide detailed vegetation management direction as well as conformity to ODOT policies and procedures. The

plan is more than just a document; the plan is a powerful tool that can be used to reduce maintenance costs, improve vegetation management results, and create more self-sustaining areas.

Preferably, an RIVM Plan would be created for each District and would be based on inventory data and roadside zone information collected in each county. It would contain customized RIVM best management practices for each district, provide annual goals for all RIVM activities, indicate particular RIVM tasks that should be subcontracted, and ultimately establish a proactive program that uses routine and preventive maintenance practices. Once established, management plans can be reviewed and updated every five years or after extreme changes in the roadside, funding levels, or staff availability. A District RIVM plan may include the following:

- Overall goals for ROW maintenance, and specific goals for Vegetation Zones One through Four
- Vegetation and roadside conditions that are desirable and undesirable to ODOT
- American Association of State Highway and Transportation Official guidance
- Schedule/maintenance cycle for the short term (mowing and herbicide) versus the long term (tree trimming and removal) RIVM work based on need
- Proactive annual maintenance schedule to minimize unproductive reactive work
- A decision-tree for determining where mature shade trees can remain on the right-of-way (e.g., providing a visual and noise buffer or aesthetic benefits) and where they cannot (e.g., because of pavement shading or proximity of targets)

GIS-Based Work Planner Software

A GIS-based, automated software program would tie together visual, statistical, and technical information about herbicide applications, weed and tree inventory data, zone mapping, asset inventory data, ODOT-driven and customer complaints and requests for work, scheduled and planned maintenance work, customer service, and claims defense. With this planning software, an ODOT manager, Public Information Officer, or administrative staff could access the system from the office and find almost any and all RIVM program information. The software could run reports on work completed and work in the queue, produce spray records required for reporting purposes, and track customer calls and how they were handled (e.g., timeliness and history with property owner).

The power of inventory data, mapping information, GPS technology, and RIVM knowledge can be packaged together to create a user-friendly software program to enhance the District's RIVM Program efficiency and effectiveness. It is recommended that ODOT create a "Work Planning" software package that can perform the following valuable, time-saving, and pro-active functions for each District.

Map and Analyze Roadside Vegetation and Associated Assets

Using aerial photographs and existing GIS data layers, create map layers that precisely show the location and size of all vegetation types and other assets in roadside management zones along all ODOT rights-of-way. This will give users the ability to locate and quantify vegetation and assets; identify special use or restricted areas; seamlessly integrate RIVM issues/needs with new construction or repair project plans; make maps for crews and contractors; and become the visual component of work tracking software.

Automate RIVM Decisions and Solutions

As part of the software's function, a software application can be created that provides an RIVM solution based on variable inputs, such as weed name, ideal control season, and desired control method (mechanical or chemical). Such an application would simplify the decision-making process for staff and would increase efficiency by quickly producing a "pre-tested" and preferred solution(s) for a given situation (e.g., most effective equipment combination, crew complement, materials, or method of control). This application could be a stand-alone application or be part of the Work Planner software, and should be designed to be compatible with a variety of computer hardware and operating systems.

Equip ODOT RIVM Vehicles with GPS Systems

Advanced GPS systems in ODOT vehicles can track where spray equipment is turned on and off on a map-based system. Applicators and other ODOT staff can update the mapping information by adding points or polygons for new and problem vegetation, track those locations to determine the need for future treatments, and schedule inspections to check on the control success or spread of the weed of concern.

Cultural Control Methods

To more effectively manage vegetation, cultural practices such as planting desirable vegetation that will compete against undesirable vegetation should be implemented. This is especially important when noxious weeds that have taken over and prevented other plants from growing are finally controlled with herbicides to prevent other undesirable species from entering the recently controlled area.

Utilization of Equipment

One of the main safety risks employees have in performing vegetation management tasks is exposure to traffic. Reducing the number of workers, frequency of maintenance, and duration of maintenance activities reduces workers' safety exposure. Using spray equipment instead of manual methods and guardrail mowers instead of string trimmers reduces unprotected manpower at the road's edge by making employees more visible and more protected in a vehicle, reduces the number of employees, can reduce the frequency of maintenance (if using herbicides), and reduces the length of time the maintenance activity takes, thereby reducing employee exposure. Chippers operated through remote controls rather than handfed reduces employee exposure to the dangers of chipping.

Provide one spray truck per county with boomless nozzles and a control panel such as purchased for this project or another sprayer of at least equal abilities. Local access to this key piece of vegetation management equipment is important to be efficient. ODOT should consider the following:

- Operating one injection truck per county
- Using pre-mixed herbicides with this equipment
- Installing a cab-mounted computer to track spraying
- Using a GPS system that tracks the locations of spraying, areas to be avoided when spraying, the location of wildflower beds, and other important features in the ROW.

Use of Contractors

RIVM on Ohio's roadsides is a team approach with both ODOT staff and contractors performing services needed to keep the ROW safe and attractive. Just as this research project has identified improvements and efficiencies for ODOT practices and standards, the work of contractors should also be reviewed and elevated to an equally high level. By completing the following, ODOT will achieve more consistent results from contractors and improve the administration of RIVM contracts:

- Review all existing contract specifications, and include detailed requirements, reporting needs, and require compliance to applicable industry standards.
- Include missing specifications into contract (e.g., herbicide use, mow-back distance, and reporting).
- Be diligent with inspections and hold contractors accountable.
- Centralize the request for proposals so that similar herbicides/rates/timing are used from district to district when contracted spray work is needed.
- Contract out specialized difficult and high-risk work.

Benefits of a RIVM Program

This research project has resulted in a wealth of valuable information and lessons learned for improving ODOT's approach to roadside vegetation management. Implementing the technical recommendations for treatment and timing of control methods will be integral for ODOT to more efficiently carry out its mission and objectives. Benefits of implementing Zone maintenance recommendations are included in Appendix D.

Implementing these recommendations will benefit highway users, right-of-way neighbors, and ODOT directly and indirectly, particularly in terms of:

- Better maintained roadway sight distances, reduced collision targets, increased aesthetic value, and reduced expenditure of tax dollars for roadside vegetation maintenance for highway travelers
- Preserved or improved environmental conditions of adjacent properties through protection and encouragement of pollinator habitat, and prevention of biological pollution (e.g., noxious and invasive weeds)
- Reduced costs for RIVM, environmental compliance, less carbon emissions from less mowing and longer maintenance cycles, safer operations for ODOT crews, and improved fleet management for ODOT

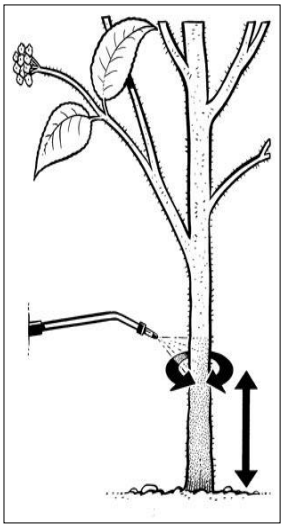
Glossary

All Terrain Tree Trimmer High volume tree trimmer with circular saw blade at the apex of a telescoping arm with a reach of 75'. These units are generally not precise enough to make proper cuts and are best utilized off road. If used on road, proper finish cuts should be made by a follow-up crew in a bucket truck. Jarraff or Sky Trim can be wheeled or tracked.

As Needed An operation that will occur when a threshold for action is reached. Depending on the goal, as needed can vary. For example, action threshold for vegetation at the road edge is 18". The operation is needed at that point to maintain proper sight distance for traveling motorists.

Bare Patch Bare soil that is exposed from equipment ruts, after machinery scrapes the vegetation away, or after herbicides take effect and kill unwanted weeds leaving bare soil behind.

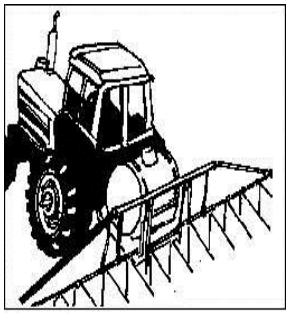
Basal Bark Application Basal bark application usually combines the herbicide with penetrant oil and applies the mixture directly to the bark of a standing tree. For trees that are less than 6 inches in diameter and have smooth bark, this method is frequently successful. However, it is important that the lower 12 to 18 inches of the stem be treated on all sides with the herbicide/oil mixture. Adequate coverage is essential, since treating only one side of the stem will result in controlling only half of the tree. Basal applications can be made any time of the year, but are most effective during the dormant season when leaves are not present. Basal applications will not provide rapid control. Herbicide injury is often not observed until several weeks after treatment and total control may require several months. Additionally, basal treatment is not effective on older trees with thick bark. For older trees, other application techniques should be employed.



Bat Wing Mower Mower with articulating deck that can be useful for terrains, that varies in grade. Batwing mowers are useful along ditches as the deck will conform to the terrain and provide a closer cut without scalping. Also, bat wings are useful for reducing deck size when needed for tighter areas.

Biological The control of a pest by the introduction of a natural enemy or predator. Grazing animals, Insects, nematodes, fungus, or bacteria can be used for biological controls.

Boom Sprayer A constructed frame that positions several nozzles in a row. The design is to provide even, thorough herbicide coverage of large turf areas with minimal waste, off-site herbicide travel, and more predictable material costs upon proper calibration. Physical objects or extreme terrain can cause issues for larger boom sprayers that cannot be operator adjusted. Boom sprayers can extend coverage areas by adding boomless sprayer extension nozzles.



Boomless Nozzle Boomless nozzles are ideal for edge of road spraying, rough terrain, or used as an extension of a boom sprayer. Boomless nozzles are cheaper, more versatile, and easier to operate but are subject to overapplication, uneven coverage, and off-site herbicide drift. Plan operations around weather. Use drift control products.

Broadleaf Dicotyledon (dicot) plants that typically have broad leaves and a deep tap root. Broad leaves include herbaceous and woody plants.

Brush Woody plants often found growing along a wood line. Brush typically has multiple stems/trunks ranging from 1–6" and are usually no larger than 20' tall. Brush is often densely populated woody plants of various species. Invasive species such as bush honeysuckle can form dense brush thickets that are difficult to maintain. Brush is usually the result of natural processes and is generally not desirable due to encroachment issues and difficulty of management.

Chemical Control Chemical control in weed management is the use of synthetic or naturally occurring compounds that are applied to noxious and invasive weed species with the intent of killing those plants.

Chipper Chippers are used to mulch tree branches and other wood debris. Chippers generally consist of a powered feed mechanism, knives mounted on a rotating disc or drum, and an internal combustion engine. Typically, employees feed branches into the infeed chute by hand. Feed rollers at the end of the infeed chute grab the branches and force them into the chipper knives. The chipper knives generally rotate from 1,000 to 2,000 revolutions per minute. The drum and its knives chip the branches and force the chips through a discharge chute.

Contact Foliar Herbicide Herbicide that is applied to the leaves of plants and is only useful while plants are green and actively growing. Plant injury occurs where the product is applied and works down into the root system under the right conditions.

Control An activity that discourages, weakens, reduces, or eliminates unwanted vegetation.

Crane A truck that has a telescoping crane which aids in tree removal. Combined with a bucket truck it provides a faster and safer, albeit more expensive, method to remove sections of, or whole trees. An excellent tool in tight working spaces.

Cultural Control Modifying the growing environment to reduce the prevalence of unwanted pests. Examples include changing soil pH or fertility levels, irrigation practices, amount of sunlight, temperature, or the use of pavement or mats.

Current ODOT Process A description of ODOT's current vegetation management processes given a specific operation. The description of ODOT's current processes is related to field observations made by Davey Resource Group research personnel and is reflective of district survey results on vegetation management operations. Generalizations have been made of ODOT's current vegetation management operations to account for the majority of operational approaches to roadside vegetation management.

Cut-Stump Application This technique is employed after cutting down a tree to eliminate or greatly reduce re-sprouts from the cut surface. The herbicide should be applied to the cut surface as quickly as possible after the sawdust has been removed. If applied immediately, an herbicide/water solution is sufficient. If herbicide treatment is delayed and the cut surface has begun to dry, an herbicide/basal oil mixture must be used and applied to the top and around the collar of the stump. A tracer dye should be included to ensure treatment of all individual stumps.

Disc Harrow Cultivator An agricultural tool that can be outfitted to a swing arm boom and be used to maintain bare ground gravel strips on the edge of the road.

Drop Zone Refers to the area around a tree that is being pruned or removed. Care should be taken to minimize safety risk exposure in the drop zone while tree work is being performed.

Extendable Arm Mower

Also referred to as Boom Mower. Mower deck is mounted on an extendable arm boom. This setup is useful for over the guardrail mowing, or mowing steep slopes and uneven terrain from stable ground. Know your equipment reach capabilities so that targeted vegetation can be reached with the extendable arm without putting the driving unit on unsafe terrain.

Feller Buncher

A mobile machine, either rubber tired or tracked, with a power plant, operator enclosure, that may have an articulating extendable arm onto which a felling head is attached. The felling head consists of grappling devices and either a disc saw or chain saw. The operator moves the machine into position in front of a tree and maneuvers the felling head to the tree trunk. The saw severs the tree from the stump and the grappling devices wrap around the tree. The machine then takes the severed vertical tree and lowers it into a horizontal position onto a pile of trees on the ground. The feller buncher can take down one large tree or bunch up several small trees for removal with one cut.

Fixed Object

A stationary object adjacent to the traveling roadway such as guardrails, signs, bridge support structures, culverts, utility poles, etc. Vegetation management around fixed objects should aim to keep vegetation from obscuring the fixed objects. Fixed objects that are not visible are considered hazards to errant recovering vehicles that leave the roadway.

Flail Mower

Used to deal with heavier grass/scrub which a normal lawn mower could not cope with. Some smaller models are self-powered, but many are PTO-driven implements, which can attach to the three-point hitches found on the rear of most tractors. This type of mower is best used to provide a rough cut to taller grass where contact with loose debris may be possible such as roadsides. Flail mowers are less likely to throw debris into the roadway than rotary mowers as the revolutions of the cutting surface spin parallel to the direction of mower travel. If a flail strikes an immovable object, it simply bounces off. Other rotary-type mowers have a tendency to grab and throw the object out of the mower deck if it is small enough.

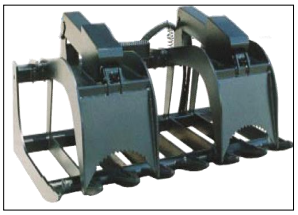
Foliar Application Directs an herbicide/water mixture directly onto the leaves of a plant. This technique can be highly effective on smaller vegetation (6 to 8 feet in height). Auxin-type herbicides (such as triclopyr) are generally most effective early in the season while enzyme-inhibiting herbicides (imazapyr and others) are most effective in the late summer or fall. Glyphosate is most effective in late summer or fall—after blooming, but prior to change in leaf color. Adequate control with foliar applications can be difficult to accomplish. This is because complete coverage of all foliage is essential for control, but over-application (that leads to spray runoff) will reduce effectiveness. Therefore, foliar applications commonly require multiple follow-up treatments before control is accomplished. It is important to control spray drift when making foliar applications.

Forestry Bucket Truck Used to lift men and tools into the tree canopy. Typical lift heights range from 40 to 100 feet (12.2 to 30.5m). Standard features include two stabilizers and a power take-off (PTO) powered by the truck engine to operate the lift hydraulics, which raises the boom and bucket. Forestry Bucket Trucks are outfitted with OSHA specified safety equipment that is unique to the tree care and forestry industries.

Forestry Mulcher A hydraulically-powered attachment that features a multi-toothed cutting wheel. The cutting wheel turns at a high rate of speed and, in the process, grinds down through trees and brush. Most models can shred shrubs and trees up to 6-8" in diameter. It can be used to reduce branches, foliage, and other unmarketable forest byproducts into mulch and chips or as a vegetation management tool for clearing away trees and brush from the sides of highways to reduce understory vegetation. Rocks and tree debris thrown through the air can reach 300–500' so be mindful of surroundings when in use. To optimize the ability of the attachment, pair it with an appropriately powered machine.

Goal A desired outcome of a vegetation management approach. For example, a goal would be to remove a tree or to trim a tree.

Grapple A grapple is a hooked or claw-like tool similar to a jaw used to grasp or clench something and move it. A standard grapple attachment is comprised of upper or lower jaws pivotally connected near the rear and having multiple elongated angular-shaped tines that open and close by a single actuator. The tines are used to dislodge, lift, and carry debris such as logs, slabs of concrete, wooden posts, rocks, and other hard-to-grab materials.



Grass Monocotyledon (monocot) plants that have fibrous root systems, slender leaves with veins that follow the leaf margin. Grasses are almost always herbaceous with a few exceptions.

Guardrail Mower A mower attachment that is specifically designed to mow vegetation under guardrails and cable rails and to articulate around rail posts eliminating the need for manual string trimming. Use of a guardrail mower by a skilled operator should roughly double the production of manual string trimming crews while improving safety by reducing manual labor at the edge of the road.

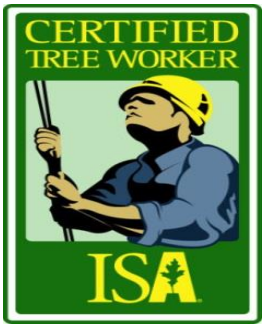
Hack and Squirt Application The hack and squirt technique is ideal for control of large trees that cannot be managed with basal applications. This method requires that you use a small ax, machete, or hatchet to cut through the thick bark and into the sapwood. When hacking, it should be done in a downward motion, leaving a "cup" to hold the herbicide solution. If the cut does not hold herbicide solution, it will leak out and become ineffective. After hacking the entire circumference of the tree, 1 squirt (approximately 1 ml) should be placed in each cut. The addition of a basal oil is not required for this procedure. This method of application is advantageous because it is highly selective and injury to surrounding species is not common. It can also be done at any time during the year, but treatment of some species in the spring can be reduced because of heavy sap flow pushing the herbicide from the cut surfaces. Rainfall soon after application will also wash the herbicide away and limit uptake.

Hazard Tree A structurally unsound tree that could strike a target when it fails.

Herbicide Chemical pesticides that are specifically made for killing, injuring, or controlling vegetation.

Indiana Bat The Indiana bat (*Myotis sodalis*) is a medium-sized mouse-eared bat native to North America. It lives primarily in eastern and midwestern states and in parts of the south of the United States. The Indiana bat is gray, black, or chestnut in color and is 1.2–2 inches and weighs 4.5–9.5 grams (0.16–0.34 oz.). It is similar in appearance to the more common little brown bat but is distinguished by its feet size, toe hair length, pink lips, and a keel on the calcar.

Indiana Bat Breeding Season	Breeding occurs in and around hibernacula in fall. During the breeding season, Indiana bats undergo a phenomenon known as swarming. During this activity, large numbers of bats fly in and out of caves from sunset to sunrise. Swarming mainly occurs during August and September and is thought to be an integral part of mating. Bats have been observed copulating in caves until early October. During the swarming/breeding period, very few bats are found roosting within the hibernacula during the day. Limited mating may also occur at the end of hibernation. Clearing of trees greater than or equal to 5" diameter at breast height is prohibited between April 1st and September 30th in areas of summer habitat and is prohibited between March 15th and November 15th in fall swarming habitat.
Integrated Vegetation Management (IVM)	A system of managing plant communities by which managers identify compatible and incompatible vegetation, consider action thresholds, evaluate control methods, and select and implement controls to achieve specific objectives. The choice of control methods is based on the anticipated effectiveness, environmental impact, site characteristics, safety, security, economics, and other factors.
Invasive Weed	Invasive weeds are common and widespread in Ohio, but are not prohibited by law. Invasive weeds are aggressive, fast growing, and usually out-compete native vegetation. Invasive weeds are a large problem for roadside maintenance programs. A list of invasive weeds is maintained by the Ohio Invasive Species Council (OIPC).
ISA	International Society of Arboriculture.
ISA Certified Arborist	Individuals who have achieved a level of knowledge in the art and science of tree care through experience and by passing a comprehensive examination developed by some of the nation's leading experts on tree care. Certified Arborists must also continue their education to maintain their certification and adhere to a Code of Ethics. Therefore, they are more likely to be up-to-date on the latest techniques in arboriculture.
ISA Certified Tree Worker	Individuals who possess knowledge and skill proven through testing to safely and productively provide quality tree care. Certified Tree Workers must continue their education to maintain their certification and adhere to a Code of Ethics. Therefore, they are more likely to be up-to-date on the latest techniques in arboriculture.
IVM Follow-Up	Additional steps that may be necessary or beneficial beyond the Recommended Improvement. IVM follow-up is not factored into operational cost, but may be highly beneficial in obtaining long-term control over undesirable vegetation and will ultimately reduce maintenance needs.



Large Tree Woody plants that are typically single stemmed. Large trees are generally over 20' tall, >6" diameter at breast height. Large trees in Ohio can reach >100' in height.

Lighting Bucket Truck Used to lift men and/or materials to lighting and sign equipment. Typical lift heights range from 15 to 40 feet (4.6 to 12.2m). Standard features include two stabilizers and a power take-off (PTO) powered by the truck engine to operate the lift hydraulics, which raises the boom and bucket. A lighting bucket truck is not set up with proper safety equipment that permits safe tree maintenance operations.

Maintained Turf Maintained turf includes all areas that are actively mowed and trimmed. The goal for maintained turf should be to establish grasses and to discourage broadleaf weeds and woody weeds. ODOT maintained turf currently contains grass, broadleaf, and woody plants.

Mechanical Control Consists of using machines or other human-made tools to suppress weeds. Mulchers, mowers, cultivators, saws, etc., are all examples of tools commonly used to mechanically manage vegetation.

Medium Sized Tree Trees that reach a mature height range of 31'–45'.

Mow Cycle/ Trim Cycle The time between mowing or trimming events. Longer intervals between cycles generally indicate successful IVM improvements.

Mud Mats Used to drive off road onto muddy ground to prevent getting stuck and reduce ground disturbance. They spread out the weight of the vehicle, thereby reducing ground pressure.

Non-Selective Herbicide Herbicide that kills or injures all vegetation.

Noxious/ Prohibited Weed Noxious plants are prohibited by the Federal, State, or Local Government.

Off-Road Work that is done completely off the paved hard surface of the road. Off-road terrain can vary from turf to woods and from flat to varying slopes.

On-Road Work is done primarily from the hard surface of the road where at least 2 tires remain on the hard surface. This work can be done from a traveling lane, or on the shoulder with proper traffic control.

Operational Cost Operational cost is a price range evaluation for a given operation that factors all labor, equipment, and material costs.

Organic Herbicide Chemicals that are derived from natural or organic materials, such as citric acid, clove oil, or vinegar.

Potential Benefits Davey Resource Group's assessment of the benefits related to acting on a Recommended Improvement. Benefits are most often related to improvements in production, cost, length of control, and safety and aesthetics.

Personnel Required The minimum number of people required to staff the Recommended Improvement.

Plant Growth Regulator (PGR) Herbicides that are labeled to stunt the growth of plants rather than killing them. Certain PGRs affect all plants while some only affect grasses. Always read labels before applying an herbicide as a PGR.

Pre-Emergent Herbicide Prevent seeds from germinating, but do not harm existing plants. This type of herbicide is especially useful in establishing shrub installations. Without an herbicide program that involves pre-emergent control, it is very difficult to establish a shrub planting. Once shrubs fill in at maturity, they will on their own prevent weeds from growing by shading and outcompeting them.

Purchase Price Purchase price is only evaluated on materials, equipment, or attachments that ODOT does not currently own or frequently implement.

Residual Herbicide Herbicides that are active in the soil and are often taken in through plant roots to kill the entire plant. Residual herbicides can provide control for longer windows of time, but can interfere with re-planting areas that have been treated with residual herbicides.

Return on Investment (ROI) A performance measure used to evaluate the efficiency of an investment or to compare the efficiency of a number of different investments.

Road Edge Area directly adjacent to the road. Guardrails are found on the road edge which may be maintained as a bare ground area or as an area where vegetation is allowed to grow to the pavement edge to prevent erosion.

Root Grafted

Refers to trees that have connected roots. This may occur between same species trees and can result in off-target herbicide damage to trees that were not treated with herbicide. Use caution when using cut-stump or basal bark applications if nearby desirable trees exist.

Rotary Mower

Machinery that uses a rotating straight blade or blades to cut vegetation. In agriculture a rotary mower takes the form of a piece of tractor machinery that is often pulled behind the tractor and powered by the PTO. Rotary mowers use thick blades of sharpened metal to cut thick grass, heavy bushes, weeds, and small trees. Due to the high torque and power associated with the implement, shields made of hanging heavy chain or thick vinyl or rubber are often provided around the discharge chute to control flying debris. Rotary mowers are known to throw debris further and more frequently into traffic when compared to flail mowers.

Selective Herbicide

Herbicides that are formulated to control a specific weed or type of weeds. Selective herbicides in general can control specific woody weeds, broadleaf weeds, and/or grassy weeds. Selective herbicides can be useful in areas where control of one plant is desired, but preservation of another plant is the goal.

Shrubs

Woody plants that are often planted and maintained for aesthetics or zone separation. Once established, shrubs can effectively suppress weeds and trees from growing in areas that can cause maintenance concerns. Shrubs are often planted on slopes or areas that are difficult to access for routine maintenance.

Skid Sprayer & Hose Reel

A spray tank mounted on a frame usually with a pump motor, hose reel, and gun attached for easy outfitting into existing ODOT trucks. Size of skid sprayers and tanks should be based on payload and bed size of available ODOT trucks.

Skid Steer Loader

Skid-steers are typically four-wheel vehicles with the wheels mechanically locked in synchronization on each side, and the left-side drive wheels can be driven independently of the right-side drive wheels. The wheels typically have no separate steering mechanism and hold a fixed straight alignment on the body of the machine. By turning the left and right wheel pairs at different speeds, the machine turns by skidding, or dragging its fixed-orientation wheels across the ground. Grapple or loader attachments are useful in forestry operations for loading materials into chippers.

Small Tree Woody plants that are typically single-stemmed and have the ability to grow over 20' tall. Small trees are generally <6" diameter at breast height.

String Trimmer Gas-powered hand tool with a spinning head and nylon line that cuts vegetation in areas that larger machinery cannot access or adequately maneuver around. Metal or serrated cutting heads can be outfitted to handle larger weeds or small woody weeds.

Susceptible Easily affected, influenced, or harmed by something. When targeting specific plants for control, ensure that control measures are scheduled around plant susceptibility that may revolve around the plant life cycle or environmental factors.

Timing/ Frequency Refers to the time of year and the number of times per year needed for successful control.

Tree Mulcher Large forestry mulcher head usually attached to extendable excavator arm. Fecon Bull Hog and Brown Brontosaurus are examples of Tree Mulchers. Tree mulchers have more horsepower, greater reach, and can process larger tree diameters than forestry mulchers. Tree mulchers remove trees by chipping and grinding all debris down to stump in one process. Just like a forestry mulcher, the advantage to this type of device is there is usually no waste to remove from the site once a tree has been removed.

TrucKat An extendable arm mower unit that is directly mounted to a truck chassis eliminating the need for a tractor and trailer on roadside mow operations.

Turf Mowable areas that are primarily comprised of herbaceous grass species mixed with broadleaf weeds and occasional woody weeds. Desirable turf is comprised of grass species only.

Water Sprouts Vigorous, upright, epicormic shoots that grow from latent buds in older wood. Water sprouts are often forced into growth just below large pruning wounds, particularly when branches have been cut to stubs. Without exception, water sprouts should be removed as soon as possible. Water sprouts can grow 10–15 feet in one year and are seldom firmly attached to the trunk or branch from which they arise.

Weed An undesirable plant found growing where it should not be.

Weed Flamer/ Burner A tractor-mounted unit that uses heat to kill or control weeds. Flames or infrared heat is applied at high enough temperatures to kill weeds and live vegetation quickly with minimal risk of wild fires.

Weed Mat Synthetic mats usually made from plastic or rubber that can be placed under guardrails and tightly around guardrail posts preventing weeds from having a place to take hold. Mats require annual debris removal maintenance so that weeds do not begin to grow in the accumulation of debris that land on the weed mats.

Wet-Blade Mower A mower that has an herbicide tank incorporated into the unit. The herbicide is applied directly to the mower blade so that as the mower is cutting, herbicide is simultaneously being applied. This setup is especially good for areas where public opinion of herbicide use is low and there is a need for discrete herbicide application methods.

Woody Weeds, shrubs and trees that have woody stems, or are entirely woody. Woody growth is referred to as secondary growth that reinforces a plant's structure and allows it to grow quite large. Woody plants are perennial.

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Appendix A
Phase I Matrices

Road Edge

Current ODOT Process

Description: Currently bareground herbicide applications are using non-selective foliar herbicides with no residual or pre-emergent properties. Maintained turf at the road edge or under Rails is not regularly targeted for selective herbicide and Plant Growth Regulator treatments.
ODOT's Challenges: Reducing the amount of labor time it takes to achieve bareground where desired. Where maintained turf is desired, the challenge is to increase time between mowing/trimming events while maintaining site distance and aesthetic qualities.
Davey Resource Group's Observations: ODOT staff have varying levels of vegetation management knowledge and experience, the vegetation management equipment/fleet compliment is not adequate nor universal across Districts; there is a need for readily available technical support on a daily and county-specific basis; contract specifications and ODOT standard operating procedures should be revised to reflect current industry standards.
Recommendations: Plan work as proactive seasonal operations and limit the reactive approach to vegetation management. Incorporate herbicides on a routine schedule allowing managers to better predict maintenance needs. Maximize utilization of equipment by combining operations that can be paired in order to reduce travel and labor costs.

Goal	Area	Recommended Improvement	Timing/ Frequency	Notes/Considerations	Potential Benefits	Herbicide/Materials Cost (not included in the Purchase Price)	Purchase Price of * Equipment	Operational Cost Per Hour	Personnel Scale	Return on Investment	IVM Follow-Up
Bare Ground	Pavement Edge (No Rail)	**Chemical:** Non-Selective Residual Herbicides* Boomless Nozzle* mounted on Spray Truck	Spring Application May 15-June 30 1-2x per year	The boomless nozzle setup is best used for side of road applications. Read all product labels to determine proper rates and restrictions. Add Non-Selective Residual Herbicides to current ODOT tank mixes. Use drift control products and larger droplet size. Herbicide control length can vary depending on product choice, application rates, environmental factors and application techniques.	Limit Applications to 1x per year with proper product selection, timing and environmental factors. Reducing annual treatments to 1x per year will cut annual labor expenses, enhance roadside aesthetics, and facilitate better road drainage. Herbicide applications take less time to control vegetation than mechanical or cultural methods and provide longer control duration.	Perspective = $73.60/Lbs. (.45 Kilograms) Esplanade = $1013/Gallon (3.8 Liters)	$$	$$	🧍	★★★★★	Monitor for effectiveness. Evaluate need for full application.
		Cultural: Weed Flamer* Tractor Truck with Trailer	Growing Season/As Needed 3-4x per year	Use ODOT tractor or truck to side mount flamer Be aware of dry conditions Only effective on actively growing weeds.	Beneficial around No-Spray zones. Provides longer control when compared to mechanical maintenance activities.	0	$$	$$$	🧍	★★	Monitor for control effectiveness.
		Cultural: Disc Harrow Cultivator* Tractor Truck with Trailer	Growing Season/As Needed 3-4x per year	Be aware of underground utilities. Can contribute to erosion issues. Do not cultivate until threshold for vegetation control has been reached to avoid erosion issues.	Beneficial around No-Spray zones. Provides longer control when compared to mechanical maintenance activities.	0	$$$	$$$	🧍	★★	Monitor for control effectiveness. Monitor for erosion issues.
		Chemical: Non-Selective Organic Herbicides* Boomless Nozzle* mounted on Spray Truck	Growing Season 2-3x per year	Read all labels be aware of applicator exposure safety concerns Use drift control products and larger droplet size.	Non-Selective Organic Herbicides can be beneficial around organic farms. Provides longer control when compared to mechanical maintenance activities.	Glufosinate $60/gallon (3.8 liters)	$$	$$	🧍	★★★	Monitor for control effectiveness. Monitor for erosion issues.
	Under Rail	**Chemical:** Non-Selective Residual Herbicide* Boomless Nozzle* mounted on Spray Truck	Spring Application May 15-June 30 1-2x per year	The boomless nozzle setup is best used for side of road applications. Read all product labels to determine proper rates and restrictions. Add Non-Selective Residual Herbicides to current ODOT tank mixes. Use drift control products and larger droplet size. Herbicide control length can vary depending on product choice, application rates, environmental factors and application techniques.	Limit Applications to 1x per year with proper product selection, timing and environmental factors. Reducing annual treatments to 1x per year will cut annual labor expenses, enhance roadside aesthetics, and facilitate better road drainage. Herbicide applications take less time to control vegetation than mechanical or cultural methods and provide longer control duration.	Perspective = $73.60/Lbs. (.45 Kilograms) Esplanade = $1013/Gallon (3.8 Liters)	$$	$$	🧍	★★★★★	Monitor for control effectiveness. Monitor for erosion issues.
		Cultural: Weed Flamer* Tractor Truck with Trailer	Growing Season/As Needed 3-4x per year	Use ODOT tractor or truck to side mount flamer Be aware of dry conditions Only effective on actively growing weeds.	Beneficial around No-Spray zones. Provides longer control when compared to mechanical maintenance activities.	0	$$	$$$	🧍	★★	Monitor for control effectiveness. Monitor for erosion issues.
		Chemical: Non-Selective Organic Herbicides * Boomless Nozzle* mounted on Spray Truck	Growing Season 2-3x per year	Read all labels be aware of applicator exposure safety concerns Use drift control products and larger droplet size.	Non-Selective Organic Herbicides can be beneficial around organic farms. Provides longer control when compared to mechanical maintenance activities.	Glufosinate $60/gallon (3.8 liters)	$$	$$	🧍	★★★	Monitor for control effectiveness. Monitor for erosion issues.
		Cultural: Pavement* Truck	All Year above freezing temperatures 1x per 5-10 years	Avoid creating high berm that would prevent roadway drainage Pavement around Rail posts can cause maintenance issues in the event replacement or repair of posts or rail is needed.	Pavement under Rail eliminates weeds for 5-10 years.	0	Asphalt = $94/ton (907.19kg) Ag Base = $18/ton (907.19kg)	$$$$$	🧍🧍🧍🧍🧍	★★	Annual debris removal to prevent vegetation. Monitor for cracking and presence of vegetation.
		Cultural: Weed Ender Mats* Truck with Trailer	All Year 1x per 15 years	Material and Labor costs are higher than all other options in Road Edge Matrix.	Weed Mats under Rails eliminates weeds for up to 15 years. Weed mats are flexible and not subject to cracking or breakage.	0	$39,000/mile (1.61 kilometers)	$$$$$	🧍🧍🧍🧍🧍	★★	Annual debris removal to prevent vegetation. Monitor for cracking and presence of vegetation.
Maintained Vegetation	Pavement Edge (No Rail)	**Chemical:** Selective Herbicides* Plant Growth Regulator (PGR) Boomless nozzle* mounted on Spray Truck	Spring/Fall Selective Herbicide Spring PGR 1-2x per year	Gain control over broadleaf and woody weeds, suppress turf height. Encourage grass growth by controlling woody and broadleaf weeds. Eliminating weeds will lengthen trim cycles. PGR is beneficial if mowing road edge on separate schedule than the rest of maintained turf in the operational zone (vehicle recovery area).	Reduce annual mowing occurrences by 1-3x Maintain site distance longer. Maintain higher quality aesthetics Limit annual mechanical maintenance by 50% or more.	Perspective = $73.60/Lbs. (.45 Kilograms) Imazapic $195/Gallon (3.8 Liters)	$$	$$	🧍	★★★★	All follow-up activities should promote desirable vegetation (grasses) and discourage weeds. A routine selective herbicide treatment combined with a plant growth regulator will decrease maintenance occurrences and improve quality and safety of desired vegetation.
		Mechanical & Chemical: Wet-Blade Mower* Selective Herbicide* Plant Growth Regulator (PGR)* Tractor Truck with Trailer	Growing Season/As Needed 2-4x per year	Gain control over broadleaf and woody weeds, suppress turf height. Combination Equipment like a Wet-Blade mower eliminates the need to make separate trips for herbicide applications. Wet-Blade mowers are beneficial if mowing road edge on separate schedule than the rest of maintained turf in the operational zone (vehicle recovery area). Use of Plant Growth regulators is optional and should only be used if road edge mowing will be done as an operation separate from operational zone (vehicle recovery area mowing.	Reduce mowing by 1-2x per year by incorporating selective herbicides. Combination Equipment like a Wet-Blade discreetly applies herbicide that may reduce public concern over spraying herbicides. Using selective herbicides will suppress fast-growing weeds that cause sight distance issues and lengthen intervals between mow cycles. PGRs can control grass height once weeds are under control, but might not be necessary as turf along road edge with no physical restrictions is quite easy to mow.	Perspective = $73.60/Lbs. (.45 Kilograms) Imazapic $195/Gallon (3.8 Liters)	$$$$	$$$	🧍	★★★★	Monitor for effectiveness and site distance issues.
		Mechanical: TrucCat* chassis mounted mower Truck	Growing Season/As Needed 2-5x per year	TrucKat can be mounted to F550 or similar truck chassis with dual steering. TrucKat can be useful if performing road edge mowing on separate schedule than operational zone (vehicle recovery area) mowing. Reduce mowing by 1-2x per year by incorporating selective herbicides as mentioned in #1 recommendation for Maintained Turf	TrucKat ground speed and versatility can increase daily road edge mowing production by up to 300% when compared to standard roadside mowers. Mowing accomplishes immediate control, but does not encourage a stable plant community alone.	0	$$$$$	$$$	🧍	★★★★	Monitor for site distance requirements. Incorporate selective herbicides.
		Mechanical: Side Mounted Flail Mower Tractor Truck with Trailer	Growing Season/As Needed 2-5x per year	If only mowing the edge of the road, this equipment setup does not improve efficiency of operations.	Mowing accomplishes immediate control, but does not encourage a stable plant community alone. Using a flail mower on the road edge is safer than a rotary mower because it is not as likely to throw projectiles into the roadway.	0	0	$$$	🧍	★	Monitor for site distance requirements. Incorporate selective herbicides.
	Under Rail	**Chemical:** Selective Herbicide* Plant Growth Regulator (PGR)* Boomless Nozzle* mounted on Spray Truck	Spring/Fall Selective Herbicide Spring PGR 1-2x per year	Gain control over broadleaf and woody weeds, suppress turf height. Encourage grass growth by controlling woody and broadleaf weeds. Eliminating weeds will lengthen trim cycles. PGR is beneficial if mowing road edge on separate schedule than the rest of maintained turf in the operational zone.	PGR will control turf height and reduce annual trimming by around 50%. Eliminating weeds will lengthen trim cycles and improve aesthetics by allowing grass to fill in. Plant Growth Regulators are more efficient that manual labor and will reduce man hours in areas that require manual labor to maintain.	Perspective = $73.60/Lbs. (.45 Kilograms) Imazapic $195/Gallon (3.8 Liters)	$$	$$	🧍	★★★★★	All follow-up activities should promote desirable vegetation (grasses) and discourage weeds. A routine selective herbicide treatment combined with a plant growth regulator will decrease maintenance occurrences and improve quality and safety of desired vegetation for erosion control.
		Mechanical: Rail Trimmer* Tractor Truck with Trailer	All Year / As Needed 4-6x per year	PTO driven can be attached in front or rear of ODOT tractors. Reduce mowing by 1-2x per year by incorporating selective herbicides as mentioned in option 1 recommendation of Maintained Vegetation Under Rail.	Can double the production rate of manual string trimming with skilled operator.	0	$$$$	$$$	🧍	★★★★	May need to manually remove woody weeds or follow up with manual string trimming. Incorporate selective herbicides as recommended above in Option 1 of Maintained Vegetation under Rail.
		Mechanical: 2 Manual String Trimmers Truck	All Year / As Needed 4-6x per year	If only manually string trimming under rails, this equipment setup does not improve efficiency of operations.	String trimming produces the highest quality trimming due to versatility of the human operator. String Trimming is beneficial where vehicle or power equipment access is prevented.	0	0	$$$	🧍🧍	★	Incorporate selective herbicides as recommended above in Option 1 of Maintained Vegetation Under Rail.

* = Factored into purchase price

Legend			
Purchase Price	**Operational Cost Per Hour**	**Personnel Scale**	**Return on Investment**
$ = 1 - 100	$ = 1 - 25	🧍 = 1 Person	★ = No Efficiency Gained
$$ = 101 - 300	$$ = 26-50	🧍🧍 = 2 People	★★ = Minor Efficiency Gained

Turf Maintenance

Current ODOT Process

Description: Current Mowing operations are done 4x-6x per year. Mowing events are scheduled around holiday events. Mowing schedule is on an as-needed basis beyond the 4 holiday events. Currently no selective herbicides are being used to promote grass species with less maintenance requirements.
ODOT's Presented Challenges: Limit annual mowing to 3 occurrences with properly timed selective herbicide applications that will promote a stable, low-growing grass community that will require less mechanical maintenance and result in improved roadside aesthetics and safety. Prevent spread of noxious and invasive weeds that can create site distance concerns or encroachment issues into the roadway or onto adjacent lands. Comply with federal or state laws for prohibited species.
Davey Resource Group's Observations: ODOT does very well at mowing. Mowing accomplishes immediate vegetation control and is the most consistent vegetation management activity from District to District. The current mowing approach is not helping to reduce required annual occurrences and labor investment. Weeds are not under control in mowed turf areas and weeds are the reason additional mows are required. Weeds grow faster and taller than grass and can contribute to site distance issues, obscure fixed objects, provide coverage for wildlife, and detract from roadside aesthetics. In areas that mowers cannot access or reach, weeds are left in uncontrolled patches that can often spread into the maintained turf requiring a greater labor investment to maintain quality roadside vegetation. Currently minimal to no herbicide use has been observed on un-mowable invasive weed patches.
Recommendations: Incorporate a scheduled herbicide program into the turf maintenance operations. Outfit existing ODOT spray trucks with a Boom Sprayer and extension nozzle to extend roadside spray capabilities. In larger areas that cannot be reached with roadside spray equipment, a tractor with a hitch Boom Sprayer attachment can be employed. Spring and/or Fall applications can be chosen based on need for control or equipment and staff availability. Control encroaching invasive weeds that are difficult to mow with an herbicide program utilizing non-selective and selective herbicides depending on target species and timing.

Goal	Area	Recommended Improvement	Timing / Frequency	Notes / Considerations	Potential Benefits	Herbicide Cost (not included in the Purchase Price)	Purchase Price of * Equipment	Operational Cost Per Hour	Personnel Scale	Return on Investment	IVM Follow-Up
Maintained Turf	Open Area	**Chemical:** Selective herbicides* Boom Sprayer* with Boomless Extension Nozzle* Mounted on Spray Truck	1-2x annually Spring/Fall Selective Herbicide	Outfit trucks that were used in Road Edge spraying with boom and extension nozzle to increase spray coverage areas. Spring applications are timed around dandelion flower emergence. Fall applications are timed around general "greening up" that is associated with cooler nights of late summer/early fall. Mow on scheduled dates only with properly timed herbicide applications.	Eliminating weeds will lengthen mow cycle intervals and reduce annual mowing by 1-2 occurrences per year. Eliminating weeds will lengthen trim cycles. Encourage a stable low growing grass community by controlling woody and broadleaf weeds. Improve road side safety and maintain clear sight distances longer while improving aesthetics.	Perspective = $73.60/Lbs. (.45 Kilograms)	$$$$	$$	🧍	★★★★	Mechanical mowing on a more predictable schedule. Monitor for herbicide effectiveness. Re-seed bare patches with desirable grass seed mix.
		Chemical: Selective herbicides* Boom Sprayer* with Boomless Extension Nozzle* Mounted on Tractor	1-2x annually Spring/Fall Selective Herbicide	Outfit tractors with spray tanks and Boom Sprayer. Perform herbicide applications separate from mowing operations. Spring Applications are timed around dandelion flower emergence. Fall Applications are timed around general "greening up" that is associated with cooler nights of late summer/early fall. Mow on scheduled dates only with properly timed herbicide applications.	Eliminating weeds will lengthen mow cycle intervals and reduce annual mowing by 1-2 occurrences per year. Encourage a stable low growing grass community by controlling woody and broadleaf weeds. Improve road side safety and maintain clear sight distances longer while improving aesthetics.	Perspective = $73.60/Lbs. (.45 Kilograms)	$$$$	$$	🧍	★★★	Mechanical mowing on a more predictable schedule. Monitor for herbicide effectiveness. Re-seed bare patches with desirable grass seed mix.
		Mechanical & Chemical: Wet-Blade system* Bat Wing Mower Selective Herbicide* Tractor Truck with Trailer	3-4x annually Mow on scheduled dates Spring/Fall herbicide applications.	Gain control over broadleaf and woody weeds, suppress turf height with mechanical and chemical control in one operation. Combination Equipment like a wet-blade mower eliminates the need to make separate trips for herbicide applications. Purchase price can be lowered if ODOT outfits existing mower decks with a wet-blade herbicide systems.	Reduce mowing by 1-2x per year by incorporating selective herbicides. Combination Equipment like a wet-blade discreetly applies herbicide that may reduce public concern over spraying herbicides. Using selective herbicides will suppress fast-growing weeds that cause sight distance issues and lengthen intervals between mow cycles.	Perspective = $73.60/Lbs. (.45 Kilograms) Insamgic $195/Gallon (3.8 Liters)*	$$$$$	$$$	🧍	★★★	Mechanical mowing on a more predictable schedule. Monitor for herbicide effectiveness. Re-seed bare patches with desirable grass seed mix.
		Mechanical & Chemical: Bat Wing Mower Tractor Non-Selective Herbicide* Spray Tank* Truck with Trailer	3-4x annually Mow on scheduled dates	Towed behind Tractor, PTO driven. Mount small electric powered spray tank to mower unit with non-selective foliar herbicides. Operators should be encouraged to spray herbicide bands around fixed objects that are difficult to maneuver a mower around. Without selective herbicide use, it may be more difficult to only mow as planned on scheduled events.	Bat Wing decks are generally the largest, most productive mower decks for large turf areas with variable terrain. Can be useful on uneven terrain as Bat Wing mower decks have scalp wheels that allow the mower deck to articulate over terrain scalping less. The deck wings can be raised to reduce deck size in tight areas.	Glyphosate $17/gallon (3.8 liters)	$$	$$$	🧍	★★	Incorporate selective herbicides to control broadleaf and woody weeds. Re-seed bare patches with desirable grass seed mix.
		Mechanical & Chemical: Flail Mower Tractor Non-Selective Herbicide* Spray Tank* Truck with Trailer	3-4x annually Mow on scheduled dates	Towed behind Tractor, PTO driven. Mount small electric powered spray tank to mower unit with non-selective foliar herbicides. Operators should be encouraged to spray herbicide bands around fixed objects that are difficult to maneuver a mower around. Without selective herbicide use, it may be more difficult to only mow as planned on scheduled events. Outfit mowers with scalp wheels if not present. Flail mower decks require more maintenance in keeping knives sharp.	Improve operational safety with flail mower. Flail mowers are not as likely to throw projectiles into traveling motorists. Improve aesthetic quality of mowing with flail mower when compared to rotary mowers. Storage of flail mowers is easier due to smaller size.	Glyphosate $17/gallon (3.8 liters)	$$	$$$	🧍	★★	Incorporate selective herbicides to control broadleaf and woody weeds. Re-seed bare patches with desirable grass seed mix.
		Mechanical & Chemical: Rotary Mower Tractor Non-Selective Herbicide* Spray Tank* Truck with Trailer	3-4x annually Mow on scheduled dates Spring/Fall herbicide applications.	Towed behind Tractor, PTO driven. Mount small electric powered spray tank to mower unit with non-selective foliar herbicides. Operators should be encouraged to spray herbicide bands around fixed objects that are difficult to maneuver a mower around. Without selective herbicide use, it may be more difficult to only mow as planned on scheduled events. Outfit mowers with scalp wheels if not present. Rotary mowers do not shred material as well as flail mower, but are cheaper to service blades. Projectiles from rotary mowers can be a safety concern to traveling motorists.	Rotary mowers are less expensive to purchase. Rotary mowers are easier and less expensive to maintain.	Glyphosate $17/gallon (3.8 liters)	$$	$$$	🧍	★★	Incorporate selective herbicides to control broadleaf and woody weeds. Re-seed bare patches with desirable grass seed mix.
	Over Guardrail or Steep Slope	**Chemical:** Selective herbicides* *Plant Growth Regulator (PGR) Boom Sprayer* with Boomless Extension Nozzle* mounted on Spray Truck	1-2x annually Spring and/or Fall	Outfit trucks that were used in Road Edge spraying with boom and extension nozzle to increase spray coverage areas. Perform herbicide applications separate from mowing operations. Use of PGR is optional, but maybe especially useful for areas that are more difficult to maintain. Areas like steep slopes, over the guardrail, and areas with limited access. If target turf area cannot be reached with roadside spray equipment, a tractor with Boom Sprayer and boomless extension nozzle can be used.	Reduce mowing by 1-3x per year by incorporating selective herbicides and PGR. Eliminating weeds will lengthen trim cycles. Encourage grass growth by controlling woody and broadleaf weeds.	Perspective = $73.60/Lbs. (.45 Kilograms) Insamgic $195/Gallon (3.8 Liters)*	$$$$	$$	🧍	★★★★	Mow as scheduled, but on a reduced schedule based on results of herbicide and/or PGR applications. Monitor for herbicide and PGR effectiveness. Re-seed bare patches with desirable grass seed mix.
		Mechanical: Flail Mower Tractor with Extendable Arm Truck with Trailer	2-4x annually or Mow as needed.	Tractor mounted arm, hydraulic driven. Provides a more quality cut than rotary mower heads and are easier to store, but may take more maintenance in keeping knives sharp. Without herbicide use, it may be more difficult to only mow as planned on schedule d events. When possible, operators should be encouraged to use this equipment in an effort to reduce patches of invasive or noxious weeds that are in and around the maintained turf areas that are generally maintained by pull behind, PTO driven mower units.	Mowing accomplishes immediate control, but does not encourage a stable plant community alone. The benefits of mowing over the guardrail with a flail mower on an extendable arm does not improve ODOT's current process if herbicides are not used.	0	$0.00	$$$	🧍	★	Incorporate selective herbicides to control broadleaf and woody weeds. Encourage a low-growing stable grass community that will require less maintenance once established. Re-seed bare patches with desirable grass seed mix.
		Mechanical: Rotary Mower Tractor with extendable arm Truck with Trailer	**Mechanical:** 2-4x annually or Mow as needed.	Tractor mounted arm, hydraulic driven. Does not shred material as well as flail mower, but is cheaper to service blades. Projectiles from rotary mowers can be a safety concern to traveling motorists. Without herbicide use, it may be more difficult to only mow as planned on scheduled events. When possible, operators should be encouraged to use this equipment in an effort to reduce patches of invasive or noxious weeds that are in and around the maintained turf areas that are generally maintained by pull behind, PTO driven mower units.	Mowing accomplishes immediate control, but does not encourage a stable plant community alone. The benefits of mowing over the guardrail with a rotary mower on an extendable arm does not improve ODOT's current process if herbicides are not used.	0	$0.00	$$$	🧍	★	Incorporate selective herbicides to control broadleaf and woody weeds. Encourage a low-growing stable grass community that will require less maintenance once established. Re-seed bare patches with desirable grass seed mix.
		Mechanical: Radio Controlled Slope Mower* 4x4 Truck with Trailer	2-4x annually or Mow as needed.	Mowing production rate is very low. Metal spikes on tracks create a great amount of ground disturbance that can contribute to weed infestations. This mower should not be used unless re-seeding is planned for the area to be mowed.	Improved safety of operations when compared to operator driven equipment.	0	$$$$$	$$$	🧍	★	Incorporate selective herbicides to control broadleaf and woody weeds. Encourage a low-growing stable grass community that will require less maintenance once established. Re-seed bare patches with desirable grass seed mix.
Remove Weeds	Un-Mowable Invasive or Noxious Weeds	**Chemical:** Non-Selective Herbicide* or Selective Herbicides* 4x4 Truck Skid Sprayer with Hose Reel*	Growing Season/As Needed	For invasive, noxious or prohibited weed infestations that cannot be reached with roadside application equipment, a tractor with a skid sprayer should be utilized to control un-mowable invasive/prohibited weed species. Ensure timing for applications given species. Allow herbicide to work and for plants to show signs of effects before mechanical removal is done.	Improve sight distance and visibility of fixed objects, culverts and ditches by controlling noxious/invasive weeds. Get improved results by knocking down vegetation with string trimmers. Comply with federal or state laws for prohibited species. Non-selective foliar herbicide does not remain in soil and will not interfere with re-seeding.	Glyphosate $17/gallon (3.8 liters) Insamgic $168/gallon (3.8 liters) Triclopyr $64/gallon (3.8 liters)	$$$	$$$	🧍🧍🧍	★★★★	Monitor for herbicide effectiveness and need for re-treatment. Manual mechanical removal with string trimmers or other hand tools. All follow-up activities should promote desirable vegetation (grasses) and discourage weeds. Follow up seeding may be necessary to encourage a desirable plant community.
		Chemical: Non-Selective Herbicide* or Selective Herbicides* Tractor Skid Sprayer with Hose Reel*	Growing Season/As Needed	For invasive, noxious or prohibited weed infestations that cannot be reached with roadside application equipment, a tractor with a skid sprayer should be utilized to control un-mowable invasive/prohibited weed species. This setup would require the tractor operator to get out of operators seat to start skid sprayer. It can be combined with mowing operations, but would not be seamless transition from mowing to spraying. Ensure timing for applications given species. Allow herbicide to work and for plants to show signs of effects before mechanical removal is done.	Improve sight distance and visibility of fixed objects, culverts and ditches by controlling noxious/invasive weeds. Get improved results by knocking down vegetation with string trimmers. Comply with federal or state laws for prohibited species. Non-selective foliar herbicide does not remain in soil and will not interfere with re-seeding.	Glyphosate $17/gallon (3.8 liters) Insamgic $168/gallon (3.8 liters) Triclopyr $64/gallon (3.8 liters)	$$$$	$$$$	🧍🧍🧍	★★★	Monitor for herbicide effectiveness and need for re-treatment. Manual mechanical removal with string trimmers or other hand tools. All follow-up activities should promote desirable vegetation (grasses) and discourage weeds. Follow up seeding may be necessary to encourage a desirable plant community.
		Mechanical: String trimmers Truck	All Year/As Needed	Perform mechanical operation after herbicide application. Allow herbicide to work and for plants to show signs of effects before mechanical removal is done. Selective herbicides may interfere with re-seeding certain plants depending on the target species, the choice of herbicide and the rate at which it is applied.	Improve sight distance and visibility of fixed objects, culverts and ditches by controlling noxious/invasive weeds. Get improved results by knocking down vegetation with string trimmers. Comply with federal or state laws for prohibited species.	0	0	$$$	🧍🧍	★★	Monitor for herbicide effectiveness and need for re-treatment. All follow-up activities should promote desirable vegetation (grasses) and discourage weeds. Follow up seeding may be necessary to encourage a desirable plant community.

* = Factored into purchase price

Legend

Purchase Price	Operational Cost Per Hour	Personnel Scale	Return on Investment
$ = 1 - 200	$ = 1 - 25	🧍 = 1 Person	★ = No Efficiency Gained
$$ = 200 - 1,000	$$ = 26-50	🧍🧍 = 2 People	★★ = More Efficiency Gained
$$$ = 1,000 - 5,000	$$$ = 51-75	🧍🧍🧍 = 3 People	★★★ = Significant Efficiency Gained
$$$$ = 5,000 - 10,000	$$$$ = 76-100		★★★★ = Substantial Efficiency Gained
$$$$$ = 10,000 +	$$$$$ = 100 +		

Brush/Shrub/Small Tree (< 6" Diameter) Maintenance & Removal

Current ODOT Process

Description: Brush, shrubs, and trees under 6" diameter are not maintained by a standardized procedure. In general the work involves mowing with a flail or rotary mower and no herbicide treatment regardless of the vegetation composition.
ODOT's Presented Challenges: Vegetation Encroachment has out-paced vegetation management activities. Crews would like to catch up but are faced with manpower time and equipment constraints.
Davey's Observations: Small trees and shrubs are left to grow larger and larger in diameter making their removal require greater effort. Often trees are maintained when they should be removed to provide a long-term solution to the vegetation on a site. Rotary and flail mowers do not leave proper cuts thus leaving vegetation susceptible to disease, pests, failure, and fast growing water sprouts that are poorly attached.
Recomendations: Tall growing vegetation that requires continued maintenance and is incompatible with ODOT's maintenance abilities should be removed. No or low maintenance vegetation should be planted to prevent competition by unwanted species. Small trees should be removed while still small to avoid vegetation encroachment and to reclaim the right of way. Herbicide should be applied by an appropriate method either before or after removal to prevent regrowth.

Goal	Approach	Recommended Improvement	Timing / Frequency	Notes / Considerations	Potential Benefit	Herbicide Cost (not included in the Purchase Price)	Purchase Price of * Equipment	Operational Cost Per Hour	Personnel Scale	Return on Investment	IVM Follow Up
Preservation & Enhancement (Maintenance through Selective Removal of Non-Desirable Vegetation) *OR* Encroachment Prevention (Removing All Vegetation)	Herbicide Treatment *BEFORE* Selective Removal	2 Backpack Sprayers* Foliar Application of Non-Selective Herbicide* Tractor and Flail Mower[1] String Trimmer Truck with Trailer	**Mechanical:** Any time of year. **Chemical:** Foliar Applications must be done during the active growing season. Basal Bark Applications can be applied anytime of year when temperatures are above freezing.	If non-desirable vegetation is well distributed, use a Skid Sprayer with Hose Reel and 4x4 Truck, if it is sparse, consider more precise, spot treatments with a Backpack Sprayer. They can also be used together in mixed areas. Allow at least one week between herbicide application and removal. It may be advisable to allow desirable grass species to establish for purposes of having ground cover until the shrub layer becomes dominant. Monitor brush for site distance or hazard potential. Standard Hand Tools for these operations include chainsaws, lopping shears and pruning saws.	Tractors, Flail, and Rotary Mowers are standard equipment in ODOT garages. Rotary mowers allow for mowing on slopes and ditches. Builds upon an already common vegetation management process. The cost of additional *Mechanical* equipment should be very low. Basal Bark and Foliar Applications allow for flexibility in timing.	Glyphosate $17/gallon (3.8 liters)	$$	$$$	🧍🧍🧍🧍	★★★	1. Prepare site for planting desired vegetation as needed. 2. Replant area with low maintenance vegetation. 3. Monitor for undesirable plant species. 4. Employ cultural practices to enhance desirable vegetation as needed. 5. Apply selective herbicides to control unwanted vegetation as needed.
		Skid Sprayer with Hose Reel* and 4x4 Truck Foliar Application of Non-Selective Herbicide* Tractor and Flail Mower[1] String Trimmer Truck with Trailer					$$$$$	$$$$	🧍🧍🧍🧍🧍	★★★★	
		2 Backpack Sprayers* Basal Bark Application with Non-Selective Herbicide* Tractor and Flail Mower[1] String Trimmer Truck with Trailer				Glyphosate $17/gallon (3.8 liters) Imazapyr $168/gallon (3.8 liters) Triclopyr $64/gallon (3.8 liters)	$$	$$$	🧍🧍🧍🧍	★★★	
		2 Backpack Sprayer* Foliar Application of Non-Selective Herbicide* Tractor and Rotary Mower[1] String Trimmer Truck with Trailer				Glyphosate $17/gallon (3.8 liters)	$$	$$$$$	🧍🧍🧍🧍	★★★★★	
		Skid Sprayer with Hose Reel* and 4x4 Truck Foliar Application of Non-Selective Herbicide* Tractor and Rotary Mower[1] String Trimmer Truck with Trailer					$$$$$	$$$$	🧍🧍🧍🧍🧍	★★★★	
		2 Backpack Sprayers* Basal Bark Application with Non-Selective Herbicide* Tractor and Rotary Mower[1] String Trimmer Truck with Trailer				Glyphosate $17/gallon (3.8 liters) Imazapyr $168/gallon (3.8 liters) Triclopyr $64/gallon (3.8 liters)	$$	$$$	🧍🧍🧍🧍	★★★	
		2 Backpack Sprayers* Foliar Application with Non-Selective Herbicide* Forestry Mulcher on Skid Steer[1] String Trimmer Truck with Trailer			For brush over 1" in diameter a forestry mulcher is extremely effective. Will reduce the need for multiple vegetation control methods. Will save time due to its ability to control a wide range of brush sizes and types, including vines and small trees. Basal Bark and Foliar Applications allow for flexibility in timing.		$$	$$$	🧍🧍🧍🧍	★★★	
		Skid Sprayer with Hose Reel* and 4x4 Truck Foliar Application with Non-Selective Herbicide* Forestry Mulcher on Skid Steer[1] String Trimmer Truck with Trailer					$$$$$	$$$$	🧍🧍🧍🧍🧍	★★★★★	
		2 Backpack Sprayers* Basal Bark Application with Non-Selective Herbicide* Forestry Mulcher on Skid Steer[1] String Trimmer Truck with Trailer					$$	$$$	🧍🧍🧍🧍	★★★	
	Herbicide Treatment *After* Selective Removal	Forestry Mulcher on Skid Steer[1] String Trimmer 2 Backpack Sprayers* Pre-Emergent Application with Selective Herbicide* Truck with Trailer	**Mechanical:** Any time of year. **Chemical:** Cut Stumps should be treated within 1 hour of cutting. Cut-Stump treatments will be less effective during heavy sap flow (February through May) or freezing conditions. Pre-Emergent Application should be done in very early spring (March). **Biological:** March--October	If non-desirable vegetation is well distributed, use a Skid Sprayer with Hose Reel and 4x4 truck, if it is sparse, consider more precise, spot treatments with a backpack sprayer. They can also be used together in mixed areas. A String Trimmer can manage areas a Flail, Rotary Mower, or Forestry Mulcher cannot. Allow at least one week between herbicide application and removal. It may be advisable to allow desirable grass species to establish for purposes of having ground cover until the shrub layer becomes dominant. Monitor brush for site distance or hazard potential. Do not use the cut-stump treatment if desirable trees of the same species being treated are nearby (within 50 feet). Brush the sawdust from the stumps before treatment. It is necessary to wet the entire surface of *small* stumps. Standard Hand Tools for these operations include chainsaws, lopping shears and pruning saws.	For brush over 1" in diameter a forestry mulcher is extremely effective. Will reduce the need for multiple vegetation control methods. Will save time due to its ability to control a wide range of brush sizes and types, including vines and small trees.	Pendimethalin $40/gallon (3.8 liters)	$$	$$$$	🧍🧍🧍🧍	★★	1. Prepare site for planting desired vegetation as needed. 2. Replant area with low maintenance vegetation. 3. Monitor for undesirable plant species. 4. Employ cultural practices to enhance desirable vegetation as needed. 5. Apply selective herbicides to control unwanted vegetation as needed.
		Forestry Mulcher on Skid Steer[1] String Trimmer Skid sprayer with Hose Reel* and 4x4 Truck Pre-Emergent Application with Selective Herbicide* Truck with Trailer					$$$$$	$$$$	🧍🧍🧍🧍🧍	★★★	
		Tractor and Rotary Mower[1] String Trimmer 2 Backpack Sprayers* Cut-Stubble Application with Non-Selective Herbicide* Truck with Trailer			Tractors, Flail, and Rotary Mowers are standard equipment in ODOT garages. Rotary mowers allow for mowing on slopes and ditches. Builds upon an already common vegetation management process. The cost of additional Mechanical equipment should be very low. Cut Stump Applications can be very effective in preventing regrowth.	Glyphosate $17/gallon (3.8 liters) Imazapyr $168/gallon (3.8 liters) Triclopyr $64/gallon (3.8 liters)	$$	$$$	🧍🧍🧍🧍	★★★	
		Tractor and Rotary Mower[1] String Trimmer Skid Sprayer with Hose Reel* and 4x4 Truck Cut-Stubble Application with Non-Selective Herbicide* Truck with Trailer or Wet-Blade boom rotary mower* Selective Herbicide* Plant Growth Regulator (PGR)* Tractor Truck with Trailer					$$$$$	$$$$	🧍🧍🧍🧍🧍	★★★★★	
		Tractor and Flail Mower[1] String Trimmer 2 Backpack Sprayers* Pre-Emergent Application with Selective Herbicide* Truck with Trailer				Pendimethalin $40/gallon (3.8 liters)	$$	$$$	🧍🧍🧍🧍	★★	
		Tractor and Flail Mower[1] String Trimmer Skid sprayer with Hose Reel* and 4x4 Truck Pre-Emergent Application with Selective Herbicide* Truck with Trailer					$$$$$	$$$$	🧍🧍🧍🧍🧍	★★★	
		Tractor and Rotary Mower[1] String Trimmer 2 Backpack Sprayers* Pre-Emergent Application with Selective Herbicide* Truck with Trailer					$$	$$$	🧍🧍🧍🧍	★★	
		Tractor and Rotary Mower[1] String Trimmer Skid sprayer with Hose Reel* and 4x4 Truck Pre-Emergent Application with Selective Herbicide* Truck with Trailer					$$$$$	$$$$	🧍🧍🧍🧍🧍	★★★	
		Goats* String Trimmer 2 Backpack Sprayers* Pre-Emergent Application with Selective Herbicide* Truck with Trailer		Contracting this service would be the most efficient allocation of resources. Goats can be a slow process but in areas where options are limited they can be extremely effective. Ensure safety by only applying herbicide *after* goats have finished grazing.	Goats work well in areas of significant slope/terrain, poor access, or when herbicides cannot be used (ex: organic farm nearby).		$	$	🧍🧍🧍	★★★	
		Goats* String Trimmer Skid sprayer with Hose Reel* and 4x4 Truck Pre-Emergent Application with Selective Herbicide* Truck with Trailer					$	$	🧍🧍🧍🧍	★★★	

* Factored into Purchase Price

[1] Be sure to scout the area ahead of time for damaging obstacles. A Flail or Rotary Mower attached to a Tractor are limited by the diameter of vegetation size whereas a Forestry Mulcher on a Skid Steer can handle larger sized vegetation.

Legend

Purchase Price	Operational Cost Per Hour	Personnel Scale	Return on Investment
$ = 1 - 250	$ = 1 - 50	🧍 = 1 Person	★ = No Efficiency Gain
$$ = 251 - 500	$$ = 51 - 100	🧍🧍 = 2 People	★★ = Minor Efficiency Gain
$$$ = 501 - 1,000	$$$ = 101 - 150	🧍🧍🧍 = 3 People	★★★ = Moderate Efficiency Gain

Large Tree Maintenance (> 6" Diameter)

Current ODOT Process

Description: Tree maintenance is performed irregularly using a variety of equipment (29' lighting bucket trucks, forestry bucket trucks, telescoping saw truck, flail mowers, rotary mowers) using in-house and contracted labor. There is no consistency in a tree maintenance method.

ODOT's Presented Challenges: Maintenance is restricted during Indiana Bat breeding season, having enough adequate equipment to perform the removal work during the allowed season.

Davey Resource Group's Observations: There are three telescoping saw trucks with only one chipper of high enough capacity to keep up with the production, not enough forestry bucket trucks of proper size to adequately perform the work, use of non-forestry "lighting" buckets are not adequate replacements of forestry buckets. Rotary and flail mowers as well as telescoping saw trucks do not leave proper cuts thus leaving the tree susceptible to disease, pests, failure, fast growing water sprouts that are poorly attached. All of these will lead to decline and failure. Telescoping saw trucks are more suited for off-road work but are being used on road. A similar sized on-road forestry bucket costs significantly less to do the same job. Tree operations do not have oversight by an ISA Certified Tree Worker which would be helpful for increasing safety, production, and longer cycles.

Recommendation: Each tool has a purpose. Use of tools outside their purpose decreases crew efficiency and effectiveness of the tool. With more equipment of sufficient reach, less outside contracting would be necessary. However, it must be realized without proper training, tree maintenance can be very dangerous work. There are trees being maintained that should be cut down to achieve greater and clearance of longer duration. Where trees are trimmed repeatedly, it will be more economical in the long-term to remove them rather than continue to maintain them.

Goal	Area	Recommended Improvement	Timing/ Frequency	Notes/Considerations [1]	Potential Benefits	Purchase Price of * Equipment	Operational Cost Per Hour	Personnel Scale	Return on Investment	IVM Follow-Up
Large Tree Maintenance to Improve Sight Distance	On Road	60' 4x2 Forestry Bucket Truck * Chipper (12" Diameter) Chainsaws Grapple* on 13k lb. Excavator Loader on Skid Steer 2 Trucks with Trailers	All Year	Requires more skill than Telescoping Saw Truck.	Grapple and Loader reduce manual labor in moving limbs and logs from drop zone to chipper.	$$$	$$	🧍🧍🧍🧍🧍	★★★★	Consider applying herbicide for side trimming new shoots 1-2 years after mechanical pruning to lengthen mechanical cycle. Can prove beneficial in inconspicuous areas. Herbicide Cost for Fosamine Ammonium = $70/pound (0.454 kilograms)
		60' 4x2 Forestry Bucket Truck* Chipper (12" Diameter) Chainsaws		Requires more skill than Telescoping Saw Truck.	Compared to a Lighting Bucket Truck, a Forestry Bucket Truck allows for better access, proper cutting techniques and is compliant with OSHA regulations for tree work.	$$$	$	🧍🧍🧍	★★★	
		Telescoping Saw Truck 60' 4x2 Forestry Bucket Truck* Chipper (21" Diameter)* Grapple* on 13k lb. Excavator Loader on Skid Steer 3 Trucks with Trailers Chainsaws		Telescoping Saw Truck leaves stub cuts which will produce weakly attached water sprouts (branches) and can cause decline in the tree due to disease and decay. For on road work especially, it is best to follow up with proper cuts which can be made by chainsaw in bucket following the Telescoping Saw Truck after the heavy wood has been removed. Use Chipper (21" Diameter) with Telescoping Saw Truck to keep up with workload.	Telescoping Saw Truck has the safety benefit of being able to keep personnel on the ground while the tree is being pruned. Telescoping Saw Truck is best at off road work and can be up to 5 times more efficient than a bucket crew. Grapple and Loader reduce manual labor in moving limbs and logs from drop zone to chipper. This combination allows for high productivity while providing proper cuts enabling greater clearance and a longer maintenance cycle.	$$$$$	$$$	🧍🧍🧍🧍🧍🧍	★★★★★	
	Off Road	60' 4x2 Forestry Bucket Truck* Chipper (12" Diameter) Chainsaws	All Year	Use 4x2 Forestry Bucket off road when soil conditions are dry or frozen. Use mud mats to extend access in muddy conditions. Requires more skill than Telescoping Saw Truck.	Compared to a Lighting Bucket Truck, a Forestry Bucket Truck allows for better access, proper cutting techniques and is compliant with OSHA regulations for tree work. Allows for better quality cutting than Telescoping Saw Truck.	$$$	$	🧍🧍🧍	★	Consider applying herbicide for side trimming new shoots 1-2 years after mechanical pruning to lengthen mechanical cycle. Can prove beneficial in inconspicuous areas. Herbicide cost for Fosamine Ammonium = $70/pound (0.454 kilograms)
		60' 4x4 Forestry Bucket Truck* Chipper (12" Diameter) Chainsaws		4x4 Forestry Bucket Truck is better for muddy ground but should still use mud mats for better access. Requires more skill than Telescoping Saw Truck.	Compared to a Lighting Bucket Truck, a Forestry Bucket Truck allows for better access, proper cutting techniques and is compliant with OSHA regulations for tree work. 4x4 allows greater off road access than 4x2 and for better quality cutting than Telescoping Saw Truck.	$$$$	$	🧍🧍🧍	★★★	
		Telescoping Saw Truck Chipper (21" Diameter)* 2 Trucks with Trailers Chainsaws		Telescoping Saw Truck leaves stub cuts which will produce weakly attached water sprouts and can cause decline in the tree due to disease and decay. Use Chipper (21" Diameter) with Telescoping Saw Truck to keep up with workload. If cutting smaller wood, Grapple and Loader may not be needed	Telescoping Saw Trucks are designed for off road use and are most adept at traversing this area and can be up to 5 times more efficient than a bucket crew.	$$$	$$	🧍🧍🧍	★★★	
		Telescoping Saw Truck Chipper (21" Diameter)* Grapple* on 13k lb. Excavator Loader on Skid Steer 4 Trucks with Trailers Chainsaws		Telescoping Saw Truck leaves stub cuts which will produce weakly attached water sprouts (branches) and can cause decline in the tree due to disease and decay. Telescoping Saw Truck is designed for off road work and biggest benefit will be achieved by using it off road. Use Chipper (21" Diameter) with Telescoping Saw Truck to keep up with workload.	Telescoping Saw Truck has the benefit of being able to keep men on the ground while the tree is being pruned. Telescoping Saw Truck is most adept at off road work and can be up to 5 times more efficient than a bucket crew. Grapple and Loader reduce manual labor in moving limbs and logs from drop zone to chipper.	$$$	$$$	🧍🧍🧍🧍🧍	★★★★	
		Helicopter with Saw Blade Forestry Mulcher on Skid Steer Grapple* on Skid Steer Chainsaws 2 Trucks with Trailers		Weather conditions limit flight days	Can reach higher into trees and is most adept on the most difficult terrain. Can be 5 times faster than a manual crew.	$	$$$$$	🧍🧍🧍🧍	★★★★	

* Factored into Purchase Price

[1] Applies to every option: All chippers should be equipped with a winch to improve efficiency of feeding the chipper and reduce manual labor. Chips and logs should be left on site whenever possible.

Legend

Purchase Price	Operational Cost Per Hour	Personnel Scale	Return on Investment
$ = 1 - 50,000	$ = 1 - 100	🧍 = 1 Person	★ = No Efficiency Gained
$$ = 50,001 - 100,000	$$ = 101 - 200	🧍🧍 = 2 People	★★ = Minor Efficiency Gained
$$$ = 100,001 - 150,000	$$$ = 201 - 300	🧍🧍🧍 = 3 People	★★★ = Moderate Efficiency Gain
$$$$ = 150,001 - 200,000	$$$$ = 300 - 1000	🧍🧍🧍🧍 = 4 People	★★★★ = Immediate and/or Substantial Gain
$$$$$ > 200,000	$$$$$ = 1001 - 2000	🧍🧍🧍🧍🧍 = 5 People	★★★★★ = Substantial Immediate and Long-term Gain

Large Tree Removal (> 6" Diameter)

Current ODOT Process

Description: Tree removal is performed on a reactive basis only using a variety of equipment (29' bucket trucks, forestry bucket trucks, telescoping sawtruck) using in-house and contracted labor. Variable use of cut-stump treatment. There is no consistency in a tree removal method.

ODOT's Presented Challenges: Removals restricted during Indiana Bat breeding season, having enough adequate equipment to perform the removal work during the allowed season.

Davey Resource Group's Observations: There are three telescoping saw trucks with only one chipper of high enough capacity to keep up with the production, not enough forestry bucket trucks of proper size to adequately perform the work, use of non-forestry "lighting" buckets are not adequate replacements of forestry buckets. Telescoping saw trucks are more suited for off-road work but are being used on road. A similar sized on-road forestry bucket costs significantly less to do the same job. Tree operations do not have oversight by an ISA Certified Tree Worker which would be helpful for increasing safety, production, and longer cycles.

Recommendation: Each tool has a purpose. Use of tools outside their purpose decreases crew efficiency and effectiveness of the tool. With more equipment of sufficient reach, less outside contracting would be necessary. However, it must be realized without proper training tree removals are very dangerous work and the larger the removal, the more difficult the work.

Goal	Area	Size	Recommended Improvement	Timing/ Frequency	Notes/Considerations[1]	Potential Benefits	Herbicide Cost (not included in the Purchase Price)	Purchase Price of * Equipment	Operational Cost Per Hour	Personnel Scale	Return on Investment	IVM Follow-Up
Large Tree Removal to Improve Sight Distance and Remove Hazard Trees	On Road	Trees 6"-24" Diameter	60' 4x2 Forestry Bucket Truck* 100' Crane* Chipper (12" Diameter) Chainsaws Grapple* on 13k lb. Excavator Loader on Skid Steer 2 Trucks with Trailers Cut-Stump Application	**Mechanical:** All year except during Indiana Bat Breeding Season **Chemical:** Cut-stump should be treated within 1 hour of cutting. Cut-Stump treatments will be less effective during heavy sap flow (February through May) or freezing conditions.	Crane - Use in conjunction with bucket truck for best results and do not overload to prevent tipping. Unless difficult to access, may not be worth the cost on three smaller trees.	Compared to a Lighting Bucket Truck, a Forestry Bucket Truck allows for better access, proper cutting techniques and is compliant with OSHA regulations for tree work. Crane takes the weight from heavy limbs and logs in removal operation. Reduces time spent per tree and improves access to trees.	Glyphosate = $17/Gallon (3.8 Liters) Triclopyr = $64/Gallon (3.8 Liters) Imazapyr = $168/Gallon (3.8 Liters)	$$$$$$	$$$$$	🧍🧍🧍🧍🧍🧍	★	Monitor for re-growth. Plant no / low maintenance vegetation to compete with tree saplings
			60' 4x2 Forestry Bucket Truck* Chipper (12" Diameter) Chainsaws Grapple* on 13k lb. Excavator Loader on Skid Steer 2 Trucks with Trailers Cut-Stump Application		Requires more skill than Telescoping Saw Truck.	Compared to a Lighting Bucket Truck, a Forestry Bucket Truck allows for better access, proper cutting techniques and is compliant with OSHA regulations for tree work. Grapple and Loader reduce manual labor in moving limbs and logs from drop zone to chipper.		$$$	$$$$	🧍🧍🧍🧍🧍	★★★	
			60' 4x2 Forestry Bucket Truck* Chipper (12" Diameter) Chainsaws Cut-Stump Application		Requires more skill than Telescoping Saw Truck.	Compared to a Lighting Bucket Truck, a Forestry Bucket Truck allows for better access, proper cutting techniques and is compliant with OSHA regulations for tree work.		$$$	$$	🧍🧍🧍	★★★	
			Telescoping Saw Truck Chipper (21" Diameter)* Grapple* on 13k lb. Excavator Loader on Skid Steer Chainsaws 4 Trucks with Trailers Cut-Stump Application		Telescoping Saw Truck is best suited for trimming but can assist in removal by taking canopy off tree leaving final cuts to ground to be performed with chainsaws. Use Chipper (21" Diameter) with Telescoping Saw Truck to keep up with workload.	Telescoping Saw Truck has the benefit of being able to keep men on the ground while the tree is being removed. Telescoping Saw Truck is most adept at off road work. A chipper with winch or grapple arm can increase speed of the debris clearing operation.		$$$	$$$$$$	🧍🧍🧍🧍🧍	★	
			Tree Mulcher* on 36k lb. Excavator 1 Truck with Trailer Cut-Stump Application		Tree debris can be thrown a few hundred feet so be mindful of surroundings.	Tree mulcher is used to remove and chip trees in one step.		$	$$$	🧍🧍	★★★★	
		Trees > 24" Diameter	60' 4x2 Forestry Bucket Truck * 100' Crane* Chipper (12" Diameter) Chainsaws Grapple* on 13k lb. Excavator Loader on Skid Steer 2 Trucks with Trailers Cut-Stump Application	Mechanical: All year except during Indiana Bat Breeding Season Chemical: Cut-stump should be treated within 1 hour of cutting. Cut-Stump treatments will be less effective during heavy sap flow (February through May) or freezing conditions.	Crane - Use in conjunction with bucket truck for best results and do not overload to prevent tipping. Crane use is best suited for difficult to access trees.	Compared to a Lighting Bucket Truck, a Forestry Bucket Truck allows for better access, proper cutting techniques and is compliant with OSHA regulations for tree work. Crane takes the weight from heavy limbs and logs in removal operation. Reduces time spent per tree and improves access to trees.	Glyphosate = $17/Gallon (3.8 Liters) Triclopyr = $64/Gallon (3.8 Liters) Imazapyr = $168/Gallon (3.8 Liters)	$$$$$$	$$$$$	🧍🧍🧍🧍🧍🧍	★★★	Monitor for re-growth. Plant no / low maintenance vegetation to compete with tree saplings
			60' 4x2 Forestry Bucket Truck* Chipper (12" Diameter) Chainsaws Grapple* on 13k lb. Excavator Loader on Skid Steer 2 Trucks with Trailers Cut-Stump Application		Requires more skill than Telescoping Saw Truck.	Compared to a Lighting Bucket Truck, a Forestry Bucket Truck allows for better access, proper cutting techniques and is compliant with OSHA regulations for tree work. Grapple and Loader reduce manual labor in moving limbs and logs from drop zone to chipper.		$$$	$$$$	🧍🧍🧍🧍🧍	★★★	
			60' 4x2 Forestry Bucket Truck* Chipper (12" Diameter) Chainsaws Cut-Stump Application		Requires more skill than Telescoping Saw Truck.	Compared to a Lighting Bucket Truck, a Forestry Bucket Truck allows for better access, proper cutting techniques and is compliant with OSHA regulations for tree work.		$$$	$$	🧍🧍🧍	★★	
			Telescoping Saw Truck Chipper (21" Diameter)* Grapple* on 13k lb. Excavator Loader on Skid Steer 4 Trucks with Trailers Chainsaws Cut-Stump Application		Telescoping Saw Truck is best suited for trimming but can assist in removal by taking canopy off tree leaving final cuts to ground to be performed with chainsaws. Use Chipper (21" Diameter) with Telescoping Saw Truck to keep up with workload.	Telescoping Saw Truck has the benefit of being able to keep men on the ground while the tree is being removed. Telescoping Saw Truck is most adept at off road work. A chipper with winch or grapple arm can increase speed of the debris clearing operation.		$$$	$$$$$$	🧍🧍🧍🧍🧍	★★★	
	Off Road	Trees 6"-24" Diameter	60' 4x2 Forestry Bucket Truck* Chipper (12" Diameter) Chainsaws Cut-Stump Application	Mechanical: All year except during Indiana Bat Breeding Season Chemical: Cut-stump should be treated within 1 hour of cutting. Cut-Stump treatments will be less effective during heavy sap flow (February through May) or freezing conditions.	Use 4x2 Forestry Bucket off road when conditions are dry or frozen. Use mud mats to extend access in muddy conditions.	Compared to a Lighting Bucket Truck, a Forestry Bucket Truck allows for better access, proper cutting techniques and is compliant with OSHA regulations for tree work.	Glyphosate = $17/Gallon Triclopyr = $64/Gallon Imazapyr = $168/Gallon (3.8 Liters)	$$$	$$	🧍🧍🧍	★	Monitor for re-growth. Plant no / low maintenance vegetation to compete with tree saplings
			60' 4x4 Forestry Bucket Truck* Chipper (12" Diameter) Chainsaws Cut-Stump Application		Requires more skill than Telescoping Saw Truck.	Compared to a Lighting Bucket Truck, a Forestry Bucket Truck allows for better access, proper cutting techniques and is compliant with OSHA regulations for tree work. 4x4 allows greater off road access than 4x2.		$$$$	$$	🧍🧍🧍	★★	
			Telescoping Saw Truck Chipper (21" Diameter)* Chainsaws 2 Trucks with Trailers Cut-Stump Application		Telescoping Saw Truck is best suited for trimming but can assist in removal by taking canopy off tree leaving final cuts to ground to be performed with chainsaws. Use Chipper (21" Diameter) with Telescoping Saw Truck to keep up with workload.	Telescoping Saw Truck has the benefit of being able to keep men on the ground while the tree is being removed. Telescoping Saw Truck is best suited to off road work. A chipper with winch or grapple arm can increase speed of the debris clearing operation.		$$$	$$$$	🧍🧍🧍🧍🧍	★	
			Telescoping Saw Truck Chipper (21" Diameter)* Grapple* on 13k lb. Excavator Loader on Skid Steer 4 Trucks with Trailers Chainsaws Cut-Stump Application		Telescoping Saw Truck is best suited for trimming but can assist in removal by taking canopy off tree leaving final cuts to ground to be performed with chainsaws. Use Chipper (21" Diameter) with Telescoping Saw Truck to keep up with workload.	Telescoping Saw Truck has the benefit of being able to keep men on the ground while the tree is being removed. Telescoping Saw Truck is most adept at off road work. A chipper with winch or grapple arm can increase speed of the debris clearing operation. Grapple and loader reduce manual labor in moving limbs and logs from drop zone to chipper.		$$$	$$$$$$	🧍🧍🧍🧍🧍	★★	
			Tree Mulcher* on 36k lb. Excavator 1 Truck with Trailer Cut-Stump Application		Tree debris can be thrown a few hundred feet so be mindful of surroundings. Head is limited on the diameter of the tree that can be taken down.	Tree mulcher is used to remove and chip trees in one step.		$	$$$	🧍🧍	★★★★	
			Small Feller Buncher* on Skid Steer Grapple* on 13k lb. Excavator Chipper (21" Diameter)* Chainsaws 3 Trucks with Trailers Cut-Stump Application		Saw blade limits the diameter of the tree that can be taken down. Use Chipper (21" Diameter) with Feller Buncher to keep up with workload.	Feller Buncher can remove multiple trees in one cut and quickly move them to a staging area. Grapple can reduce manual labor in moving limbs and logs from staging area to chipper.		$$$$	$$$$$	🧍🧍🧍🧍🧍	★★★★	
			Medium Feller Buncher* on 13k lb. Excavator Grapple* on 13k lb. Excavator Chipper (21" Diameter)* 3 Trucks with Trailers Cut-Stump Application		Saw blade limits the diameter of the tree that can be taken down. Use Chipper (21" Diameter) with Feller Buncher to keep up with workload.	High production rate as feller buncher can remove multiple trees in one cut and quickly move them to a staging area. Grapple can reduce manual labor in moving limbs and logs from staging area to chipper.		$$$$	$$$$$	🧍🧍🧍🧍🧍	★★★★★	
		Trees > 24" Diameter	60' 4x2 Forestry Bucket Truck* Chipper (12" Diameter) Chainsaws Cut-Stump Application	Mechanical: All year except during Indiana Bat Breeding Season Chemical: Cut-stump should be treated within 1 hour of cutting. Cut-Stump treatments will be less effective during heavy sap flow (February through May) or freezing conditions.	Use 4x2 Forestry Bucket off road when conditions are dry or frozen. Use mud mats to extend access in muddy conditions. Requires more skill than Telescoping Saw Truck.	Compared to a Lighting Bucket truck, a Forestry Bucket truck has better reach, safety, and is compliant with OSHA regulations for tree work.	Glyphosate = $17/Gallon (3.8 Liters) Triclopyr = $64/Gallon (3.8 Liters) $168/Gallon (3.8 Liters)	$$$	$$	🧍🧍🧍	★	Monitor for re-growth. Plant no / low maintenance vegetation to compete with tree saplings
			60' 4x4 Forestry Bucket Truck* Chipper (12" Diameter) Chainsaws Cut-Stump Application		Requires more skill than Telescoping Saw Truck.	Compared to a Lighting Bucket Truck, a Forestry Bucket Truck allows for better access, proper cutting techniques and is compliant with OSHA regulations for tree work. 4x4 allows greater off road access than 4x2.		$$$$	$$	🧍🧍🧍	★★	
			Telescoping Saw Truck Chipper (21" Diameter)* Grapple* on 13k lb. Excavator Loader on Skid Steer 4 Trucks with Trailers Chainsaws Cut-Stump Application		Telescoping Saw Truck is best suited for trimming but can assist in removal by taking canopy off tree leaving final cuts to ground to be performed with chainsaws. Use Chipper (21" Diameter) with Telescoping Saw Truck to keep up with workload.	Telescoping Saw Truck has the benefit of being able to keep men on the ground while the tree is being removed. Telescoping Saw Truck is most adept at off road work. A chipper with winch or grapple arm can increase speed of the debris clearing operation. Grapple and Loader reduce manual labor in moving limbs and logs from drop zone to chipper.		$$$	$$$$$$	🧍🧍🧍🧍🧍	★★★	
			Telescoping Saw Truck Chipper (21" Diameter)* 2 Trucks with Trailers Chainsaws Cut-Stump Application		Telescoping Saw Truck is best suited for trimming but can assist in removal by taking canopy off tree leaving final cuts to ground to be performed with chainsaws. Use Chipper (21" Diameter) with Telescoping Saw Truck to keep up with workload.	Telescoping Saw Truck has the benefit of being able to keep men on the ground while the tree is being removed. Telescoping Saw Truck is most adept at off road work. A chipper with winch or grapple arm can increase speed of the debris clearing operation.		$$$	$$$$	🧍🧍🧍	★	
Lower Stump Height	Off Road	Any Size	Portable Stump Grinder	All year	Grind stump as needed for other maintenance operations. Small self-propelled grinders are most appropriate for ODOT operations.	Will prevent damage to mowing equipment.		$	$	🧍	★	

* = Factored into purchase price

[1] Applies to every option: Cut stump to 4" high if not grinding stump to allow mowers to pass over. Where there are no access constraints, routinely apply herbicide to re-sprouting species that are not root grafted to prevent trees from re-growing.

All chippers should be equipped with a winch to improve efficiency of feeding the chipper and reduce manual labor. Chips and logs should be left on site whenever possible.

Before each tree is felled, conditions such as, but not limited to, snow and ice accumulation, wind, lean of tree, dead limbs, and the location of other trees, shall be evaluated by the crew and precautions taken so a hazard is not created for the crew or public. Consult an International Society of Arboriculture (ISA) Certified Tree Worker when unsure of how to proceed with an operation.

Legend

Purchase Price	Operational Cost Per Hour	Personnel Scale	Return on Investment
$ = 1-50,000	$ = 1 - 50	🧍 = 1 Person	★ = No Efficiency Gained
$$ = 50,001 - 100,000	$$ = 51-100	🧍🧍 = 2 People	★★ = Minor Efficiency Gained
$$$ = 100,001 - 150,000	$$$ = 101 - 150	🧍🧍🧍 = 3 People	★★★ = Moderate Efficiency Gain
$$$$ = 150,001 - 200,000	$$$$ = 151 - 200	🧍🧍🧍🧍 = 4 People	★★★★ = Immediate and/or Substantial Gain
$$$$$ = 200,001-250,000	$$$$$ = 201 - 250	🧍🧍🧍🧍🧍 = 5 People	★★★★★ = Substantial Immediate and Long-term Gain
$$$$$ = >250,000	$$$$$$ = 251 - 300	🧍🧍🧍🧍🧍🧍 = 6 People	

Planning and Operations

Current ODOT Process

Description: Beyond obtaining new equipment and implementing improved field operations, ODOT can gain efficiencies for vegetation management activities by improving a variety of administrative, operational, and personnel processes.
ODOT's Challenges: Decentralized and disproportionate distribution of equipment and trained/experienced staff; lack of readily available technical resources in the Districts; outdated work specifications.
Davey Resource Group's Observations: ODOT staff have varying levels of vegetation management knowledge and experience; the vegetation management equipment/fleet compliment is not adequate nor universal across Districts; there is a need for readily available technical support on a daily and county-specific basis; contract specifications and ODOT standard operating procedures should be revised to reflect current industry standards.
Recommendations: ODOT management should make technical resources available to the Districts that are customized for the local conditions; work specifications should be updated; staff should be trained on new techniques and basic vegetation management subjects so they can make quick, independent decision appropriate for their County.

Area	Recommended Improvement	Notes/Considerations	Potential Benefits	Purchase Price	Return on Investment
Administration	Central Equipment Database	Update and maintain central equipment database and provide easy access to District managers. Use more descriptive and standardized categories to track equipment.	Facilitates easier sharing of equipment within and between districts to maximize use of equipment.	$	★★
	IVM Computer Aided Decision Tool	Create a software application that automates decision-making for VM Best Practices and solutions. A user-friendly computer application that provides a VM solution based on variable inputs; compatible with a variety of computer hardware and operating systems.	Simplifies decision making process. Increases efficiency by quickly producing a "pre-tested" and preferred solution(s) for a given situation, i.e. most effective equipment combinations, crew compliments, materials, etc.	$$$$$	★★★
	Review VM Contracts	Review and update all VM labor and materials contract specifications. Add into contracts missing specifications (herbicide use, distance to mow to side, accountability).	Achieve more consistent results from contractors; incorporate current industry standards.	$	★★★
	IVM Public Education	Perform greater public awareness/education about ODOT VM practices. Create public education pieces that can be distributed by field staff and posted on websites; encourage the public/business/organizations to support no-mow and restored native landscape areas.	Less complaints; more cooperation during projects; financial support for VM activities and programs.	$$	★★
Operations	Integrated Vegetation Management Plan	Create a Vegetation Management Plan for each District. Customize VM best management practices for each unique District; provides yearly goals for all VM activities to ultimately establish a proactive program that uses routine and preventive maintenance practices.	Begins a structured effort to be more pro-active and set goals; addresses local VM challenges more precisely yet creates consistency statewide; identifies particular VM tasks that could be subcontracted.	$$$$ (per district)	★★★★
	Herbicide Manual	Create customized herbicide use manuals for each County. Printed and/or digital document that provides descriptions, photographs, and precise prescriptions for local weed control options.	Streamline herbicide application practices so end user knows what plants should be sprayed with which chemical in what quantities and when to apply.	$$ (per county)	★★★★
	Equipment Utilization	Retrofit equipment only used seasonally to have additional uses. Find alternate uses for equipment that is only used seasonally. to justify the purchase of additional pieces so they are not so in-demand during the prime season. Example 1: Retrofit dump trucks that plow snow and salt and sand roads with herbicide spray equipment during the growing season. Example 2: Forestry bucket trucks can be used by lighting and sign department when not needed for tree work.	Seasonally used equipment retrofitted for additional uses enables more hours from the same piece of equipment. Finding alternate uses for equipment that is only used occasionally to justify the purchase of additional pieces so when they are needed in-season there are more of them available.	$	★★★
	Update ODOT MOM	Update ODOT Vegetation Management Manual to include new, revised, improved, and complete Best Management Practices. Based on findings of VM Research Project, ODOT's VM Manual would be revised to include proven, efficient VM practices, and presented in a format that includes all aspects of the operation (including staff and public safety, environmental concerns, regulatory restrictions, etc.) which combined define a true Best Management Practice.	Statewide consistency of VM; official documentation of practices that are vetted and proven to be cost-efficient, effective, safe, and regulatory compliant. Elevation of ODOT VM program to a premiere program among peers and citizens.	$$$$$	★★
	Invasive Insect/Disease Threat & Risk Tree Management	Actively inspect large diameter trees that are dead or rapidly declining due to insect and disease impacts, physical damage, or natural mortality. For EAB, consider treating trees that are less than 30% affected with EAB to lengthen the time available before tree death and failure occurs. Start a systematic plan of inspection and removal for trees in ODOT ROW that pose a significant threat to safety of ODOT crews and the traveling public.	Proactive inspection and removal increases safety of the ROW and decreases liability. For EAB, treatment extends the timeframe for ash removal so they aren't all at a critical stage at the same time which allows for "staging of removals" (less of a budget impact and burden on a equipment and manpower in the short and long terms.	$$$$$	★★★★
Personnel	Certifications	Maintain qualified and certified personnel for herbicide applications and tree maintenance in each District. Assess current staff qualifications; train and certify staff for ODA Pesticide Applicators License and ISA Tree Worker or Certified Arborist designations; maintain professional qualifications, training, and recertification dates in a database.	Staff will know how to perform related tasks safer, better, and more efficiently; increased professionalism of ODOT VM staff as viewed internally by other State departments and externally by the general public.	$$	★★★
	Training	Provide annual/periodic general VM training for all staff. Includes: plant ID, insect/disease identification, pesticide use, equipment use and calibration, safe work procedures, erosion avoidance and mitigation, Migratory Bird Act, State and Federal Endangered Species Acts, OH noxious species list.	Increased staff professionalism; quicker and appropriate decision-making on the local level; less accidents and equipment damage/repairs; fine reduction.	$$	★★
	Internal Collaboration	Encourage inter-county and inter-district site VM visits and communication. Employees at various levels could go on rotation getting hands-on practice in each area, assisting and/or learning how other Districts or Counties perform VM operations while sharing their area's ideas.	Better transfer of knowledge and "cross-pollination" between counties and districts among the staff that are performing the work. Encourages staff cohesiveness; increases professionalism, builds teams.	$	★★★★

Legend

Purchase Price (initial investment)	Return on Investment
$ = no direct cost; management effort/time only	★ = No Efficiency Gained
$$ = $1,000 - $5,000	★★ = Minor Efficiency Gained
$$$ = $5,000 - $10,000	★★★ = Moderate Efficiency Gained
$$$$ = $10,000 - $20,000	★★★★ = Immediate and/or Substantial Gain
$$$$$ = $20,000+	★★★★★ = Substantial Immediate and Long-term Gain

Appendix B
Test Fact Sheets

ODOT Evaluating Vegetation Management Practices
District 4 Fact Sheet

Zone One: Test 1, Maintain Bare Ground under Guardrail or Cable Rail with Spray Truck and Boomless Nozzle

Goals

- Control all vegetation under rails
- Reduce frequency for roadside vegetation maintenance
- Improve roadside safety

Study Areas: I-77 South, 2 Test Sites under Cable Rail
Mile Marker 117-116, Summit County

- Experimental design: Randomized Complete Blocks
- 2 Study areas: 3 replications: 19,602 ft., sq. ft., or 0.45 acre
  - Replication I (Green): 1,089 ft. x 6 ft.
    - 3 Plots: 363 ft. x 6 ft., or 1/20th acre
  - Replication II (Blue): 1,089 ft. x 6 ft.
    - 3 Plots: 363 ft. x 6 ft., or 1/20th acre
  - Replication III (Red): 1,089 ft. x 6 ft.
    - 3 Plots: 363 ft. x 6 ft., or 1/20th acre

Equipment and Materials

Method 1: Treatment 1: Standard Operating Procedure:

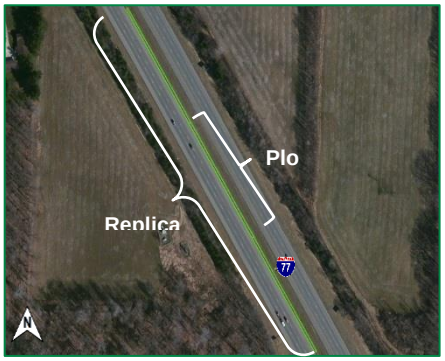
- F-450 dump truck with 425-gallon skid sprayer with boomless nozzle
- Herbicide = Rodeo® (*glyphosate*)
- Treatment: 3 times per season

Method 2: Treatment 1:

- F-450 dump truck with 425-gallon skid sprayer with boomless nozzle
- Herbicide = EsplAnade® 200 SC (*indaziflam)* + Perspective® (*aminocyclopyrachlor, chlorsulfuron*) + Rodeo® (*glyphosate*)
- Treatment: 1 time per season

Method 2: Treatment 2:

- F-450 dump truck with 425-gallon skid sprayer with boomless nozzle
- Herbicide = EsplAnade® 200 SC (*indaziflam*) + Oust® XP (*sulfometuron*) + Rodeo® (*glyphosate*)
- Treatment: 1 time per season



ODOT Fieldwork Time

- Herbicide application = 3 days
- Monitoring = 1 × per month using Davey Site Monitoring Form

Evaluation Factors

- Vegetation growth rates
- Duration of control
- Labor cost and time
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Bare Ground under Cable Rail

1,089′

Rodeo®	EsplAnade® 200 SC + Oust® XP + Rodeo®	EsplAnade® 200 SC + Perspective® + Rodeo®

6′

ODOT Evaluating Vegetation Management Practices
District 4 Fact Sheet

Zone One: Test 2, Maintain Vegetation under Cable Rail or Guardrail with Guardrail Mower

Goals

- Reduce manual labor for maintenance of vegetation under rails
- Determine best equipment for maintaining vegetation under cable rail
- Improve roadside safety

Study Area: I-77 South, Mile Marker 115, Summit County

- Experimental design: Randomized Complete Blocks
- Study area: 3 replications: each 1,584 ft., or 1/20 mile
  - Replication I (Green): 528 ft. x 5 ft.
    - 2 Plots: 264 ft. x 5 ft.
  - Replication II (Blue): 528 ft. x 5 ft.
    - 2 Plots: 264 ft. x 5 ft.
  - Replication III (Red): 528 ft. x 5 ft.
    - 2 Plots: 264 ft. x 5 ft.

Equipment and Materials

Method 1: Standard Operating Procedure

- String Trimmers

Method 2:

- John Deere 6115R Tractor with US Ditcher, Inc. GRM-60 Spider Guardrail Mower

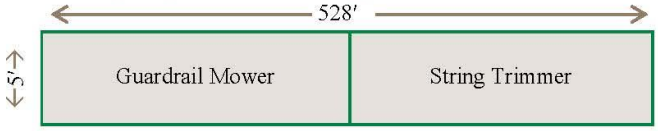
ODOT Fieldwork Time

- Mowing = 1 day per mow cycle
- String Trim = 1 day per mow cycle
- Monitoring = 1 × per month using Davey Site Monitoring Form

Evaluation Factors

- Vegetation composition
- Safety
- Labor costs and time
- Equipment costs and time
- Effectiveness
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Maintain Vegetation under Cable Rails



ODOT Evaluating Vegetation Management Practices
District 4 Fact Sheet

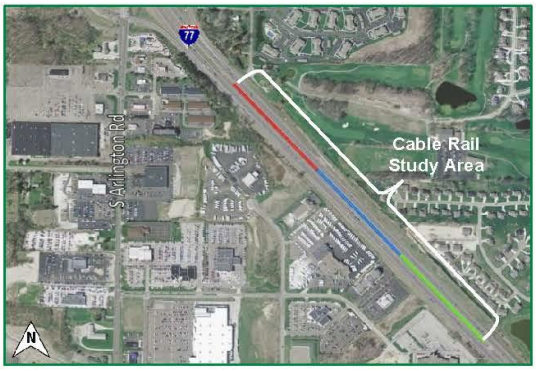
Zone One: Test 2, Maintain Vegetation under Cable Rail or Guardrail with Guardrail Mower

Goals

- Reduce manual labor for maintenance of vegetation under rails
- Determine best equipment for maintaining vegetation under cable rail
- Improve roadside safety

Study Area: I-77 North, Mile Marker 119, Summit County

- Experimental design: Randomized Complete Blocks
- Study area: 3 replications: each 3,168 ft., or 0.6 mile
  - Replication I (Green): 1,056 ft. x 5 ft.
    - 2 Plots: 528 ft. x 5 ft.
  - Replication II (Blue): 1,056 ft. x 5 ft.
    - 2 Plots: 528 ft. x 5 ft.
  - Replication III (Red): 1,056 ft. x 5 ft.
    - 2 Plots: 528 ft. x 5 ft.



Equipment and Materials

Method 1: Standard Operating Procedure:

- 2 String Trimmers

Method 2:

- John Deere 6115R Tractor with US Ditcher, Inc. GRM-60 Spider Guardrail Mower

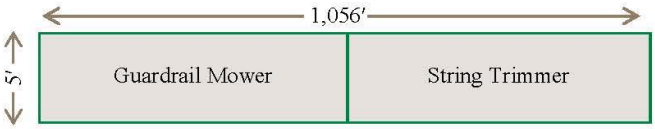
ODOT Fieldwork Time

- Mowing = 1 day per mow cycle
- String Trim = 1 day per mow cycle
- Monitoring = 1 × per month using Davey Site Monitoring Form

Evaluation Factors

- Vegetation composition
- Safety
- Labor costs and time
- Equipment costs and time
- Effectiveness
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Maintain Vegetation under Cable Rails



ODOT Evaluating Vegetation Management Practices
District 7 Fact Sheet

Zone One: Test 2, Maintain Vegetation under Cable Rail or Guardrail with Guardrail Mower

Goals

- Reduce manual labor for maintenance of vegetation under rails
- Determine best equipment for maintaining vegetation under guardrail
- Improve roadside safety

Study Area: Dayton International Airport Access Road (on ramp to 70 East), Montgomery County

- Experimental design: Randomized Complete Blocks
- Study area: 3 replications: 1,266 ft. x 5 ft., or 0.24 mile
  - Replication I (Green): 422 ft. x 5 ft.
    - 2 Plots: 211 ft. x 5 ft., or 0.04 mile
  - Replication II (Blue): 422 ft. x 5 ft.
    - 2 Plots: 211 ft. x 5 ft., or 0.04 mile
  - Replication III (Red): 422 ft. x 5 ft.
    - 2 Plots: 211 ft. x 5 ft., or 0.04 mile

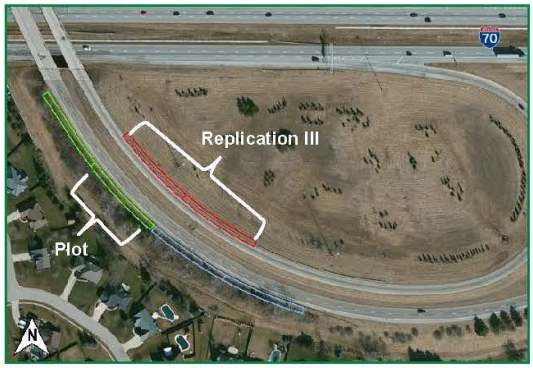
Equipment and Materials

Method 1: Standard Operating Procedure

- String Trimmer

Method 2:

- John Deere 6115R tractor with US Ditcher, Inc. GRM-60 Spider Guardrail Mower



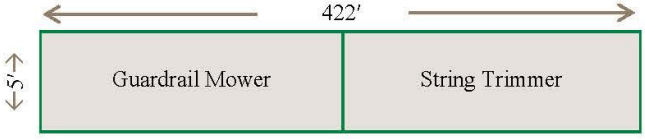
ODOT Fieldwork Time

- Mowing = 1 day per mow cycle
- String Trim = 1 day per mow cycle
- Monitoring = 1 × per month using Davey Site Monitoring Form

Evaluation Factors

- Vegetation composition
- Safety
- Labor costs and time
- Equipment costs and time
- Effectiveness
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Maintain Vegetation under Guardrail



ODOT Evaluating Vegetation Management Practices
District 8 Fact Sheet

Zone One: Test 2, Maintain Vegetation under Cable Rail or Guardrail with Guardrail Mower

Goals

- Reduce manual labor for maintenance of vegetation under rails
- Determine best equipment for maintaining vegetation under guardrail
- Improve roadside safety

Study Area: US 42 North and South Wilberforce, Greene County

- Experimental design: Randomized Complete Blocks
- 2 study areas: 3 replications: 1,830 ft. x 5 ft., or 0.21 acre
  - Replication I (Green): 610 ft. x 5 ft., or 0.07 acre
    - 2 Plots: 305 ft. x 5 ft., or 0.035 acre
  - Replication II (Blue): 610 ft. x 5 ft., or 0.07 acre
    - 2 Plots: 305 ft. x 5 ft., or 0.035 acres
  - Replication III (Red): 610 ft. x 5 ft., or 0.07 acre
    - 2 Plots: 305 ft. x 5 ft., or 0.035 acre

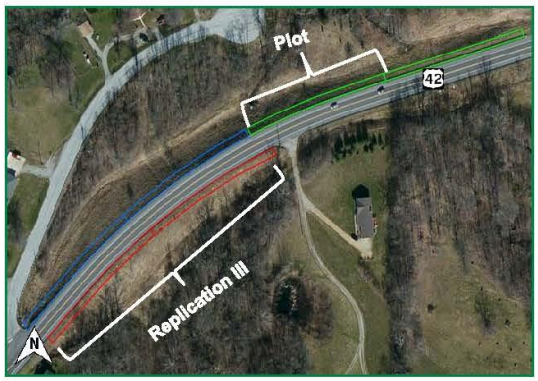
Equipment and Materials

Method 1: Standard Operating Procedure

- String Trimmer

Method 2:

- John Deere 6115R tractor with US Ditcher, Inc. GRM-60 Spider Guardrail Mower



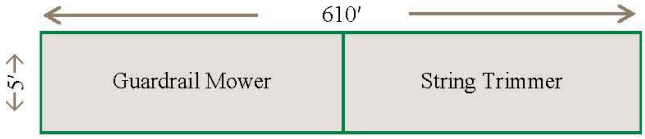
ODOT Fieldwork Time

- Mowing = 1 day per mow cycle
- String Trim = 1 day per mow cycle
- Monitoring = 1 × per month using Davey Site Monitoring Form

Evaluation Factors

- Vegetation composition
- Safety
- Labor costs and time
- Equipment costs and time
- Effectiveness
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Maintain Vegetation under Guardrail



ODOT Evaluating Vegetation Management Practices
District 4 Fact Sheet

Zone Two: Test 1, Maintain Turf in Open Areas with Spray Truck and Boomless Nozzle

Goals

- Determine the best use of plant growth regulator
- Slow growth rate of turf
- Control broadleaf weeds and woody species growing in turf
- Reduce need for roadside vegetation maintenance
- Improve roadside safety

Study Area: I-77 South, Mile Marker 117, Summit County

- Experimental design: Randomized Complete Blocks
- Study area: 3 replications: 65,340 sq. ft., or 1.5 acre
  - Replication I (Green): 990 ft. x 22 ft.
    - 5 Plots: 198 ft. x 22 ft., or 1/10th acre
  - Replication II (Blue): 990 ft. x 22 ft.
    - 5 Plots: 198 ft. x 22 ft., or 1/10th acre
  - Replication III (Red): 990 ft. x 22 ft.
    - 5 Plots: 198 ft. x 22 ft., or 1/10th acre

Equipment and Materials

Method 1: Treatment 1: Standard Operating Procedure

- New Holland tractor with batwing mower

Method 2: Treatment 1:

- F-450 dump truck with 425-gallon skid sprayer with boomless nozzles
- New Holland tractor with batwing mower
- Herbicide = Perspective® (*aminocyclopyrachlor, chlorsulfuron*)

Method 2: Treatment 2:

- F-450 dump truck with 425-gallon skid sprayer with boomless nozzles
- New Holland tractor with batwing mower
- Herbicide = Triclopyr 3 (*triclopyr*)

Method 3: Treatment 1:

- F-450 dump truck with 425-gallon skid sprayer with boomless nozzles
- New Holland tractor with batwing mower
- Herbicide = Triclopyr 3 (*triclopyr*) + Plateau® (*imazapic*)

Method 3: Treatment 2:

- F-450 dump truck with 425-gallon skid sprayer with boomless nozzles
- New Holland tractor with batwing mower
- Herbicide = Perspective® (*aminocyclopyrachlor, chlorsulfuron*) + Embark® 2S IVM (*mefluidide*)

ODOT Evaluating Vegetation Management Practices
District 4 Fact Sheet

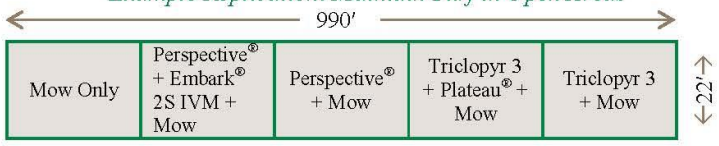
ODOT Fieldwork Time

- Herbicide application = 1 day
- Mowing = as needed
- Monitoring = 1 × per month using Davey Site Monitoring Form

Evaluation Factors

- Vegetation composition
- Vegetation growth rates
- Duration of control
- Frequency of mows
- Labor cost and time
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Maintain Turf in Open Areas



ODOT Evaluating Vegetation Management Practices
District 3 Fact Sheet

Zone Two: Test 2, Maintain Turf under Guardrail or Cable Rail with Spray Truck and Boomless Nozzle

Goals

- Determine the best use of plant growth regulator
- Slow growth rate of turf
- Control broadleaf weeds and woody species growing in turf
- Reduce frequency of roadside vegetation maintenance
- Improve roadside safety

Study Area: I-71 Median, Mile Marker 211.6, Medina County

- Experimental design: Randomized Complete Blocks
- Study area: 3 replications: 19,620 sq. ft., or 0.45 acre
  - Replication I (Green): 654 ft. x 10 ft.
    - 3 Plots: 218 ft. x 10 ft., or 1/20th acre
  - Replication II (Blue): 654 ft. x 10 ft.
    - 3 Plots: 218 ft. x 10 ft., or 1/20th acre
  - Replication III (Red): 654 ft. x 10 ft.
    - 3 Plots: 218 ft. x 10 ft., or 1/20th acre

Equipment and Materials

Method 1: Treatment 1: Standard Operating Procedure

- John Deer tractor with batwing mower 4x/year
- String trimmers 4x/year

Method 2: Treatment 1:

- F-450 dump truck with 425-gallon skid sprayer with boomless nozzles
- John Deer tractor with batwing mower as needed
- String trimmers as needed
- Herbicides:
  - Triclopyr 3 (*triclopyr*)

- Plateau® (*imazapic*) Method 2 Treatment 2:
  - F-450 dump truck with 425-gallon skid sprayer with boomless nozzles
  - John Deer tractor with batwing mower as needed
  - String trimmers as needed
  - Herbicide:
    - Perspective® (*aminocyclopyrachlor, chlorsulfuron*)
    - Embark® 2S IVM (*mefluidide*)

ODOT Fieldwork Time

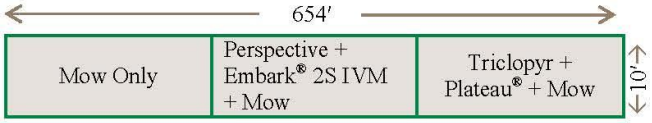
- Herbicide application = 2 days
  - Plant growth regulators applied mid-April
  - Broadleaf herbicides to be applied mid-May
- Mowing = as needed
- String Trimming = as needed
- Monitoring = 1 × per month using Davey Site Monitoring Form

ODOT Evaluating Vegetation Management Practices
District 3 Fact Sheet

Evaluation Factors

- Vegetation composition
- Vegetation growth rates
- Duration of control
- Frequency of mows
- Labor cost and time
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Maintain Turf under Cable Rail



ODOT Evaluating Vegetation Management Practices
District 4 Fact Sheet

Zone Two: Test 3, Maintain Turf at Road Edge, no Rail with Spray Truck and Boomless Nozzle

Goals

- Slow growth of turf
- Control broadleaf weeds and woody species growing in turf
- Reduce need for roadside vegetation maintenance
- Improve roadside safety

Study Area: US 30, Mile Markers 28-30, Stark County

- Experimental design: Randomized Complete Blocks
- Study area: 3 replications: 19,599 sq. ft., or 0.5 acre
  - Replication I (Green): 653.3 ft. x 10 ft.
    - 3 Plots: 217.8 ft. x 10 ft., or 1/20th acre
  - Replication II (Blue): 653.3 ft. x 10 ft.
    - 3 Plots: 217.8 ft. x 10 ft., or 1/20th acre
  - Replication III (Red): 653.3 ft. x 10 ft.
    - 3 Plots: 217.8 ft. x 10 ft., or 1/20th acre

Equipment and Materials

Method 1: Treatment 1: Standard Operating Procedure

- New Holland tractor with side-mounted flail mower
- Mowed: 2 times per season

Method 2: Treatment 1:

- F-450 dump truck with 425-gallon skid sprayer with boomless nozzles
- Herbicide = Triclopyr 3 (*triclopyr*) + Plateau® (*imazapic*)
- Treatment: 2 times per season
- New Holland tractor with side-mounted flail mower
- Mowed: 1 time per season

Method 2: Treatment 2:

- F-450 dump truck with 425-gallon skid sprayer with boomless nozzles
- Herbicide = Perspective® (*aminocyclopyrachlor, chlorsulfuron*) + Embark® 2S IVM (*mefluidide*)
- Treatment: 1 time per season
- New Holland tractor with side-mounted flail mower
- Mowed: 1 time per season

ODOT Fieldwork Time

- Herbicide application = 2 days
- Mowing = as needed
- Monitoring = 1 × per month using Davey Site Monitoring Form

Evaluation Factors

- Vegetation composition
- Vegetation growth rates
- Duration of control
- Frequency of mows
- Labor cost and time
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Maintain Turf at Road Edge, no Rail

217.8′

Mow Only	Perspective® + Embark® 2S IVM + Mow	Triclopyr 3 + Plateau® + Mow

10′

ODOT Evaluating Vegetation Management Practices
District 8 Fact Sheet

Zone Two: Test 4, Maintain Turf with Batwing WetBlade™ System

Goals:

- Slow growth rate of turf
- Control broadleaf and woody species growing in turf
- Reduce the need for roadside vegetation maintenance
- Improve sight distance and roadside safety

Study Area: US 35 West Mile Marker 49, Xenia, Greene County:

- Experimental design: Randomized Complete Block
- Study area: 3 replications: 98,010 sq. ft., or 2.25 acres
  - Replication I (Green): 726 ft. x 45 ft.
    - 3 Plots: 242 ft. x 45 ft., or 1/4th acre
  - Replication II (Blue): 363 ft. x 90 ft.
    - 3 Plots: 363 ft. x 30 ft., or 1/4th acre
  - Replication III (Red): 363 ft. x 30 ft.
    - 3 Plots: 363 ft. x 30 ft., or 1/4th acre

Equipment and Materials:

Method 1: Treatment 1: Standard Operating Procedure:

- John Deere tractor with 15-ft. batwing mower

Method 2: Treatment 1:

- John Deere tractor with Diamond WetBlade™ 15-ft. batwing mower
- Herbicide = Triclopyr 3 (*triclopyr*) + Plateau® (*imazapic*)

Method 1: Treatment 2:

- John Deere tractor with Diamond WetBlade™ 15-ft. batwing mower
- Herbicide = Milestone® (*aminopyralid*) + Plateau® (*imazapic*)

ODOT Fieldwork Time:

- Simultaneous herbicide application and mowing = 1 day
- Additional Mowing = as needed
- Monitoring = 1× per month using Davey Site Monitoring Form

Evaluation Factors:

- Percent of undesirable weed cover
- Vegetation growth rates
- Duration of control
- Frequency of mows
- Labor time and cost
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Maintain Turf with Batwing WetBlade™ System

726'

Mow Only	Milestone® + Plateau® + Mow	Triclopyr 3 + Plateau® + Mow

45'

ODOT Evaluating Vegetation Management Practices
District 4 Fact Sheet

Zone Two: Test 5, Maintain Turf on Slope or over Guardrail with Spray Truck and Boomless Nozzle

Goals

- Control broadleaf weeds and woody species growing in turf
- Improve ability to maintain turf on slopes or over guardrails
- Reduce need for roadside vegetation maintenance
- Improve roadside safety

Study Area: I-77 Median, Mile Marker 114, Summit County

- Experimental design: Randomized Complete Blocks
- Study area: 3 replications: 78,413 sq. ft., or 1.8 acres
  - Replication I (Green): 1,045.5 ft. x 25 ft.
    - 3 Plots: 348.5 ft. x 25 ft., or 1/5 acre
  - Replication II (Blue): 1,045.5 ft. x 25 ft.
    - 3 Plots: 348.5 ft. x 25 ft., or 1/5th acre
  - Replication III (Red): 1,045.5 ft. x 25 ft.
    - 3 Plots: 348.5 ft. x 25 ft., or 1/5th acre

Equipment and Materials

Method 1: Treatment 1: Standard Operating Procedure:

- Unmaintained, Mow only if there are complaints

Method 2: Treatment 1:

- F-450 dump truck with 425-gallon skid sprayer with boomless nozzles
- Herbicide = Milestone® (*aminopyralid*)

Method 2: Treatment 2:

- F-450 dump truck with 425-gallon skid sprayer with boomless nozzles
- Herbicide = Perspective® (*aminocyclopyrachlor, chlorsulfuron*)

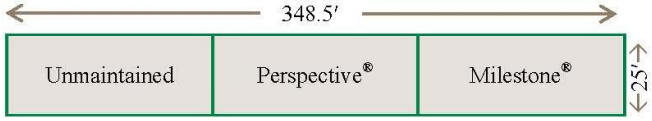
ODOT Fieldwork Time

- Herbicide application = 1 day
- Mowing = as needed
- Monitoring = 1 × per month using Davey Site Monitoring Form

Evaluation Factors

- Vegetation composition
- Vegetation growth rates
- Duration of control
- Frequency of mows
- Labor cost and time
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Maintain Turf on Slope over Wall



ODOT Evaluating Vegetation Management Practices
District 7 Fact Sheet

Zone Two: Test 6, Maintain Turf or General Vegetation Maintenance on Steep Slopes with Slope Mower

Goals

- Improve production
- Improve safety of slope mowing
- Improve ability to maintain vegetation on slopes

Study Area: Maintained Vegetation:

I-70 West on SR 235 North on Ramp, Montgomery County

- Experimental design: Randomized Complete Block
- Study area: 3 replications: totaling 18,000 sq. ft., or 0.4 acre
  - Replication I (Green): 200 ft. x 30 ft., 24.91° slope
    - 2 Plots: 100 ft. x 30 ft., or 0.07 acre
  - Replication II (Blue): 200 ft. x 30 ft., 29.03° slope
    - 2 Plots: 100 ft. x 30 ft., or 0.07 acre
  - Replication III (Red): 200 ft. x 30 ft., 19.8° slope
    - 2 Plots: 100 ft. x 30 ft., or 0.07 acre

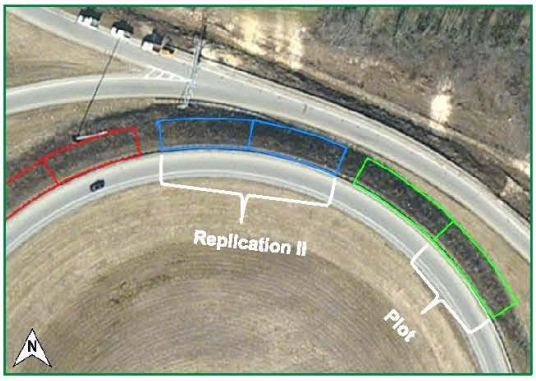
Equipment & Materials

Method 1: Treatment 1:

- Kut Kwick Super-Slope Master™ 72" chariot style rotary mower
- Truck and trailer to transport mower

Method 1: Treatment 2:

- Alamo Traxx™ RF remote-controlled 51" flail mower deck
- Truck and trailer to transport mower



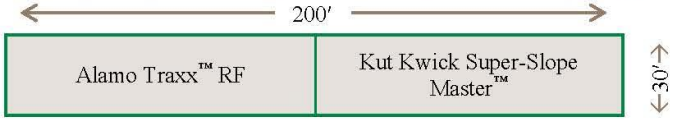
ODOT Fieldwork Time

- Mowing = 1 day for each occurrence; mowers operating simultaneously
- Monitoring = 1× per month using Davey Site Monitoring Form

Evaluation Factors

- Production efficiency
- Slope limitations
- Maneuverability
- Labor
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Vegetation Maintenance on Steep Slopes



ODOT Evaluating Vegetation Management Practices
District 7 Fact Sheet

Zone Two: Test 6, Maintain Turf or General Vegetation Maintenance on Steep Slopes with Slope Mower

Goals

- Improve production
- Improve safety of slope mowing

Study Area: Maintained Turf:
I-75 & I -70 Interchange, Mile Marker 61, I-75 South, Montgomery County

- Experimental design: Randomized Complete Block
- Study area: 3 replications: totaling 26,100 sq. ft., or ~0.6 acre
  - Replication I (Green): 290 ft. x 30 ft., 19.29° slope
    - 2 Plots: 145 ft. x 30 ft., or 1/10th acre
  - Replication II (Blue): 200 ft. x 43.5 ft., 21.8° slope
    - 2 Plots: 100 ft. x 43.5 ft., or 1/10th acre
  - Replication III (Red): 290 ft. x 30 ft., 14.04° slope
    - 2 Plots: 145 ft. x 30 ft., or 1/10th acre

Equipment & Materials

Method 1: Treatment 1:

- Kut Kwick Super-Slope Master™ 72" chariot style rotary mower
- Truck and trailer to transport mower

Method 1: Treatment 2:

- Alamo Traxx™ RF remote-controlled 51" flail mower deck
- Truck and trailer to transport mower

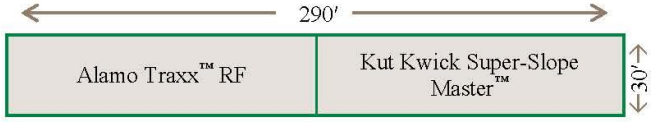
ODOT Fieldwork Time

- Mowing = 1 day for each occurrence; mowers operating simultaneously
- Monitoring = 1× per month using Davey Site Monitoring Form

Evaluation Factors

- Production efficiency
- Slope limitations
- Maneuverability
- Labor
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Maintain Turf on Steep Slope



ODOT Evaluating Vegetation Management Practices
District 10 Fact Sheet

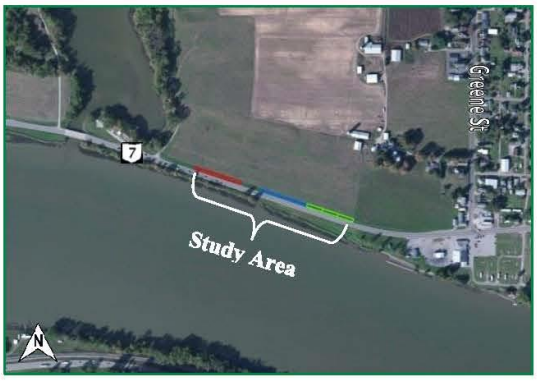
Zone Three: Test 1, Johnsongrass (Sorghum halepense) Control

Goals

- Reduce or eliminate Johnsongrass in turfgrass
- Determine best control method
- Reduce need for roadside vegetation maintenance
- Improve roadside safety

Study Area: SR7 South, Mile Marker 38, Newport, Washington County

- Experimental design: Randomized Complete Block
- Study area: 3 replications: 19,602 sq. ft., or 0.45 acre
  - Replication I (Green): 326.7 ft. x 20 ft.
    - 3 Plots: 108.9 ft. x 20 ft., or 1/20th acre
  - Replication II (Blue): 326.7 ft. x 20 ft.
    - 3 Plots: 108.9 ft. x 20 ft., or 1/20th acre
  - Replication III (Red): 326.7 ft. x 20 ft.
    - 3 Plots: 108.9 ft. x 20 ft., or 1/20th acre



Equipment and Materials

Method 1: Treatment 1: Standard Operating Procedure

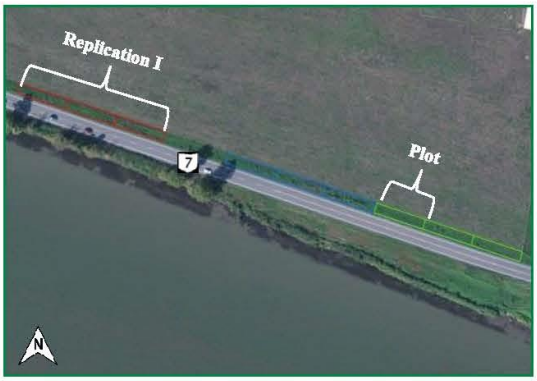
- John Deere tractor with batwing mower

Method 2: Treatment 1:

- Pickup truck with 200-gallon skid sprayer with hose, reel, and handgun
- Herbicide = Outrider® (*sulfosulfuron*)
- John Deere tractor with batwing mower

Method 2: Treatment 2:

- Pickup truck with 200-gallon skid sprayer with hose, reel, and handgun
- Herbicide = Rodeo® (*glyphosate*)
- John Deere tractor with batwing mower



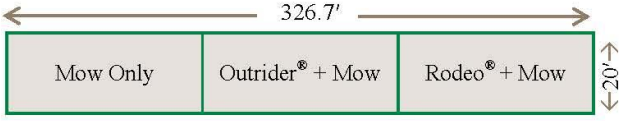
ODOT Fieldwork Time

- Herbicide application = 1 day each season
- Mowing = as needed throughout season
- Monitoring = 1 x per month using Davey Site Monitoring Form

Evaluation Factors

- Percent of noxious weed
- Vegetation growth rates
- Duration of control
- Frequency of annual mows
- Labor
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Johnsongrass Control



ODOT Evaluating Vegetation Management Practices
District 10 Fact Sheet

Zone Three: Test 2, Japanese Knotweed (Fallopia japonica var. japonica) Control

Goals

- Reduce or eliminate Japanese knotweed
- Determine best control method
- Reduce need for roadside vegetation maintenance
- Improve sight distance

Study Area: SR 7, Mile Marker 21, Clarington, Monroe County

- Experimental design: Randomized Complete Block
- Study Area: 3 replications: 39,204 sq. feet, or 0.9 acre
  - Replication I (Green): 653.4 ft. x 20 ft.
    - 3 Plots: 217.8 ft. x 20 ft., or 1/10th acre
  - Replication II (Blue): 653.4 ft. x 20 ft.
    - 3 Plots: 217.8 ft. x 20 ft., or 1/10th acre
  - Replication III (Red): 653.4 ft. x 20 ft.
    - 3 Plots: 217.8 ft. x 20 ft., or 1/10th acre

Equipment & Materials

Method 1: Treatment 1: Standard Operating Procedure:

- John Deere 6415 tractor with arm-mounted rotary mower

Method 2: Treatment 1:

- Pickup truck with 200-gallon skid sprayer with hose, reel, and handgun
- Herbicide = Milestone® (*aminopyralid*)
- John Deere 6415 tractor with arm-mounted rotary mower

Method 2: Treatment 2:

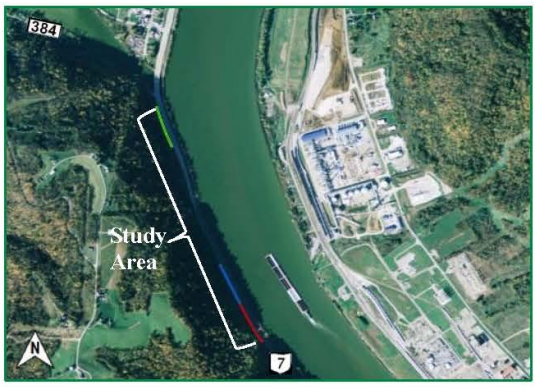
- Pickup truck with 200-gallon skid sprayer with hose, reel, and handgun
- Herbicide = Ecomazapyr 2 SL (*imazapyr*)
- John Deere 6415 tractor with arm-mounted rotary mower

ODOT Fieldwork Time

- Herbicide application = 1 day per season
- Mowing = 1 day per season, at least 30 days after treatment
- Monitoring = 1× per month using Davey Site Monitoring Form

Evaluation Factors

- Percent of noxious weed
- Vegetation growth rates
- Duration of control
- Labor
- Aesthetics
- Treatment feedback from ODOT and public



Example Replication: Japanese Knotweed Control

653.4′

Mow Only	Ecomazapyr 2 SL + Mow	Milestone® + Mow

20′

ODOT Evaluating Vegetation Management Practices
District 10 Fact Sheet

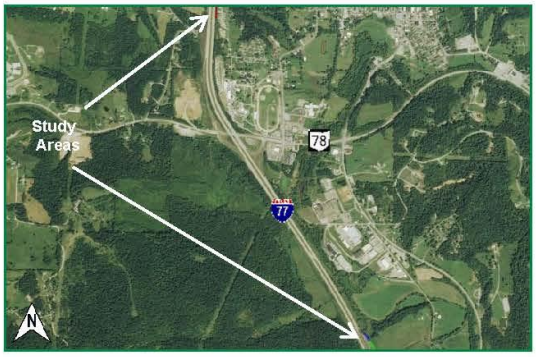
Zone Three: Test 3, Poison Hemlock (Conium maculatum) Control

Goals:

- Control poison hemlock
- Determine best control method
- Improve sight distance and reduce the need for roadside vegetation maintenance by preventing regrowth of the tall-growing herbaceous plant

Study Area: I-77 North, Mile Marker 25 & 24, Noble County

- Experimental design: Randomized Complete Block
- Study area: 3 replications: 19,602 sq. ft., or 0.45 acre
  - Replication I (Green): 261.3 ft. x 25 ft.
    - 3 Plots: 87.1 ft. x 25 ft., or 1/20th acre
  - Replication II (Blue): 217.8 ft. x 30 ft.
    - 3 Plots: 72.6 ft. x 30 ft., or 1/20th acre
  - Replication III (Red): 217.8 ft. x 30 ft.
    - 3 Plots: 72.6 ft. x 30 ft., or 1/20th acre



Equipment and Materials:

Method 1: Treatment 1: Standard Operating Procedure:

- John Deere 6105M Tractor with 15' batwing mower for end of season mowback

Method 2: Treatment 1:

- Pickup truck with 200-gallon skid sprayer with hose, reel, and handgun
- Herbicide = Perspective® (*aminocyclopyrachlor + chlorsulfuron)*
- John Deere 6105M Tractor with 15' batwing mower for end of season mowback

Method 2: Treatment 2:

- Pickup truck with 200-gallon skid sprayer with hose, reel, and handgun
- Herbicide = Milestone® (*aminopyralid)*
- John Deere 6105M Tractor with 15' batwing mower for end of season mowback

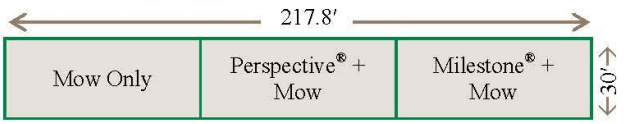
ODOT Fieldwork Time:

- Herbicide application = 1 day
- Mowing = as needed, at least 30 days after treatment
- Monitoring = 1 x per month using Davey Site Monitoring Form

Evaluation Factors:

- Percent of poison hemlock control
- Duration of control
- Labor costs and time
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Poison Hemlock Control



ODOT Evaluating Vegetation Management Practices
District 10 Fact Sheet

Zone Three: Test 4, Kudzu (Pueraria montana var. lobata) Control

Goals

- Reduce or eliminate Kudzu
- Determine best control method
- Reduce need for roadside vegetation maintenance
- Improve roadside safety

Study Area: SR7, Mile Marker 4, Middleport, Meigs County

- Experimental design: Randomized Complete Block
- Study area: 3 replications: 13,064 sq. ft., or 0.3 acre
  - Replication I (Green): 114.6 ft. x 38 ft.
    - 3 Plots: 38.2 ft. x 38 ft., or 1/30th acre
  - Replication II (Blue): 114.6 ft. x 38 ft.
    - 3 Plots: 38.2 ft. x 38 ft., or 1/30th acre
  - Replication III (Red): 114.6 ft. x 38 ft.
    - 3 Plots: 38.2 ft. x 38 ft., or 1/30th acre

Equipment and Materials

Method 1 Treatment 1:

- Tractor with batwing mower

Method 2 Treatment 1:

- Pickup truck with 200-gallon skid sprayer with hose, reel, and handgun
- Herbicide = Streamline® (*aminocyclopyrachlor + metsulfuron*)

Method 2 Treatment 2:

- Pickup truck with 200-gallon skid sprayer with hose, reel, and handgun
- Herbicide = Milestone® (*aminopyralid*)

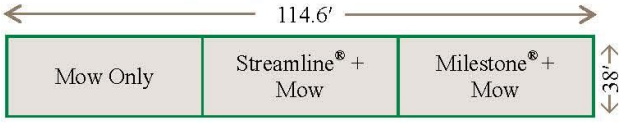
ODOT Fieldwork Time

- Herbicide application = 1 day
- Mowing = 1 day, at least 14 days after treatment
- Monitoring = 1 x per month using Davey Site Monitoring Form

Evaluation Factors

- Percent of noxious weeds
- Vegetation growth rates
- Duration of control
- Frequency of annual mows
- Labor
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Kudzu Control



ODOT Evaluating Vegetation Management Practices
District 10 Fact Sheet

*Zone Three: Test 5, Autumn Olive (*Elaeagnus umbellata*) Control with Foliar Application*

Goals

- Control autumn olive
- Determine best control method
- Reduce need for roadside vegetation maintenance
- Improve roadside safety

Study Area: I-77 South, Mile Marker 27-26, Noble County

- Experimental design: Randomized Complete Block
- Study area: 3 replications: 7,846.5 sq. ft., or 0.18 acre
  - Replication I (Green): 174.3 ft. x 15 ft.
    - 3 Plots: 58.1 ft. x 15 ft., or 1/50th acre
  - Replication II (Blue): 130.8 ft. x 20 ft.
    - 3 Plots: 43.6 ft. x 20 ft., or 1/50th acre
  - Replication III (Red): 130.8 ft. x 20 ft.
    - 3 Plots: 43.6 ft. x 20 ft., or 1/50th acre

Equipment and Materials

Method 1: Treatment 1: Standard Operating Procedure:

- John Deere 6415 tractor with rotary arm-mounted mower

Method 1: Treatment 1:

- Pickup truck with 200-gallon skid sprayer with hose, reel, and handgun
- Herbicide = Triclopyr 4 *(triclopyr BEE)* + Milestone® *(aminopyralid)*
- John Deere 6415 tractor with rotary arm-mounted mower + backpack sprayer

Method 1: Treatment 2:

- Pickup truck with 200-gallon skid sprayer with hose, reel, and handgun
- Herbicide = Triclopyr 4 *(triclopyr BEE)* + Streamline® *(aminocyclopyrachlor + metsulfuron)*
- John Deere 6415 tractor with rotary arm-mounted mower + backpack sprayer

ODOT Fieldwork Time

- Herbicide application = 1 day
- Mowing = 1 day, at least 30 days after treatment
- Monitoring = 1 x per month using Davey Site Monitoring Form

Evaluation Factors

- Vegetation regrowth rates
- Duration of control
- Labor time
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Autumn Olive Control

174.3′

Mow Only	Triclopyr 4 + Milestone® + Mow	Triclopyr 4 + Streamline® + Mow

15′

ODOT Evaluating Vegetation Management Practices
District 8 Fact Sheet

Zone Three Test 6: Brush Control <1" with Flail Mower and Herbicide Application

Goals

- Control woody plants along the roadway
- Determine best control method
- Reduce need for roadside vegetation maintenance
- Improve roadside safety

Study Area: US 35 West Mile Marker 7, Xenia, Greene County

- Experimental design: Randomized Complete Block
- Study area: 3 replications: 26,136 sq. ft., or 0.6 acre
  - Replication I (Green): 435.6 ft. x 20 ft.
    - 4 Plots: 108.9 ft. x 20 ft., or 1/20th acre
  - Replication II (Blue): 435.6 ft. x 20 ft.
    - 4 Plots: 108.9 ft. x 20 ft., or 1/20th acre
  - Replication III (Red): 435.6 ft. x 20 ft.
    - 4 Plots: 108.9 ft. x 20 ft., or 1/20th acre

Equipment and Materials

Method 1: Treatment 1: Standard Operating Procedure:

- Case 621F wheel loader with side-mounted flail mower

Method 2: Treatment 1:

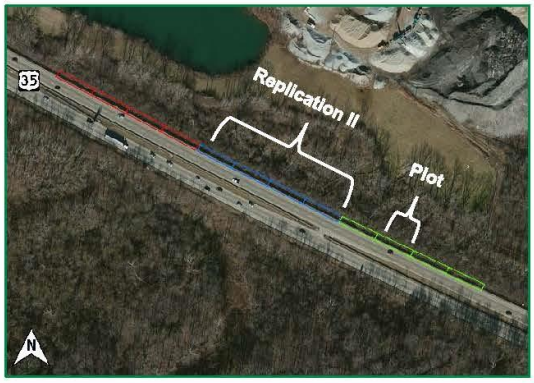
- Case 621F wheel loader with side-mounted flail mower
- Pickup truck with 425-gallon skid sprayer, hand gun, hose, and reel
- Herbicide = Tordon® K (*picloram*)

Method 3: Treatment 1:

- Case 621F wheel loader with side-mounted flail mower
- Pickup truck with 425-gallon skid sprayer, hand gun, hose, and reel
- Herbicide = Rodeo® (*glyphosate*)

Method 3: Treatment 2:

- Case 621F wheel loader with side-mounted flail mower
- Pickup truck with 425-gallon skid sprayer, hand gun, hose, and reel
- Herbicide = Streamline® (*aminocyclopyrachlor*)



ODOT Fieldwork Time

- Herbicide application = 1 day for spray after removal, 1 day for spray before removal
- Mowing = 1 day
- Monitoring = 1 x per month using Davey Site Monitoring Form

Evaluation Factors

- Percent of woody vegetation control
- Duration of control
- Labor
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Brush Control <1" with Flail Mower and Herbicide Application

435.6'

Mow Only	Mow + Tordon® K	Rodeo®	Streamline®

20'

ODOT Evaluating Vegetation Management Practices
District 8 Fact Sheet Study Year

Zone Three: Test 7, Brush Control with Rotary WetBlade™ System

Goals:

- Lengthen maintenance cycles for woody plants
- Promote grasses by controlling broadleaf and woody plants
- Improve sight distance and roadside safety
- Reduce labor by simultaneously applying herbicide while mowing

Study Area: US 35 West Mile Marker 7 Xenia, Greene County

- Experimental design: Randomized Complete Block
- Study area: 3 replications: 19,602 sq. ft., or 0.45 acre
  - Replication I (Green): 326.7 ft. x 20 ft.
    - 3 Plots: 108.9 ft. x 20 ft., or 1/20th acre
  - Replication II (Blue): 326.7 ft. x 20 ft.
    - 3 Plots: 108.9 ft. x 20 ft., or 1/20th acre
  - Replication III (Red): 326.7 ft. x 20 ft.
    - 3 Plots: 108.9 ft. x 20 ft., or 1/20th acre

Equipment and Materials:

Method 1: Treatment 1: Standard Operating Procedure

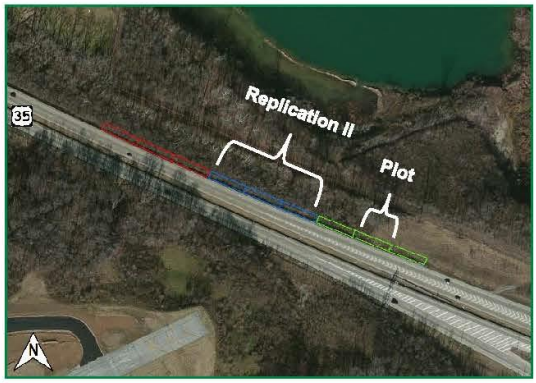
- Case 621F wheel loader
- Diamond 60" rotary mower

Method 2: Treatment 1:

- Case 621F wheel loader
- Diamond WetBlade™ 60" rotary mower
- Herbicide = Milestone® (*aminopyralid*)

Method 2: Treatment 2:

- Case 621F wheel loader
- Diamond WetBlade™ 60" rotary mower
- Herbicide 2 = Triclopyr 3 (*triclopyr*)



ODOT Fieldwork Time:

- Simultaneous herbicide application and mowing = 1 day
- Monitoring = 1× per month using Davey Site Monitoring Form

Evaluation Factors:

- Percent of woody vegetation control
- Duration of control
- Frequency of mows
- Labor costs and time
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Brush Control with Rotary WetBlade™ System

326.7′

Mow Only	Milestone® + Mow	Triclopyr 3 + Mow

20′

ODOT Evaluating Vegetation Management Practices
District 8 Fact Sheet Study Year

Zone Three: Test 7, Brush Control with Rotary WetBlade™ System

Goals:

- Lengthen maintenance cycles for woody plants
- Promote grasses by controlling broadleaf and woody plants
- Improve sight distance and roadside safety
- Reduce labor by simultaneously applying herbicide while mowing

Study Area: US 35 West Mile Marker 7 Xenia, Greene County

- Experimental design: Randomized Complete Block
- Study area: 3 replications: 19,602 sq. ft., or 0.45 acre
  - Replication I (Green): 326.7 ft. x 20 ft.
    - 3 Plots: 108.9 ft. x 20 ft., or 1/20th acre
  - Replication II (Blue): 326.7 ft. x 20 ft.
    - 3 Plots: 108.9 ft. x 20 ft., or 1/20th acre
  - Replication III (Red): 326.7 ft. x 20 ft.
    - 3 Plots: 108.9 ft. x 20 ft., or 1/20th acre

Equipment and Materials:

Method 1: Treatment 1: Standard Operating Procedure

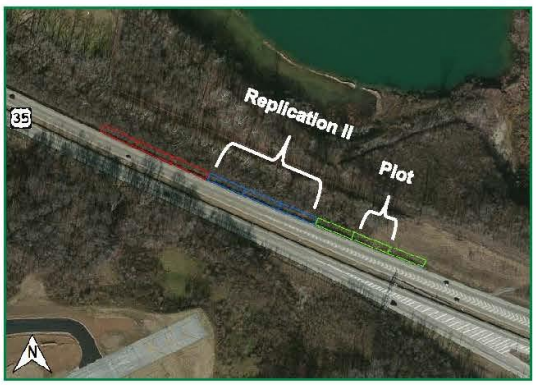
- Case 621F wheel loader
- Diamond 60" rotary mower

Method 2: Treatment 1:

- Case 621F wheel loader
- Diamond WetBlade™ 60" rotary mower
- Herbicide = Milestone® (*aminopyralid*)

Method 2: Treatment 2:

- Case 621F wheel loader
- Diamond WetBlade™ 60" rotary mower
- Herbicide 2 = Triclopyr 3 (*triclopyr*)



ODOT Fieldwork Time:

- Simultaneous herbicide application and mowing = 1 day
- Monitoring = 1× per month using Davey Site Monitoring Form

Evaluation Factors:

- Percent of woody vegetation control
- Duration of control
- Frequency of mows
- Labor costs and time
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Brush Control with Rotary WetBlade™ System

326.7'

Mow Only	Milestone® + Mow	Triclopyr 3 + Mow

20'

ODOT Evaluating Vegetation Management Practices
District 10 Fact Sheet

Zone Three: Test 9, Selective Brush Control with Foliar Application

Goals

- Reduce or eliminate woody vegetation
- Determine best control method
- Reduce need for roadside vegetation maintenance
- Improve roadside safety

Study Area: SR 7 South, Mile Marker 20, Marietta, Washington County

- Experimental design: Randomized Complete Block
- Study area: 3 replications: 52,272 sq. ft., or 1.2 acres
  - Replication I (Green): 435.6 ft. x 40 ft.
    - 4 Plots: 108.9 ft. x 40 ft., or 1/10th acre
  - Replication II (Blue): 435.6 ft. x 40 ft.
    - 4 Plots: 108.9 ft. x 40 ft., or 1/10th acre
  - Replication III (Red): 435.6 ft. x 40 ft.
    - 4 Plots: 108.9 ft. x 40 ft., or 1/10th acre

Equipment and Materials

Method 1: Treatment 1: Standard Operating Procedure:

- Manual crew with chainsaws

Method 2: Treatment 1:

- Herbicide = Triclopyr 3 (*triclopyr*)

Method 2: Treatment 2:

- Pickup truck with 200-gallon skid sprayer with hose, reel, and handgun
- Herbicide = Ecomazapyr 2 SL (*imazapyr)*

Method 2: Treatment 3:

- Herbicide = Rodeo® (*glyphosate*)

ODOT Fieldwork Time

- Herbicide application = 1 day
- Removal = 2 days, at least 30 days after treatment
- Monitoring = 1× per month using Davey Site Monitoring Form

Evaluation Factors

- Percent of woody vegetation
- Vegetation growth rates
- Duration of control
- Labor
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Selective Brush Control with Foliar Application

435.6′

Removal only	Ecomazapyr 2 SL	Triclopyr 3	Rodeo®

40′

ODOT Evaluating Vegetation Management Practices
District 10 Fact Sheet

Zone Three: Test 10, Selective Brush Control with Basal Bark Application

Goals:

- Reduce or eliminate woody vegetation
- Determine best control method
- Reduce the need for roadside vegetation maintenance by preventing regrowth of trees
- Improve sight distance and roadside safety

Study Area: SR7 South, Mile Marker 20, Marietta, Washington County:

- Experimental design: Randomized Complete Block
- Study area: 3 replications: 19,605 sq. ft., or 0.45 acre
  - Replication I (Green): 261.4 ft. x 25 ft.
    - 3 Plots: 87.1 ft. x 25 ft., or 1/20th acre
  - Replication II (Blue): 261.4 ft. x 25 ft.
    - 3 Plots: 87.1 ft. x 25 ft., or 1/20th acre
  - Replication III (Red): 261.4 ft. x 25 ft.
    - 3 Plots: 87.1 ft. x 25 ft., or 1/20th acre

Equipment and Materials:

Method 1: Treatment 1: Standard Operating Procedure:

- Untreated

Method 2 Treatment 1:

- 4-gallon backpack sprayers
- Herbicide = Tordon K® (*picloram*) + Milestone® (*aminopyralid*)

Method 2: Treatment 2:

- 4-gallon backpack sprayers
- Herbicide = Triclopyr 4 (*triclopyr*)

ODOT Fieldwork Time:

- Herbicide application = 1 day
- Removal = 2 days, at least 30 days after treatment
- Monitoring = 1 x per month using Davey Site Monitoring Form

Evaluation Factors:

- Percent of woody vegetation control
- Labor costs and time
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Selective Brush Control with Basal Bark Application

261.4'

Untreated	Milesetone ® +Tordon K®	Triclopyr 4

25'

ODOT Evaluating Vegetation Management Practices
District 10 Fact Sheet

Zone Three: Test 11, Tree-of-Heaven (Ailanthus altissima) Control with Basal Bark Application

Goals:

- Control tree-of-heaven
- Determine best control method
- Reduce the need for roadside vegetation maintenance by preventing regrowth of fast-growing tree species
- Improve sight distance and roadside safety by removing weak wooded trees

Study Area: I-77 North, Mile Marker 25 & I-77 South, Mile Marker 24, Noble County:

- Experimental design: Randomized Complete Block
- Study area: 3 replications: 19,602 sq. ft., or 0.45 acre
  - Replication I (Green): 217.8 ft. x 30 ft.
    - 3 Plots: 72.6 ft. x 30 ft., or 1/20th acre
  - Replication II (Blue): 163.4 ft. x 40 ft.
    - 3 Plots: 54.4 ft. x 40 ft., or 1/20th acre
  - Replication III (Red): 163.4 ft. x 40 ft.
    - 3 Plots: 54.4 ft. x 40 ft., or 1/20th acre

Equipment and Materials:

Method 1: Treatment 1: Standard Operating Procedure:

- Manual crew with chainsaws

Method 2: Treatment 1:

- 4-gallon backpack sprayers
- Herbicide = Tordon K® (*picloram*) + Triclopyr 4 (*triclopyr*)

Method 2: Treatment 2:

- 4-gallon backpack sprayers
- Herbicide = Triclopyr 4 (*triclopyr*)

ODOT Fieldwork Time:

- Herbicide application = 1 day
- Removal = 2 days, at least 30 days after treatment
- Monitoring = 1 x per month using Davey Site Monitoring Form

Evaluation Factors:

- Percent of tree-of-heaven control
- Tree-of-heaven regrowth rates
- Duration of control
- Labor costs and time
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Tree-of-Heaven Control with Basal Bark Application

217.8′

Removal Only	Tordon K® + Triclopyr 4	Triclopyr 4

30′

ODOT Evaluating Vegetation Management Practices
District 11 Fact Sheet

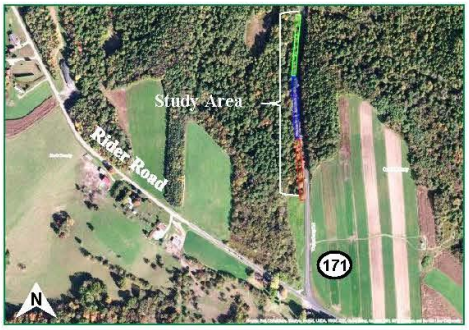
Zone Four: Test 1, Tree Maintenance, Chemical Control of Lateral Limbs (Chemical Side Trim)

Goals

- Reduce lateral tree limb growth
- Determine best control method
- Reduce need for roadside vegetation maintenance
- Improve roadside safety

Study Area: SR 171, Mile Marker 1, Waynesburg, Carroll County

- Experimental design: Randomized Complete Block
- Study Area: 3 replications: 39,204 sq. ft., or 0.9 acre
  - Replication I (Green): 435.6 ft. x 30 ft.
    - 3 Plots: 145.2 ft. x 30 ft., or 1/10th acre
  - Replication II (Blue): 435.6 ft. x 30 ft.
    - 3 Plots: 145.2 ft. x 30 ft., or 1/10th acre
  - Replication III (Red): 435.6 ft. x 30 ft.
    - 3 Plots: 145.2 ft. x 30 ft., or 1/10th acre

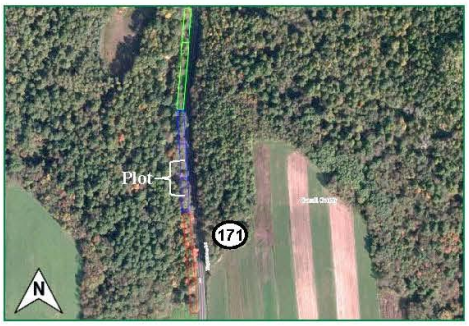


Equipment & Materials

Method 1: Treatment 1:
- Unmaintained (control)

Method 2: Treatment 1:
- Pickup truck with 200-gallon skid sprayer with hose, reel, and handgun
  Herbicide 1 = Krenite S® (*fosamine*)

Method 2: Treatment 2:
- Pickup truck with 200-gallon skid sprayer with hose, reel, and handgun
- Herbicide 2 = Triclopyr 3 (*triclopyr*)



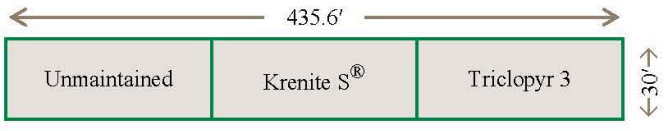
ODOT Fieldwork Time

- Herbicide Application = 1 day
- Monitoring = 1 × per month using Davey Site Monitoring Form

Evaluation Factors

- Lateral limb length
- Vegetation growth rates
- Duration of control
- Labor
- Aesthetics
- Treatment feedback from ODOT and public

Example Replication: Tree Maintenance, Chemical Side Trim



ODOT Evaluating Vegetation Management Practices
District 11 Fact Sheet

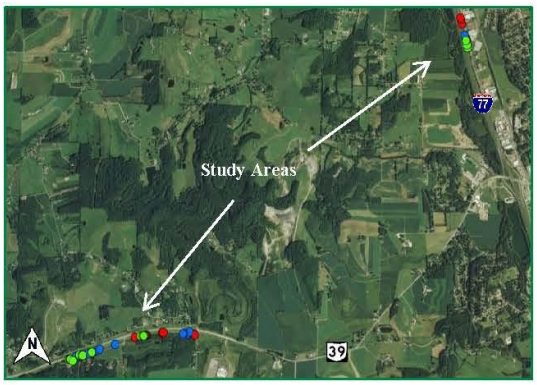
Zone Four: Test 1, Tree Maintenance, Chemical Control of Lateral Limbs (Chemical Side Trim)

Goals

- Determine response of targeted species to application
- Reduce lateral tree limb growth
- Determine best control method
- Reduce need for roadside vegetation maintenance
- Improve roadside safety

Study Areas: SR 39 East, Mile Marker 6 and I-77 North Mile Marker 84, Dover, Tuscarawas County

- Experimental design: Completely Random
- Study Area: 3 replications of seven species
- Targeted species = red maple, American elm, white oak, white ash, black locust, black cherry



Equipment & Materials

Method 1: Treatment 1: Standard Operating Procedure

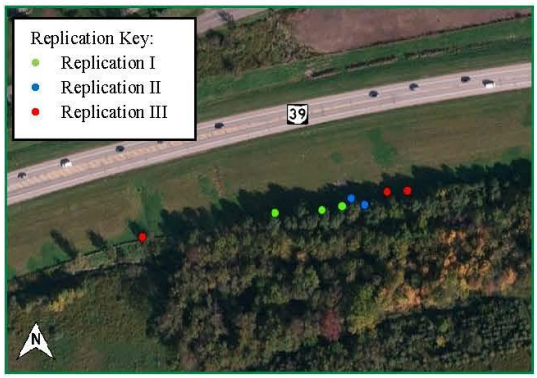
- No herbicide or trimming

Method 2: Treatment 1:

- D.B. Smith 4-gallon Max Backpack Sprayer
- Herbicide = Krenite S® (*fosamine*)

Method 2: Treatment 2:

- D.B. Smith 4-gallon Max Backpack Sprayer
- Herbicide 2 = Triclopyr 3 (*triclopyr*)



ODOT Fieldwork Time

- Herbicide Application = 1 day
- Monitoring = 1 × per month using Davey Site Monitoring Form

Evaluation Factors

- Limb response to treatment
- Tree response to treatment
- Percentage of control
- Lateral growth
- Aesthetics
- Treatment feedback from ODOT and public

ODOT Evaluating Vegetation Management Practices
District 11 Fact Sheet

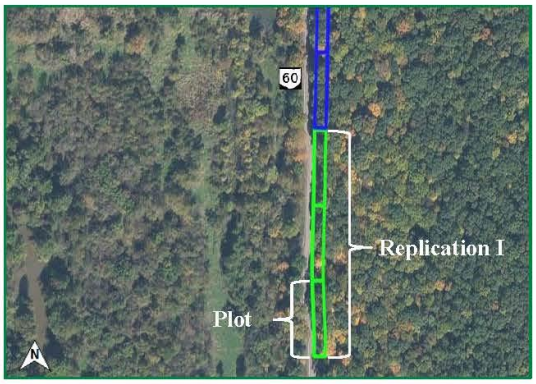
Zone Four: Test 2, Tree Maintenance, Equipment On-Road

Goals

- Proper pruning cuts will:
  - Reduce public complaints
  - Leave a healthier crown by reducing the potential for disease and decay to enter tree
  - Reduce adventitious sprouts enabling a longer maintenance cycle to be achieved
- Determine if the additional cost is worth the potential benefits

Study Area: SR 60, Mile Marker 2, Killbuck, Holmes County

- Experimental design: Randomized Complete Block
- Study Area: 3 replications: 0.3 mile
  - Replication I (Green): 528 ft.
    - 3 Plots: 176 ft., or 1/20th mile
  - Replication II (Blue): 528 ft.
    - 3 Plots: 176 ft., or 1/20th mile
  - Replication III (Red): 528 ft.
    - 3 Plots: 176 ft., or 1/20th mile
    - Break in plot 301 due to utility pole being avoided for time tracking purposes as it may slow pruning down



Equipment

Method 1:

- 60' boom Altec forestry bucket truck
- Chainsaws
- Vermeer® BC1500 brush chipper
- Kobelco 80 CS Acera Midi excavator
- Case SR 250 skid steer with loader attachment
- Dump truck

Method 2:

- Kershaw SkyTrim 75 ft. boom G2
- Vermeer® BC1500 brush chipper
- Kobelco 80 CS Acera Midi excavator
- Case SR 250 skid steer with loader attachment
- Dump truck

Method 3:

- Kershaw SkyTrim 75 ft. boom G2
- 60' boom Altec forestry bucket truck
- Vermeer® BC1500 brush chipper
- Kobelco 80 CS Acera Midi excavator
- Case SR 250 skid steer with loader attachment
- Chainsaws
- Dump truck

ODOT Fieldwork Time

- Tree pruning operations = 3 days
- Monitoring = 1× per month using Davey Site Monitoring Form

Evaluation Factors

- Percent of limbs with proper pruning cuts
- Vegetation growth rates from cuts
- Duration of control
- Labor and equipment cost
- Tree health
- Treatment feedback from ODOT and public

ODOT Evaluating Vegetation Management Practices
District 11 Fact Sheet

Example Replication: Tree Maintenance, Equipment On-Road

528′

SkyTrim +Altec Bucket Truck + Kobelco Excavator + Case Skid Steer + Chainsaws + Vermeer Brush Chipper	SkyTrim + Kobelco Excavator + Case Skid Steer + Chainsaws + Vermeer Brush Chipper	Altec Bucket Truck + Vermeer Brush Chipper + Kobelco Excavator + Chainsaws

ODOT Evaluating Vegetation Management Practices
District 11 Fact Sheet

Zone Four: Test 3, Tree Maintenance, Equipment Off-Road

Goals

- Improve tree maintenance production efficiency
- Reduce labor for tree maintenance
- Reduce safety risk for employees pruning trees

Study Area: US 250 East and West, Mile Marker 16, New Philadelphia, Tuscarawas County

- Experimental design: Randomized Complete Blocks
- Study area: 3 replications:
  - Replication I (Green): 528 ft., or 0.1 mile
    - 2 Plots: 264 ft.
  - Replication II (Blue): 528 ft., or 0.1 mile
    - 2 Plots: 264 ft.
  - Replication III (Red): 528 ft., or 0.1 mile
    - 2 Plots: 264 ft.

Equipment and Materials

Method 1: Standard Operating Procedure

- Kershaw SkyTrim 75 G2
- CAT® 308 E2CR SB excavator with thumb
- Case® 1845C skid steer to propel chipper
- Stihl® chainsaws
- Vermeer® BC1500 brush chipper

Method 2:

- Kershaw SkyTrim 75 G2
- Bandit 1850 disc-style track whole tree chipper with cab and loader

Projected ODOT Fieldwork Time

- Trimming and debris cleanup = 2 days
- Monitoring = 1 × per month using Davey Site Monitoring Form

Evaluation Factors

- Vegetation composition
- Labor costs and time
- Equipment cost and time
- Advantages, disadvantages, and limitations of equipment
- Safety
- Treatment feedback from ODOT and public

Example Replication: Tree Maintenance, Equipment Off-Road

528′

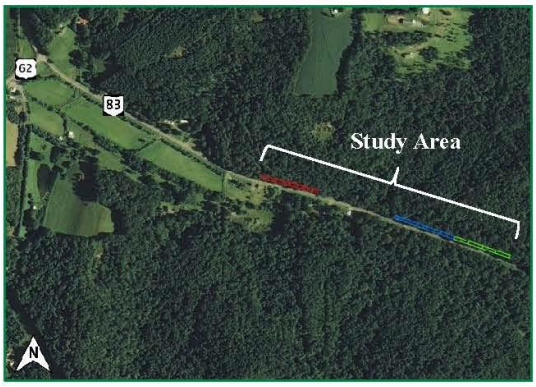
SkyTrim + Bandit Chipper	SkyTrim + Excavator + Skid Steer + Chainsaws + Vermeer® Chipper

ODOT Evaluating Vegetation Management Practices
District 11 Fact Sheet

Zone Four: Test 4, Tree Removal, Equipment On-Road

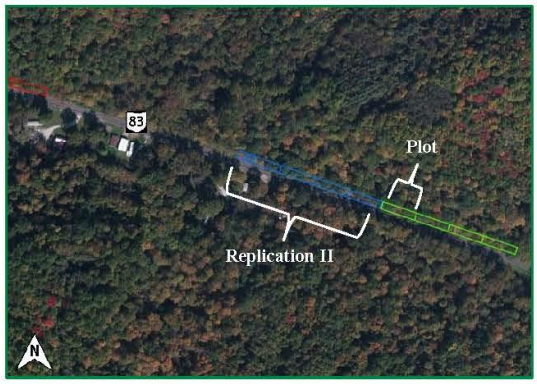
Goals

- Improve tree removal production efficiency
- Reduce labor for tree removal
- Reduce safety risk for employees removing trees
- Improve roadside safety by decreasing likelihood of tree failure
- Decrease canopy coverage over road



Study Area: SR 83, Mile Marker 5, Millersburg, Holmes County

- Experimental design: Randomized Complete Block
- Study Area: 3 replications: 4,350 sq. ft., or 1.2 acres
  - Replication I (Green): 580 ft. x 30 ft., or 0.4 acre
    - 4 Plots: 145 ft. x 30 ft., or 0.1 acre
  - Replication II (Blue): 580 ft. x 30 ft., or 0.4 acre
    - 4 Plots: 145 ft. x 30 ft., or 0.1 acre
  - Replication III (Red): 580 ft. x 30 ft., or 0.4 acre
    - 4 Plots: 145 ft. x 30 ft., or 0.1 acre



Equipment and Materials

Method 1:

- Lighting bucket truck with 40-ft. boom
- Backhoe with thumb attachment
- Skid Steer with grapple attachment
- Chainsaws
- Vermeer® BC1500 brush chipper
- No herbicide

Method 2:

- Kershaw SkyTrim 75-ft. boom G2
- Backhoe with thumb attachment
- Skid Steer with grapple attachment
- Chainsaws
- Vermeer® BC1500 brush chipper
- No herbicide

ODOT Evaluating Vegetation Management Practices
District 11 Fact Sheet

Method 3:

- Kershaw SkyTrim 75-ft. boom G2
- Backhoe with thumb attachment
- Chainsaws
- Bandit 1850 disc-style track whole tree chipper with cab and loader
- D.B. Smith 4-gallon Max Backpack Sprayer
- Triclopyr 4 (Triclopyr)

Method 4:

- Altec® forestry bucket truck with 60-ft. boom
- Backhoe with thumb attachment
- Skid steer with grapple attachment
- Chainsaws
- Vermeer® BC1500 brush chipper
- D.B. Smith 4-gallon Max Backpack Sprayer
- Triclopyr 4 (Triclopyr)

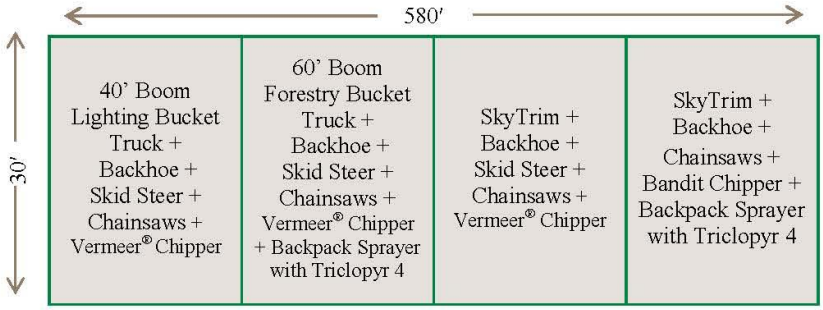
ODOT Fieldwork Time

- Tree removal, debris cleanup, and cut-stump treatment = 2 weeks
- Monitoring = 1× per month using Davey Site Monitoring Form

Evaluation Factors

- Vegetation composition
- Vegetation regrowth from stump sprouts
- Safety
- Advantages, disadvantages, and limitations of equipment
- Frequency of maintenance
- Labor costs and time
- Equipment cost and time
- Treatment feedback from ODOT and public

Example Replication: Tree Removal Equipment On-Road



ODOT Evaluating Vegetation Management Practices
District 11 Fact Sheet

Zone Four: Test 5, Tree Removal, Equipment Off-Road

Goals

- Improve tree removal production efficiency
- Reduce labor for tree removal
- Reduce safety risk for employees removing trees
- Improve roadside safety by decreasing likelihood of tree failure

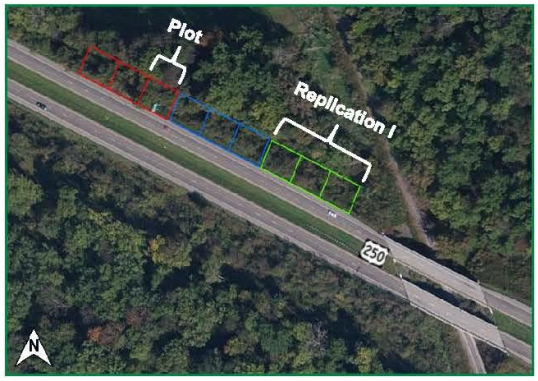
Study Area: US 250 West, Mile Marker 16, New Philadelphia, Tuscarawas County

- Experimental design: Randomized Complete Blocks
- Study area: 3 replications: Each 39,204 sq. ft., or 0.9 acre
  - Replication I (Green): 217.8 ft. x 60 ft.
    - 3 Plots: 72.6 ft. x 60 ft., or 0.1 acre
  - Replication II (Blue): 217.8 ft. x 60ft.
    - 3 Plots: 72.6 ft. x 60 ft., or 0.1 acre
  - Replication III (Red): 217.8 ft. x 60 ft.
    - 3 Plots: 72.6 ft. x 60 ft., or 0.1 acre

Equipment and Materials

Method 1:

- CAT® 308 E2CR SB excavator with thumb
- Case® 1845C skid steer to propel chipper
- Stihl® chainsaws
- Vermeer® BC 1500 brush chipper
- D.B. Smith 4-gallon Max Backpack Sprayer
- Triclopyr 4 (*triclopyr)*



Method 2:

- Kershaw SkyTrim 75 G2
- CAT® 308 E2CR SB excavator with thumb
- Case® 1845C skid steer to propel chipper
- Stihl® chainsaws
- Vermeer® BC1500 brush chipper
- D.B. Smith 4-gallon Max Backpack Sprayer
- Triclopyr 4 (*triclopyr)*

Method 3:

- Kershaw SkyTrim 75 G2
- CAT® 308 E2CR SB excavator with thumb
- Stihl® chainsaws
- Bandit 1850 disc-style track whole tree chipper with cab and loader
- D.B. Smith 4-gallon Max Backpack Sprayer
- Triclopyr 4 (*triclopyr)*

ODOT Evaluating Vegetation Management Practices
District 11 Fact Sheet

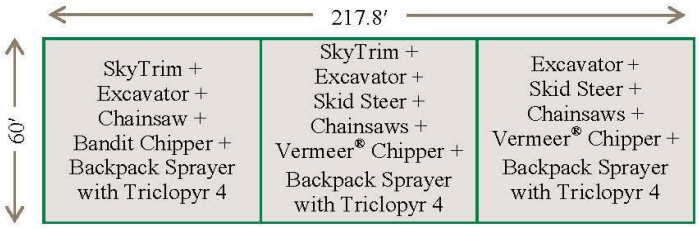
Projected ODOT Fieldwork Time

- Removal, debris cleanup, and cut-stump treatment = 4 days
- Monitoring = 1 × per month using Davey Site Monitoring Form

Evaluation Factors

- Vegetation composition
- Labor costs and time
- Equipment cost and time
- Advantages, disadvantages, and limitations of equipment
- Safety
- Treatment feedback from ODOT and public

Example Replication: Tree Removal Equipment Off-Road



ODOT Evaluating Vegetation Management Practices
District 5 Fact Sheet

Zone Four: Test 6, Tree Removal with Tree Mulcher

Goals

- Improve tree removal production efficiency
- Reduce labor for tree removal
- Reduce safety risk for employees removing trees

Study Area: I-70 East and West Mile Marker 166-167 Norwich, Muskingum County

- Experimental design: Randomized Complete Block
- Study area: 3 replications: 52,272 sq. ft., or 1.2 acres
  - Replication I (Green): 387.2 ft. x 45 ft.
    - 2 Plots: 193.6 ft. x 45 ft., or 1/5th acre
  - Replication II (Blue): 387.2 ft. x 45 ft.
    - 2 Plots: 193.6 ft. x 45 ft., or 1/5th acre
  - Replication III (Red): 387.2 ft. x 45 ft.
    - 2 Plots: 193.6 ft. x 45 ft., or 1/5th acre

Equipment and Materials

Method 1:

- CAT® 320EL hydraulic excavator with Brown Brontosaurus EVO-Fixed Tooth 3.0 EM
- Skid steer with forestry mulcher head
- Sweeper
- Blower
- Chainsaw
- Dump truck
- Skid sprayer with 20' boom to reach front half of plots
- Herbicide = Triclopyr 3 (*triclopyr*) + Platoon®+ Overdrive® (*diflufenzopyr, dicamba*)

Method 2: Standard Operating Procedure

- Chainsaws
- 70' Terex® bucket truck
- Vermeer® BC1500 brush chipper
- Skid Steer
- Sweeper
- Blower
- Dump truck
- Backpack sprayer
- Herbicide = Pathway® RTU (*picloram, 2,4-D*)

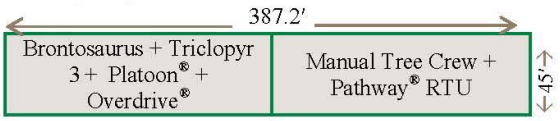
ODOT Fieldwork Time

- Tree removal, debris cleanup, and cut-stump treatment with backpack sprayer application = 8 days
- Foliar broadcast herbicide application = 1 day, next growing season
- Monitoring = 1 x month using Davey Site Monitoring Form

Evaluation Factors

- Vegetation composition
- Vegetation growth rates
- Labor costs and time
- Equipment cost
- Effectiveness of herbicide methods and products
- Safety
- Feedback from ODOT and public

Example Replication: Tree Removal with Tree Mulcher



Appendix C
Equipment and Material Costs

Equipment Purchased

Company Name	Equipment Name	Purchase Price
Altec® Industries, Inc.	LRV60 Articulating Over-center Type Tree Trimming Aerial Device	$147,273
A.M. Leonard	D.B. Smith Field King Max Backback Sprayer 4-gallon	$83
Bandit Industries, Inc.	Model 1850 Track Whole Tree Chipper with Cab and Loader	$284,567
Chemical Containers Inc.	425-Gallon Skid Sprayer with Boominator Nozzles and Raven	$8,073
Diamond Mowers™	15’ Flexwing WetBlade™ PTO	$40,287
Diamond Mowers™	50” Rotary Boom Mower WetBlade™ System	$19,708
Gregson-Clark Spraying	200-Gallon V-200 ST Skid Sprayer	$4,425
John Deere	6115R Tractor	$94,888
US Ditcher, Inc.	GRM60-Spider Guardrail Mower	$48,650

Additional Equipment Tested

Company Name	Equipment Name	Purchase Price
Alamo	Traxx™ RF Remote-Contolled 51" Flail Mower Deck	$86,914
Caterpillar	320 EL	$183,916
John C. Brown & Sons, Inc.	Brontosaurus EVO-Fixed Tooth 3.0 EM	$23,500
Kut Kwick	Super - Slope Master™ 72" Chariot Style Rotary Mower	$36,755
Vermeer®	BC1500 Brush Chipper	$42,383

Altec Industries, Inc.

May 20, 2014

Quote for:

Ohio DOT

Attn: Scott Bates

OH STS Contract #7751501908

LRV60 Articulating Over-center type Tree
Trimming Aerial Device

Item	Quantity	Description

1. 1 #217 Altec Model LRV60 Articulating Overcenter Aerial Device with an insulated lower boom, insulated upper boom and an insulated ISO-GripTM (Patent Applied For) system at the boom tip, for installation behind the cab, built in accordance to Altec's standard specifications and to include the following features:

   A. Ground to Bottom of Platform Height: 60.3 feet

   B. Working Height: 65.3 feet

   C. Maximum Reach to Edge of Platform with Upper Boom Overcenter: 48.4 feet

   D. Maximum Reach to Edge of Platform with Upper Boom Not Overcenter and Lower Boom at 125 degrees: 44.8 feet

   E. Side by Side Boom Configuration: Travel height approximately 12.4 feet

   F. Lower Boom Articulation: 0 to 125° (35° beyond vertical) accomplished by single hydraulic cylinder with a spherical bearing at the lower boom

Item	Quantity	Description

connection. Equipped with integral holding valves which lock boom in place in the event of a hydraulic line failure and a cushion valve for controlled movement into position at maximum lower boom articulation.

G. Upper Boom Alticulation: 270° in relation to lower boom, accomplished by dual cylinders **with maintenance free Patented walking link drive system.** Cylinders are equipped with integrnl holding valves to lock boom in place in the event of hydraulic line failure or loss of power.

H. Pedestal-Subbase: Fabricated from a 16 inch outside diameter x ½ inch (406 x 13 mm) wall steel tube welded into a fabricated steel subbase. Rotation bearing support ring is 1-5/8 inches (41 mm) thick.

I. Lower Boom: Fabricated of 12 x 12 x ¼ inch (305 x 305 x 6 mm) wall steel tubing. Length of lower boom is 254 inches (6452 mm) from centerline of lower pivot to centerline of outer pivot.

J. Lower Boom Fiberglass Insulator: Filament wound fiberglass insulator with 11-3/8 inch square X 5/8 inch (289 x 16 mm) wall thickness, located in lower end of lower boom. Provides 15 inch (381 mm) clear isolation gap.

K. Upper Boom: Filament wound fiberglass with IO inch (254 mm) inside diameter contains insulated conduit for routing of hydraulic lines and fully contains upper boom leveling system. End of boom shaft has ring for attachment of fall protection system lanyard.

L. Rotation: Continuous rotation provided by hydraulic motor driving through a worm gear speed reducer and gear beating. Capable of rotating full rated platform capacity up a 5° slope (9% grade). Gear box is rated at 22,378 inch pounds. ¾ inch attachment bolts are used

M. Platform: Molded fiberglass one-man, side-mounted, fixed mounting.

N. Mechanical Platform Leveling System: A positive mechanical parallelogram system of fiberglass insulating rods. Adjustment of leveling system made with turnbuckles located inside the cover on the lower boom and by adjusting studs accessible from the lower end of the upper boom. Platform level adjustment is easily accessible from external location on lower pivot.

0. Platform Tilting System - mechanical pin type allows easy removal of water or debris from the platform

P. Hydraulic System: Open center hydraulic system functions at 6.5 gpm and 3,100 psi (21 375 kPa). Includes 25 gallon (94.6 I) reservoir, suction

strainer, return line filter, sectional control valves and plwnbing.

Q. ISO-Grip™ System: The Altec ISO-Grip™ (Patent Applied For) System includes the following boom tip components that can provide an additional layer of secondary electrical contact protection. This is not a primary protection system.
   1. Control Handle: An insulated single handle controller that is dielectrically tested to 40 kV AC with no more than 400 microampers of leakage. The control handle is green in color to differentiate it from other non-tested controllers. The handle also includes an interlock guard that reduces the potential for inadvertent boom operation.
   2. Auxiliary Control Covers: Non-tested blue silicon covers for auxiliary controls.
   3. Control Console: Non-tested non-metallic control console plate.
   4. Boom Tip Covers: Non-tested non-metallic boom tip covers. The covers are not dielectrically tested, but they may provide some protection against electrical hazards.

R. Hydraulic Tool Circuit: Single tool circuit at boom tip, including one (I) set of Bruning HTMA quick disconnect couplings. Circuit provides 5 - 6 gpm (18.9 - 22.71pm) at 2,000 psi (13 789 kPa). Operates open center tools.

S. Upper Boom Storage Support: Cradle and tie down strap installed for horizontal stow units. "Low Stow" position also available.

T. Outrigger/Boom Interlock System: Helps prevent operator from using unit until all outriggers are lowered.

U. Outrigger/Unit Selector Control: Located near the outrigger controls, allows operator to divert hydraulic oil from machine circuit for outrigger operation. This reduces the potential for inadvertent outrigger movement during machine operation if outrigger controls are bumped.

V. Outrigger Motion Alarm: Provides audible alarm when any of the outriggers are in motion.

W. Back-up Alarm, installed

X. Diagnostic Pressure Test Quick Disconnect Couplings: are located at the turntable to allow a mobile service technician to quickly and easily attach a test gauge to verify system and tool circuit pressure. This reduces life cycle cost.

Y. Manuals: Two (2) Operator's and two (2) Maintenance/Parts manuals.

Altec Model LRV60

Item	Quantity	Description
		Z. Paint: Painted white with the Altec Powder Coat Paint Process which provides a finish-painted surface that is highly resistant to chipping, scratching, abrasion and corrosion. Paint is electro-statically applied to the ***inside*** as well as outside of fabricated parts then high temperature cured prior to assembly ensuring maximum coverage and protection.
2.		#395 Manual stow securing system
3.		#282 Pedestal & Subbase - Configuration for forestry package (behind the cab) Pedestal and subbase welded together. One three bank valve for installation on curb side for outrigger, outrigger/unit selector and chip box, and one single bank valve for installation on street side for outrigger furnished.
4.		#241 Outriggers, Primary - Forestry package , swivel shoe A-frame, 154 in ches (3912 mm) at maximum spread (outside of footpad to outside of footpad) and 7 inches penetration at 40 inch chassis frame height.
5.	1	#319 Category C, 46kV and below
6.		Pedestal - for behind cab mount
7.	1	#214 Single one man side mounted, fiberglass platform with shaft-mounted controls (controls are located on the side of the platform nearest the upper boom). Platform is 24 x 24 x 42 inches (610 x 610 x 1067 mm), and is rated at 350 pounds (159 kg)
8.	1	#296/310 Engine Start/Stop with Secondary Stowage System, 12 VDC electric powered. Includes pump and motor, operates from chassis battery. Control is captive air operated from the platform and toggle switch operated from the lower controls. This option allows the operator to completely stow the booms and platform in a situation wherein the primary hydraulic source fails. NOTE: Requires code 397 Slip Ring
9.		#343 Throttle Control, Captive Air - Throttle relay and solenoid allows operator to increase engine speed from platform.
10.		#397 Slip Ring **NOTE: Required for engine start/stop and secondary stowage system options**

11. **24 x 30** Platform

Altec Model LRV60

Item	Quantity	Description
12.		Platform Cover - for single, side mounted platform, soft vinyl, **24 x 30** inch
13.		Platform Liner 50 kV -for single platform **24 x 30 x 42** inches
14.		#229 Platform Step - located on front outside wall. In stowed position, step will be side of platform nearest elbow.
15.	1	Automatic boom stow mechanism
16.	1	Power Distribution Module is a compact self-contained electronic system that provides a standardized interface with the chassis electrical system.
17.	**1**	The **PDM** provides benefits to the customer by providing a standardized, centrally located box that greatly reduces troubleshooting time when evaluating ancillary electrical system malfunctions, thereby reducing maintenance costs.
18.	1	#294 Tool Circuit at Boom Tip, Dual Hydraulic - dual set of Bruning HTMA quick disconnect couplings provides 5.0 - 6.0 gpm at 2,000 psi (19 to 23 1pm at 13 789 kPa). This in lieu of standard single set of quick disconnect couplings. Operates open center tools.
19.		#355 Fall Protection System to include one body harness and decelerating type lanyard. Harness has adjustable slide buckle on shoulder straps, Velcro chest strap, interlocking buckles on leg straps and nylon web loop fall arrest attachment on back. Lanyard has built in shock absorber that allows 28 inches (71l mm) of automatic adjustability.
		#369 Shut-Off Valve - at return filter

UNIT AND HYDRAULIC ACCESSORIES

20.	l	Hydraulic Oil and Lubricants, installed.
21.		Hot shift PTO for automatic transmission.
22.		Hydraulic pump, right hand rotation
23.		Pair, rubber wheel chocks - 1O" L x **8"W x** 5 ½"H, installed.

BODY

24. Forestry Body, all components, except structural members, fabricated from A-60 galvanneal coated steel

Altec Model LRV60

Item **Quantity** **Description**

A. Body: Chip Dump Body 14.5 cubic yard (11.1 m^3) capacity 93 inches wide x 63 inches long (2,362 x 1,600 x 3,353 mm) with:

Structural Channel stringers and floor channel. 14 gauge roof.
14 gauge sides and front with full length die-formed reinforcing ribs
12 gauge floor plate with (4) full length die-formed reinforcing ribs.
Rear top and sides of body reinforced for lower boom support.
22½ inches (571 mm) high tailgate, **hinged curb side** with provision to hold open for dumping.
12 gauge rear under body skirt panels
Truck-Lite lighting package with rubber grommet shock mounts and wiring harness in automotive type loom.
Class "C" Hydraulic hoist, **installed, with 45 degree dump angle and body prop.**

Street side built-in ladder compartment, 12 inches wide x 26 inches high (305 x 660 mm) with rear plastisol. Roller and internal security chain.
Pole pruner compartment, l l inches high (279.4 mm), above ladder compartment with rear locking door.
Interior of chip body finished with coal tar epoxy.
Underside of chip body undercoated (except stringer channels). Front of chip box to be tapered at 45 degrees

8. Thru Box: Thm Box tool compartment 48 inches wide x 50 inches high x 93.5 inches long (1219 x 1270 x 2375 mm) with 26.5 inch (673 mm) deep curb and street side compartments with the following compartmentation:

14 gauge top plate
16 gauge side and bottom panels
Street side - single compartment with vertical doors, not over-lapped. Left side has two (2) fixed shelves. Right side has four (4) unequal transverse compartments open to curb side. Compartment bottom 0.5- inch (12.7 mm) plywood liner partitioned for chain saw gas can and wedge storage. Security chain for chain saw provided in bottom.
Curb side - single compartment with vertical doors, not over-lapped. Left side has four (4) unequal transverse compartments open to street side. All compartments have 0.5-inch (12.7 mm) plywood shelf liners. Top center has two (2) fixed shelves. Top right has six (6) swivel rope hooks (3-0-3).
All grip on walking surfaces.

C. Standard features: Rivet

door locks.

Altec Model LRV60

Item	Quantity	Description
		Double acting spring type door holders. Door locks are attached by rivets. Paint compartment interiors gray. Rain deflectors above all doors.
25.	1	Cab Guard
26.		Cab Guard Accessory Kit.
27.		Cab Guard Access Ladder.
28.	2	Wheel chock holders, installed
		BODY ACCESSORIES
29.	2	Splash aprons, installed
30.	2	18 x 18 x 1 composite outrigger pads installed in holders.
31.		Triangular reflector kit, shipped loose
32.		Fire extinguisher, 5 pounds, with bracket, shipped loose
33.		Pintle hook, BP-IOOA Buyers Products, mowited 22-23 (unloaded), to include safety chain eyes. inches above ground
34.		Front bumper assembly, installed
35.		Manual Pouch installed behind driver's side seat.
		ELECTRICAL ACCESSORIES
36.	I	Lights and reflectors in accordance with FMVSS #l 08 lighting package installed.
37.		
38.	I	

6-way trailer receptacle,		includes wiring harness installed at rear.
		Outrigger Motion Alarm: Provides audible alarm when any of the outriggers are in motion.
39.		Backup alarm, installed at rear
40.		Hour meter installed to record PTO operating hours

AJtec Model LRV60

Item	Quantity	Description
41.	2	LED Strobe lights, installed one on cab guard and one at rear comer of chip box.
42.	1	4-Comer amber strobe system, front strobes mounted on the grille, and the rear strobes (4" round), installed in the upper comers of the rear of the body
43.	I	Install Altec MP System for in-cab accessory switch panel. Includes dual lit switches for function identification and function activation.
		INSTALLATION
44.	1	Install AJtec aerial device
45.		AJtec Aerial Device painted white with the Altec Powder Coat Paint Process which provides a finish-painted surface that is highly resistant to chipping, scratching, abrasion and corrosion. Paint is electro-statically applied to the ***inside*** as well as outside of fabricated parts then high temperature cured prior to assembly ensuring maximum coverage and protection
46.		Mounting body and accessories
47.		Painting body and accessories white with urethane enamel to match the chassis
48.	1	Safety and instructional signs installed
49.		Vehicle height placard is to be placed in view of the driver
50.	1	Delivery of completed vehicle
51.	1	DOT certification of completed vehicle
52.		Paint underneath black
53.		Ferrox applied to all walking surfaces

54. Test complete unit in accordance with OSHA/ANSI requirements and provide documentation.

STATE DISCOUNTED PRICE (less chassis) **$80,886.00**

CHASSIS

2015 Freightliner model M2, 4x2 cab and chassis
138 " C A

Altec Model LRV60

Item **Quantity** **Description**

12,000-lb. FAWR

21,000-lb. RAWR

33,000-lb. GVWR

Transmission: Allison 3000RDS, 5 speed automatic transmission, Cummins Diesel Engine: 240HP/620lb-ft

Block Heater Vertical exhaust

Front suspension: 14,6001b Rear suspension: 23,000lb

Fuel tank, 50 gallon, mounted under cab LH Exterior Color: White

Conventional aluminum cab Fiberglass tilting front end

Front tires- (2) G149 or equivalent
Rear tires- (4) G177 or equivalent Dual air brake system

Remote engine throttle control Electric brake controller provision

Front and rear automatic slack adjusters Air dryer with heater

Air compressor- 13.2 CFM Auto moisture ejectors

Tilting and telescoping steering column 12-volt electrical system

Vinyl bench seat

Intermittent windshield wipers Cigar lighter

160 amp alternator

Battery system- Total of2 with 2200CCA AM/FM radio

Air horn

Halogen headlights Cruise Control

Auxiliary power point on dash Engine block heater

Driver seat, fixed, high back with integral headrest

Two-man high back passenger seat, integrated headrest in both occupant positions

Break-away mirrors, West coast style with convex spots Air conditioner with heater and defroster

Deluxe trim

STATE DISCOUNTED CHASSIS PRICE **$66,387.00**

Altec Model LRV60

Item	Quantity	Description	
		GRAND TOTAL (entire package)	**$147,273.00**

MISCELLANEOUS

One (1) year parts warranty

One (1) year labor warranty

Ninety (90) days warranty for travel charges

For so long as the initial purchaser owns the product, major components warranty at an Altec service facility (See Altec Limited Warranty)

ESTIMATED DELIVERY OF COMPLETED PACKAGE:
270-300 Days A.R.O.

Limited Warranty

Products designed and manufactured by Altec Industries, Inc. are warranted to be free from defects in material and workmanship at the time of initial delivery subject to the following provisions:

For one (1) year following initial delivery of the product, Altec will, at its option, repair or replace any part found by Altec to be defective in material or workmanship at the time of initial delivery. During the first ninety (90) days following initial delivery, no charge for parts, labor or travel to the customer's location shall be made for such repair or replacement at the customer's location. During the remainder of such one (1) year, no charge for parts or labor shall be made for such repair or replacement at an Altec service facility.

For so long as the initial purchaser owns the product, Altec will, at its option, repair or replace any of the following major components found by Altec to be structurally impaired due to defects in material or workmanship which existed at the time of initial delivery: booms, boom articulation links, hydraulic cylinder structures, outrigger weldments, pedestals, subbases, turntables, body structures, and reel lifting arms. No charge for parts or labor shall be made for such repair or replacement when performed at an Altec service facility. The limited warranty in this paragraph (2) does not cover wear components.

This limited warranty does not cover: (a) products which have not been operated and maintained in accordance with Altec operators and maintenance manuals, programs and bulletins; (b) products which have not been mounted in accordance with Altec installation procedures; (c) products not manufactured by Altec which are supplied by Altec on special order; (d) products which are repaired without using original Altec parts; or (e) transportation or delivery to an Altec service facility or the customer's location.

This limited warranty is expressly in lieu of any other warranties, express or implied, including, but not limited to, any warranty of merchantability or fitness for a particular purpose. Except as specified above, no associate, agent or representative of Altec is authorized to extend any warranty on Altec's behalf. Remedies under this limited warranty are expressly limited to the provision and installation of parts and labor, as specified above, and any claims for other loss or damages of any type (including, but not limited to, loss from failure of the product to operate for any period of time, other economic or moral loss, or direct, immediate, special, indirect, incidental or consequential damage) are expressly excluded.

Altec Industries, Inc.

Revised 3-96

ODOT - Request for Quotation
Labor & Materials

SENT: 5/20/2014 **RETURN BY:** 5/27/2014 **AT:** 12:00 PM EST

FROM: 22
1980 West Broad St.
Columbus, Ohio 43223
CONTACT: Scott Lucas
PHONE: 614-644-6603
E-MAIL: Scott.Lucas@dot.state.oh.us
FAX: 614-728-5590

TO: A.M. Leonard
241 Fox Drive
Piqua, Ohio 45356-0816
CONTACT:
PHONE: 1 (800) 543-8955
OAKS ID: 0000044955 Address Code:
FAX or E-Mail: sales@amleo.com

ODOT may split quotes among bidders unless **ALL ITEMS ONLY** is marked by ODOT **ALL ITEMS ONLY** ☐

Description of work to be done

[redacted]

Qty	UM	Description	Price per Unit	Total
8	EA	4 gallon D.B. Smith Field King Max Backpack sprayer with the no leak design, piston pump and dual-paddle agitator.	82.99	663.92

Prices guaranteed until: 6/20/2014 [redacted]

Total Labor (Include All Pages)
Total Materials (Include All Pages)

By returning a quote, vendors acknowledge that they accept ODOT Terms and Conditions as found at:
http://www.dot.state.oh.us/Divisions/ContractAdmin/Pages/PurchasingGuidance.aspx

IMPORTANT: Prices shall be considered F.O.B. destination unless otherwise specified.

ODOT IS TAX EXEMPT

Delivery by: June 20,2014
Delivery to: Tom Corey
Address: 2201 Reiser Ave.
Address 2:
City, State, Zip: New Philadelphia, Ohio 44663

GRAND TOTAL 663.92

We do not wish to bid. ☐

Vendor Authorization: Shelly Campbell Exec. Acct. Mgr. Shelly R. Campbell 5/20/14
(PRINT NAME) (TITLE) (SIGNATURE) (DATE)

PRICE SCHEDULE:

Bidders shall not insert a unit cost more than 3 digits after the decimal point. Digit(s) beyond 3, after the decimal point, shall be dropped by the Office of Procurement Services and not used in evaluation and any subsequent order.

ITEM NO.	QTY.	UNIT	DESCRIPTION	UNIT PRICE	EXTENDED AMOUNT
1.	1	EA	Model 1850 Track – (18" Disc Style) Track Whole Tree Chipper with all standard equipment	$ 159,166.00	$ 159,166.00
2	1	EA	Model 1850 Track unit with Cab and Hydraulic controlled Loader	$ 45,302.00	$ 45,302.00
3.	1	EA	Minimum 325 horsepower engine including a two (2) year/2,000 hour engine warranty.	$ 67,075.00	$ 67,075.00
4.	1	EA	Supersized spring loaded slide box feed system with two (2) horizontal feed wheels. Top feed wheel is chain driven and is 15 ¾" diameter x 32" wide. Bottom feed wheel is 10 5/8" diameter x 32" wide.	$ 2,244.00	$ 2,244.00
5.	1	EA	Wide profile, tapered infeed hopper with 5 ½" long infeed conveyor	$ 10,120.00	$ 10,120.00
6.	1	EA	Engine pre-cleaner – Engine Air	$ 308.00	$ 308.00
7.	1	EA	Hand crank height adjustable discharge	$ 352.00	$ 352.00
8.	1	EA	2 ½ pound fire extinguisher with mount	$ STANDARD	$ Standard
				Total:	$ 284,567.00

Bill to address will be:
*ODOT – Ohio Dept. of Transportation
2201 Reiser Ave. SE
New Philadelphia, OH 44663

Ship to address will be:
*ODOT – Ohio Dept. of Transportation
2201 Reiser Ave. SE
New Philadelphia, OH 44663

*Indicates update to the "Bill To" and "Ship To" addresses.

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CCl425TBSK1D

425 Gallon Truck Bed Skid Sprayer
Specifications

- 425 Gallon Norwesco Horizontal Leg Tank and Tie-Down Bands
- Steel Skid Designed to Fit into a Truck Bed. Painted Black
- Hypro 9203C Centrifugal Pump
- 8 Horsepower Electric Start Honda Engine
- Micro-Trak Roadmaster Console *(See Included Flash-Drivefor Manual)*
- Hannay 300' ½" Hose Electric Hose Reel
- 300' of½" 600 PSI Heavy Duty Hose
- Specified Boominator Nozzles
- Udor Adjustable Spray Gun w/ Extra Specified Nozzles
- Micro-Trak Flow Meter, Control Valve, and Boom Shut Off Valves
- Built to Fit Specifications

Chemical Containers Inc. 413 ABC Road Lake
Wales, FL. 33859 PH: 863-638-1407
Fax: 863-638-1863 www.chemicalcontainers.com

Vendor Name:	chemical containers Inc.		
Make/Model:	CCl425TBSK1D		
Insert Warranty Description:	One Year for Skid, Plumbing, and Parts. Three Years for Tank.		
Items 1 & 2 will beawarded together based on the arand total of Items 1 & 2. You must bid on both items to be considered for			
Item	Unit of Measure	Description	Unit Price
1	Each	One skid sprayer unit meeting or exceeding the requirements	$8,073.00
2	Each	One skid sprayer unit meeting or exceedina the requirements	$8,073.00
		TOTAL:	$ 16,146.00

Invoice

Invoice Number: 0087946-IN
Invoice Da10: 612712014

Order Number: 0034511
Order **Date** 6/6/2014

Salesperson: 0009
Customer Number: OHDOT

Remit To:

27134 PARKLANEDR
SIOUX FALLS SD5710S
(605) 368-5865

THE LIMITED WARRANTV AND TERMS OF SALE ON THE REVERSE SIDE ARE INCORPORATEDHERE IN

Sold To:

OHDOT DISTRICT 11
2201 REISER AVE SE

New Philadelphia. OH 44663

Confirm To:

Ship To:

OH DOT DISTRICT 11
622 STATE ROUTE 380

Xen ia. OH 45385

Customer P.O.	Ship VIA	F.0.8.	Terms
344654	BEST WAY		NET30 DAYS

Item Code	Unit	Ordered	Shipped	Beck Ordered	Price	Amount
49-5059	EACH	1.0000	1.0000	0.0000	40,287.00	40 287.00
WFW·180-C 15'FLEXWING WETBLADE•PTO						
SERIA. NO. 9322 Serlel Number: 9322			1.0000			

PO/Debh Voucher/EDI/Petty Cash Payments
Date Goods/SerivcesRec'd *(g ·.27 -/ Y*
CostCenre r c&/ t. '/ <J ODOT PO#*3.* 7'.1/G.*Sf*
OAKS ID# **cro:J** */'(l22/*

PmtAmtSS:fZlt7 EMS PO#-:--- -,---- -

Add 'J Oescriphon f c7

[redacted]

Signature

Net Invoice:	40,287.00
Less Oisccunt:	0.00
Freigt11:	0.00
Sales Tex:	o.o_o
Invoice Total:	40,287.00

finance Charges of 1% per month wrn be added to au accounts past 30 days

27134 S. Parklene Drive Sioux

Office: 605.368.5865
Fax: 605.'198.1222

www.diamondmowers.com
info@diam ondmowe,s .com

DEMAND BRILLIANCE.

Equipment #	6400605	**Price Sold**	
Equipment Category	640 - MOWER,ROTARY,TOV	**Replacement Miles**	
License Plate #		**Replacement Hours**	
Make	CHEVROLET	**Useful life (Month)**	144
Model	1500	**Depreciation Method**	
Year	2015	**Original Cost**	$40,287.0000
Model Code		**Equipment Total Value**	$40,287.0000
Color		**Salvage value**	$4,028.7000
Body type	MOWER ROTARY	**Current Depreciated Val**	$37,852.9938
Gross Vehicle Weight		**Equipment Age (Month)**	10
Number of Axles		**Expected Remaining Us**	134.2
VIN#	9322	**Delivery Date**	6/23/2014
Engine Description		**Date in District**	6/23/2014
Transmission Type		**Inservice Date**	7/24/2014
Equipment Status	IN-SERVICE	**Disposal Date**	5/22/2026
Equipment Condition		**Receiving Party Address**	
Home Location	0008 6600 - Preble County G	**Receiving Party Phone**	
Physical Location	0008 6600 - Preble County G	**Receiving Party Email**	
Driver		**Is Purchased?**	☐
Primary Fuel		**Leased**	☐
Secondary Fuel		**Has Manuals?**	☐
Fuel Capacity (Gal.)		**Parent Equipment #**	
Meter 1 (Primary Meter)	0	**Requisition #**	044404
Meter 1 Type	NONE	**ODOT PO#**	344654
Date of Last Meter1	11/3/2014	**OAKS PO#**	344654
Meter 2 (Secondary Mete		**No PO#**	☐
Meter 2 Type	NONE	**Turn In Equipment**	No Turn in
Date of Last Meter2		**Sell By Date**	
Odometer Source	Repair Order	**Turned In**	☐
Disposal Method		**Equipment Sharing Con**	
Disposal Reason		**Pool Vehicle**	☐
Charge Type	Hours	**NAFA Code**	
Mileage Rate		**Comments**	MOWER
Hourly Rate	$4.2500	**Att.**	
Equipment Buyer		**Date Update**	4/23/2015

Invoice

Remit To:
27134 PARKLANE DR
SIOUX FALLS SD 57106
(605) 368-5865

Invoice Number: 0090531-IN
Invoice Date: 8/28/2014

Order Number: 0034509
Order Date 6/6/2014
Salesperson: 0009
Customer Number: OHDOT

THE LIMITED WARRANTY AND TERMS OF SALE ON THE REVERSE SIDE ARE INCORPORATED HEREIN.

Sold To:
OH DOT DISTRICT 11
2201 REISER AVE SE
New Philadelphia, OH 44663
Confirm To:

Ship To:
OH DOT DISTRICT 7 GARAGE
1001 ST MARYS AVE
Sidney, OH 45365

Customer P.O.	Ship VIA	F.O.B.	Terms
344644	BEST WAY		NET 30 DAYS

Item Code	Unit	Ordered	Shipped	Back Ordered	Price	Amount
60-4459	EACH	1.0000	1.0000	0.0000	17,733.00	17,733.00
WBR050-H						
50" ROTARY BOOM MOWER WETBLADE SYSTEM						
SERIAL NO. 9321						
Serial Number: 9321			1.0000			

Net Invoice	17,733.00
Less Discount:	0.00
Freight:	1,975.00
Sales Tax:	0.00
Invoice Total:	19,708.00

Finance Charges of 1% per month will be added to all accounts past 30 days

Equipment #	6420238	Price Sold	
Equipment Category	642 - MOWER,EXT TYPE,RC	Replacement Miles	
License Plate #		Replacement Hours	
Make	DIAMOND	Useful life (Month)	144
Model	WBR050-H	Depreciation Method	
Year	2014	Original Cost	$17,733.0000
Model Code		Equipment Total Value	$17,733.0000
Color		Salvage value	$1,773.3000
Body type	MOWER ROTARY	Current Depreciated Vali	$16,838.9613
Gross Vehicle Weight		Equipment Age (Month)	8
Number of Axles		Expected Remaining Us	135.8
VIN#	9321	Delivery Date	8/28/2014
Engine Description		Date in District	8/28/2014
Transmission Type		Inservice Date	9/10/2014
Equipment Status	IN-SERVICE	Disposal Date	7/9/2026
Equipment Condition		Receiving Party Address	
Home Location	0007 6800 - Montgomery Cou	Receiving Party Phone	
Physical Location	0007 6800 - Montgomery Cou	Receiving Party Email	
Driver		Is Purchased?	☐
Primary Fuel		Leased	☐
Secondary Fuel		Has Manuals?	☐
Fuel Capacity (Gal.)		Parent Equipment #	
Meter 1 (Primary Meter)	0	Requisition #	044384
Meter 1 Type	NONE	ODOT PO#	344644
Date of Last Meter1	10/23/2014	OAKS PO#	079113
Meter 2 (Secondary Mete		No PO#	☐
Meter 2 Type	NONE	Turn In Equipment	No Turn in
Date of Last Meter2		Sell By Date	
Odometer Source	Repair Order	Turned In	☐
Disposal Method		Equipment Sharing Con	
Disposal Reason		Pool Vehicle	☐
Charge Type	Hours	NAFA Code	
Mileage Rate		Comments	Model # WBR050-H
Hourly Rate	$4.2500	Att.	
Equipment Buyer		Date Update	5/7/2015

GREGSON-CLARK
Spraying Equipment
A Division of Rhett M. Clark, Inc.

3213 Lehigh Street Caledonia, NY 14423
(800) 706-9530 • 585-538-9570 • Fax 585-538-9577
www.gregsonclark.com

Quotation

Quote Number: 4068

Quote Date: Jun 6, 2014

Page: 1

Quoted to: SCOTT BATES
ODOT DISTRICT 11
2201 REISER AVE SE

NEW PHILADELPHIA, OH 44663

Phone: 330-308-7823
Fax: 330-308-6970

Ship to: SCOTT BATES
ODOT DISTRICT 11
2201 REISER AVE SE
NEW PHILADELPHIA, OH 44663

Phone: 330-308-7823

Customer ID	Payment Terms	Sales Rep
ODOT11	Net 30 Days	RHETT CLARK

Quantity	Item	Description	Unit Price	Extension
1.00	V-200 ST	200 Gallon V-Series skid sprayer complete with components shown below:		
1.00	V-200	V-200 Skid Sprayer tank and frame w/ strainer, suct. and agit. lines installed, powdercoat finish (black)	1,286.00	1,286.00
1.00	H5.5/K43 HP	Honda GX160 engine coupled with Udor Kappa-43/GR (12.0 gpm, 560 psi)	1,622.00	1,622.00
1.00	E1530-17-18-INST	Hannay Reel, capacity 400 feet 1/2" ID hose, 12-volt rewind-installed	688.00	688.00
1.00	RTWA	6-gauge wiring assy. w/ circuit breaker and quick disconnect for powering reel with vehicle battery.	75.00	75.00
1.00	A-1661-1/2X300	1/2" lawn spray hose 600 psi, PVC/PU blend, yellow-300 foot coil	314.00	314.00
1.00	38505	Green Garde GES Spray Gun with adjustable spray pattern	95.00	95.00
1.00	CRATE200	Shipping Crate for V-Series Skid Sprayer (44" x 72" x 49 1/2" high)	135.00	135.00
1.00	SHIPPING	Shipping & Handling	210.00	210.00

AUTHORIZING SIGNATURE

SCOTT BATES DATE

Subtotal	4,425.00
Sales Tax	
Total	4,425.00

US Ditcher,1Nc.

1805 South Port Road, Tel.(1) 864 948 0884. Fax. (1) 864 948 0987.

Spartanburg, SC. 29306 / USA. cusditchcr@carthlink. neo

www.guardra ilmower.com

Date: June 2005

SPECIFICATIONS FOR GUARDRAIL MOWERS COVERING OUR "GRM" SERIES.

MODEL GRM60-SP1DER.

Patent No: US 6,860,093 82 of March l, 2005

Patent No: US 6, 959,528 Bl of November 1, 2005

DESCRIPTION: The Guardrail mower is made with heavy duty rectangular telescoping steel frame, PTO powered, and has a multiple standard 3point category II SAE tractor hitch, suitable for installing the guardrail mower to the **Front** 3point hitch and/or the **Rear** 3point hitch of a farm, industrialtool carrier, and/or utility tractor, and equipped with a PTO connection at 1000RPM (540RPM available on request) output shaft, and hydraulic category II hitch lift arms suitable for 4000lbs lifting capacity.

GRM60-SPIDER: Is a 3point hitch category II guardrail mower with front and/or rear 3point hitch mounting, J000RPM PTO (540RPM available on request) powered, built with heavy duty rectangular steel (frame approx.., 3307lbs, 1500kgs), with two (2) mowing arms and two (2) mowing heads capable of straddling over the guardrail and/or media safety cables, able to mow simultaneously on either side and under the guardrail and/or media safety cables with a mowing width of 30" inches on each side of the guardrail (total of 60" inches both sides) on a straight mowing pattern.

TELESCOPING FRAME, MOWING HEADS & ARTICULATIONS: The unit is designed to mow under the guardrail, media cables, fences, and/or ornamental trees, brush and bushes with a minimum speed of0.5MPH to maximum 3MPH, depending on terrain contour, vegetation, growth, access and visibility. Each rotary mowing head has a 34.5" structural diameter and 31" cutting diameter allowing mowing from 57" to 62" wide on a straight mowing pattern. Both mowing heads are equipped with free rotating scalping protection cups and spring loaded articulation will undulate-free 9 degrees floating-up-down horizon following the mowing contour. The telesc oping frame during the mowing operation will telescope in-and-or-out oscillating from O" to max., 32" giving the operator the ability to correct and adjust mowing position and maintain a straight mowing pattern, without the need of time consuming carrier maneuvering corrections . The mowing arms have 15 degrees to 27 degrees front and/or rear inclination tilt (54 degrees radius) above and/or below horizon when mowing to the rear-right and/or rear-left hand side with right hand traffic flow (Left hand traffic England, Commonwealth, Japan etc.,) in order to bring the mowing heads in trailing position from each other (overlapping from 3" to 5") to avoid leaving un-mowed lines under the guardrail.

POWER: The guardrail mower requires I 000RPM - PTO, powered by the REAR or the FRONT PTO with a minimum 65PTOHP preferably 4WD (JD6320 SyncroPlus w/LaForge front hitch - 9F/3R or 12F/12R changer) , with **creeper transmission** at l /2MPH.(4WD-85PTOHP recommended).

STEEL FRAME: The unit consists of a main body chassis made of tubular steel frame FE520 steel 1/2" thick, with a double 3point hitch hook-up (Front & Rear) and can be installed to the **front and/or the rear** of a category 1-11tractor. A double telescoping tubular frame incorporated into the main frame and supported with sliding pads connects to the first and second mowing arms. Both mowing arms are made of tubular steel, forming an arch (**D)** enabling the straddling of the guardrail with a clearance of 60" inches from the ground to the upper middle clearance of the arch, and 46" inches clearance between the two mowing arms when fully closed. The mowing arms telescope 22" inches up-down allowing for ground clearance adjustments. This unit can be easily converted for mowing to the **front right hand, front left hand, rear right hand, and/or rear left hand side of the tractor.**

HYDRAULIC SYSTEM: The unit has a self contained hydraulic system with a 38 US gallon (140lts) hydraulic fluid (SAE45) tank, feeding the main triple tandem pump drive. The main pump drive and gear box is PTO powered at 1000RPM, 65 PTO HP min. The pump drive consists of two (2) hydraulic pumps each of which is powering individually the hydraulic motor on each of the mowing head, and one pump for the hydraulic articulations. An electro-hydraulic manifold with six **(6)** solenoid valves connects the hydraulic controls to a main electrical control box, installed adjacent to the operator. **Five**
(5) hydraulic cylinders are installed on the main and mowing frames of the unit, each of which is used for:

a. **Unfolding the mowing arms** from transport to the mowing and/or straddling position and vise- Versa.
b. **Moving the Telescopic frame** to mowing position, allow the operator to make width and reach- out adjustments and con-ections during mowing,
c. **Moving and adjusting the mowing arms** up and/or down during mowing,
d. **Lifting and Lowering Outer Mowing Arm** during mowing in order to clear road signs and other obstacles such as trees and ornamental bushes when their height and width are over the arch limits of this model,
e. **Tilting adjustments** for Right-hand and/or Left-hand mowing head adjustment,
f. **and a master dumping valve, suitable for open and/or closed hydraulic circuit system, and to prevent manifold overheating.**
All hydraulic hoses etc., are installed away from the operator. An electrical control box with joystick controls, installed for easy reach to the right side of the operator, connects via a multi- core electrical cable to the electro-manifold.

HEAT EXCHANGER HYDRAULIC COOLER. A 12VDC/11Okw hydraulic fluid radiator cooler- heat-exchanger thennostatica1ly controlled installed with every unit.

OPERATIONAL SYSTEM: Guard-Rail mowing to the inside, behind and under the guardrail, at the same time, is made easy with this unique mowing implement. The operator engages the tractor PTO and the pump drives are ready to do the mowing. The unit wil1 be raised from the parked position to the right and/or left hand mowing side and lowering the mowing anns to the ground allowing about 4 inches clearance (recommended) with the inner arm to the near tractor side and the outer arm over the outer side of the guardrail to get the unit ready for mowing. The inner and outer mowing heads-discs should be placed under the guardrail or the centerline cables. The outer aim should be fully closed with a rear inclination from I 5 degrees to 27 degrees, the outer mowing head should be behind the inner mowing head with about 4 inches ground and overlapping clearance, without coming in contact with each other. The operator engages the electrical solenoid motor activation control for each indi vidual mowing head and starts mowing. **During the mowing process, the mowing heads-discs will come in contact and will roll around the guaa·drail or cable vertical supports and mow to the inner and outer side of the supports with about 1" clearance without leaving unmowed lines/spaces. The**

 unit has a very unique feature, in **that the arch tilts above or below horizon of about 20 degrees allowing the mowing heads to follow the ground contour and mowing path in order to prevent unmowed patches and lines. The mowing decks remain in contact while they rotate on and around the supports with a-break-away inner and outer swing movement when passing from the rear to the front of the support without causing damage to the**

mowing heads or the supports, while the mowing path remains the same width at 61" inches without leaving a zigzag mowing pattern.

SAFETY FEATURES: A limit switch will stall both mowing heads if the operator brings the arch to the parking position before disengaging the PTO. Also when the outer mowing ann is raised above the mowing position in order to clear a road sign etc., the mowing head will stall as soon as the ann is raised to about 18 inches above the ground, and will re-engage as soon as is lowered back to mowing position. The outer ann will rise up 180 degrees from mowing position to clear signs, trees and other obstacles, or while mowing inside side (near side) of a fence and the arch will not clear the height of the fence. Either of the mowing heads will stall when scalping the ground or coming in contact with heavy growth. During mowing in heavy growth or heavy clusters of brush, the creeper speed is highly Recommended. To restart the mowing heads/discs, reduce tractor and/or carrier engine RPM to idle revolutions , slightly raise the arch off the ground in order to reengage the stalled hydraulic motors , and resume mowing.

INSTALLATION: The unit can be easily installed by the buyer. We can install the unit on your carrier at a nominal charge.

TRAINING: One of our qualified teclmicians will conduct one day training to all buyers, for preventive maintenance, and repairs at NO cost to the buyer operating and will bring 3 copies of the operator and parts manuals , (I copy for the operator, 1 copy for the shop and I co py for the office) additional copies are free of charge.

PARTS AND SERVICES: Replacement parts are available usua lly with same day shipping. During the 12 month warranty period, US Ditcher, Inc., will assist operators and shop personnel with telephone instructions and, if needed wiJl dispatch a technician on a per day charge for on the job assistance.

WARRANTY: The unit is covered under warranty against flaws in workmanship and defects in material for a period of 12 months starting the date the unit is put in service, but not later than 30days after the delivery date to the buyer. US Ditcher, Inc., will NOT cover under warranty mowing blades, deflectors and mowing decks, hydraulic fluid, hydraulic hoses, paint and general abuse.

OPTIONAL EQUIPMENT & SERVICES: On request and for newly ordered units only, a herbicide plumbing installation with a I Ogallon tank, electrical pump and electrical controls, can be installed on all NEW units as an optional feature. Buyers can request a complete plumbing installation for liquid herbicide application that can manually, automatically and/or selectively apply liquid herbicides and/or other retardants and fertilizers, during the mowing process.

GRM70-SPIDER Available on request, this is an optional larger model , with the same and/or larger frame, with 70" inches mowing width or larger mowing widths (80" Max.).

As we are constantly improving our equipment, this specification data might change without notice.

THE MANAGEMENT US DITCHER, INC.

Bates, Scott

From: Frank Scordilis <usditch er@usditcher.us>
Sent: To: Wednesday, October 01, 2014 1:56 PM Bates,
Subject: Scott

Attachments: RE: GRM60 -Spide· r

Specs GRM60 0605 01.doc; Alaska DOT PO 8 18 14 $14081810200.pdf; MODOT &

Importance: MDSHA 4 22 10 007jpg; MODOT & MDSHA 4 22 10 033.jpg

Sensitivity: High
Confidential

Hello Mr., Bates,

Further to our telephone conversation price and availability for: lea GRM60-SPIDER Guardrail mower complete with

PTO Drive shaft at 1000RPM

Remote electrical controls
Self-contained hydraulic system Shipping
on skid shrink wrapped 34101bs
Current cost sold to ALL government agencies delivered $ 48,650.00

Delivery: 6 to 10 weeks ARO possibly earlier .

NOTE: In the event of an order, we will send our technician for one day (two days if needed), to supervise Installation on your tractor, and train your operator and mechanic

For preventive maintenance and efficient performance, at NO expense to ODOT. IMPORTANT: We are SOLE SOURCE covered by two (2) US and two (2) Canadian patents as follows :

US PATENT NO: 6,959,528 81 and 6,860,093 .-

We would welcome the possibility to enter into statewide contract with ODOT.
Looking forward to hearing from you at your earliest convenience.

Sincerely

Frank P Scordilis President

US Ditcher, Inc.,

FIN : 57-1057839

www.usditcher.com
www.guardrailmower.com Tel.
(1)888 842 1631

Cel.(1) 864 494 9386

From: Bates, Scott [mailto:Scott.Bates@dot.state.oh.us]
Sent: Tuesday, September 30, 2014 12:05 PM
To: fscordilis@usditcher.us
Subject: GRM60-Spider
Good afternoon,

Per our phone conversation I am requesting an updated quote and a sole source letter for the GRM60-Spider.

Thank you,

Chemicals Evaluated - Rates and Pricing

Herbicide and Adjuvants	Rates		Cost/Acre at Tested Rate
	Ounce/Acre	Ounce/Gallon	
Alligare 90		1.28	$0.09
Alligare 90	32		$2.13
Alligare Anti-foamer	1		$0.17
Alligare COC	16		$0.62
Alligare Drift Control	16		$4.10
BAS-Oil Red		0.25	$0.44
Ecomazapyr 2 SL	64		$9.81
Ecomazapyr 2 SL	96		$14.72
Elite Vigor	32		$5.90
Embark® 2S IVM	16		$16.05
Embark® 2S IVM	32		$32.10
EsplAnade® 200 SC	7		$57.42
Hy-Grade I		102.4	$1.82
Hy-Grade I		104.5	$1.86
Krenite®	512		$100.67
Milestone®		1.28	$1.20
Milestone®	7		$6.56
Nufilm®	16		$4.26
Oust® XP	8		$6.43
Outrider®	0.75		$0.50
Overdrive	8		$14.00
Pathway® RTU	128		$27.68
Perspective®	5		$4.60
Perspective®	7		$6.44
Plateau®	4		$3.43
Platoon®	96		$9.38
Rodeo®	192		$11.10
Rodeo®	256		$14.80
Rodeo®	64		$3.70
Streamline®	11.5		$59.23
Streamline®	9.5		$48.93
Tordon® K	64		$22.58
Triclopyr 3	192		$22.05
Triclopyr 3	341.76		$39.25
Triclopyr 3	328		$37.67
Triclopyr 3	384		$44.10
Triclopyr 3	64		$7.35
Triclopyr 4		20.9	$2.95
Triclopyr 4		25.6	$3.61

Chemical Cost per Container

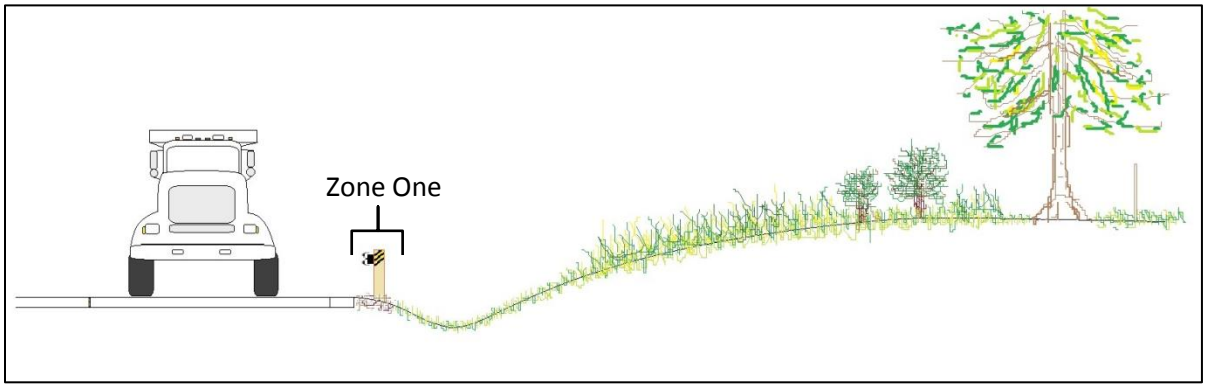
Product Name	Container Units	Container Size	Cost per Container	Cost per Ounce*
Alligare 90	gallon	1	$8.50	$0.07
Alligare Anti-foamer	quart	1	$5.30	$0.17
Alligare COC	gallon	2.5	$12.40	$0.04
Alligare Drift Control	quart	1	$8.20	$0.26
BAS-Oil Red	pint	1	$28.35	$1.77
Ecomazapyr 2 SL	gallon	2.5	$49.05	$0.15
Elite Vigor	quart	1	$5.90	$0.18
Emark® 2S IVM	gallon	2.5	$321.00	$1.00
Esplanade® 200 SC	quart	1	$262.50	$8.20
Hy-Grade I	gallon	5	$11.40	$0.02
Krenite® S	gallon	2.5	$62.92	$0.20
Milestone®	gallon	2.5	$299.73	$0.94
Mirage	gallon	1	$30.60	$0.24
NuFilm®	gallon	1	$34.10	$0.27
Oust® XP	ounce	64	$51.40	$0.80
Outrider®	ounce	20	$13.27	$0.66
Overdrive®	pound	1	$28.00	$1.75
Pathway® RTU	gallon	1	$27.68	$0.22
Perspective®	pound	5	$73.60	$0.92
Plateau®	gallon	1	$109.90	$0.86
Platoon®	gallon	1	$12.50	$0.10
Rodeo®	gallon	2.5	$18.50	$0.06
Streamline®	pound	1	$82.40	$5.15
Tordon® K	gallon	2.5	$112.88	$0.35
Triclopyr 3	gallon	2.5	$36.75	$0.11
Triclopyr 4	gallon	2.5	$45.15	$0.14
Propylene glycol	gallon	1	$6.00	$0.05

*Costs are rounded to the nearest cent

Appendix D
Test Methods, Results, and Recommendations by Management Zone

Zone One – Vegetation Free Zone

Figure 1. Diagram of ODOT's Roadside Management Zone One



Goal: Zone One is also known as the Vegetation Free Zone (bare ground) (Figure 1). This Zone is designed to be free of vegetation to allow for surface drainage, provide visibility and maintenance of roadside hardware, prevent pavement breakups by invasive plants, and to provide sight distance for passing, stopping, and intersections (Ohio Maintenance Operations Manual, 803.1).

Overview of Current Maintenance Practices: In order to meet the Goal of Zone One, post-emergent, non-selective herbicides such as glyphosate are commonly used. As the results of using glyphosate alone don't last long, the application is repeated three to four times per growing season to obtain sufficient results. When the overall goal of bare ground in Zone One is not the desired goal on a particular stretch of roadway and vegetation has been allowed to grow, mechanical vegetation maintenance is performed to provide sight distance clearance. The SOP for mechanical maintenance is mowing along areas with no rails and string trimming along guardrails and cable rails. While mowing is relatively labor-intensive, string trimming is much slower, even more labor-intensive, and generally involves one to three workers. In Zone One, mechanical maintenance is performed an average of four times per growing season. Challenges with the current maintenance practices in Zone One include the labor needed to maintain bare ground and maintain vegetation where bare ground is not desired. Current methods are not as safe, effective, or efficient as they should be.

Safety: Risks associated with vegetation management in Zone One are the workers' proximity to traffic, slips, trips and fall injuries, injuries from projectiles, and hearing loss from equipment noise. Reducing the number of workers and work time spent within Zone One would reduce safety exposure. Utilizing driven power equipment (i.e., tractors or spray trucks) instead of manual mechanical methods (i.e., string trimming crews) would reduce safety risks to workers in this Zone.

Objective: When total vegetation control is desired, Test 1 determines which herbicide spray mix is most effective at maintaining bare ground with one application per season. When vegetation is overgrown and immediate clearance is needed under rails, Test 2 determines which mechanical method is most effective with respect to vegetation maintenance.

Zone One: Test 1, Maintain Bare Ground under Guardrail or Cable Rail with Spray Truck and Boomless Nozzle

The goal for this test was to evaluate total vegetation control with one application of a mixture of herbicides compared to controlling vegetation with multiple applications of a single herbicide. This test evaluated the efficiency of three separate herbicide mixtures in controlling vegetation under and around cable rails and guardrails in Zone One.

Methods

The equipment used in this test was a truck equipped with a 425-gallon skid sprayer and a 6-foot boomless nozzle (Photograph 1). Testing was performed in the center median at the road edge along a cable rail by spraying with a 6-foot spray pattern to control vegetation under and around cable rails. This test used two different spray trucks; the skid sprayer and nozzles were moved onto a different truck in the second year of testing. See Table 1 for equipment information.

Table 1. Zone One: Test 1, Equipment

Equipment	Equipment Number
Spray Truck, Ford F450 CC	2533083
Spray Truck, GMC T7500	3210114
Skid Sprayer, Chemical Container 425-Gallon	8100160
Boominator 1876 Right 6-foot Nozzle	N/A

Method 1: (1 Treatment) Post-Emergent Non-Selective Herbicide: In this method, a tank mixture of a non-selective herbicide was prepared for broadcast application. Broadcast applications were made each season starting in late spring and were repeated approximately every 60 days for a total of 3 times per year (Photograph 2).

Treatment 1: Rodeo® (glyphosate) (SOP)

Method 2: (2 Treatments) Post-Emergent Non-selective + Pre-Emergent Non-Selective + Selective Herbicide Combination: In this method, tank mixtures combining post-emergent non-selective, pre-emergent non-selective, and selective herbicides were prepared for broadcast applications. In both 2015 and 2016, a single broadcast application was made in late spring of each year (Photograph 3).

Treatment 1: Rodeo® (glyphosate) + EsplAnade® 200 SC (indaziflam) + Perspective® (aminocyclopyrachlor + chlorsulfuron)

Treatment 2: Rodeo® (glyphosate) + EsplAnade® 200 SC (indaziflam) + Oust® (metsulfuron)

Photograph 1. Initial herbicide application to bare vegetated test site.

Photograph 3. Herbicide results after two years of herbicide treatments with Rodeo® + EsplAnade® 200 SC + Oust®.

Photograph 2. Herbicide results after two years of herbicide treatments with Rodeo®.

Results

At the start of testing in 2015, vegetation was growing up to the road edge (Photograph 1). Both herbicide combination treatments in Method 2 significantly reduced total vegetation percent coverage compared to Method 1 Treatment 1 of Rodeo® only. After two consecutive late spring herbicide applications from 2015 to 2016, the Rodeo® only plot contained significantly more total vegetation than the Rodeo®, EsplAnade® 200 SC, and Perspective® plots or the Rodeo®, EsplAnade® 200 SC, and Oust® plots (34%, 1%, and 2%, respectively) (Figure 2).

Method 1 Treatment 1: Rodeo® (SOP): Rodeo® plots were at 83% total vegetation coverage at the start of testing in 2015. Three broadcast applications of Rodeo® in 2015 reduced total vegetation coverage by 34%, resulting in 49% total vegetation coverage by fall 2015. Through 2015, acceptable control only lasted 60 days on average. Three applications were made per the typical SOP. In spring 2016, Rodeo® only plots reached a maximum of 60% total vegetation coverage (Photograph 2). By the end of testing, Rodeo® did reduce total vegetation cover but contained significantly more vegetation (34% coverage) than both of the herbicides combinations used in Method 2.

Method 2 Treatment 1: Rodeo® + EsplAnade® 200 SC + Perspective®: Rodeo®, EsplAnade® 200 SC, and Perspective® plots were at 83% total vegetation coverage at the start of testing in 2015. The first broadcast application of Rodeo®, EsplAnade® 200 SC, and Perspective® in spring 2015 reduced total vegetation coverage by 30%, resulting in 53% total vegetation coverage by fall 2015. In an effort to improve the bare ground results, Perspective® was increased from the 2015 rate of 5 ounces per acre to 7 ounces per acre for the second year of testing. The second broadcast application of Rodeo®, EsplAnade® 200 SC, and Perspective® in spring 2016 reduced total vegetation percent coverage by an additional 46%, resulting in 2% total vegetation coverage by fall 2016. By the end of the testing, Rodeo®, EsplAnade® 200 SC, and Perspective® significantly reduced total vegetation coverage compared to Method 1 Treatment 1 (Rodeo®) and ended testing with 2% total vegetation coverage (P=<0.0001).

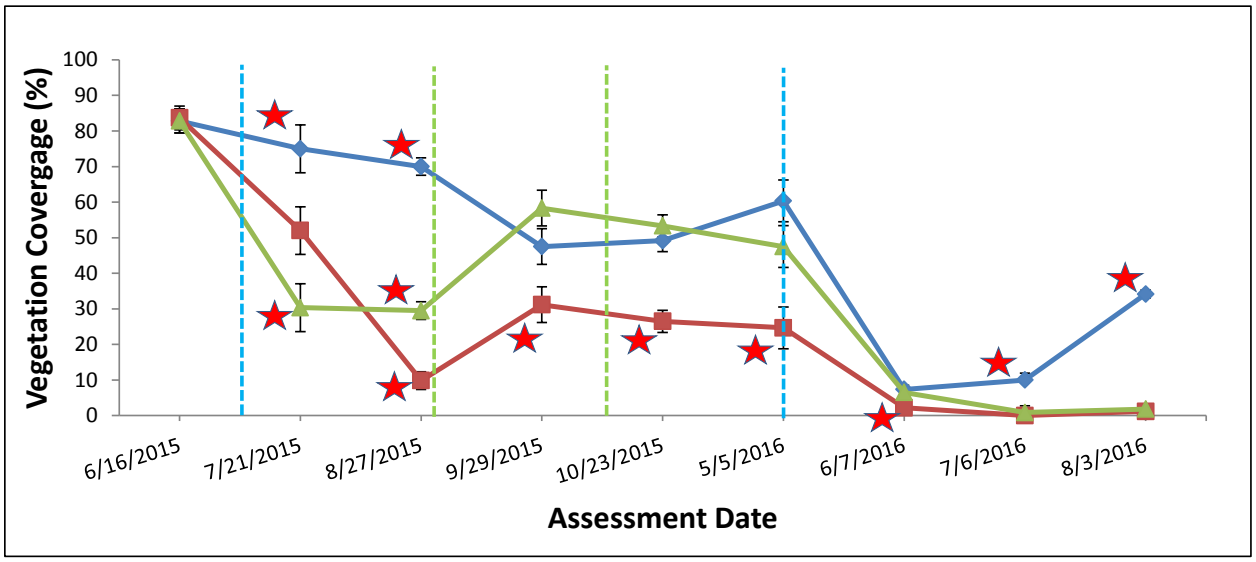
Method 2 Treatment 2: Rodeo® + EsplAnade® 200 SC + Oust®: Rodeo®, EsplAnade® 200 SC, and Oust® plots started at 84% total vegetation coverage in spring 2015. The first broadcast application of Rodeo®, EsplAnade® 200 SC, and Oust® in spring 2015 reduced total vegetation percent coverage by 57%, resulting in 27% total vegetation coverage by fall 2015. The second broadcast application of Rodeo®, EsplAnade® 200 SC, and Oust® in 2016 reduced total vegetation percent coverage by an additional 24%, resulting in 1% coverage by fall 2015. By the end of testing, Rodeo®, EsplAnade® 200 SC, and Oust® significantly reduced total vegetation coverage compared to Method 1 Treatment 1 (Rodeo®) and ended testing with 1% total vegetation coverage (P=<0.0001) (Photograph 3).

Treatment Cost Comparisons: Tables 2 and 3 shows per-mile and per-acre labor costs for Zone One total vegetation control. Labor costs for making broadcast applications with a spray truck and a 6-foot boomless nozzle spray pattern are much more cost-effective than any mechanical vegetation removal method in Zone One. Table 4 shows the herbicide costs for each treatment per acre and per mile for a year.

Equipment Review: For herbicide applications, the spray equipment used for this project worked well and was easy to use. The Road Master control panel was integral to ensuring that the herbicide was applied at the proper rate. Prior to the second year of applications, the spray tank was modified with Davey Resource Group's support. Modifications included the addition of the following:

- Shut-off valves
- An extension handle for the applicator to reach external controls without the necessity of climbing onto the truck
- A step for easy access onto the back of the truck
- Plumbed a Cleanload™ Chemical Eductor to add herbicides into the spray tank and triple rinse empty containers

Figure 2. Zone One: Test 1, Vegetation Coverage



Key to Figure 2.

Statistically Significant Event

+ Oust® + EsplAnade® 200 SC

+ Perspective® + EsplAnade® 200 SC

Herbicide Application (all broadleaf herbicides)

Herbicide Application (Rodeo® only)

Error Bars

Table 2. Zone One: Test 1, IVM Labor Comparison

IVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre	Miles per Hour	Labor Hours per Mile	Cost per Mile
Spray Truck (6-foot spray nozzle)	1	$19.10	6.57	0.16	$3.06	9.04	0.11	$2.10

Table 3. Zone One: Test 1, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Total Cost per Acre per Year	Total Labor Hours per Mile per Year	Total Cost per Mile per Year
Method 1 Treatment 1: Rodeo®	0	3	0.48	$9.17	0.33	$6.30
Method 2 Treatment 1: Rodeo® + EsplAnade® 200 SC + Perspective®	0	1	0.16	$3.06	0.11	$2.10
Method 2 Treatment 2: Rodeo® + EsplAnade® 200 SC + Oust®	0	1	0.16	$3.06	0.11	$2.10

Table 4. Zone One: Test 1, Herbicide Mixture Cost Comparison

Tank Mix	Rate (oz. per acre)	# Products	Spray Pattern Width (ft.)	Cost per Acre	Cost per Mile	Occurrences per Year	Total Cost per Acre per Year	Total Cost per Mile per Year
Method 1 Treatment 1: Rodeo® (SOP)	64	1	6	$3.70	$2.69	3	$11.10	$8.07
Method 2 Treatment 1: Rodeo® + Perspective® + EsplAnade® 200 SC	64 7 7	3	6	$67.56	$49.14	1	$67.56	$49.14
Method 2 Treatment 2: Rodeo® + Oust® + EsplAnade® 200 SC	64 8 7	3	6	$67.55	$49.13	1	$67.55	$49.13

Zone One: Test 1, Recommendation

If total vegetation control is the goal of Zone One, using herbicides applied by a spray truck and 6-foot boomless nozzle is effective and efficient in achieving that goal; however, depending on herbicide mixture, this activity may need to be repeated multiple times per season. Use a mixture of post-emergent non-selective herbicide (Rodeo® at 64 oz./acre) with a selective herbicide (Oust® 8 oz./acre or Perspective® 7 oz./acre), and a pre-emergent non-selective herbicide (EsplAnade® 200 SC 7 oz./acre) to gain season-long total vegetation control with only one application. Timing of this application is usually late spring, one month after grass green-up in a 6-foot pattern applied to the ground and to existing vegetation. To reduce runoff possibility, avoid applications of EsplAnade® 200 SC when rainfall is forecast within 48 hours following application. If the material costs of either herbicide mixture containing post-emergent non-selective, selective, and pre-emergent non-selective herbicide is unacceptable, then a post-emergent non-selective herbicide should be applied up to four times per year (Rodeo® at a 64 oz./acre rate). The cost per mile or per acre is lower per year, but the challenge to this approach is scheduling manpower to make properly timed applications to stay ahead of the growing vegetation. Note that when using mixes with Oust® at 8 oz./acre, Perspective® at 7 oz./acre, or EsplAnade® 200 SC at 7 oz./acre, only one application per year can be made at maximum rate restrictions.

Calibration and verification that equipment is properly working should be conducted with water only before herbicide applications are made. Verify that the 6-foot boomless nozzle is properly set, and that the nozzle delivers a 6-foot pattern at the specified pressure range. Make sure ground speed-controlled sprayers are set to operate within a 5-10 mph range. Calibrate the equipment to make applications at 25 gallons per set speed range. A full 400-gallon tank making 6-foot-wide applications will treat 16 acres, or 22 miles.

Zone One: Test 2, Maintain Vegetation under Cable Rail or Guardrail with Guardrail Mower

The goal of this test was to improve mechanical vegetation maintenance efficiency and worker safety under cable rails and guardrails. Note that allowing vegetation to grow within Zone One does not accomplish the vegetation management goal of total vegetation control established in ODOT's Ohio Maintenance Operations Manual. This test evaluated two different mechanical methods for removal of vegetation under and around cable rails and guardrails in Zone One. This test was designed to compare the current SOP of string trimmers to a guardrail mower with respect to effectiveness of vegetation control, cost, and safety.

Methods

The equipment used in this test included hand-held string trimmers and a guardrail mower mounted on a tractor (Photograph 4). See Table 5 for equipment information.

Table 5. Zone One: Test 2, Equipment

Equipment	Equipment Number
Stihl 4- Stroke String Trimmer	N/A
Mower, U.S. Ditcher, Inc. GRM-60 Spider Guardrail Mower	6590004
Tractor, John Deere 6115 R	8931844

Testing was completed at locations with vegetation growing under guardrails and cable rails (Photograph 5).

Method 1: String Trimmer (SOP): In this method, a string trimmer crew was used to trim vegetation under guardrails or cable rails.

Method 2: Mechanical Guardrail Mower: A mechanical guardrail mower was used to trim vegetation under guardrails and cable rails.

Method 3: Mechanical Guardrail Mower followed by String Trimmer: A mechanical guardrail mower was used to trim vegetation under a guardrail or cable rail, followed by a string trimmer to clean up vegetation missed by the mower.

Photograph 4. U.S. Ditcher Inc. GM-60 Spider Guardrail Mower mounted on John Deere 6115 R Tractor

Photograph 5. String Trimmer vs. Guardrail Mower Test Site, Montgomery County

Results

This test determined that using the guardrail mower significantly reduced the labor hours per mile compared to using a string trimmer crew. The guardrail mower was tested in four locations with an average of 0.98 labor hour per mile production rate and was significantly faster than string trimming crews at testing locations in Green, Summit mile marker 115, Montgomery, and Summit mile marker 119 (P=0.0024, P=0.0049, P=0.0149, and P=0.0007, respectively) (Figure 3). Guardrail mower labor hours were based on one employee operating the equipment. The string trimmer was also tested at those four locations, with crews varying in size from one to three string trimmers. The string trimmer crews had significantly higher labor hours per mile than the guardrail mower (4.8–8.0 labor hours per mile).

Method 1 String Trimmer (SOP): String trimmers are capable of accessing all areas of guardrail and cable rail. String trimmers move slowly enough and the operators are close enough to their work that they can correct any missed vegetation with an additional pass before moving farther down the rail to trim.

Method 2 Mechanical Guardrail Mower: The guardrail mower cannot access all areas that need to be trimmed. The mower heads must be able to fit under the lowest part of the guardrail or cable rail in order to overlap and do a thorough mowing. Most guardrails and cable rails will be high enough, but there could be very low guardrails or cable rails in various areas. The guardrail mower cannot mow the end terminals of guardrails where there is a lot of hardware for that same reason. The guardrail mower can miss vegetation due to operator error, or if the strip of vegetation between the guardrail or cable rail and the road are wider than the mower head. In general, the guardrail mower was able to effectively mow the vegetation around the posts and along the rails as well as the string trimmers. Sometimes a narrow strip of vegetation was missed along the edge of the road, but the amount varied by location and equipment operator (Figure 4).

Method 3 Mechanical Guardrail Mower followed by String Trimmer: A string trimmer crew was utilized to remove vegetation that the guardrail mower missed in Method 3 (Summit Mile Marker 115). When using this combination method of guardrail mower, followed by a string trimmer crew to remove missed vegetation, production is 2.0 labor hours per mile and is significantly faster than the string trimmer crew alone (P=0.01).

Treatment Cost Comparisons: Tables 6 and 7 show the per-mile labor cost for controlling vegetation under guardrails or cable rails with mechanical methods. This labor time is adjusted by the number of employees and time it took the crew to complete the work. The most efficient number of string trimmers (2) was used as a comparison to other methods in Table 6. Note how the cost of Method 3 Treatment 1 is calculated in Table 7: guardrail mower plus a string trimmer to mow missed vegetation, with a total cost per mile of $103.14 ($75.64 + $27.50). While this is more expensive than the guardrail mower option, the cost of Method 3 Treatment 1 is significantly less expensive than the SOP (string trimmer crew) at $635.65 per mile.

Equipment Review: The guardrail mower head can be swapped during the course of work to operate on the left or right side of a tractor, which is helpful when mowing the median or outside edge of the road. The head height is easily adjusted by the operator to achieve desired mow height or avoid obstacles. The head can easily be pulled up out of the way for signs in the shoulder. Although the unit is easy to operate, there are a few drawbacks to the U.S. Ditcher, Inc. GRM-60 Spider Guardrail Mower. The unit must be placed on a tractor equipped with a PTO connection at 1,000 RPM (540 RPM available on request) output shaft, which is not readily available in the maintenance garages. By design, the hydraulics are not installed in a good location; when storing the head for transport, the hydraulics can be snapped off if the operator does not perform the movements in the proper sequence in order to stow away the heads. An old low guardrail was found in one of the counties tested that would not allow the heads to freely move under the rail, thereby preventing thorough trimming and leaving behind an unmowed strip.

Figure 3. Zone One: Test 2, Labor Hours

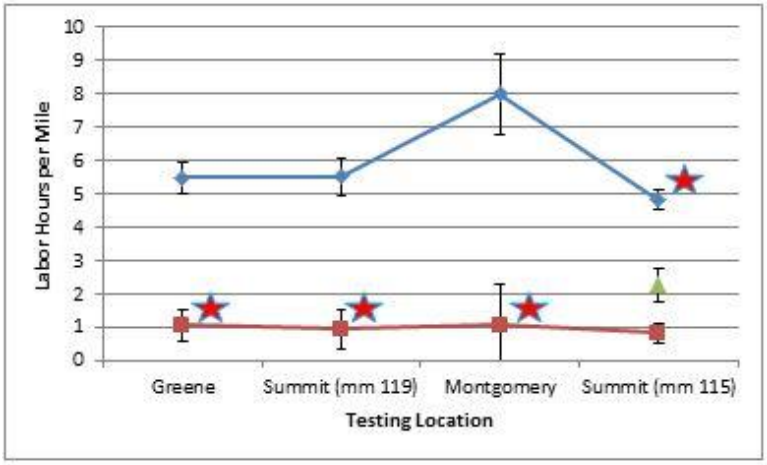
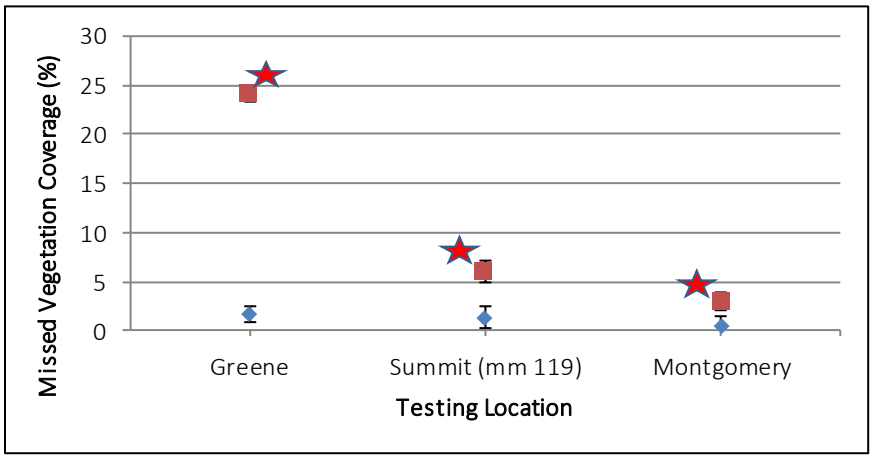


Figure 4. Zone One: Test 2, Missed Vegetation



Key to Figures 3-4.

- Statistically Significant Event
- String Trimmer Crew
- Guardrail Mower
- Guardrail Mower w/ String Trimmer Clean-up Crew
- Error Bars

Table 6. Zone One: Test 2, IVM Labor Comparison

IVM Method	# Staff	Average Wage	Miles per Hour	Labor Hours per Mile	Cost per Mile
String Trimmer (SOP)	2	$19.10	0.32	8.32	$158.91
Mechanical Guardrail Mower	1	$19.10	1.03	0.99	$18.91
Mechanical Guardrail Mower Followed by String Trimmer	2	$19.10	3.87	1.36	$25.79

Table 7. Zone One: Test 2, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Total Cost per Acre per Year
Method 1: String Trimmer (SOP)	4	0	33.28	$635.65
Method 2: Mechanical Guardrail Mower	4	0	3.96	$75.64
Method 3: Mechanical Guardrail Mower Followed by String Trimmer	4	0	5.40	$103.14

Zone One: Test 2, Recommendation

When overgrown vegetation needs to be cleared along guardrails or cable rails, a guardrail mower should be used. If an occasional narrow strip of vegetation remaining at the edge of the road is not aesthetically acceptable, or is unacceptable for other reasons, a string trimmer crew (one employee) could follow the guardrail mower and remove vegetation that the mower missed. Not only can more miles of vegetation removal per hour be achieved, but the total labor investment per mile is also lower than using string trimmers alone.

A number of safety concerns are created by using string trimmers such as: trip/fall hazards, weather exposure, worker traffic exposure, road debris, wildlife encounters, and dangers associated with operating a string trimmer. Many of these safety concerns can be eliminated or minimized by using the guardrail mower, since the operator of this equipment works from inside the protective tractor cab, and the tractor has built-in safety equipment (e.g., seatbelt, mirrors, lights, etc.). This alleviates worker exposure to many of these hazards and reduces other hazards.

Zone One Summary

The testing and analysis conducted for vegetation control in Zone One indicates that the most cost-effective and efficient method of vegetation control is the application of an herbicide mixture using a spray truck at all times (Photograph 6). See Table 8 for a comparison of Zone One recommended vegetation management options. The baseline labor cost for Zone One labor comparison is a string trimming crew removing vegetation four times per year. The labor cost of a spray truck is much lower than any of the mechanical options and cost savings can justify a return on investment. The results of testing indicate that only one application per year is needed if using an herbicide combination with non-selective, soil active, and pre-emergent herbicides. The spray truck is the most cost-effective method in Zone One, with a return on investment in only 13 miles of Zone One management per year.

Photograph 6. Production efficiency of a spray truck making herbicide applications can provide labor savings of $633.54 per mile per year when compared to string trimming the mile four times per year. In 13 miles of Zone One management, the cost of the equipment has been returned in labor savings.

When vegetation cannot be controlled with herbicides and becomes overgrown around cable rails or guardrails, a guardrail mower is recommended. Although the guardrail mower would also be used four times per year, the guardrail mower labor cost per mile is significantly lower than a crew using string trimmers. Due to access limitations around the terminal ends of guardrails, the guardrail mower cannot access all areas of guardrail or cable rail that need to be cleared. Therefore, a follow-up string trimmer crew may be needed to clear vegetation missed by the guardrail mower with a return on investment that is still significantly lower than using a string trimming crew alone.

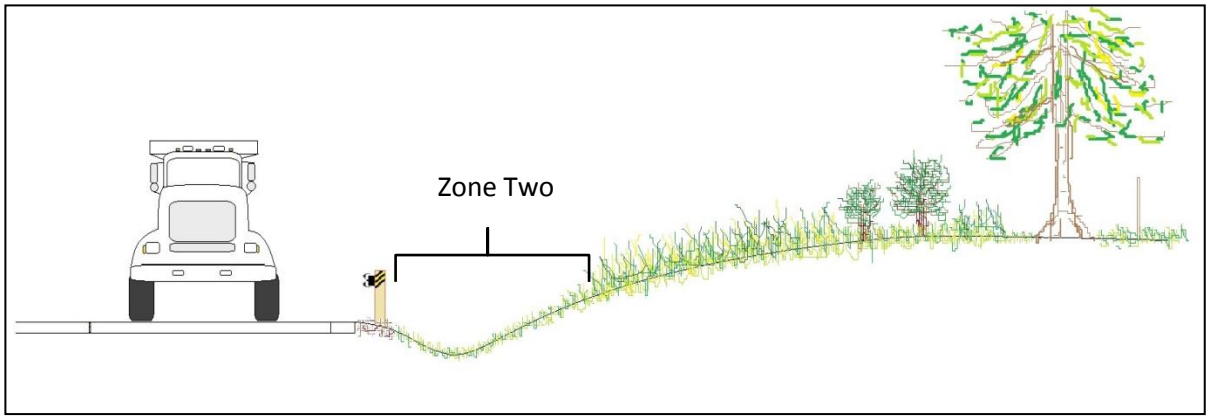
Return On Investment: See Table 8 Zone One Return On Investment - Per Mile Labor Cost Savings Analysis. The baseline labor cost for Zone One labor comparison is using string trimming crew to clear vegetation under a cable rail. The labor cost of using a skid spray with boomless nozzles is much lower than any of the mechanical options. With the savings incurred by eliminating the need for mechanical mowing, a return on investment for the spray equipment is quickly realized. The results of testing reveal that spraying a 6-foot width of herbicide along a cable rail or guardrail can eliminate the need for mechanical maintenance. Even with three applications per year, the labor savings of using a skid sprayer compared to using mechanical methods is significant. A skid sprayer with boomless nozzles is the most cost-effective method for achieving total vegetation control in Zone One. When using the skid sprayer, a return on investment through labor savings can be realized in 13 miles of vegetation management in Zone One. If using the Spider Guardrail Mower head, a return on investment through labor savings can be realized in 87 miles of Zone One vegetation maintenance. If a tractor purchase is required to run this mower head, a return on investment through labor savings can be realized in 256 miles of Zone One vegetation maintenance. String trimming can cost up to $635.64 per mile for labor when repeated four times per year, compared to $2.10 per mile per year for labor of one herbicide application.

Table 8. Zone One: Return On Investment - Per Mile Labor Cost Savings Analysis

Recommend Methods Compared to SOP	Purchase Price	Labor Cost Per Mile Per Year	Labor Cost Savings per Mile per Year	Miles Needed for ROI	Hours to Accomplish ROI
Test 2 Method 1: String Trimmer (SOP)	-	$635.64	N/A	N/A	N/A
Test 1 Method 1: Skid Sprayer with 6-ft. Boomless Nozzle	$8,073.00	$6.30	$629.34	13	1
Test 1 Method 2: Skid Sprayer with 6-ft. Boomless Nozzle	$8,073.00	$2.10	$633.54	13	1
Test 2 Method 2: Guardrail Mower Head Only	$48,650.00	$75.64	$560.00	87	84
Test 2 Method 2: Guardrail Mower with Tractor Purchase	$143,538.00	$75.64	$560.00	256	249
Test 2 Method 3: Guardrail Mower with Tractor Purchase and String Trimmer Clean-up	$143,538.00	$103.16	$532.48	270	262

Zone Two - Operational Zone

Figure 5. Diagram of ODOT's Roadside Management Zone Two



Zone Goal: Zone Two is also called the 'safety recovery zone'; it begins where Zone One ends behind the bare ground area (Figure 5). While the widths of Zone Two can vary depending on the type of right-of-way, Zone Two is typically 30 feet wide along interstate and divided highways. This area is managed to: provide a clearly visible area for vehicle recovery, provide sight distance for stopping on curves and at intersections, maintain visible and clear ditches, eliminate hazardous trees and tree canopy shading pavement, control weeds, prevent erosion, accommodate underground utilities, and enhance visual quality (Ohio Maintenance Operations Manual, 803.2). Broadleaf and woody weeds grow taller and faster than grass. This disparity often creates sight distance and visual quality concerns that are addressed with vegetation maintenance. Challenges in Zone Two include managing turf height and cover while also controlling tall weeds and maintaining visual quality.

Overview of Current Maintenance Practices: Zone Two vegetation management activities can include mechanical mowing and broadcast chemical applications of plant growth regulators (PGR) and/or broadleaf selective herbicides. Mowing without PGR or herbicide treatment is the standard operating procedure (SOP) for maintenance in this zone across many districts and is typically performed three to five times per year, generally around the growing season holidays, with an additional mow at the beginning and/or end of the season.

Safety: On highways, turf height and weeds can cause sight distance issues and create unsafe conditions for traveling motorists. For employees, risks associated with vegetation management in Zone Two relate to the extensive hours spent in this zone, along with repeated exposure due to mowing occurring multiple times per year. Safety risks include: proximity to traffic; injury from projectiles; working on or near slopes; equipment rollovers; and exposure to weather, wildlife, and harmful insects. More frequent mowing occurrences per season result in additional time that employees are exposed to these risks.

Objective: All of the following tests in Zone Two addressed turf height and weed coverage as the most significant factors in reducing labor and mowing occurrences. The objectives of the tests were to evaluate various mechanical and/or chemical control methods for controlling turf height and reducing broadleaf weed coverage in several different scenarios. These scenarios included:

- Interstate/divided highway open areas
- Interstate/divided highway areas containing guardrails or cable rails
- Two-lane highways with narrow shoulders, numerous fixed obstacles, and difficult terrain
- Areas with limited access where mowing is not possible ("no-mow" areas)
- Areas with steep slopes

Zone Two: Test 1, Maintain Turf in Open Areas with Spray Truck and Boomless Nozzle

This test was intended for interstates or other areas that are frequently mowed and have few obstacles. This test evaluated vegetation response to five combinations of chemical and mechanical control, as well as equipment, material, and labor costs to determine the recommended method of maintenance.

Methods

The equipment used in this test was a truck equipped with a 425-gallon skid sprayer and boomless nozzle with a 22-foot-wide spray pattern (Photograph 7) to perform chemical applications. This test used two different spray trucks; the skid sprayer and nozzles were moved onto a different truck in the second year of testing. A batwing mower mounted on a tractor (Photograph 8) was used to perform mechanical mowing. See Table 9 for equipment information.

Table 9. Zone Two: Test 1, Equipment

Equipment	Equipment #
Spray Truck, Ford F450 CC	2533083
Spray Truck, GMC T7500	3210114
Skid Sprayer, Chemical Container 425-Gallon	8100160
Boominator 3750 RS 22-foot Nozzle	N/A
Tractor, New Holland TS100	8931118
Batwing Mower, Alamo Eagle 15	6400516

Method 1: (1 Treatment) Mow Only (SOP): Mowing occurred as needed in 2015 and 2016 to maintain height for sight distance on the usual schedule (three to five times per season).

Method 2: (2 Treatments) Broadleaf Selective Herbicide + Mowing: In this method, two different broadleaf, selective herbicides were applied in late spring/early summer to control broadleaf herbaceous and woody weeds. In 2015 and 2016, mowing occurred as needed to maintain vegetation height for sight distance.

Treatment 1: Perspective® (aminocyclopyrachlor + chlorsulfuron)

Treatment 2: Triclopyr 3 (triclopyr)

Method 3: (2 Treatments) PGR + Broadleaf Selective Herbicide + Mowing: In this method, two different treatments of PGR and broadleaf selective herbicides were used. In 2015, PGR and broadleaf herbicides were combined in a tank mix and applied at the same time so that the herbicides could be applied on one day to minimize hours needed for ODOT staff. In 2016, PGR was applied in the spring two weeks after the grass turned green. One month later, broadleaf selective herbicide was applied. In 2015 and 2016, mowing occurred to maintain vegetation height for sight distance.

Treatment 1: Plateau® (imazapic) + Triclopyr 3 (triclopyr)

Treatment 2: Embark® 2S IVM (mefluidide) + Perspective® (aminocyclopyrachlor + chlorsulfuron)

Photograph 7. Spray truck making broadcast herbicide application with a 22-foot-wide spray nozzle.

Photograph 8. Tractor mowing with a rear-mounted, hitch-drawn, 15-foot batwing mower deck.

Results

All herbicide treatments significantly reduced broadleaf weed percent coverage compared to the mow-only treatment, allowing for a reduction in mowing occurrences in the herbicide treated plots. Testing started in 2015 with an early spring mow of every plot to establish a baseline for testing. After two consecutive spring herbicide applications in 2015 to 2016, the mow-only plots contained significantly more broadleaf weed coverage (38%) than broadleaf herbicide plots (average of 6%). The application of PGR suppressed grass height when applied at the ideal time, allowing for further reduction in mow events (Figures 6 and 7). Mow-only plots were mowed three to four times each year compared to one to two mows each year for the plots where PGR and broadleaf herbicides were applied. Assessments ended in summer 2016 before a fall mow was recorded; this fall mow is expected to take place for all methods in 2016.

Method 1 Treatment 1: Mow Only (SOP): At the start of testing in 2015, mow-only plots had 10% broadleaf weed coverage. Three mowing events in 2015 maintained grass height at an average of 8 inches. In 2015, broadleaf weed coverage reached a maximum of 41%, which was significantly higher than herbicide treatments at that time. Broadleaf weed coverage was also significantly higher than all other treatments at the end of the 2015 season and start of the 2016 season (22% and 38%, respectively) (Photograph 9). Mowing in 2015 had little effect on reducing broadleaf coverage. Three mowing events in 2016 maintained grass height at an average of 8 inches. Assessments ended in summer 2016; although a fourth mow (fall mow back) is typical for this location and is expected to occur, a 2016 fall mow back was not recorded in the assessments. In 2016, broadleaf weed coverage reached a maximum of 43%. Every assessment in 2016 indicated that broadleaf weed coverage was significantly higher in the mow-only plots than it was in every other treatment. Mowing in 2016 seemed to have little effect on reducing broadleaf coverage. By the end of testing, mow-only plots maintained grass height with seven recorded mowing events from 2015 to 2016.

Method 2: Broadleaf Selective Herbicide + Mowing: Both broadleaf herbicides (Perspective® and Triclopyr 3) significantly reduced the percent of broadleaf weed coverage (Photograph 10). With a reduction in broadleaf weeds in both 2015 and 2016, the number of mows was reduced to between two and four times per year in the broadleaf herbicide plots compared to the mow-only (SOP) plots, with three to four mows per year.

Treatment 1: Perspective® + Mowing: At the start of testing in 2015, Perspective® plots had 10% broadleaf coverage and a grass height of 8 inches. The spring 2015 application maintained grass height throughout the growing season without needing to be mowed until fall. Grass height remained at an average of 9 inches in 2015. The 2015 application eliminated the seasonal summer peak of broadleaf weeds experienced in the mow only plots. By the end of 2015 with 5% coverage, broadleaf weeds were significantly lower than in the mow only plots. The spring 2016 application of Perspective® and two mows in 2016 maintained grass height to an average of 11 inches. With continued effects from the treatment in 2015 and a treatment in 2016, Perspective® significantly reduced broadleaf weed coverage compared to mow-only plots in every assessment in 2016 and ended testing with 2% broadleaf weed coverage (P=0.0091). By the end of testing, Perspective® plots maintained grass height with five recorded mowing events from 2015 to 2016 (reduced mowing from seven times in the SOP plots in the same time period).

Treatment 2: Triclopyr 3 + Mowing: At the start of testing in 2015, Triclopyr 3 plots had 11% broadleaf coverage and a grass height of 8 inches. The spring 2015 application maintained grass height throughout the growing season without needing to be mowed until fall. Grass height remained at an average of 10 inches in 2015. The 2015 application eliminated the seasonal summer peak of broadleaf weeds experienced in the mow-only plots. By the end of 2015 with 6% coverage, broadleaf weeds were significantly lower than in the mow-only plots. The spring 2016 application of Triclopyr 3 and three mows in 2016 maintained grass height at an average of 9 inches. With continued effects from the treatment in 2015 and a treatment in 2016, Triclopyr 3 significantly reduced broadleaf weed coverage (compared to mow-only plots in every assessment in 2016) and ended testing with 7% broadleaf coverage (P=0.0209). By the end of testing, Triclopyr 3 plots maintained grass height with six recorded mowing events from 2015 to 2016 (reduced mowing from seven times in the SOP plots in the same time period).

Method 3: PGR +Broadleaf Selective Herbicide +Mowing: In 2015, PGR and broadleaf herbicides were combined in a tank mix and applied at the same time so that the herbicides could be applied on one day to minimize hours needed for ODOT staff. In order to make this combined application, a compromise between the ideal date for applying PGR and the ideal date for applying broadleaf application was made. The compromise lead to a slightly late application of PGR and a slightly early application of broadleaf herbicide. Results from this combined application reduced the number of mows from the mow-only plots by one mow and had the same amount of mows as the plots where only broadleaf herbicide was applied. In 2016, two separate application days were used to determine whether better results could be obtained by applying the PGR and selective herbicide separately, each in their ideal spray window. The result of separating the PGR and broadleaf herbicide was a further reduction in mowing, with only a fall mow back needed in these plots, while the plots that only received the broadleaf herbicide needed up to four mows in 2016. The reduction in mowing was worth the extra cost of labor in making two separate applications.

Treatment 1: Embark® 2S IVM + Perspective® + Mowing: At the start of testing in 2015, Embark® 2S IVM + Perspective® plots had 10% broadleaf weed coverage and a grass height of 8 inches. The combined application of Embark® 2S IVM + Perspective® occurred in spring 2015 and maintained grass height throughout 2015 without needing to be mowed until fall 2015. Grass height remained at an average of 9 inches in 2015. The 2015 application eliminated the seasonal summer peak of broadleaf weeds experienced in the mow-only plots. With 6% coverage by the end of 2015, broadleaf weeds were significantly lower than in the mow-only plots. In 2016, the application of Embark® 2S IVM two weeks after grass green-up, followed one month later by Perspective®, maintained grass height throughout the 2016 testing period at an average of 8 inches tall. This average was maintained without mowing. Perspective® has the ability to reduce seed head and grass height, which lengthened the benefit of the PGR application (Photograph 11). With continued effects from the treatment in 2015, and a treatment in 2016, Embark® 2S IVM + Perspective® had significantly reduced broadleaf weed coverage (compared to mow-only plots in

every assessment in 2016) and ended testing with less than 1% broadleaf weed coverage (P=0.0080). By the end of testing, Embark® 2S IVM + Perspective® plots maintained grass height with three recorded mowing events from 2015 to 2016 (reduced mowing from seven times in the SOP plots in the same time period).

Treatment 2: Plateau® + Triclopyr 3 + Mowing: At the start of testing in 2015, Plateau® + Triclopyr 3 plots had 9% broadleaf weed coverage and a grass height of 8 inches. The combined application of Plateau® + Triclopyr 3 was in spring 2015 and maintained grass height throughout 2015 without needing to be mowed until fall 2015. Grass height remained at an average of 9 inches in 2015. The 2015 application eliminated the seasonal summer peak of broadleaf weeds experienced in the mow-only plots. With 3% coverage by the end of 2015, broadleaf weeds were significantly lower than in the mow-only plots. In 2016, the application of Plateau® two weeks after grass green-up, followed one month later by Triclopyr 3, maintained grass height throughout the 2016 testing period at an average of 10 inches tall. This average was maintained without mowing. The Triclopyr 3 applied after PGR had significantly longer grass than the PGR + Perspective® plots, but the grass appeared to be healthier in this year with minimal precipitation. With continued effects from the prior year's treatment and a treatment in 2016, Plateau® + Triclopyr 3 significantly reduced broadleaf weed coverage compared to mow-only plots in every assessment in 2016 and ended testing with 3% broadleaf coverage (P=0.0114). By the end of testing, Plateau® + Triclopyr 3 plots maintained grass height, with three recorded mowing events from 2015 to 2016 (reduced mowing from seven times in the SOP plots in the same time period).

Figure 6. Grass Height Comparison

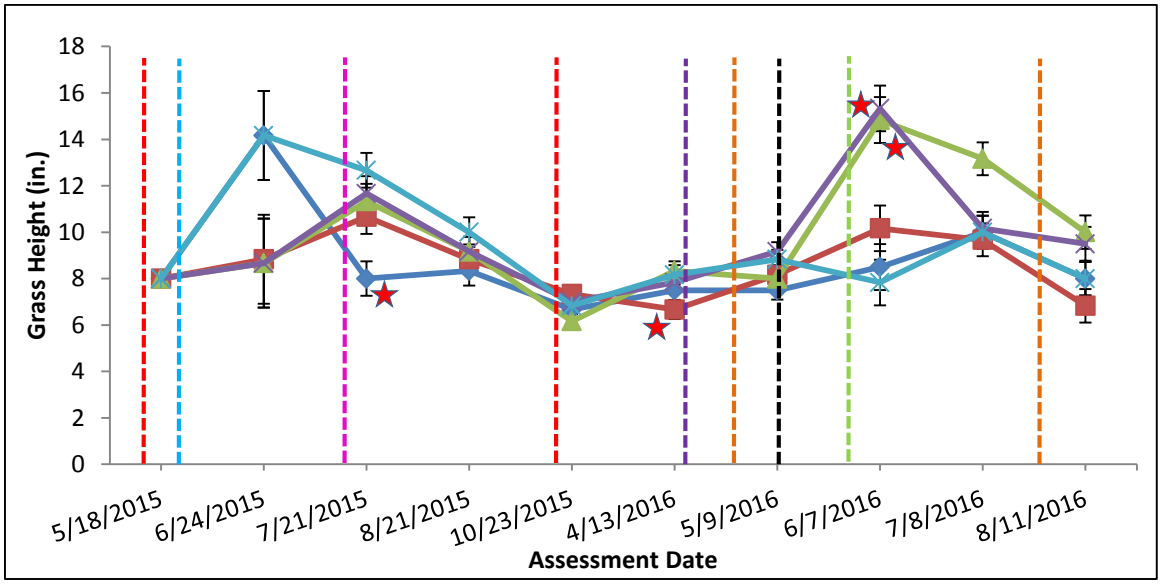
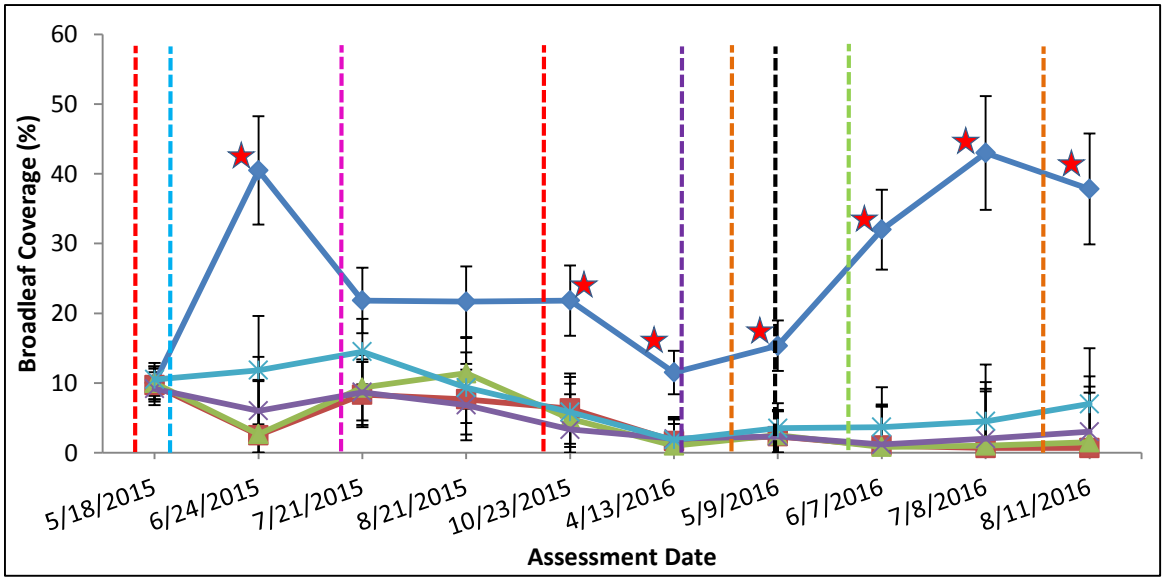


Figure 7. Broadleaf Coverage Comparison



Key to Figures 6-7.

- Statistically Significant Event
- Mow Only
- Perspective® + Embark® 2S IVM
- Perspective®
- Triclopyr 3 + Plateau®
- Triclopyr 3
- Mechanical Control (mow all)
- Mechanical Control (mow only)
- Mechanical Control (mow only and broadleaf only)
- Mechanical Control (mow only and Triclopyr 3)
- Herbicide Control (both broadleaf herbicides + PGR)
- Herbicide Control (PGR only)
- Herbicide Control (both broadleaf herbicides)
- Error Bars

Photograph 9. Mow-only plots grew taller and faster and had a larger percent of broadleaf weeds.

Photograph 10. Grass dominates sites that received only broadleaf selective herbicide applications. Grass is greener but taller.

Photograph 11. Turf height is controlled as a result of properly timed PGR application but has slight brown color with Perspective® application.

Treatment Cost Comparisons: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing these labor costs, there are several factors that influence the costs, such as variations in methods, equipment efficiency, number of staff, and occurrences per year. Table 10 describes the labor cost to mow one acre compared to spraying one acre with a 22-foot spray nozzle. Table 11 describes the labor cost to treat one acre for one year with each method used in this test. The materials costs are located in Table 12, which shows the per-acre and per-mile cost of each herbicide used in this test. The cost of materials can be added to the labor cost for each method to see the total cost per method.

Equipment Review: The following skid sprayer equipment review is the same for all tests in Zone Two where the spray truck was used. For herbicide applications, the spray equipment used for this project worked well and was easy to use. The Road Master control panel was integral to ensuring that the herbicide was applied at the proper rate. Prior to the second year of applications, the spray tank was modified with Davey Resource Group's support. Modifications included the addition of the following:

- Shut-off valves
- An extension handle for the applicator to reach external controls without the necessity of climbing onto the truck
- A step for easy access onto the back of the truck
- Plumbed a Cleanload™ Chemical Eductor to add herbicides into a spray tank and triple rinse empty containers

Table 10. Zone Two: Test 1, RIVM Method Labor Comparison

RIVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre
Batwing Mower (15-foot width)	1	$19.10	3.86	0.27	$5.16
Spray Truck (22-foot spray nozzle)	1	$19.10	24.47	0.04	$0.76

Table 11. Zone Two: Test 1, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Total Cost per Acre per Year
Method 1 Treatment 1: Mow Only (SOP)	4	0	1.08	$20.63
Method 2 Treatment 1: Perspective® + Mowing	2	1	0.58	$11.08
Method 2 Treatment 2: Triclopyr 3 + Mowing	3	1	0.85	$16.24
Method 3 Treatment 1: Embark® 2S IVM + Perspective® + Mowing	1	2	0.35	$6.69
Method 3 Treatment 2: Plateau® + Triclopyr 3 + Mowing	1	2	0.35	$6.69

Table 12. Zone Two: Test 1, Herbicide Mixture Cost Comparison

Maintain Turf in Open Areas Herbicide Mix	Rate (oz./acre)	# Products	Spray Pattern Width (ft.)	Cost per Acre	Cost per Mile	Occurrences per Year	Total Cost per Acre per Year	Total Cost per Mile per Year
Method 3 Treatment 1: Plateau® (PGR)	4	1	22	$3.43	$9.15	1	$3.43	$9.15
Method 3 Treatment 2: Embark® 2S IVM (PGR)	32	1	22	$32.10	$85.60	1	$32.10	$85.60
Method 2 Treatment 2: Triclopyr 3	64	1	22	$7.35	$19.60	1	$7.35	$19.60
Method 2 Treatment 2: Perspective®	5	1	22	$4.60	$12.27	1	$4.60	$12.27
Method 3 Treatment 1: Plateau® (PGR) + Triclopyr 3	4 64	2	22	$10.78	$28.75	1	$10.78	$28.75
Method 3 Treatment 2: Embark® 2S IVM (PGR) + Perspective®	16 5	2	22	$36.70	$97.87	1	$36.70	$97.87

Zone Two: Test 1, Recommendation

Spray PGR to established turf stands followed by late spring/early summer broadleaf selective herbicide to reduce mowing down to one to two occurrences per year. PGR should be applied every other year to allow grass to go to seed in the off years and increase the grass stand. Spray broadleaf herbicide annually to keep weeds under control, allowing grass to persist in order to maintain visual quality and sight distance in Zone Two. Plateau® is the recommended PGR, as the cost per acre is much lower than Embark® 2S IVM, and the results are similar. Perspective® is the recommended broadleaf herbicide, as its properties suppress turf height. Triclopyr 3 is the recommended herbicide if the health or appearance of turf is more important than height suppression, or the goal is to allow grass to produce seed in an effort to improve turf stands. PGR could also be used selectively in directed applications around areas that require significant amounts of annual mechanical labor.

Zone Two: Test 2, Maintain Turf under Guardrail or Cable Rail with Spray Truck and Boomless Nozzle

This test was intended for interstates or other areas that are frequently mowed and where vegetation is maintained in front of and under cable rails such as along I-71. This test area featured a cable rail set back 10 feet from the road edge with 10 feet of mowable turf between the rail and road edge. This test evaluated vegetation response to three combinations of chemical and mechanical control, as well as equipment, material, and labor costs to determine the recommended method of maintenance.

Table 13. Zone Two: Test 2, Equipment

Equipment	Equipment Number
Spray Truck, GMC T7500	3210114
Skid Sprayer, Chemical Container 425-Gallon	8100160
Boominator 2651 Right 10-Nozzle	N/A
Tractor, John Deere 5085M	8931612
Batwing Mower, Alamo Eagle 15	6400546

Methods

The equipment used in this test was a truck equipped with a 425-gallon skid sprayer and boomless nozzle with a 10-foot-wide spray pattern (Photograph 12) to perform chemical applications. A tractor with a rear-mounted mower (Photograph 13) was used to perform mechanical mowing, and manual string trimming crews cleared vegetation under the cable rail (Photograph 14). See Table 13 for equipment information.

Method 1: (1 Treatment) Mow Only (SOP): Mowing and string trimming was done on an as-needed basis for sight distance.

Method 2: (2 Treatments) PGR + Broadleaf Selective Herbicide + Mowing: In this method, two different treatments of PGR and Broadleaf Selective Herbicide were used. PGR was applied in the spring two weeks after grass green-up. Approximately one month later, broadleaf selective herbicide was applied. Mowing and string trimming was done on an as-needed basis for sight distance.

Treatment 1: Plateau® (*imazapic*) + Triclopyr 3 (*triclopyr*)

Treatment 2: Embark® 2S IVM (*mefluidide*) + Perspective® (*aminocyclopyrachlor* + *chlorsulfuron*)

Photograph 12. Spray truck making PGR application in April 2016 with a 10-foot-wide spray nozzle pattern. The goal is to stop turf growth for 8 weeks.

Photograph 13. Tractor pulling rear-mounted mower deck to clear overgrown vegetation between cable rail and shoulder.

Photograph 14. Manual string trimmer crew clears overgrown vegetation under cable rails in June 2016.

Results

Both PGR treatments significantly suppressed grass height compared to the mow-only plots. Both broadleaf herbicide applications significantly reduced broadleaf weed coverage compared to the mow-only plots. The reduced weeds and reduced grass heights allowed for a reduction in the number of mowing events in the treated plots (Figures 8 and 9). The PGR, followed by broadleaf herbicide plots, contained significantly less broadleaf weed coverage (average of 1%) compared to the mow-only plots (15%). Mow-only plots were mowed twice during testing, while PGR + broadleaf herbicide plots were mowed once in midsummer. Assessments ended in summer 2016 before a fall mow was recorded; this fall mow is expected to take place in 2016 for all methods.

Method 1 Treatment 1: Mow Only (SOP): Testing began in spring 2016, with mow-only plots at 2% broadleaf weed coverage and a grass height of 7 inches. The grass grew to a maximum of 45 inches in June before the first scheduled mow. Broadleaf weed coverage reached a maximum of 15% and was significantly higher than all other treatments in May, June, and July, even with the dip in broadleaf weed coverage in June (Photograph 15).

Method 2 Treatment 1: Embark® 2S IVM + Perspective®+ Mowing: Prior to the spring 2016 application, the Embark® 2S IVM + Perspective® plots had less than 1% broadleaf weed coverage and a grass height of 7 inches. The application of Embark® 2S IVM, followed by Perspective®, maintained grass height without needing to be mowed until mid-July (Photograph 16). Grass height remained at an average of 12 inches in 2016 and was significantly shorter than Triclopyr 3 + Plateau® through June and July. The application eliminated the seasonal summer peak of broadleaf weeds experienced in the mow-only plots. By the end of testing, broadleaf weed coverage was less than 1% (P=0.0075), which was significantly less than the mow-only plots.

Method 2 Treatment 2: Plateau® + Triclopyr 3 + Mowing: Prior to the spring 2016 application, the Plateau® + Triclopyr 3 plots had 0% broadleaf weed coverage and a grass height of 8 inches. The application of Plateau® followed by Triclopyr 3 maintained grass height without needing to be mowed until mid-July (Photograph 17). By the end of testing, Triclopyr 3 + Plateau® plots had significantly longer grass (18 inches) than both mow-only plots (11 inches) after one mow and Embark® 2S IVM + Perspective® (13 inches) plots with no mows. Sixty days after the PGR application, the turf in the Plateau® + Triclopyr 3 plots appeared to be healthier than the other methods The broadleaf herbicide application eliminated the seasonal summer peak of broadleaf weeds experienced in the mow-only plots. By the end of testing, broadleaf weed coverage was 2% (P=0.0098), which was significantly less than the mow-only plots.

Figure 8. Broadleaf Coverage Comparison

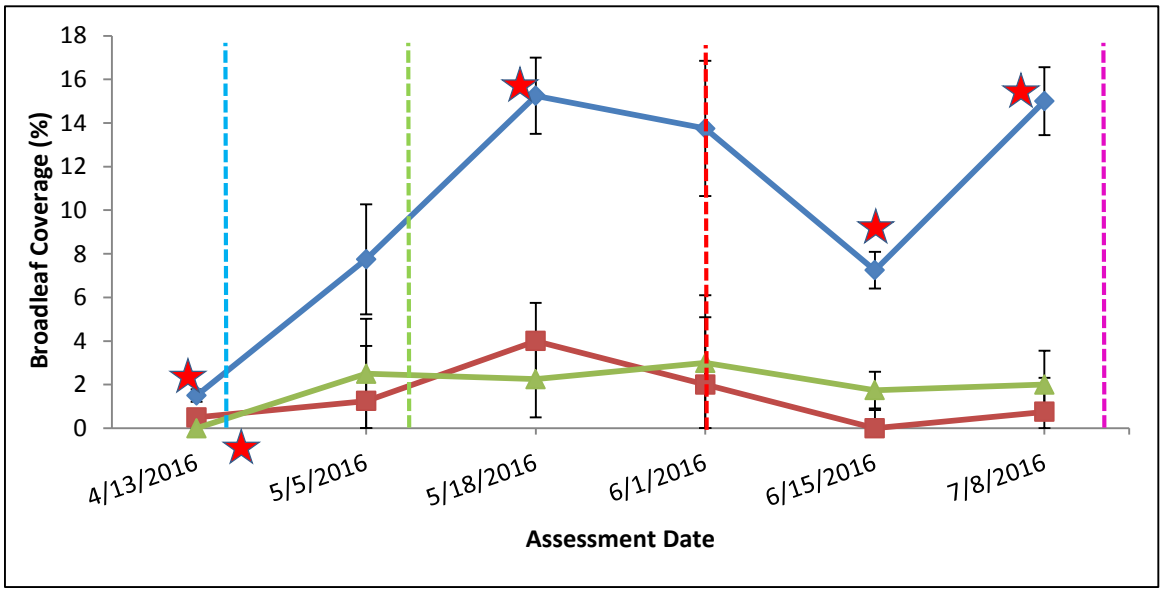
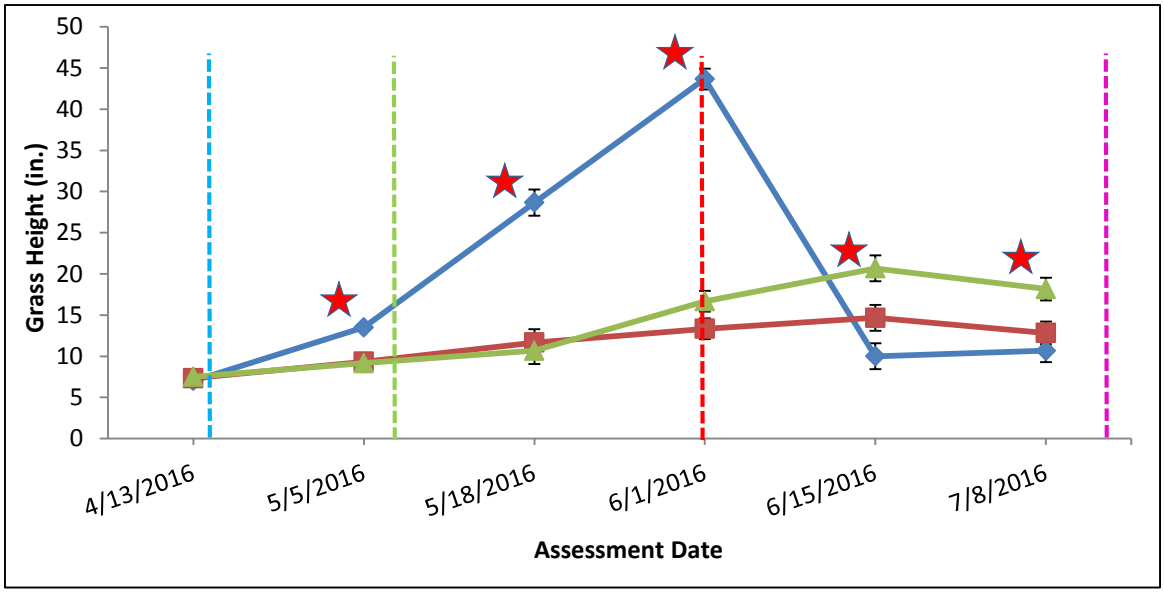


Figure 9. Grass Height Comparison



Key for Figures 8-9.

- Statistically Significant Event
- Mow Only
- Perspective® + Embark® 2S IVM
- Triclopyr 3 + Plateau®
- Mechanical Control (mow only)
- Mechanical Control (mow all)
- Herbicide Control (both PGR)
- Herbicide Control (both broadleaf herbicides)
- Error Bars

Photograph 15. This picture shows significant grass height differences between plots treated with PGR in the foreground and mow-only plots in the background.

Photograph 16. Turf height is controlled as a result of properly timed Embark® application. The cable rail is visible, although no mechanical clearing has been performed.

Photograph 17. Turf height is controlled as a result of properly timed Plateau® application. The cable rail is visible, although no mechanical clearing has been performed.

Treatment Cost Comparisons: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing these labor costs, there are several factors that influence the costs, such as variations in methods, equipment efficiency, number of staff, and occurrences per year. Table 14 describes the labor cost to mow one acre compared to spraying one acre with a 10-foot spray nozzle. Table 15 describes the labor cost to treat one acre for one year with each method used in this test. The materials costs are located in Table 16, which shows the per-acre and per-mile costs of each herbicide used in this test. To determine the total cost per method, the cost of materials can be added to the labor cost for each method.

Table 14. Zone Two: Test 2, RIVM Method Labor Comparison

RIVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre
Batwing Mower (15-foot width)	1	$19.10	1.36	0.73	$14.55
String Trimming	2–3	$19.10	0.17–0.37	5.54–21.45	$105.81–$409.70
Spray Truck (10-foot spray nozzle)	1	$19.10	12	0.08	$1.59

Table 15. Zone Two: Test 2, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Total Cost per Acre per Year
Method 1 Treatment 1: Mow Only (SOP)	4	0	25.10–88.74	$481.48–1,697.00
Method 2 Treatment 1: Embark® 2S IVM + Perspective® + Mowing	3	2	18.99–66.72	$364.15–1,275.82
Method 2 Treatment 2: Plateau® + Triclopyr 3 + Mowing	3	2	18.99–66.72	$364.15–1,275.82

Table 16. Zone Two: Test 2, Herbicide Mixture Cost Comparison

Herbicide Mix	Rate (oz./acre)	# Products	Spray Pattern Width (ft.)	Cost per Acre	Cost per Mile	Occurrences per Year	Total Cost per Acre per Year	Total Cost per Mile per Year
Method 2 Treatment 1: Embark® 2S IVM (PGR)	32	1	10	$32.10	$38.91	1	$32.10	$38.91
Method 2 Treatment 1: Perspective®	5	1	10	$4.60	$5.58	1	$4.60	$5.58
Method 2 Treatment 2: Plateau® (PGR)	4	1	10	$3.43	$4.16	1	$3.43	$4.16
Method 2 Treatment 2: Triclopyr 3	64	1	10	$7.35	$8.91	1	$7.35	$8.91

Zone Two: Test 2, Recommendation

Spray PGR to established turf stands in spring followed by late spring/early summer broadleaf selective herbicide applications to postpone spring or early summer mowing until midsummer. PGR should be applied every other year to allow grass to go to seed in the off years and increase the grass stand so it can better compete against weeds. Plateau® is the recommended PGR, as the results are similar and the cost per acre is much lower than Embark® 2S IVM. PGR could also be selectively used in directed applications around areas that require significant amount of annual mechanical labor.

Spray selective broadleaf herbicide on an annual basis to keep weeds under control and allow grass to persist in order to maintain visual quality and sight distance in Zone Two. Perspective® is the recommended broadleaf herbicide, as it has properties that extend the duration of turf height suppression. Triclopyr 3 is the recommended herbicide if the health or appearance of turf is more important than height suppression, or if the goal is to allow grass to produce seed in an effort to improve turf stands.

Following these recommendations will allow ODOT to skip one mow per year along rails, thereby reducing costs and freeing up staff to work on other maintenance work. It will also reduce the exposure risk associated with maintenance workers maintaining vegetation on the right of way thereby increasing employee safety.

Zone Two: Test 3, Maintain Turf at Road Edge, no Rail with Spray Truck and Boomless Nozzle

This test was intended for two-lane highways or similar areas where the ROW is narrow and there are many obstacles such as mailboxes and signs which make mowing difficult and inefficient. This test evaluated vegetation response to three combinations of chemical and mechanical control, as well as equipment, material, and labor costs to determine the recommended method of maintenance.

Methods

The equipment used in this test was a truck equipped with a 425-gallon skid sprayer and boomless nozzle with a 10-foot-wide spray pattern (Photograph 18) to perform chemical applications. This test used two different spray trucks; the skid sprayer and nozzles were moved onto a different truck in the second year of testing. A tractor with rear and side-mounted flail mowers (Photograph 19) was used to perform mechanical mowing. See Table 17 for equipment information.

Table 17. Zone Two: Test 3, Equipment

Equipment	Equipment Number
Spray Truck, Ford F450 CC	2533083
Spray Truck, GMC T7500	3210114
Skid Sprayer, Chemical Container 425-Gallon	8100160
Boominator 2651 Right 10-Nozzle	N/A
Tractor, New Holland TS115	8931436
Alamo Flail Mower	6540210
Alamo Flail Mower	6549493

Method 1: (1 Treatment) Mow Only (SOP): Mowing was performed as needed to maintain height for sight distance.

Method 2: (2 Treatments) PGR + Broadleaf Selective Herbicide + Mowing: In this method, two different treatments of PGR and Broadleaf Selective Herbicide were used (Photograph 20). In 2015, PGR and broadleaf herbicides were combined in the tank and applied at the same time. In 2015, a second application of the broadleaf herbicide used in Treatment 1 was made. In 2106, PGR was applied in the spring two weeks after the grass greened up. One month later, broadleaf selective herbicide was applied. Mowing occurred as needed in 2015 and 2016 to maintain vegetation height for sight distance.

Treatment 1: Plateau® (imazapic) + Triclopyr 3 (triclopyr)

Treatment 2: Embark® 2S IVM (mefluidide) + Perspective® (aminocyclopyrachlor + chlorsulfuron)

Photograph 18. Spray truck used in 2016 to make broadcast applications with boomless nozzle.

Photograph 19. Tractor with flail mowers.

Results

All herbicides significantly reduced broadleaf weed coverage compared to the mow-only treatment (Photograph 21). The application of PGR suppressed grass height, allowing for a reduction in the amount of mowing events per growing season (Figures 10 and 11). After two consecutive spring herbicide applications in 2015 and 2016, the mow-only plots contained significantly more broadleaf weed coverage (53%) than Embark® 2S IVM + Perspective® and Plateau® + Triclopyr 3 plots (19%, and 5%, respectively). Also PGR applications in 2015 and 2016 allowed for up to 60 days of height suppression.

Assessments from testing in 2016 ended earlier than planned due to ditching that occurred in one replication and utility spraying in another replication. Assessments and analysis are based on results seen prior to those interferences at the test site.

Method 1 Treatment 1: Mow Only (SOP): Mow-only plots started testing in 2015, with 38% broadleaf coverage (Photograph 22). Mowing did not reduce the broadleaf weed coverage from 2015 to 2016. Mow-only plots in summer 2015 reached a maximum of 38%. In summer 2016, broadleaf coverage reached a maximum of 53%. Mowing also provided temporary grass height control but needed repeated mowing to control the height. The grass grew to a maximum of 14 inches in summer 2015 before the second mow. The grass grew to a maximum of 12 inches before the first mow in 2016. By the end of testing in 2016, the mow-only plots contained the most broadleaf weed coverage (53%) and had an average grass height of 12 inches, with one mow in 2016. Mow-only plots were mowed three times in 2015 and are likely to be mowed three times in 2016.

Method 2: PGR + Broadleaf Selective Herbicide + Mowing: In 2015, PGR and broadleaf herbicides were combined in a tank mix and applied at the same time so that the herbicides could be applied on one day to minimize hours needed for ODOT staff. In order to make this combined application, a compromise between the ideal date for applying PGR and the ideal date for applying broadleaf application was made. The compromise led to a slightly late application of PGR and a slightly early application of broadleaf herbicide. Results from this combined application showed a reduction in the number of mows from the mow-only plots. In 2016 two separate application days were used to determine if better results could be obtained by separately applying the PGR and selective herbicide, each in their ideal spray window. The benefits of separating the PGR showed that each suppressed grass height for 30 days after PGR application, but the Triclopyr 3 experienced a dramatic increase in grass height compared to the Perspective® application. Herbicide results from this test can be compared to Zone One: Test 1.

Treatment 1: *Plateau® + Triclopyr 3 + Mowing:* At the start of testing in spring 2015, Plateau® + Triclopyr 3 plots had 22% broadleaf weed coverage. With an application of Triclopyr 3 + Plateau® in spring 2015, and a second application of Triclopyr 3 60 days later, this treatment reduced broadleaf herbicide coverage by 20%, resulting in 2% broadleaf weed coverage by fall 2015. The 2015 PGR application resulted in an average grass height of 10 inches, with two mows in spring and fall. The 2016 application of Plateau® resulted in an average grass height of 10 inches, with no mows prior to the end of assessments in 2016; however, grass height seemed to increase after the Triclopyr 3 application. The application of Triclopyr 3 kept broadleaf weed coverage down to 5% by the last assessment in 2016. By the end of testing in 2016, Plateau® + Triclopyr 3 had the lowest broadleaf coverage (5%) and the highest grass height (15 inches) with no mows by July 2016.

Treatment 2: Embark® 2S IVM + Perspective® + Mowing: At the start of testing in spring 2015, Embark® 2S IVM + Perspective® plots had 19% broadleaf weed coverage. The 2015 application eliminated the seasonal summer peak of broadleaf weeds experienced in the mow-only plots. The application kept broadleaf weed coverage low throughout the season and resulted in 3% broadleaf weed coverage by fall 2015. This herbicide and PGR application resulted in an average grass height of 10 inches with two mows in spring and fall of 2015. The 2016 application of Embark® 2S IVM resulted in an average grass height of 7 inches, with no mows prior to the end of assessments. The application of Perspective® in 2016 kept broadleaf weed coverage down to 19% by the last assessment of the year. By the end of testing in 2016, Embark® 2S IVM + Perspective® had the lowest average grass height (9 inches), with no mows by 2016.

Figure 10. Grass Height Comparison

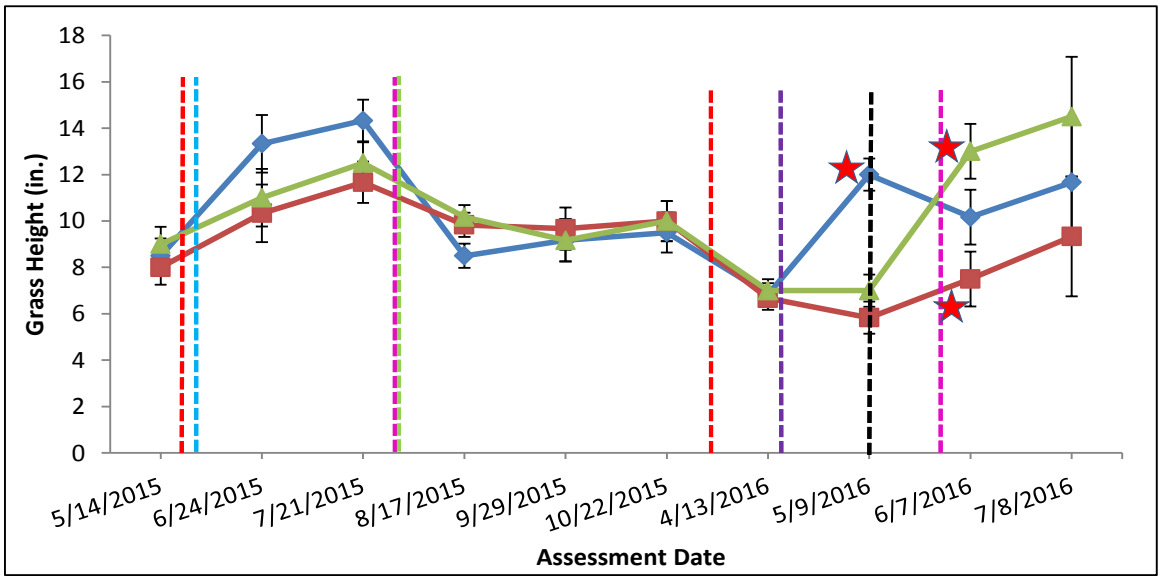
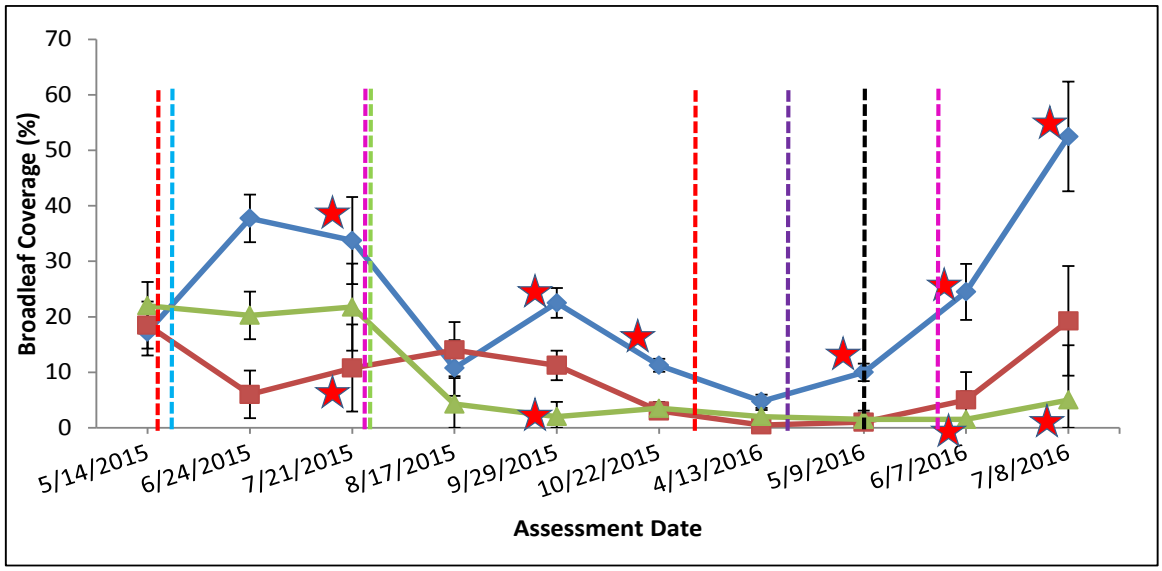


Figure 11. Broadleaf Coverage Comparison



Key to Figures 10-11.

- Statistically Significant Event
- Mow Only
- Perspective® + Embark® 2S IVM
- Triclopyr 3 + Plateau®
- Mechanical Control (mow all)
- Mechanical Control (mow only)
- Herbicide Control (both broadleaf herbicides + PGR)
- Herbicide Control (Triclopyr 3 only)
- Herbicide Control (PGR only)
- Herbicide Control (both broadleaf herbicides)
- Error Bars

Photograph 20. Spray truck making a 10-foot-wide broadcast application along a typical two-lane highway.

Photograph 21. All methods are pictured. In the foreground is tall grass in mow-only plots; in the middle, the turf growth is still suppressed and slightly brown in the Embark® 2S IVM + Perspective® plots; and in the back, where the turf is just starting to actively grow again, are the Plateau® + Triclopyr 3 plots.

Photograph 22. A high percentage of broadleaf weeds are present in the mow-only plots. Weed height causes more of a concern to sight distance than turf height.

Treatment Cost Comparisons: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing these labor costs, there are several factors that influence the costs, such as variations in methods, equipment efficiency, number of staff, and occurrences per year. Table 18 describes the labor cost to mow one acre compared to spraying one acre with a 10-foot spray nozzle. Table 19 describes the labor cost to treat one acre for one year with each method used in this test. The materials costs are located in Table 20, which shows the per-acre and per-mile cost of each herbicide used in this test. The cost of materials can be added to the labor cost for each method to see the total cost per method.

Table 18. Zone Two: Test 3, RIVM Method Labor Comparison

RIVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre
Flail Mower	1	$19.10	2.75	0.41	$7.83
Spray Truck (10-foot spray nozzle)	1	$19.10	11.25	0.09	$1.72

Table 19. Zone Two: Test 3, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Total Cost per Acre per Year
Method 1 Treatment 1: Mow Only (SOP)	3	0	1.23	$23.49
Method 2 Treatment 1: Plateau® + Triclopyr 3 + Mowing	2	2	1.00	$19.10
Method 2 Treatment 2: Embark® 2S IVM + Perspective® + Mowing	3	2	1.00	$19.10

Table 20. Zone Two: Test 3, Herbicide Mixture Cost Comparison

Herbicide Mix	Rate (oz./acre)	# Products	Spray Pattern Width (ft.)	Cost per Acre	Cost per Mile	Occurrences per Year	Total Cost per Acre per Year	Total Cost per Mile per Year
Method 2 Treatment 1: Plateau® (PGR)	4	1	10	$3.43	$4.16	1	$3.43	$4.16
Method 2 Treatment 1: Triclopyr 3	64	1	10	$7.35	$8.91	1	$7.35	$8.91
Method 2 Treatment 1: Plateau® + Triclopyr 3	4 64	2	10	$10.78	$13.07	1	$10.78	$13.07
Method 2 Treatment 2: Embark® 2S IVM (PGR)	32	1	10	$32.10	$38.91	1	$32.10	$38.91
Method 2 Treatment 2: Perspective®	5	1	10	$4.60	$5.58	1	$4.60	$5.58
Method 2 Treatment 2: Embark® 2S IVM (PGR) + Perspective®	16 5	2	10	$36.70	$44.48	1	$36.70	$44.48

Zone Two: Test 3, Recommendation

Spray PGR to established turf stands in spring followed by late spring/early summer broadleaf selective herbicide to postpone spring or early summer mowing until midsummer. Spray broadleaf herbicide on an annual basis to keep weeds under control and allow grass to persist in order to maintain visual quality and sight distance in Zone Two. Following these recommendations will allow for mowing to be reduced down to one to two occurrences per year.

Plateau® is the recommended PGR, as the results are similar and the cost per acre is much lower than Embark® 2S IVM. Perspective® is the recommended broadleaf herbicide, as Perspective® has soil active properties that improve the duration of turf height suppression. Triclopyr 3 is the recommended broadleaf herbicide if the health or appearance of turf is more important than height suppression, or if the goal is to allow grass to produce seed in an effort to improve turf stands. A PGR could also be selectively used in directed applications around areas that require significant amounts of annual mechanical labor. A second Triclopyr 3 application in late summer is common as a substitute to mowing in order to keep broadleaf weeds under control to maintain sight distance and visual quality of the ROW.

Zone Two: Test 4, Maintain Turf with Batwing WetBlade™ System

This test was intended for anywhere a batwing mower would be appropriate to use. This test evaluated vegetation response to three combinations of chemical and mechanical control, as well as equipment, material, and labor costs to determine the recommended method of maintenance. The test site chosen was an open field heavily infested with broadleaf weeds; however, for testing purposes, the site was maintained as if it were on the road edge receiving the same number of mows.

Table 21. Zone Two: Test 4, Equipment

Equipment	Equipment Number
Batwing Mower, Diamond WetBlade™ WFH180C	6400605
Tractor, John Deere 6410	8931163

Methods

In this test, a Diamond WetBlade™ 15-foot batwing mower deck (Photograph 23) mounted on a tractor (Photograph 24) was used to simultaneously apply herbicide while mowing compared to mowing with no chemicals. This equipment features a 25-gallon herbicide tank mounted on the mower deck that drips concentrated herbicide solution at a total volume rate of 2.5 gallons per acre. The equipment is designed to deliver herbicide to the cut surface of vegetation with the rotation of the mower blade. See Table 21 for equipment information.

Method 1: (1 Treatment) Mow Only (SOP): Mowing was performed on an as-needed basis to maintain height on the usual ODOT schedule.

Method 2: (2 Treatments) Simultaneous Mowing + PGR + Broadleaf Selective Herbicide: In this method, two treatments of PGR and broadleaf selective herbicide were used. In fall 2014 and late spring 2016, broadleaf herbicides were applied while simultaneously mowing. In spring 2015, PGR and broadleaf herbicides were combined and applied during mowing.

Treatment 1: Plateau® (imazapic) + Triclopyr 3 (triclopyr)

Treatment 2: Plateau® (imazapic) + Milestone® (aminopyralid)

Photograph 23. Diamond WetBlade™ 15-foot batwing mower deck.

Photograph 24. Tractor with Diamond WetBlade™ mowing and applying broadleaf herbicide simultaneously.

Results

Both broadleaf herbicides significantly reduced broadleaf weed percent coverage compared to mowing only. In 2014, all plots started with a very high percent coverage of broadleaf weeds compared to other similar tests. After three herbicide applications from 2014 to 2016, the mow-only plots contained significantly more broadleaf weeds than the Milestone® and Triclopyr 3 plots (31%, 2%, and 7%, respectively) (Figures 12 and 13).

Method 1 Treatment 1: Mow Only (SOP): At the start of testing in 2014, the mow-only plots had 62% broadleaf weed coverage. In 2015, they reached a high of 60%, and in 2016 they reached a high of 75%. Based on this increase in broadleaf coverage, mowing alone did not control the broadleaf weeds that dominated the plots. The mow-only plots received one more mow than both herbicide plots in 2015 and one more mow than the Milestone® plots in 2016. By the end of testing, mow only had significantly more broadleaf weed coverage and significantly less grass coverage than Milestone® and Triclopyr 3 plots (Photograph 25). Mow-only plots are expected to be mowed in fall 2016, resulting in three total mows in 2016.

Method 2 Treatments 1 and 2: Simultaneous Mowing + PGR + Broadleaf Selective Herbicide: The application of PGR + broadleaf selective herbicide was applied in 2015. In 2016, only broadleaf selective herbicide was applied due to an attempt to increase grass health and seed production. With the use of PGR in 2015, there were only two mowing events; however, when PGR was not used in 2016, there were three mowing events. Through successive herbicide applications, broadleaf weed coverage was reduced and grass coverage was significantly increased compared to the mow-only treatment.

Treatment 1: Simultaneous Mowing + Plateau® + Triclopyr 3: At the start of testing in 2014, Triclopyr 3 plots had 65% broadleaf weed coverage. The first batwing WetBlade™ cut stem herbicide application in fall 2014 reduced broadleaf weed coverage, resulting in a high of 27% broadleaf coverage by spring 2015 just prior to the second application. The spring 2015 application of Plateau® + Triclopyr 3 further reduced broadleaf weed coverage to a low of 13% in July 2015, and a high of 34% just prior to the 2016 application. The use of PGR in this application was an effort to reduce mowing occurrences, and the results from this PGR application allowed for one less mow compared to mow-only plots. In spring 2016, PGR was not used in the third batwing WetBlade™ cut stem herbicide application in an effort to support healthy grass growth and seed production. The spring 2016 application of Triclopyr 3 further reduced broadleaf weed coverage to 10% through summer 2016. In late summer 2016, a fourth and final batwing WetBlade™ cut stem herbicide application was applied to further reduce broadleaf coverage and resulted in 7% broadleaf coverage by the last assessment. Through 2016, Triclopyr 3 plots were mowed at the same occurrences as the mow-only plots and were mowed one more time than the Milestone® plots. Each herbicide application reduced broadleaf weed coverage and caused an increase in grass coverage, resulting in significantly more grass coverage in Triclopyr 3 plots (81%) than mow-only plots (28%) by the end of testing in 2016 (P=0.0006).

Treatment 2: Simultaneous Mowing + Plateau® + Milestone®: At the start of testing in 2014, Milestone® plots had 65% broadleaf coverage. The first batwing WetBlade™ cut stem herbicide application in fall 2014 significantly reduced broadleaf weed coverage compared to mow only and reached a maximum of 24% in spring 2015 just prior to the second application. The spring 2015 application of Plateau® + Milestone® further reduced broadleaf weed coverage to a low of 3% after the application, and a high of 14% just prior to the 2016 application. The use of PGR in this application served as an effort to reduce mowing occurrences. The results from this PGR application allowed for one less mow compared to mow-only plots. PGR was not used in the third and final batwing WetBlade™ cut stem herbicide application in spring 2016 in an effort to support healthy grass growth and seed production. The spring 2016 application of Milestone® further reduced broadleaf weed coverage so that it only reached a high of 10% in 2016 and a low of 2% by the last assessment (Photograph 26). Each herbicide application reduced broadleaf weed coverage and caused an increase in grass coverage, resulting in significantly more grass coverage in Milestone® plots (88%) than mow-only plots (28%) by the end of testing in 2016 (P=0.0003).

Figure 12. Broadleaf Cover Comparison

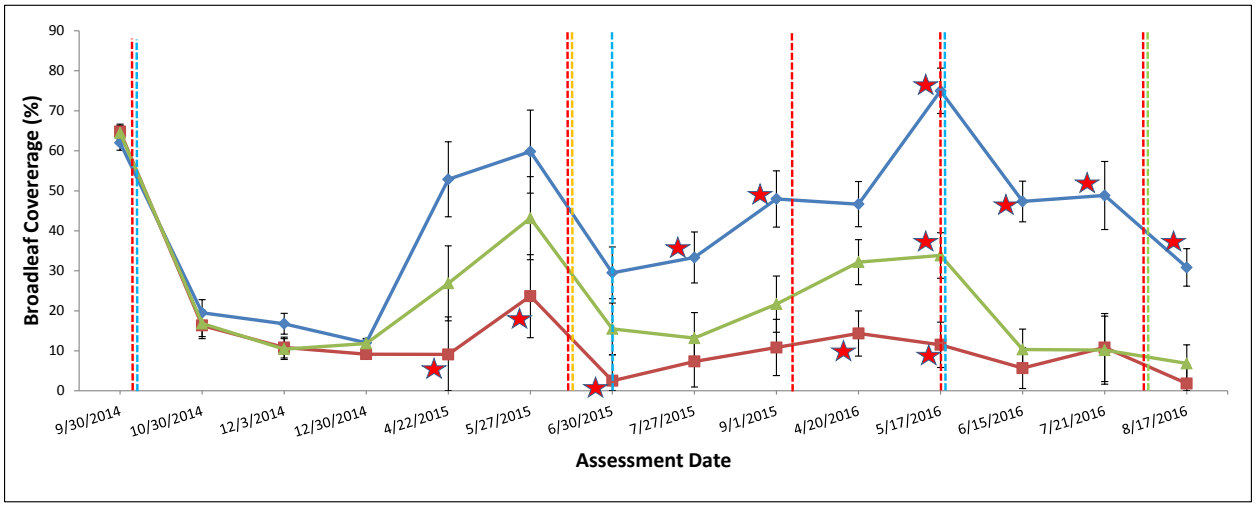
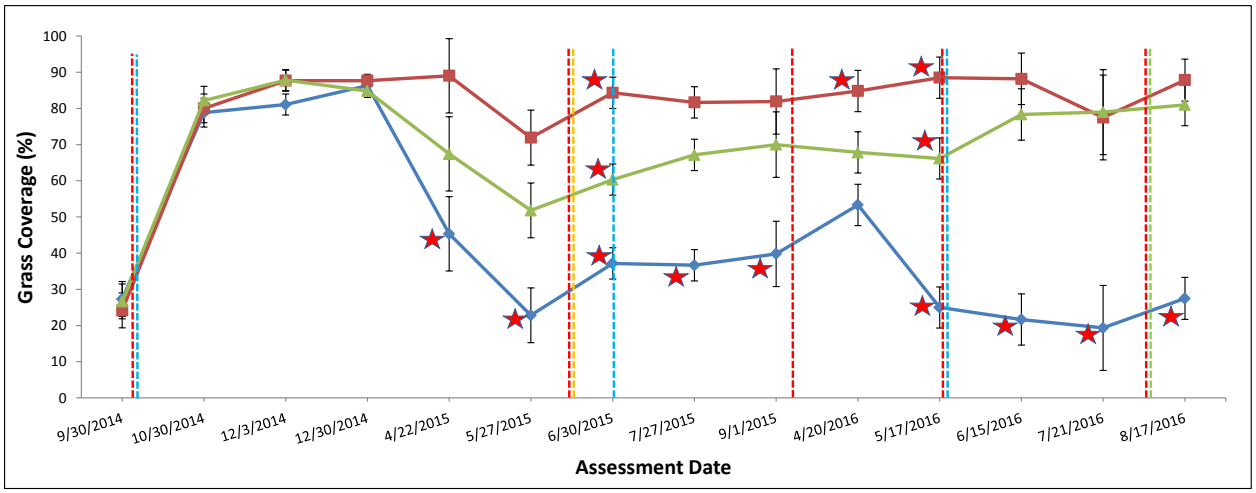


Figure 13. Grass Cover Comparison



Key to Figures 12-13.

- Statistically Significant Event
- Mow Only
- Milestone® + Plateau®
- Triclopyr 3 + Plateau®
- Mechanical Control (mow all)
- Mechanical Control (mow only)
- Herbicide/Mechanical Control (both PGR + broadleaf herbicides)
- Herbicide/Mechanical Control (both broadleaf herbicides)
- Herbicide/Mechanical Control (Triclopyr 3 only)
- Error Bars

Photograph 25. Plots that do not receive broadleaf selective herbicide applications have a higher percentage of broadleaf weeds. Broadleaf weeds grow taller than turf.

Photograph 26. Grass dominates plots that received broadleaf selective herbicide applications only. Note that some grass types grow taller than others.

Photograph 27. Very short mow height combined with PGR caused significant brownout in grass after our spring 2015 application.

Treatment Cost Comparisons: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing these labor costs, there are several factors that influence the costs, such as variations in methods, equipment efficiency, number of staff, and occurrences per year. Table 22 describes the labor cost to mow one acre compared to the combination of chemical applications while simultaneously mowing one acre with a Diamond WetBlade™ mower. Table 23 describes the labor cost to treat one acre for one year with each method used in this test. For Method 2, costs are based on the number of mows that took place due to the herbicide being applied simultaneously with mowing. Notably, there were mow events to Method 2 that did not involve an herbicide application. The materials costs are located in Table 24, which shows the per-acre and per-mile cost of each herbicide used in this test. To determine the total cost per method, the cost of materials can be added to the labor cost for each method.

Equipment Review: The Diamond WetBlade™ System is a new technology that incorporates chemical applications while simultaneously mowing. This piece of equipment is a discrete way to apply water-based herbicides in areas that need mowing at the same time. The Diamond WetBlade™ System and the accompanying Raven control panel administers the herbicide mixture at a rate of 270 ounces per acre. The system uses herbicide at a concentrated rate; the herbicide comes out slowly while mowing. This rate allows for 11.85 acres to be mowed prior to needing a refill. However, even with the concentrated application method, a 25-gallon tank is too small for a full day's application and will need a refill at some point in the day. Issues arose during testing when the mower deck was set at too low of a deck height. The resulting issues included grass damage and large clumps of cut material left behind the mower (Photograph 27). These clumps of cut material had concentrations of herbicide, which left bare ground patches throughout the test plots. The bare patches created an opportunity for weeds to fill in which negatively affected the results of testing. On later applications, the mow height was raised and this issue was avoided.

Table 22. Zone Two: Test 4, RIVM Method Labor Comparison

RIVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre
Batwing Mower (15-foot mower)	1	$19.10	3.61	0.30	$5.71
Batwing WetBlade™ Mower (15-foot mower + herbicide)	1	$19.10	3.61	0.30	$5.71

Table 23. Zone Two: Test 4, Labor Cost Comparison

Method and Treatment	Simultaneous Events		Total Labor Hours per Acre per Year	Total Cost per Acre per Year
	Mow Occurrences per Year	Spray Occurrences per Year		
Method 1 Treatment 1: Mow Only (SOP)	3	0	0.90	$17.13
Method 2 Treatment 1: Triclopyr 3 + Mowing	3	2	0.90	$17.13
Method 2 Treatment 2: Milestone® + Mowing	3	1	0.90	$17.13
Method 2 Treatment 1: Plateau® + Triclopyr 3 + Mowing	2	1	0.60	$11.42
Method 2 Treatment 2: Plateau® + Milestone® + Mowing	2	1	0.60	$11.42

Table 24. Zone Two: Test 4, Herbicide Mixture Cost Comparison

Herbicide Mix	Rate (oz./ acre)	# Products	Application Width (ft.)	Cost per Acre	Cost per Mile	Occurrences per Year	Total Cost per Acre per Year	Total Cost per Mile per Year
Method 2 Treatments 1, 2: Plateau® (PGR)	4	1	15	$3.43	$6.24	1	$3.43	$6.24
Method 2 Treatment 1: Triclopyr 3	192	1	15	$22.05	$40.09	1	$22.05	$40.09
Method 2 Treatment 1: Plateau® + Triclopyr 3	4 192	2	15	$25.48	$46.33	1	$25.48	$46.33
Method 2 Treatment 2: Milestone®	7	1	15	$6.56	$11.93	1	$6.56	$11.93
Method 2 Treatment 2: Plateau® + Milestone®	4 7	2	15	$9.99	$18.16	1	$9.99	$18.16

Zone Two: Test 4, Recommendation

Enhance conversion of heavily weeded areas into established turf stands by making cut stem applications with the Diamond WetBlade™ or similar simultaneous mowing and application system. The advantage of this type of equipment is there is no increased labor for separate mechanical removal and chemical application to control broadleaf weeds. Removal and application can be performed simultaneously. This test can be compared to Zone One: Test 1; there is no extra labor cost as would be the case with a foliar application separate from a mow. The goal to eliminate one mow per year by reducing broadleaf weeds and reducing turf growth rate can be achieved with a combined application of PGR and broadleaf herbicide. Plateau® is the recommended PGR. The mower deck should be no lower than 6" when mowing, especially when applying PGR. A lower deck can cause dragging and clumps of cut vegetation being unevenly dispersed, which may prevent herbicide from reaching the cut stem and may cause dieback of vegetation from the clumps left in patches. A mowing deck height which is too low can also leave bare patches, which are easily invaded by broadleaf weeds. Milestone® is the recommended herbicide as the cost per acre is less expensive, the amount needed to mix is significantly less, and the results are slightly better than Triclopyr 3. The advantage of Triclopyr 3 was that two applications per year were allowable based on the rate that was used. Milestone® was applied at the maximum rate per year, so no additional application could be performed. With the results achieved, however, there was no desire for an additional application with Milestone®. An advantage to this type of simultaneous mowing and application equipment is it can make applications far away from the road edge in areas that cannot be reached with a spray truck making applications with boomless nozzles.

Since the unit is more complicated than a traditional batwing mower, a dedicated operator to use the equipment is recommended. Also, introducing new operators each time the unit is used lengthens the learning curve. The unit should be used throughout the mowing season to keep the hydraulics running smoothly. The WetBlade™ System should be used with water in the tank when herbicides are not applied to prevent issues caused by the seals drying out. Even with the concentrated application method, the 25-gallon tank provided with the WetBlade™ System is too small for a full day's mowing/application. A 50-gallon tank should replace the 25-gallon tank to allow the operator to get in a full day's work without needing to request additional water and herbicides be delivered into the field.

Zone Two: Test 5, Maintain Turf on Slope or over Guardrail with Spray Truck and Boomless Nozzle

The goal of this test was to maintain turf on a slope that could not be accessed with mechanical equipment. This test evaluated vegetation response to two broadleaf selective herbicides in a no-mow situation beyond a guardrail or on a slope as well as equipment, material, and labor costs to determine the recommended method of maintenance. In this test, there were two methods tested; neither method involved mechanical removal of vegetation. The test site was located on a sloped center median enclosed by two, 4-foot barrier walls (Photograph 28).

Table 25. Zone Two: Test 5, Equipment

Equipment	Equipment Number
Spray Truck, Ford F450 CC	2533083
Spray Truck, GMC T7500	3210114
Skid Sprayer, Chemical Container 425-Gallon	8100160
Boominator 3750RS 22-foot Nozzle	N/A

Methods

The equipment used in this test was a truck equipped with a 425-gallon skid sprayer and boomless nozzle with a 22-foot-wide spray pattern (Photograph 29) to perform chemical applications. This test used two different spray trucks; the skid sprayer and nozzles were moved onto a different truck in the second year of testing. Mechanical equipment could not get into the site for maintenance, so the herbicide treatments were compared to an unmaintained treatment. See Table 25 for equipment information.

Method 1 (1 Treatment): Unmaintained: In this method, no maintenance activity took place. Mechanical vegetation removal in these areas is often difficult or labor-intensive; therefore, these areas are often left unmaintained.

Method 2 (2 Treatments): Broadleaf Selective Herbicide: In this method, two treatments of broadleaf selective herbicides were applied with a boomless nozzle in late spring summer to control broadleaf herbaceous and woody weeds.

Treatment 1: Milestone® (aminopyralid)

Treatment 2: Perspective® (aminocyclopyrachlor)

Photograph 28. This test plot treated with Perspective® contains significantly less weeds than the control plots.

Photograph 29. Spray truck making a broadcast application over a barrier wall with a 22-foot spray pattern. Note the spray nozzle head height was adjusted to reach over the barrier wall.

Results

Both herbicides significantly reduced broadleaf weed coverage compared to the unmaintained method; broadleaf weed control from spring applications lasted all year. At the end of testing in the second year, the unmaintained plots contained significantly more broadleaf weeds than Milestone® and Perspective® plots (73%, 3%, and 2%, respectively) (Figures 14, 15, and 16).

Method 1 Treatment 1: Unmaintained: At the start of testing in spring 2015, unmaintained plots had 37% broadleaf weed coverage. These plots were left unmaintained due to access difficulties. From 2015–2016, unmaintained plots averaged 60% broadleaf weed coverage (Photograph 30).

Method 2 Treatments 1 and 2: Broadleaf Selective Herbicide: Both broadleaf selective herbicides were applied once each spring. Considering there were only two herbicide applications throughout testing, the observed results were remarkable. Broadleaf coverage was significantly lower than the unmaintained plots as soon as 30 days after the first application. By the end of testing, broadleaf weeds, compared to unmaintained plots, were significantly reduced to as low as 2%.

Treatment 1 Milestone®: At the start of testing in spring 2015, Milestone® plots had 36% broadleaf weed coverage. The 2015 application of Milestone® reduced broadleaf weed coverage by 35%, resulting in 1% broadleaf weed coverage just prior to the 2016 application. The 2016 application did not reduce broadleaf weed coverage any further but resulted in a slight increase in broadleaf weed coverage to 3% by August 2016. By the end of testing, Milestone® had significantly reduced broadleaf weed coverage compared to the unmaintained plots and ended testing with 3% broadleaf weed coverage (P= <0.0001). By the end of testing, Milestone® significantly increased the grass coverage compared to unmaintained plots and ended testing with 96% grass coverage (P=0.0003) (Photograph 31).

Treatment 2 Perspective®: At the start of testing in spring 2015, Perspective® plots had 31% broadleaf weed coverage. The 2015 application of Perspective® reduced broadleaf weed coverage by 19%, resulting in 12% broadleaf weed coverage just prior to the 2016 application. The 2016 application of Perspective® reduced broadleaf weed coverage by 10%, resulting in 2% coverage by August 2016. By the end of testing, Perspective® had significantly reduced broadleaf weed coverage compared to the unmaintained plots and ended testing with 2% broadleaf coverage (P= <0.0001). By the end of testing, Perspective® significantly increased the grass coverage compared to unmaintained plots and ended testing with 88% grass coverage (P=0.0006) (Photograph 32).

Figure 14. Grass Coverage Comparison

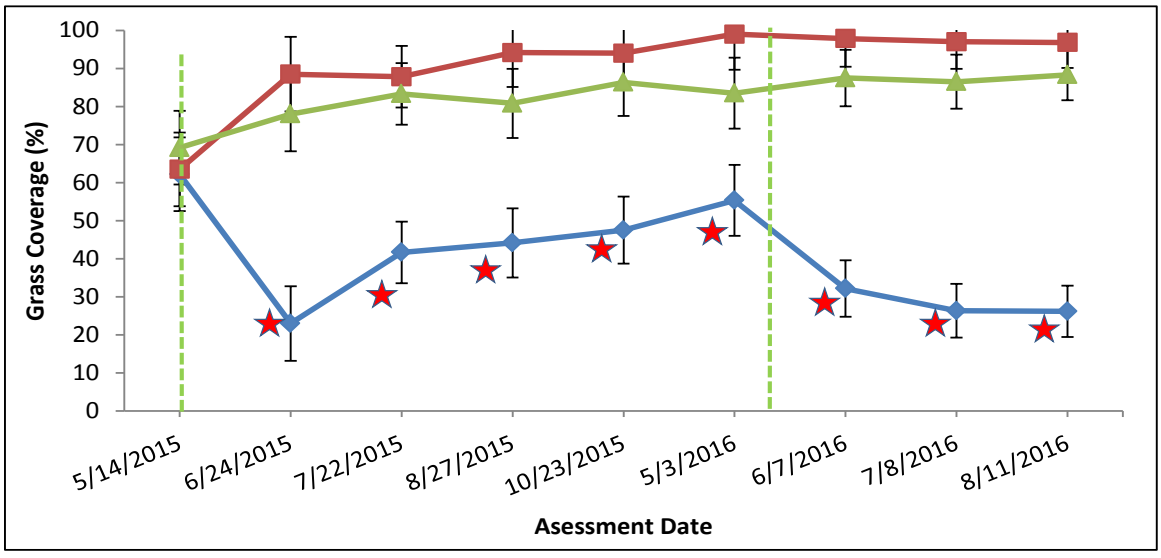


Figure 15. Broadleaf Coverage Comparison

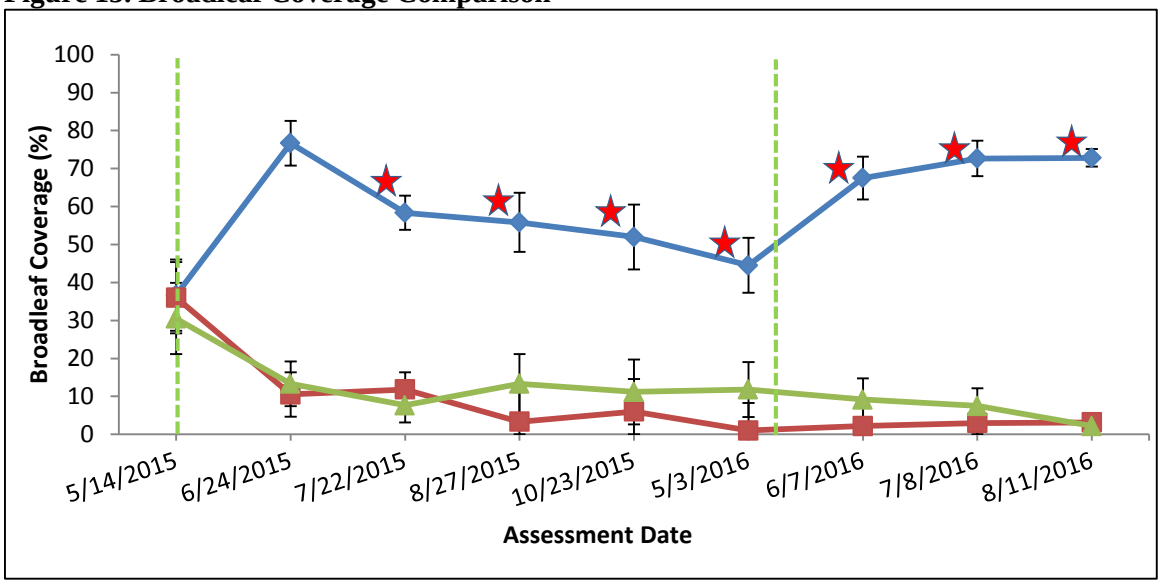
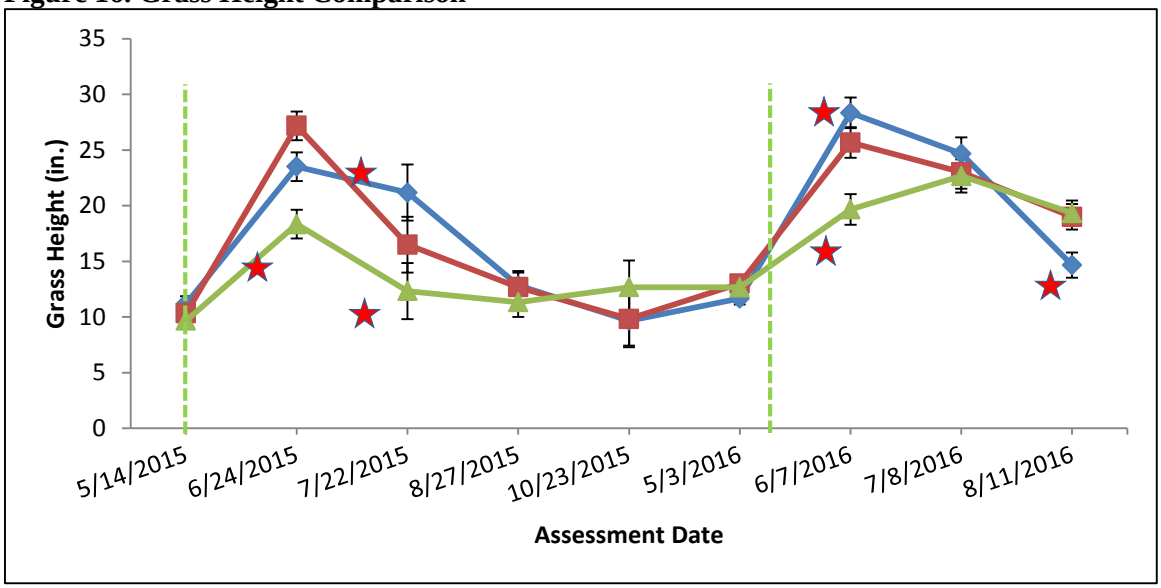


Figure 16. Grass Height Comparison



Key to Figures 14-16.

- Statistically Significant Event
- Mow Only
- Milestone®
- Perspective®
- Herbicide Application (both broadleaf)
- Error Bars

Photograph 30. Unmaintained Plot

Photograph 31. Milestone® Plot

Photograph 32. Perspective® Plot

Treatment Cost Comparisons: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing these labor costs, there are several factors that influence the costs, such as variations in methods, equipment efficiency, number of staff, and occurrences per year. Table 26 shows the labor cost to leave one acre unmaintained compared to spraying one acre with a 22-foot spray nozzle. Table 27 shows the labor cost to treat one acre for one year with each method used in this test. The materials costs are located in Table 28, which shows the per-acre and per-mile cost of each herbicide used in this test. The cost of materials can be added to the labor cost for each method to see the total cost per method.

Table 26. Zone Two: Test 5, RIVM Method Labor Comparison

RIVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre
Unmaintained	0	$0.00	0.00	0.00	$0.00
Spray Truck (22-foot spray nozzle)	0	$19.10	26.24	0.03	$0.55

Table 27. Zone Two: Test 5, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Total Cost per Acre per Year
Method 1 Treatment 1: Unmaintained	0	0	0.00	$0.00
Method 2 Treatment 1: Milestone®	0	1	0.03	$0.55
Method 2 Treatment 2: Perspective®	0	1	0.03	$0.55

Table 28. Zone Two: Test 5, Herbicide Mixture Cost Comparison

Herbicide Mix	Rate (oz./acre)	# Products	Spray Pattern Width (ft.)	Cost per Acre	Cost per Mile	Occurrences per Year	Total Cost per Acre per Year	Total Cost per Mile per Year
Method 2 Treatment 1: Milestone®	7	1	22	$6.56	$17.49	1	$6.56	$17.49
Method 2 Treatment 2: Perspective®	5	1	22	$4.60	$12.27	1	$4.60	$12.27

Zone Two: Test 5, Recommendation

Mowing is not necessary in this management situation if annual herbicide applications are made. Make broadcast herbicide applications once a year in late spring or early summer. Alternate herbicide products yearly between Milestone® at 7 oz./acre and Perspective® at 5 oz./acre. If winter annual weeds or perennial weeds in fall become a problem, a fall application of Perspective® can be made. Milestone® seems to be a gentler herbicide on grass. There is no height control benefit from Milestone®; the grass stays green and will develop seed heads. Allowing grass to produce seed will help improve the turf stand and increase grass coverage. Only one application per year can be made with the Milestone® at the 7 ounce-per-acre rate, as this rate is the highest allowable per acre per year.

Perspective® is harsher on grass, and in situations where large amounts of broadleaf weeds are controlled, bare ground areas will be left without being filled in with grass as readily as when Milestone® is used. The use of Perspective® over Milestone® is only recommended for to its ability to restrict turf height by suppressing seed head formation.

Milestone® is the recommended herbicide for steep slopes as Milestone® allows grass seed heads to develop. This is important because slopes are often gravelly, void of nutrients, and may be sparse in grass coverage. By using Milestone® grass will stay green and develop seed heads that may help improve the turf stand to help prevent erosion.

Zone Two: Test 6, Maintain Turf or General Vegetation Maintenance on Steep Slopes with Slope Mower

The goal of this test was to maintain turf or general vegetation on a slope with specialized mowers. This test evaluated production, labor, capabilities, and turf disruption associated with each mower type to determine the recommended method of maintenance. In this test, there were two methods tested; neither method involved chemical treatment of vegetation.

Table 29. Zone Two: Test 6, Equipment

Equipment	Equipment #
Slope Mower, Alamo TRAXX™ RF Remote Control	6480052
Slope Mower, Kut Kwick Super Slope Master™ SSM38-72D	6500859

Methods

A side-by-side comparison of two slope mowers was made at two test sites with different vegetation types and heights. See Table 29 for equipment information.

The following two testing sites were established:

Site 1: Maintained Turf: A landscaped interchange consisting of more turf than weeds kept short for aesthetic reasons. The soils were poor, and vegetation was approximately 2 feet tall and a bit sparse. Slopes ranged from 25–40%, or 14.04-21.8 degrees, or 4:1 to approximately a 2.5:1 slope. Mowers were tested twice at this site (Photograph 34).

Site 2: General Vegetation Maintenance: A wild-looking slope with vegetation consisting of more broadleaf weeds than turf. The vegetation was approximately 3 feet tall and thick. Slopes ranged from 25–57%, or 14.04-30 degrees, or 4:1 to just under a 2:1 slope. Mowers were tested once at this site (Photograph 35).

Method 1 (2 Treatments): Mechanical Maintenance. In this method, two mowers designed for mowing on steep slopes (Photographs 33 and 34) were compared.

Treatment 1: Kut Kwick Super Slope Master™ SSM38-72D riding mower with 72” rotary head capable of mowing on slopes up to 40 degrees

Treatment 2: Alamo Traxx™ RF remote controlled mower with 51” flail head capable of mowing on slopes up to 60 degrees

Photograph 33. Site 1 Treatment 1: Kut Kwik chariot-style riding mower with 72” rotary deck.

Photograph 34. Site 1 Treatment 2: Alamo Traxx™ RF Remote Control Mower with 51” front-mounted flail head.

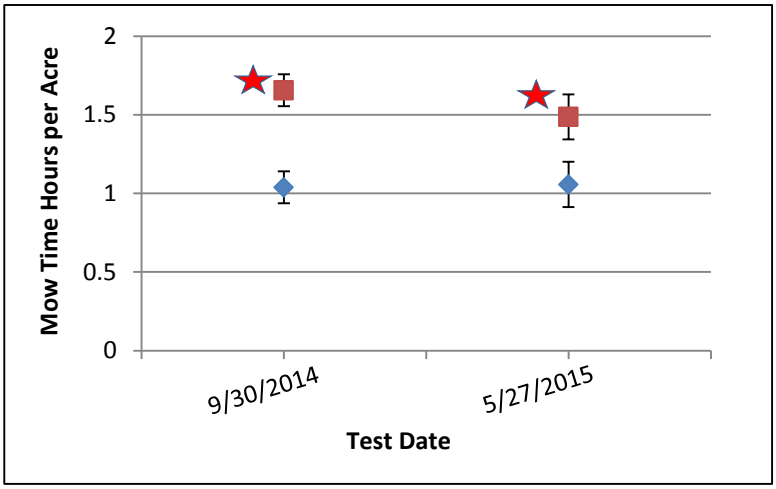
Photograph 35. Site 2: Slopes covered in 3-foot-tall weeds.

Results

Method 1 Treatments 1 and 2: Testing Site 1: At Site 1, the Kut Kwik mower was significantly more efficient than the Alamo Traxx™ RF mower at mowing maintained turf (P=0.0065) (Figure 17). The Alamo Traxx™ RF mower's speed ranged from 1.66 to 1.49 hours per acre. The Kut Kwik slope mower's speed ranged from 1.04 to 1.06 hours per acre. When considering the significantly faster mow speed of the Kut Kwick mower, values can be expanded into labor costs. Table 31 shows the costs associated with mowing a slope similar to Site 1 with maintained turf. The Kut Kwick would lead to a savings of nearly $40 per acre per year over the Alamo Traxx™ RF. However, these labor costs for mowing should be compared to Labor Table 26 of Zone Two: Test 5 to compare the cost for spraying a slope to maintain the vegetation; these are both viable methods for maintaining slopes. There was no significant difference between the two mowers in the amount of disturbed soil (rutting) from turning around on the plots. Operators of both units have a practice of running the units and making as few turns as possible to avoid disturbing the soil in normal operating conditions. The operator's ease of equipment use ratings can be seen in Figure 18. In the first year of testing, a veteran operator on Site 1 used the Kut Kwick mower and felt very confident in the unit. In the second year of testing, an operator with less experience on Site 1 used the Kut Kwick mower and felt more uneasy on the steeper of the slopes. The variation seen in operator's ease of use rating calls to the possible dangers associated with an operator riding on this style of mower. The operator of the Alamo Traxx™ RF was the same in both years of testing at Site 1 and reported the same confidence in operating on these slopes.

Method 1 Treatments 1 and 2: Testing Site 2: Site 2 had very different results from Site 1. The Alamo Traxx™ RF was able to successfully complete the plots with no trouble. The Kut Kwick attempted to mow two (out of three replications) of the lesser sloped plots but was unable to complete either one. The Kut Kwick mower kept sliding down the hill and could not stay in the boundaries of the plots to perform the mowing. This is attributed to the moisture held in the long, thick weeds and loss of traction.

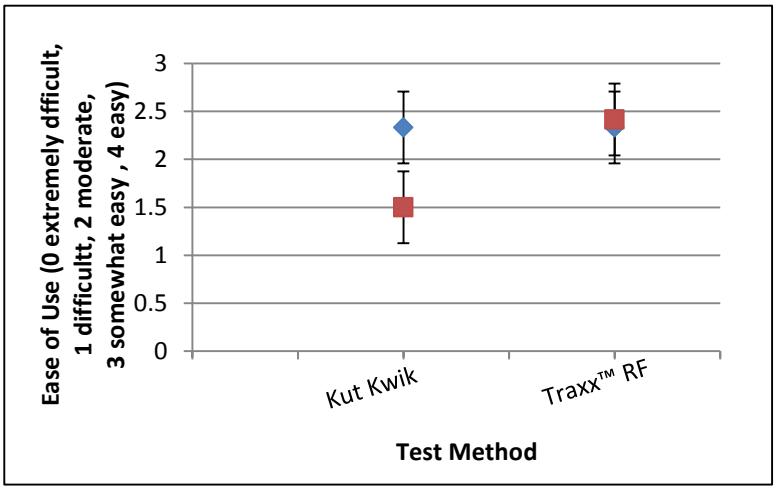
Figure 17. Mower Efficiency Comparison



Key to Figure 17.

- Statistically Significant Event
- Kut Kwick
- Alamo Traxx™ RF
- Error Bars

Figure 18. Ease of Use Comparison



Key to Figure 18.

- Statistically Significant Event
- 9/30/2014
- 5/27/2015
- Error Bars

Treatment Cost Comparisons: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing these labor costs, there are several factors that influence the costs, such as variations in methods, equipment efficiency, number of staff, and occurrences per year. Table 30 shows the labor cost to mow one acre with the Kut Kwick mower compered to mowing one acre with the Alamo Traxx™ RF. Table 31 shows the labor cost to treat one acre for one year with each method used in this test.

Equipment Review: The two slope mowers tested revealed they each have their own ideal vegetation types that maximized the individual piece of equipment's efficiency and performance abilities.

For the Kut Kwick, it excels at slopes that are mostly occupied by turfgrass and where the slope does not exceed 40 degrees. In these settings, this mower can mow with minimal turf damage and quickly mow an acre with its wide mow pattern. As a compromise to efficiency, there are danger risks associated with this ride-on style of mower. With an operator on the equipment, there are risks to that operator's safety if there was a roll-over scenario or other mowing hazards such as culverts and holes.

The Alamo Traxx™ RF on the other hand excelled on the slope that was overgrown with dense broadleaf and small woody vegetation and can easily maintain its traction on slopes up to 60 degrees. The advantage of the metal tracks that this mower rides along was observed as it gripped into the hillside and worked through this dense vegetation. Also, the flail-style mower head is ideal for mulching this dense type of vegetation. Although this piece of equipment was not as fast as the Kut Kwick, it increased safety for the operator. As the operator stands at a distance on flat ground, the risks associated with roll-over types of accidents are practically non-existent. In addition, the risks of other mowing hazards are reduced, as the operator can be as far as 1,000 feet away from the mower while operating.

Table 30. Zone Two: Test 6, RIVM Method Labor Comparison

RIVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre
Method 1 Treatment 1: Slope mower, Kut Kwick	1	$19.10	1.02	1.05	$20.06
Method 1 Treatment 2: Slope mower, Alamo Traxx™ RF	1	$19.10	0.64	1.58	$30.18

Table 31. Zone Two: Test 6, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Total Cost per Acre per Year
Method 1 Treatment 1: Slope mower, Kut Kwick	2	0	2.10	$40.11
Method 1 Treatment 2: Slope mower, Alamo Traxx™ RF	2	0	3.16	$60.36

Zone Two: Test 6, Recommendation

Mowing on steep slopes should only be done when immediate sight distance clearance is needed. In situations where mowing is desired on slopes for maintenance or aesthetics, the Kut Kwick mower should be used. The Kut Kwick has a faster ground speed and larger deck, making it a more productive option with less labor hours per acre when mowing slopes. In those cases, where vegetation is dense and tall, the Alamo Traxx™ RF mower should be used. The advantage is the flail mower head is mounted on a front boom, which allows the deck to be raised and lowered to contact vegetation before being run over by a deck, wheels, or tracks. However, slopes should generally be managed with herbicides and no mechanical mowing for a quicker and more efficient use of staff time (see Zone Two: Test 5). This can be achieved with properly timed broadleaf selective herbicide applications.

Zone Two Summary

Vegetation challenges in Zone Two include managing turf height and cover, while controlling tall weeds and maintaining visual quality. The previous six tests addressed many scenarios in which these challenges were overcome in Zone Two. In all six tests, trained operators need to be consistently assigned to new or specialized equipment to optimize equipment performance.

Utilizing a truck mounted with a skid sprayer with boomless nozzles and a control panel can significantly lower costs compared to the costs of mowing per acre or per mile. Through testing, the spray truck has proven to be a versatile and inexpensive piece of equipment that can obtain significant results along the ROW. A spray tuck equipped with boomless nozzles can accomplish a variety of vegetation management activities in Zone Two. Obtain and utilize boomless spray nozzles that fit the width requirements for mowing and maintaining Zone Two management areas. Broadleaf selective herbicides applied by a spray truck and boomless nozzle are effective and efficient in reducing broadleaf weed coverage along the ROW. The reduction of these nuisance and/or unwanted plants reduces the need to mow.

In general, to control turf height or broadleaf weeds, make one to two annual broadcast applications with a spray truck equipped with boomless nozzles. In order to reduce mowing requirements in Zone Two where maintained turf is present, the first annual application should be a PGR (Plateau® at 4 oz./acre) application made in spring. The second application should be a selective broadleaf herbicide (Milestone® at 7 oz./acre or Perspective® at 5 oz./acre) made in late spring or early fall, depending on broadleaf weed composition. Always read herbicide labels, and make sure to never exceed maximum allowable rates per acre per year. Depending on herbicide rate and vegetation response, multiple applications per year may be made. Perspective® applications can be made twice per year at the 5 ounce per acre rate if needed. By making these applications, annual mowing can be reduced by one to two occurrences per growing season. In areas with slopes that are difficult to access, mowing may not be necessary at all when herbicides are used to control tall-growing broadleaf weeds. Reducing the need for mowing reduces the exposure of maintenance employees to the safety hazards associated with working along the right-of-way.

Return On Investment: The ROI for Zone Two is realized when frequency of annual mows is reduced and time between mows is lengthened. Herbicides will allow for less frequent mowing as broadleaf weeds are controlled. PGR can also reduce one mow in the spring by suppressing seed heads. The labor hours that would have been spent mowing multiple times per year can be spent performing other tasks.

There are equipment costs associated with herbicide use and specialized mowers. The following are descriptions of specific Zone Two management activities and their ROI based on the most efficient, effective, and safest options for accomplishing the vegetation management goals.

Photograph 36. A spray truck driving 9 miles per hour, making applications with a 22-foot nozzle, can treat 24.47 acres per hour, compared to mowing at 3.86 acres per hour. Only 917 acres per year needs to be managed with the spray truck to realize a return on investment by labor savings in reduced mowing requirements.

Maintain Turf: The baseline labor cost for Zone Two: Maintained Turf labor comparison is four yearly mowing occurrences with a 15-foot batwing mower (Table 32). The labor cost of a spray

truck is much lower than any of the mechanical options, and cost savings can justify a ROI by reducing annual mow occurrences. The results of testing indicate that spraying PGR followed by broadleaf herbicide or only making broadleaf herbicide applications can reduce annual mowing occurrences. The spray truck with boomless nozzles is the most cost-effective method for keeping turf height and weeds under control. If spraying PGR is followed by broadleaf herbicide, a ROI through labor savings can be realized in 917 acres of Zone Two open turf management per year (Photograph 36). If spraying only broadleaf herbicide, a ROI through labor savings can be realized in 1,835 acres of Zone Two open turf per year. Mowing costs $20.64 per acre per year when mowing four times compared to $11.89 per acre per year when spraying twice and mowing twice. The batwing WetBlade™ can help reduce annual mowing occurrences when used, but would take 8,739 acres of Zone Two turf management to ROI, compared to a traditional mower head if an additional batwing mower deck was to be purchased. As the batwing WetBlade™ can perform traditional mowing in addition to mowing with herbicide application, it can be purchased to replace an old traditional batwing mower head (at a cost of $13,911), and the difference in price would be used to calculate the ROI instead of the full purchase price as calculated in the table below. The advantage of the batwing WetBlade™ is its ability to apply herbicides while mowing to areas a spray truck with boomless nozzles cannot reach. In areas a spray truck can reach, it is less expensive to apply herbicides with that equipment and follow up when needed with a traditional batwing mower.

Table 32. Zone Two: Maintain Turf Return On Investment - Per Acre Labor Cost Savings

Maintain Turf Control Methods	Purchase Price	Labor Cost Savings per Acre per Year	Acres Needed for ROI	Hours to Accomplish ROI
Test 1: Method 1: Mow Only (SOP)	-	$0.00	N/A	N/A
Test 1: Method 2: Skid Sprayer with 22-ft. Nozzle, PGR + Broadleaf Herbicide + Mow	$8,073.00	$8.80	917	37
Test 1: Method 3: Skid Sprayer with 22-ft. Nozzle, Broadleaf Herbicide + Mow	$8,073.00	$4.40	1835	75
Test 4: Diamond WetBlade™ Batwing Mower, Broadleaf Herbicide	$40,287.00	$4.61	8,739	2,421

Maintain Turf Under Guardrail or Cable Rail: The baseline labor cost for Zone Two: Maintained Turf Under Rail labor comparison is four annual mowing and string trimming occurrences with mowers and a string trimming crew (Table 33). The labor cost of a spray truck is much lower than any of the mechanical options, and cost savings can justify a ROI by reducing annual mowing and string trimming occurrences. The results of testing indicate that spraying PGR followed by broadleaf herbicide (or only making broadleaf herbicide applications) will reduce annual mowing occurrences. The spray truck is the most cost-effective method for keeping turf height and weeds under control. If spraying PGR is followed by broadleaf herbicide, a ROI through labor savings can be realized in 39 miles of Zone Two: Maintained Turf Under Rail management per year. Mowing and string trimming costs $422.44 per mile when done four times per year, compared to $215.04 per mile per year when spraying twice and mowing twice.

Table 33. Zone Two: Maintain Turf Under Rail Return On Investment - Per Mile Labor Cost Savings

Maintain Turf Under Guardrail or Cable Rail Control Methods	Purchase Price	Labor Cost per Mile per Year	Labor Cost Savings per Mile per Year	Miles Needed for ROI	Hours to Accomplish ROI
Method 1: Mowing and String Trimming Only (SOP)	-	$422.44	$0.00	N/A	N/A
Method 2: Spray Truck with 10-ft. Nozzle, PGR + Broadleaf Herbicide	$8,073.00	$215.04	$207.40	39	4

Maintain Turf at Road Edge, No Rail: The baseline labor cost for Zone Two: Maintained Turf Under Rail labor comparison is three annual mowing occurrences (Table 34). The labor cost of a spray truck is much lower than any mechanical option, and cost savings can justify a ROI by reducing yearly

mowing requirements. The results of testing indicate spraying PGR followed a few weeks later by a broadleaf herbicide application or only making broadleaf herbicide applications will reduce annual mowing occurrences. The spray truck is the most cost-effective method for keeping turf height and weeds under control. If spraying PGR is followed by broadleaf herbicide, a ROI through labor savings can be realized in 1,509 miles of Zone Two Maintained Turf at Road Edge management per year. Mowing costs $28.65 per mile when performed four times per year, compared to $23.30 per mile per year when spraying twice and mowing twice.

Table 34. Zone Two: Maintain Road Edge Return On Investment - Per Mile Labor Cost Savings

Maintain Turf at Road Edge, No Rail Control Methods	Purchase Price	Labor Cost per Mile per Year	Labor Cost Savings per Mile per Year	Miles Needed for ROI	Hours to Accomplish ROI
Method 1: Mowing Only (SOP)	-	$28.65	$0.00	N/A	N/A
Method 2: Spray Truck with 10-ft. Nozzle, PGR + Broadleaf Herbicide	$8,073.00	$23.30	$5.35	1509	163

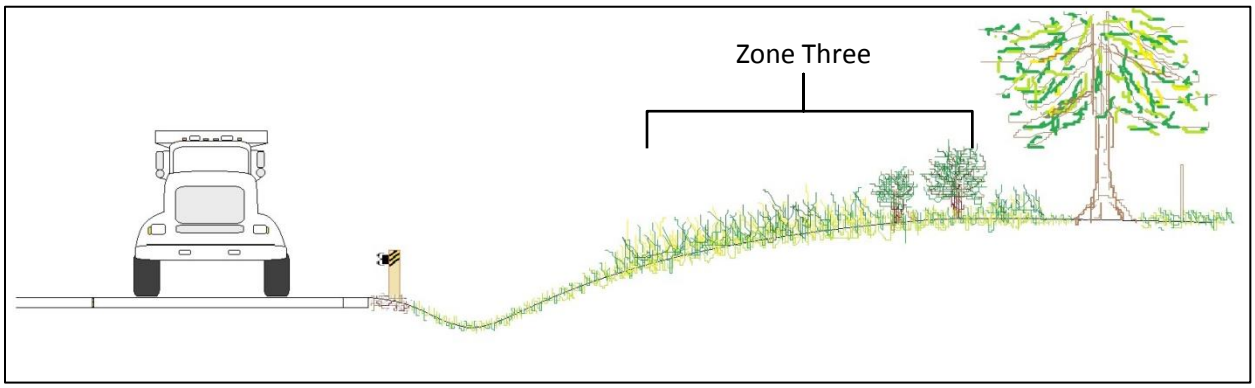
Maintain Turf on Slopes: The baseline labor cost for Zone Two: Maintained Turf Under Rail labor comparison is using a remote control slope mower (Table 35). Note that the labor cost of a spray truck is much lower than any of the mechanical options. Cost savings can justify a ROI by eliminating the need for mechanical mowing. The results of testing indicate that spraying broadleaf herbicide in spring can eliminate the need for mowing on slopes. The spray truck is the most cost-effective method for keeping turf height and weeds under control on slopes. When using the spray truck for slopes, a ROI through labor savings can be realized in 135 acres of Zone Two slope management per year. If using the Kut Kwick slope mower, a ROI through labor savings can be realized in 1,816 acres of Zone Two slope management per year. Mowing with the remote control mower costs $60.36 (or $40.12 with the Kut Kwick slope mower) per acre when performed twice per year, compared to $0.55 per acre per year when spraying once. As the Alamo Traxx™ RF is slower than the Kut Kwick, there is no ROI from labor savings.

Table 35. Zone Two: Maintain Slope Return On Investment - Per Acre Labor Cost Savings

Test 5: Maintain Turf on Steep Slopes Control Methods	Purchase Price	Labor Cost per Acre per Year	Labor Cost Savings per Acre per Year	Acres Needed for ROI	Hours to Accomplish ROI
Test 6 Treatment 2: Alamo Traxx™ RF	$86,914	$60.36	$0.00	N/A	N/A
Test 6 Treatment 1: Kut Kwick Super Slope Master	$36,755.00	$40.12	$20.24	1816	1729
Test 5 Method 2: Skid Sprayer with 22-ft. nozzle, Broadleaf Herbicide	8,073.00	$0.55	$59.81	135	5

Zone Three – The Transition Zone

Figure 19. Diagram of ODOT's Roadside Management Zone Three



Overview

Zone Goal: Zone Three requires selective vegetation management (Figure 19). Management in this zone promotes low-maintenance plant communities, blends and/or screens adjacent surroundings, controls noxious and invasive weeds, prevents erosion, maintains and enhances visual quality, preserves wetlands and wildlife habitat, accommodates utilities, and preserves or conserves native plants and wildflowers (Ohio Maintenance Operations Manual, 803.3).

Overview of Current Maintenance Practices: Zone Three vegetation management activities include using mechanical and chemical methods to selectively control vegetation. Challenges for controlling noxious and invasive weeds, brush, and small trees in Zone Three include access, terrain, size of plants, and rapid regrowth. The SOP for vegetation control is mechanical removal with a mower or mulcher head. This type of maintenance is typically performed once per year but may occur more frequently, with fast, tall-growing vegetation causing sight distance problems. Annual and even more frequent mechanical maintenance in problem spots requires a large amount of labor and equipment, preventing crews from making progress and keeping maintenance staff in a reactive mode.

Safety: Risks associated with vegetation management in Zone Three include exposure to traffic, difficult access or terrain, and working with large, overgrown, or toxic vegetation. Zone Three access and terrain issues include guardrails, preventing access and uneven or sloped terrain. These constraints make mechanical maintenance time-consuming and dangerous for ODOT employees. Mechanical removal does not control undesirable vegetation in Zone Three and often promotes rapid regrowth. Repeat mechanical removal becomes necessary, thereby increasing safety risk exposure. If undesirable vegetation is left uncontrolled, encroachment and safety issues could manifest for traveling motorists.

Objective: Controlling noxious and invasive weeds, brush, and small trees will reduce the need for mechanical removal and reduce safety risk exposure to workers controlling vegetation in Zone Three. Control can be safely and efficiently obtained with the use of chemical methods, thereby reducing or eliminating the need for mechanical maintenance. Chemical methods of vegetation control tested in Zone Three include foliar spraying, basal bark treatments, and directed treatments to control brush, shrubs, small-diameter trees, and noxious or invasive plants. The objectives of using chemical methods were to control noxious and invasive weeds, shrubs, and small trees to improve sight distance, lengthen the cycle between maintenance activities, reduce labor and costs involved with each maintenance activity, and reduce employee exposure in Zone Three.

Zone Three: Test 1, Johnsongrass (Sorghum halepense) *Control*

Johnsongrass is a perennial grass that begins rapid growth in midsummer, with a mature height of over 8 feet. The rapid growth rate of Johnsongrass causes site distance concerns between mowing events. Testing of Johnsongrass occurred off the edge of the paved road to the fence line of a two-lane state route (Photograph 37). This test evaluated two different herbicides with mowing compared to mowing alone in controlling this noxious weed.

Methods

The chemical applications in this test were applied using directed spray gun applications. For these applications, a 200-gallon skid sprayer with a spray gun and hose reel were used (Photograph 38). For the mechanical maintenance, a 15-foot batwing mower being pulled by a tractor was used. See Table 36 for equipment information.

Table 36. Zone Three: Test 1, Equipment

Equipment	Equipment Number
Spray Truck, GMC 2500 4WD	2220786
Spray Equipment, 200-gal. spray tank, pump, spray gun, and powered hose reel	8100159
Tractor, John Deere 6105M	8931838
Mower, Schulte XH1500	6400504

Method 1: (1 Treatment) Mow Only (SOP): Mowing was performed on the same schedule as the rest of the highway north and south of the test site.

Method 2: (2 Treatments) Skid Sprayer Directed Application + Mowing: Midsummer directed herbicide applications were made with a skid sprayer and spray gun to Johnsongrass before seed heads developed. The mowing schedule was checked and adjusted as needed so as not to occur two weeks before or after the herbicide application. Otherwise, mowing was performed on the same schedule as the rest of the highway north and south of the test site.

Treatment 1: Grass Selective Herbicide Outrider® (sulfosulfuron)

Treatment 2: Non-Selective Herbicide Rodeo® (glyphosate)

Photograph 37. Johnsongrass growing along the ROW in a mow-only plot over 8 feet tall. Flowers can be seen above the plant with their spreading pinnacle form.

Photograph 38. ODOT employee applying directed herbicide to Johnsongrass in test plots. The herbicide application was timed for when the Johnsongrass is days to weeks away from fully opening its flowers.

Results

Prior to testing in summer 2014, all plots started with between 44% and 57% Johnsongrass coverage. With three consecutive herbicide applications from 2014 to 2016, Outrider® and Rodeo® significantly reduced Johnsongrass percent coverage compared to the mow-only method (1%, 23%, and 63%, respectively) (see Figure 20).

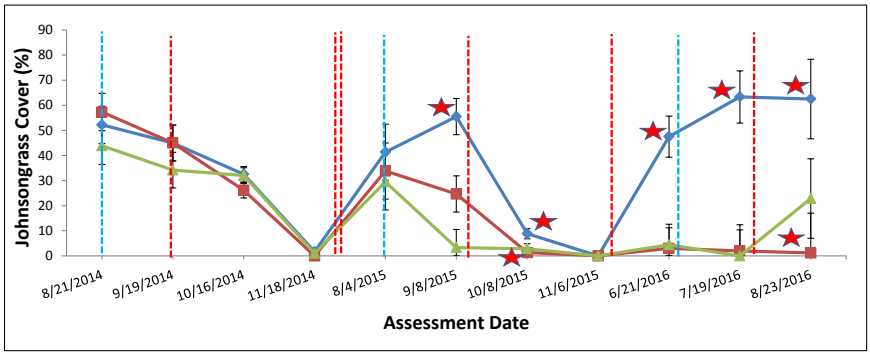
Method 1 Treatment 1: Mow Only (SOP): Mow-only plots started testing in 2014, with 52% Johnsongrass coverage. Although mow-only plots were mowed six times throughout testing, the mowing of Johnsongrass did not provide any control throughout testing from 2014 to 2016. Additionally, sight distance was only maintained until summer when Johnsongrass grew rapidly as it matured. In summer 2015, Johnsongrass coverage reached a maximum of 56% coverage; in summer 2016, Johnsongrass reached a maximum of 63% coverage (Photograph 39). By the end of testing, mow only did not provide any control of Johnsongrass and had significantly more Johnsongrass coverage (63%) than Outrider® (1%) and Rodeo® (23%).

Method 2: Skid Sprayer Directed Application + Mowing

Treatment 1: Outrider® + Mowing: Outrider® plots started testing in 2014 with 57% Johnsongrass coverage. The summer 2014 application reduced Johnsongrass percent cover by 23%, resulting in 34% coverage in summer 2015. The summer 2015 application further reduced Johnsongrass percent cover by 31%, resulting in 3% coverage in summer 2016. The final application in summer of 2016 reduced Johnsongrass percent cover by an additional 2%, resulting in 1% coverage in summer 2016 (Photograph 40). By the end of testing, Outrider® significantly reduced Johnsongrass coverage compared to mow only and ended testing with 1% Johnsongrass coverage (P=0.0339).

Treatment 2: Rodeo® + Mowing: Rodeo® plots started testing in 2014 with 44% Johnsongrass coverage. The summer 2014 application reduced Johnsongrass percent cover by 14%, resulting in 30% coverage in summer 2015. The summer 2015 application further reduced Johnsongrass percent cover by 26%, resulting in 4% coverage in summer 2016. The final application in summer of 2016 reduced Johnsongrass percent cover by an additional 4%, resulting in 0% coverage 30 days after application (Photograph 41). However, by the end of testing, Rodeo® plots had an increase in Johnsongrass coverage to 23%. Although reductions in Johnsongrass coverage seemed consistent through 2015 and most of 2016, the final assessment in August 2016 showed regrowth of Johnsongrass in an area that had been treated and burned out.

Figure 20. Johnsongrass Coverage Comparison



Key to Figure 20.

- Statistically Significant Event
- Mow Only
- Outrider®
- Rodeo®
- Mechanical Control (Mow all plots)
- Herbicide Application (both herbicides)
- Error Bars

Photograph 39. Mow-Only Plot.

Photograph 40. Outrider® Plot.

Photograph 41. Rodeo® Plot.

Treatment Cost Comparison: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. Analysis of labor costs indicated that several factors influence these costs such as variations in methods, equipment efficiency, number of staff, and occurrences per year. Table 37 shows the labor cost to mow one acre of Johnsongrass compared to spraying one acre of Johnsongrass with a skid sprayer and directed spray gun application. Table 38 describes the labor cost to treat one acre of Johnsongrass for one year with each method used in this test. The materials costs are located in Table 39, which shows the per-acre and per-mile costs of each herbicide used in this test. The cost of materials can be added to the labor cost for each method to determine the total cost per method.

Equipment Review: The following skid sprayer equipment review is the same for Zone Three Tests 1-5 and Test 9 where directed applications with a skid sprayer were made. The skid sprayer was slid into the back of a pickup truck and could easily be slid out when the bed was needed for other uses and in the off-season. Since the equipment was in a pickup truck, the truck was lightweight enough to drive off-road to reach vegetation in the back of the right-of-way. The hose was long enough to reach long distances and the hose reel made rewinding the hose easy. The spray gun was easy to use and performed well. The only modification made to the unit was the addition of a flow meter to calibrate the applicators to avoid underapplication and overapplication. This additional piece of equipment was put in place by Davey Resource Group researchers for testing purposes. The skid sprayer and the applicators who use it could benefit from the addition of a permanent flow meter for calibration purposes.

Table 37. Zone Three: Test 1, RIVM Method Labor Comparison

RIVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre
Batwing Mower (15-foot width)	1	$19.10	4.79	0.21	$4.01
Skid Sprayer Directed Application	1	$19.10	1.41	1.39	$26.55

Table 38. Zone Three: Test 1, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Total Cost per Acre per Year
Method 1 Treatment 1: Mow Only (SOP)	5	0	1.05	$20.06
Method 2 Treatment 1: Outrider® + Mowing	5	1	2.44	$46.60
Method 2 Treatment 2: Rodeo® + Mowing	5	1	2.44	$46.60

Table 39. Zone Three: Test 1, Herbicide Mixture Cost Comparison

Herbicide Mix	Rate (oz./acre)	Cost per Acre	Cost per Mile
Method 2 Treatment 1: Outrider®	0.75	$0.50	$1.21
Method 2 Treatment 2: Rodeo®	192	$11.10	$26.91

Recommendation

Controlling Johnsongrass is necessary to maintain sight distance and aesthetic quality along the road. Mowing is not necessary to control Johnsongrass and will not control it. Johnsongrass usually grows among desirable turf; mowing in these areas will be needed to maintain the desired height of other grasses. Annual herbicide applications are necessary until populations are controlled to prevent the spread of this noxious weed.

Make directed spray gun applications to dense colonies of Johnsongrass during midsummer when the grass reaches 18–24" in height, just before seed head formation. At that growth stage (boot-to-head), Johnsongrass is most susceptible to herbicide applications, and the height of the grass has not yet caused maintenance concerns. Both herbicides successfully controlled Johnsongrass on the test site. However, be aware that Johnsongrass has shown resistance to Rodeo® in other locations. Applications of Rodeo® should, therefore, be monitored for resistance.

Outrider® at 0.75 oz./acre rate is selective to Johnsongrass but will not injure desirable turf such as tall fescue. Because Outrider® is selective at that rate, broadcast spray truck applications are recommended and should be made in areas where Johnsongrass is common along roadways. For areas of Ohio where Johnsongrass is prevalent, large colonies can be reduced or prevented by making annual broadcast applications at the proper time during midsummer. For smaller, dense patches of Johnsongrass, make directed, midsummer applications with a spray gun. If mowing is needed, make sure to allow sufficient time to pass as specified on the label, depending on whether mowing before application or after application. If spraying after mowing, allow two weeks of regrowth or when Johnsongrass reaches 18–24" in height. If spraying before mowing, it may be best to allow two weeks for herbicide to work before cutting.

Rodeo® is non-selective and will kill all vegetation that is sprayed. Therefore, Rodeo® is only recommended for spray gun applications to dense colonies of Johnsongrass, or in areas where total vegetation control is desired, such as around signs or guardrails. If spraying after mowing, allow two weeks of regrowth or when Johnsongrass reaches 18–24" in height. If spraying before mowing, it may be best to allow two weeks for herbicide to work before cutting.

Outrider® is the recommended herbicide, as it has shown better control of Johnsongrass at the test site. Johnsongrass has not shown resistance to Outrider® which will not kill other grasses when it is applied.

Zone Three: Test 2, Japanese Knotweed (Fallopia japonica *var* japonica) *Control*

Japanese knotweed is a perennial broadleaf that begins rapid growth in spring with a mature height of over ten feet. The rapid growth rate of Japanese knotweed causes site distance concerns between mowing events. To reduce the possibility of disturbance to the test, the chosen site had knotweed growing beyond the ditch line (Photograph 42) and just behind a guardrail, but knotweed can just as easily be growing all the way up to the road edge, causing sight distance issues and requiring frequent maintenance. This test evaluated the effectiveness of two different herbicides compared to mowing alone in controlling this noxious weed.

Methods

The chemical applications in this test were applied using directed spray gun applications. For these applications, a 200-gallon skid sprayer with a spray gun and hose reel were used. For the mechanical maintenance a side-arm rotary mower attached to a tractor was used. See Table 40 for equipment information.

Table 40. Zone Three: Test 2, Equipment

Equipment	Equipment Number
Spray Truck, GMC 2500 4WD	2220786
Spray Equipment, 200-gal. spray tank, pump, spray gun and powered hose reel	8100159
Tractor, John Deere 6415	8931478
Rotary Arm Mower, Tiger TRB50C	6420188

Method 1: (1 Treatment) Mow Only (SOP): In 2014 and 2015, mowing was completed towards the end of the growing season to simulate a fall mow back to determine the time spent on mowing. In 2016, mowing occurred at the same time as the herbicide application, during the active growing season to determine how long the benefits of increased sight distance would last if the knotweed were near the road edge and immediate removal was necessary.

Method 2: (2 Treatments) Skid Sprayer Directed Application + Mowing: Late-summer directed herbicide applications were made in 2014 and 2015 with a skid sprayer and spray gun to Japanese knotweed just after flowers developed. In 2016, a late spring application was made. In 2014, all plots were mowed 30 days after herbicide application to simulate a fall mow back. In 2015, all plots were mowed 60 days after herbicide application to simulate a fall mow back. In 2016, no mowing was performed in these plots.

Treatment 1: Milestone® (aminopyralid)

Treatment 2: Ecomazapyr 2 SL (imazapyr)

Photograph 42. Japanese Knotweed test site, Monroe County

Results

Both herbicides significantly reduced Japanese knotweed percent coverage compared to mow-only plots by the end of 2016. Ecomazapyr 2 SL proved to be the most successful treatment at controlling Japanese knotweed. Due to the nature of this plant and the timing of its life cycle, results from the summer 2014 and 2015 herbicide trials were most dramatically seen in the spring following herbicide treatments. After three consecutive years of herbicide applications from 2014 to 2016, the mow-only plots contained significantly more Japanese knotweed than Milestone® and Ecomazapyr 2 SL plots (92%, 55%, and 6%, respectively) (see Figures 21 and 22).

Method 1 Treatment 1: Mow Only (SOP): Mow-only plots started testing in 2015 with 85% Japanese knotweed coverage. Mowing of Japanese knotweed in fall 2014 increased Japanese knotweed coverage by 8%, resulting in 93% Japanese knotweed coverage in late summer 2015. The mowing of Japanese knotweed in fall 2015 increased Japanese knotweed coverage by 3%, resulting in 96% Japanese knotweed coverage in spring 2016. The final mow in spring 2016 reduced Japanese knotweed percent coverage by 4%, resulting in 92% Japanese knotweed coverage in late summer 2016. By the end of testing, mow only contained significantly higher Japanese knotweed coverage compared to both of the herbicides (Photograph 43).

Method 2: Skid Sprayer Directed Application + Mowing

Treatment 1: Milestone®+ Mowing: Milestone® plots started testing in 2014, with 94% Japanese knotweed coverage. The first application of Milestone® in late summer 2014 reduced Japanese knotweed coverage by 6%, resulting in 88% Japanese knotweed coverage in late summer 2015. The late summer 2015 application of Milestone® reduced Japanese knotweed percent coverage by 31%, resulting in 57% Japanese knotweed coverage in spring 2016. The spring 2016 application of Milestone® reduced Japanese knotweed percent coverage by an additional 2%, resulting in 55% coverage in late summer 2016 (Photograph 44). By the end of testing, Milestone® significantly reduced Japanese knotweed coverage compared to mow only and ended testing with 55% Japanese knotweed coverage (P=0.0041).

Treatment 2: Ecomazapyr 2 SL+ Mowing: Ecomazapyr 2 SL plots started testing in 2014 with 87% Japanese knotweed coverage. The first application of Ecomazapyr 2 SL in late summer 2014 reduced Japanese knotweed coverage by 58%, resulting in 29% Japanese knotweed coverage in late summer 2015. The late summer 2015 application of Ecomazapyr 2 SL reduced Japanese knotweed percent coverage by an additional 28%, resulting in 1% Japanese knotweed coverage in late summer 2016. The spring 2016 application of Ecomazapyr 2 SL increased Japanese knotweed percent coverage by 5%, resulting in 6% coverage in late summer 2016 (Photograph 45). By the end of testing, Ecomazapyr 2 SL significantly reduced Japanese knotweed coverage compared to both Milestone® and mow only and ended testing with 6% Japanese knotweed coverage (P=0.0009, and P=<0.0001, respectively).

Figure 21. Japanese Knotweed Coverage Comparison

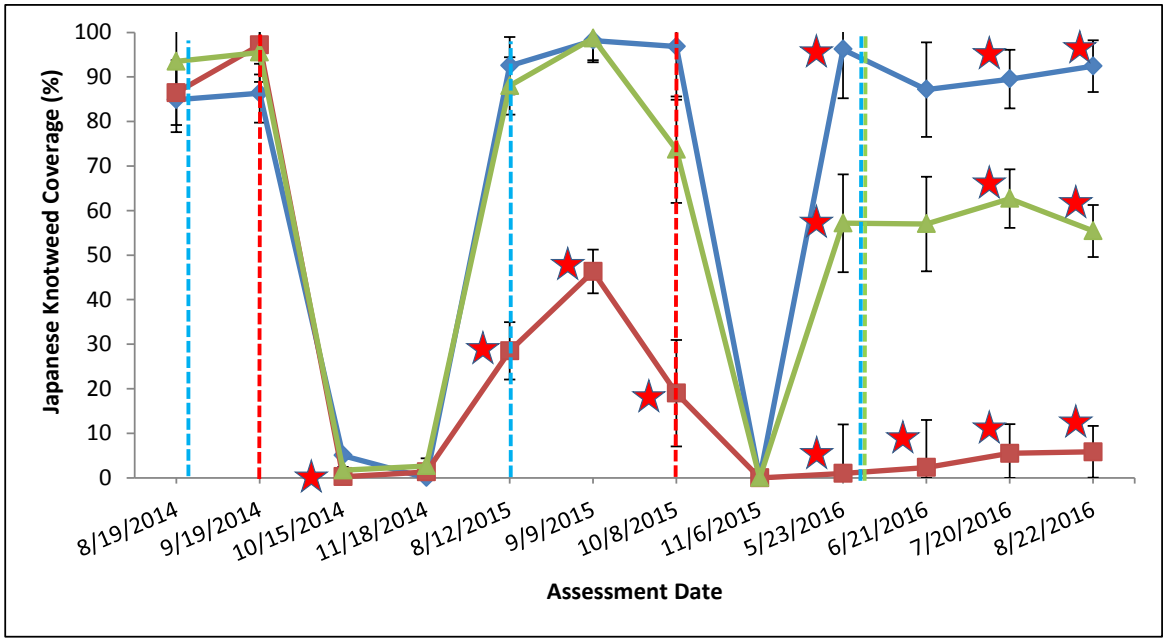
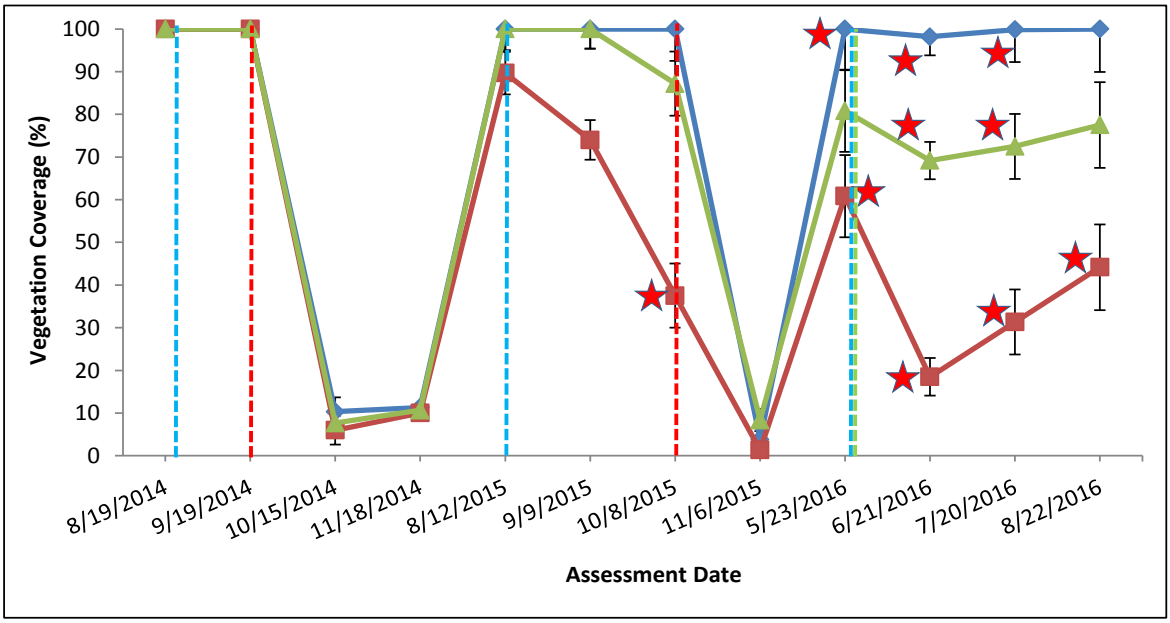


Figure 22. Vegetation Coverage Comparison



Key to Figures 21-22.

- Statistically Significant Event
- Mow Only
- Ecomazapyr 2 SL
- Milestone®
- Mechanical Control (mow all)
- Mechanical Control (mow only)
- Herbicide Control (both broadleaf herbicides)
- I Error Bars

Treatment Cost Comparison: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing these labor costs, there are several factors that influence the costs, such as variations in methods, equipment efficiency, number of staff, and occurrences per year. Table 41 describes the labor cost to mow one acre of Japanese knotweed compared to spraying one acre of Japanese knotweed with a skid sprayer and directed spray gun application. Table 42 describes the labor cost to treat one acre of Japanese knotweed for one year with each method used in this test. The materials costs are located in Table 43, which shows the per-acre and per-mile costs of each herbicide used in this test. The cost of materials can be added to the labor cost for each method to see the total cost per method.

Photograph 43. Mow-Only Plot

Photograph 44. Milestone® Plot

Photograph 45. Ecomazapyr 2 SL Plot

Table 41. Zone Three: Test 2, RIVM Method Labor Comparison

RIVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre
Rotary Arm Mower	1	$19.10	0.30	3.56	$68.00
Skid Sprayer Directed Application	1	$19.10	0.75	1.50	$28.65

Table 42. Zone Three: Test 2, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Total Cost per Acre per Year
Method 1 Treatment 1: Mow Only (SOP)	1	0	3.56	$68.00
Method 2 Treatment 1: Milestone® + Mowing	1	1	4.31	$82.32
Method 2 Treatment 2: Ecomazapyr 2 SL + Mowing	1	1	4.31	$82.32

Table 43. Zone Three: Test 2, Herbicide Mixture Cost Comparison

Herbicide Mix	Rate (oz./acre)	Cost per Acre	Cost per Mile
Method 2 Treatment 1: Milestone®	7	$6.56	$15.89
Method 2 Treatment 2: Ecomazapyr 2 SL	64	$9.81	$23.78

Recommendation

Mowing does not control Japanese knotweed. In fact, mowing can exacerbate Japanese knotweed problems by dropping cuttings as the mower drives down the road and those cuttings can propagate to start populations of Japanese knotweed at new locations. Japanese knotweed colonies may start away from the road edge beyond the ditch, but with a rapid growth rate, Japanese knotweed is capable of growing to the edge of the roadway and over guardrails and signs if left uncontrolled. Mowing without herbicide application allows Japanese knotweed to increase in density per acre; however, this course of action may be necessary to maintain sight distance in certain cases leading up to herbicide applications. The results of this test suggest that annual successional herbicide treatments are needed to reduce and completely control Japanese knotweed.

If mowing is necessary to achieve sight distance, plan and coordinate around applications (as specified on the label). If mowing before an application, allow sufficient time to pass before applying herbicide to allow foliage regrowth for sufficient surface area to receive the herbicide. If applying herbicide before mowing, allow sufficient time for herbicide to travel through foliage and into the stems for effective treatment before mowing. If mowing can wait, the best option is to make a late summer application, and wait until fall before mechanically removing. Directed spray gun applications should be made to Japanese knotweed in late summer while it is still actively growing. As a perennial plant, Japanese knotweed is most susceptible to herbicide applications in the late summer as nutrients are being transported to the root system.

Although both herbicides outperformed mowing in respect to injuring or controlled Japanese knotweed, Ecomazapyr 2 SL performed significantly better than Milestone®. Herbicide injury was observed by the application of Milesonte® but within the timeframe of testing Japanese knotweed coverage rarely was significantly lower than mowing only. On the other hand, Ecomazapyr 2 SL significantly reduced Japanese knotweed coverage compared to mow only and Milestone® in 2015 and 2016. Foliar applied Ecomazapyr 2 SL @ 64 oz./acre can injure established turfgrass; since the Japanese knotweed colonies are so dense; however, Japanese knotweed is often the only plant growing in those areas. Turfgrass injury, thus, shouldn't be too much of a concern. Keep in mind that Ecomazapyr 2 SL persists in the soil and may prevent grass seed germination for up to one year after treatment.

Foliar applied Milestone® at the 7 oz./acre rate was not as effective as Ecomazapyr 2 SL at controlling Japanese knotweed. However, Milestone® has shown to be more effective at controlling Japanese knotweed than mowing after the second application. The Milestone® label recommends allowing at least 14 days for herbicide to work before mowing, but if more time is allowed control results may be improved. Milestone® will not injure established turf. Only one application per year can be made with Milestone® at the 7 oz./acre rate which is the maximum allowable rate per acre per year.

Zone Three: Test 3, Poison Hemlock (Conium maculatum) *Control*

Poison hemlock is a biennial broadleaf weed that begins rapid growth in spring with a mature height of over ten feet. Poison hemlock can cause site distance concerns, but it is also highly toxic to humans and animals. It is usually found growing in areas that are not frequently mowed. To reduce the possibility for disturbance to the test, the chosen site had poison hemlock set back along the ROW fence of an interstate (Photographs 46 and 47). This test evaluated the effectiveness of two different herbicides compared to mowing alone in controlling this noxious weed.

Methods

The chemical applications in this test were applied using directed spray gun applications. For these applications, a 200-gallon skid sprayer with a spray gun and hose reel were used. For the mechanical maintenance, a 15-foot batwing mower attached to a tractor was used. See Table 44 for equipment information.

Table 44. Zone Three: Test 3, Equipment

Equipment	Equipment Number
Spray Truck, GMC 2500 4WD	2220786
Spray Equipment, 200-gal. spray tank, pump, spray gun, and powered hose reel	8100159
Tractor, John Deere 6105M	8931837
Batwing Mower, Schulte XH1000-S3	6400471

Method 1: (1 Treatment) Mow Only (SOP): Mowing took place in the fall of 2014 prior to the start of testing to reduce the height of dead standing vegetation. In fall 2015, mowing occurred again.

Method 2: (2 Treatments) Skid Sprayer Directed Application + Mowing: In this method, directed herbicide applications were made in the early spring (just after the last frost and before the poison hemlock rosettes bolted) of 2015 and 2016 with a skid sprayer and spray gun. In fall 2014, mowing took place to reduce the height of dead standing vegetation in preparation for the spring 2015 application. Mowing occurred again in fall 2015.

Treatment 1: Perspective® (aminocyclopyrachlor)

Treatment 2: Milestone® (aminopyralid)

Photograph 46. Poison hemlock rosettes growing in early spring at test site (Noble County).

Photograph 47. Poison hemlock preparing to flower in May at test site (Noble County).

Results

Both herbicides significantly reduced poison hemlock percent coverage compared to the mow-only plots. After two consecutive spring herbicide applications from 2015 to 2016, the mow only plots contained significantly more poison hemlock than Milestone® and Perspective® plots (44%, 5%, and 0%, respectively) (see Figures 23 and 24).

Method 1 Treatment 1: Mow Only (SOP): At the start of testing in 2015, mow-only plots had 48% poison hemlock coverage. The mowing of poison hemlock may have reduced the poison hemlock coverage seasonally but did not reduce the poison hemlock seedling emergence from 2015 to 2016. This can be seen in the poison hemlock coverage from May 2015 (48%) compared to May 2016 (48%). The mow-only plots experienced a 36% increase in poison hemlock coverage from fall 2015 (end of season dieback) to spring 2016, resulting in spring poison hemlock coverage of 36%. Mow-only plots in spring 2016 reached a maximum of 48% poison hemlock coverage. By the end of testing, mow only contained significantly higher poison hemlock coverage than both of the herbicides and ended testing with 44% coverage (Photograph 48).

Method 2: Skid Sprayer Directed Application + Mowing

Treatment 1: Perspective®+ Mowing: At the start of testing in 2015, Perspective® plots had 56% poison hemlock coverage. The first foliar application of Perspective® in spring 2015 reduced poison hemlock percent coverage by 48%, resulting in 8% poison hemlock coverage by August 2015. The Perspective® plots experienced a 35% increase in poison hemlock coverage from fall 2015 (end of season dieback) to spring 2016, resulting in spring 2016 poison hemlock coverage of 38%. The second foliar application of Perspective® in spring 2016 reduced poison hemlock percent coverage by 38%, resulting in 0% poison hemlock coverage in June and July 2016. By the end of testing, Perspective® significantly reduced poison hemlock coverage compared to mow only and ended testing with 0% poison hemlock coverage (P=0.0013) (Photograph 49).

Treatment 2: Milestone® + Mowing: At the start of testing in 2015, Milestone® plots had 52% poison hemlock coverage. The first foliar application of Milestone® in spring 2015 reduced poison hemlock percent coverage by 39%, resulting in 13% poison hemlock coverage by August 2015. The Milestone plots experienced only a mild increase (8%) in poison hemlock coverage from fall 2015 (end of season dieback) to spring 2016, resulting in spring poison hemlock coverage of 21%. The second foliar application of Milestone® in spring 2016 reduced poison hemlock percent coverage by an additional 16%, resulting in 5% coverage. By the end of testing, Milestone® significantly reduced poison hemlock coverage compared to mow only and ended testing with 5% poison hemlock coverage (P=0.0025) (Photograph 50).

Figure 23. Poison Hemlock Coverage Comparison

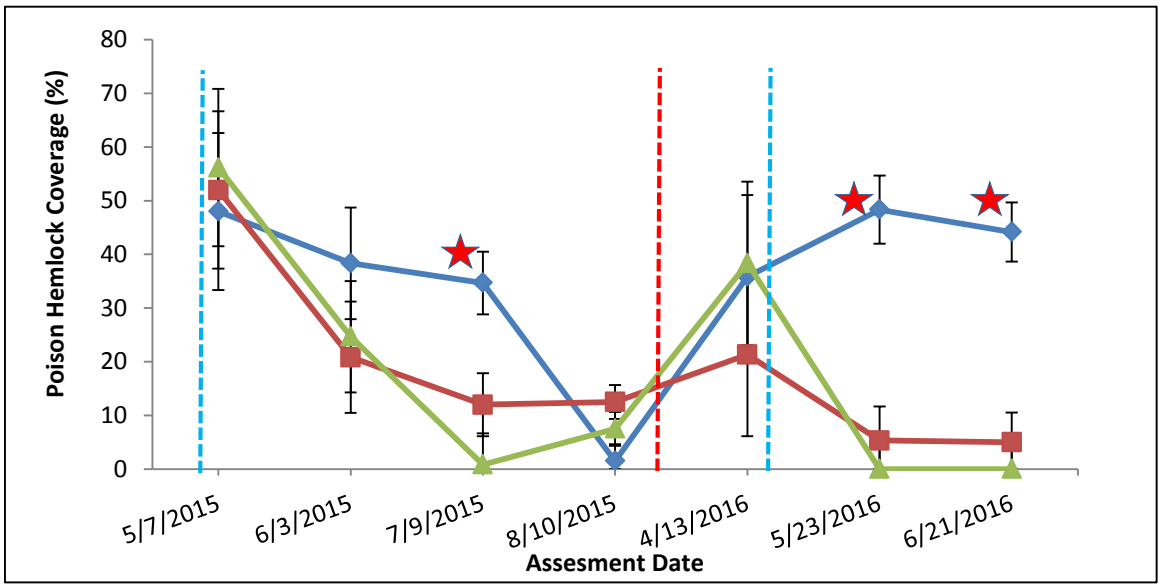
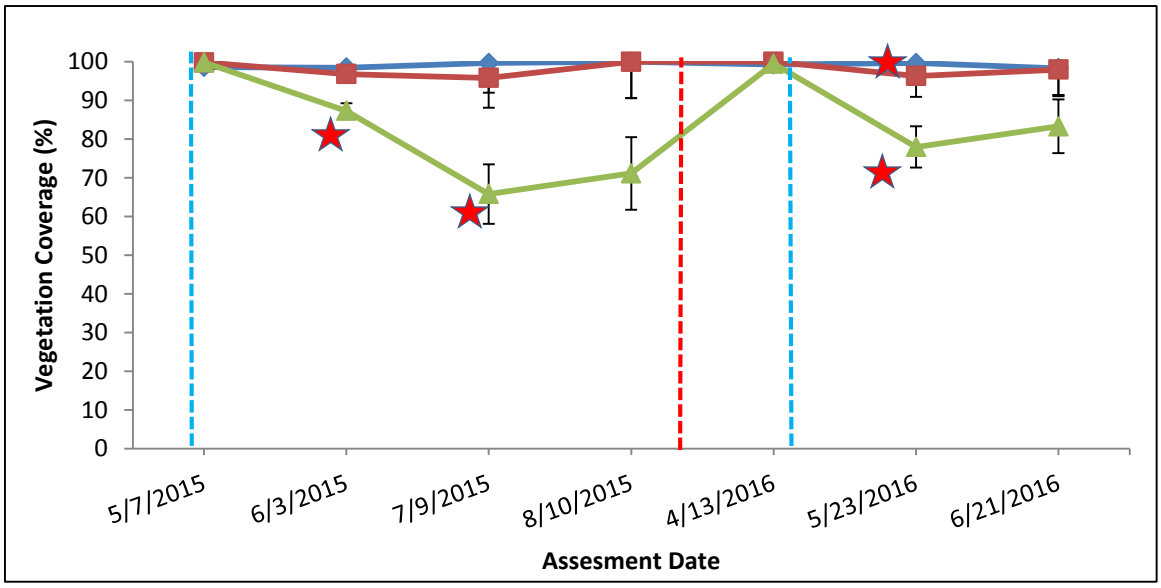


Figure 24. Vegetation Coverage Comparison



Key to Figures 23-24.

- Statistically Significant Event
- Mow Only
- Milestone®
- Perspective®
- Mechanical Control (mow all)
- Herbicide Control (both broadleaf herbicides)
- Error Bars

Photograph 48. Mow-Only Plot

Photograph 49. Perspective® Plot

Photograph 50. Milestone® Plot

Treatment Cost Comparison: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing these labor costs, there are several factors that influence the costs such as variations in methods, equipment efficiency, number of staff, and occurrences per year. Table 45 describes the labor cost to mow one acre of poison hemlock compared to spraying one acre of poison hemlock with a skid sprayer and directed spray gun application. Table 46 describes the labor cost to treat one acre of poison hemlock for one year with each method used in this test. The materials costs are located in Table 47, which shows the per-acre and per-mile cost of each herbicide used in this test. The cost of materials can be added to the labor cost for each method to see the total cost per method.

Table 45. Zone Three: Test 3, RIVM Method Labor Comparison

RIVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre
Batwing Mower (15-foot width)	1	$19.10	3.00	0.33	$6.30
Skid Sprayer Directed Application	1	$19.10	0.72	1.43	$27.31

Table 46. Zone Three: Test 3, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Total Cost per Acre per Year
Method 1 Treatment 1: Mow Only (SOP)	1	0	0.33	$6.30
Method 2 Treatment 1: Perspective® + Mowing	1	1	1.76	$33.62
Method 2 Treatment 2: Milestone® + Mowing	1	1	1.76	$33.62

Table 47. Zone Three: Test 3, Herbicide Mixture Cost Comparison

Herbicide Mix	Rate (oz./acre)	Cost per Acre	Cost per Mile
Method 2 Treatment 1: Perspective®	7	$6.44	$15.61
Method 2 Treatment 2: Milestone®	7	$6.56	$15.89

Recommendation

Mowing did not provide significant control of poison hemlock, but mowing can help reduce colony density or reduce seed production if properly timed. Poison hemlock is often found in areas that are not frequently mowed. The results of this test reveal that annual successional herbicide treatments are needed to reduce and completely control poison hemlock.

Directed spray gun applications to poison hemlock should be made in the early spring while plants are actively growing, but before rosettes bolt and develop vertical stems. As a biennial weed, poison hemlock is most susceptible to herbicide applications during spring while in rosette form when leaves are tightly arranged and plants are still relatively short. Both herbicides successfully controlled poison hemlock, and either Perspective® at 7 oz./acre or Milestone® 7 oz./acre are acceptable choices for controlling poison hemlock.

Foliar applied Milestone® is a gentler herbicide on grass. Grass in the Milestone® plots was healthier and able to develop seed heads, allowing grass to reseed the plots previously heavily populated with poison hemlock. This helped improve the turf stand, which increased grass coverage and provided competition to poison hemlock. Only one application per year can be made with Milestone® at the 7 oz./acre rate because this is the maximum allowable rate per acre per year.

Foliar applied Perspective® is harsher on grass than Milestone®. Since grass seed heads were not able to develop in the Perspective® plots when the poison hemlock was controlled, grass did not fill in the bare ground patches as readily as grass filled in the areas poison hemlock was controlled in the Milestone® plots. The bare ground patches in the Perspective® plots were found to allow more poison hemlock to germinate and could have led to increased poison hemlock coverage if left untreated in the future. The second application was able to effectively control poison hemlock and left less bare ground patches. Consider making applications at 5 oz./acre if turf preservation is desired. Only one application per year can be made with Perspective® at the 7 oz./acre rate because the maximum allowable rate is 11 oz./acre per year.

Annual herbicide applications will need to be made until poison hemlock is under control. Consider rotating herbicides on an annual basis to resist herbicide tolerance and allow grass to produce seed, thereby enhancing turf coverage and its ability to outcompete weeds.

*Zone Three: Test 4, Kudzu (*Pueraria montana *var*. lobata*) Control*

Kudzu is a perennial broadleaf vine that begins rapid growth in summer and is capable of climbing over trees, brush, signs, and into the roadway (Photograph 51). The test site chosen was located in Meigs County. The kudzu was growing in from the fence line up to the ditch and up to a guardrail on a two-lane state route. This test evaluated the effectiveness of two different herbicides compared to mowing alone in controlling this noxious weed.

Methods

The chemical applications in this test were applied using directed spray gun applications. For these applications, a 200-gallon skid sprayer with a spray gun and hose reel were used. For the mechanical maintenance, a 15-foot batwing attached to a tractor was used. See Table 48 for equipment information.

Table 48. Zone Three: Test 4, Equipment

Equipment	Equipment Number
Spray Truck, GMC 2500 4WD	2220786
Spray Equipment, 200-gal. spray tank, pump, spray gun and powered hose reel	8100159
Tractor, John Deere 6105M	8931784
Batwing Mower, Schulte XH1000-S3	6400402

Method 1: (1 Treatment) Mow Only (SOP): Mowing took place in the fall 2015 as a mow back.

Method 2: (2 Treatments) Skid Sprayer Directed Application + Mow: A single directed broadleaf selective herbicide application was made in late summer 2014 with a skid sprayer and spray gun. Mowing took place the following fall as part of the mow back to clear dead vines.

Treatment 1: Streamline® (aminocyclopyrachlor)

Treatment 2: Milestone® (aminopyralid)

Photograph 51. Kudzu overtaking vegetation on hillside and encroaching ROW, Belmont County.

Results

Both herbicides significantly reduced kudzu percent coverage compared to the mow-only plots. After one foliar herbicide application and three years of assessments from 2014 to 2016, the mow-only plots contained significantly more kudzu than the Milestone® and Streamline® plots (60%, 4%, and 4%, respectively) (see Figures 25 and 26 and Photographs 52 and 53).

Method 1 Treatment 1: Mow Only (SOP): Mow-only plots started testing in 2014 with 84% Kudzu coverage. An assessment of mow-only plots in fall 2015 showed a decrease in kudzu percent coverage by 24%, resulting in 59% kudzu coverage in fall 2015. The mow in fall 2015 was followed by a return of kudzu with a slight increase in percent coverage of 1%, resulting in 60% kudzu coverage in summer 2016. By the end of testing, mow only remained with significantly higher kudzu coverage compared to both herbicides and ended testing with 60% kudzu coverage.

Method 2: Skid Sprayer Directed Application + Mow

Treatment 1: Streamline® + Mow: Streamline® plots started testing in 2014 with 96% kudzu coverage. Foliar application of Streamline® in fall 2014 reduced kudzu percent coverage by 96%, resulting in 0% kudzu coverage in fall 2015. The mow in fall 2015 was followed by an increase of 4% kudzu coverage by summer 2016. By the end of testing, Streamline® significantly reduced kudzu coverage compared to mow only and ended testing with 4% kudzu coverage (P=0.045).

Treatment 2: Milestone® + Mow: Method 2 Treatment 2, Milestone® plots started testing in 2014 with 95% kudzu coverage. Foliar application of Milestone® in fall 2014 reduced kudzu percent coverage by 95%, resulting in 0% kudzu coverage in fall 2015. The mow in fall 2015 was followed by an increase of 4% kudzu coverage by summer 2016. By the end of testing, Milestone® significantly reduced kudzu coverage compared to mow only and ended testing with 4% kudzu coverage (P=0.044).

Figure 25. Kudzu Coverage Comparison

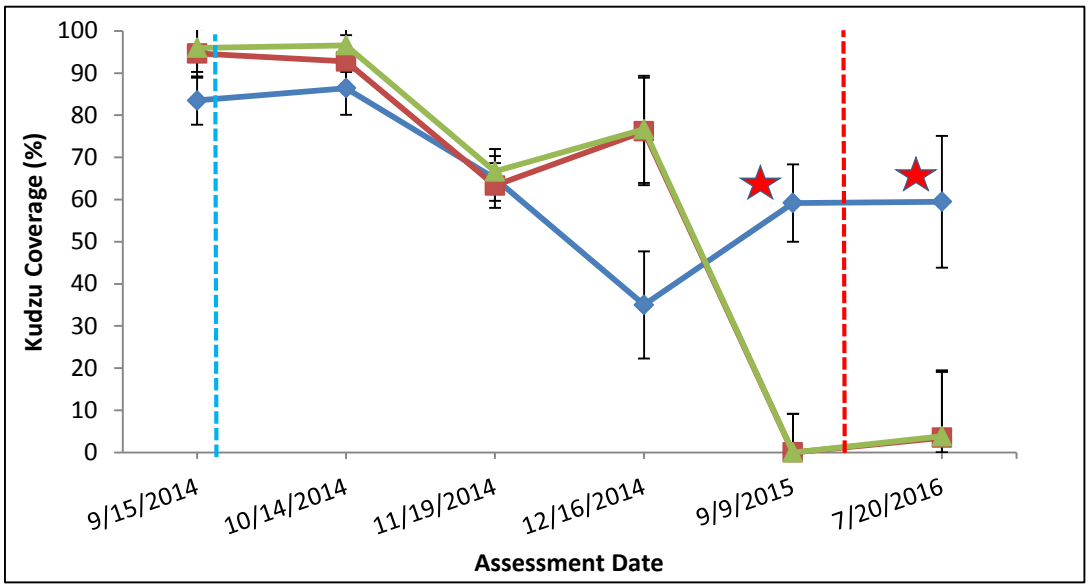
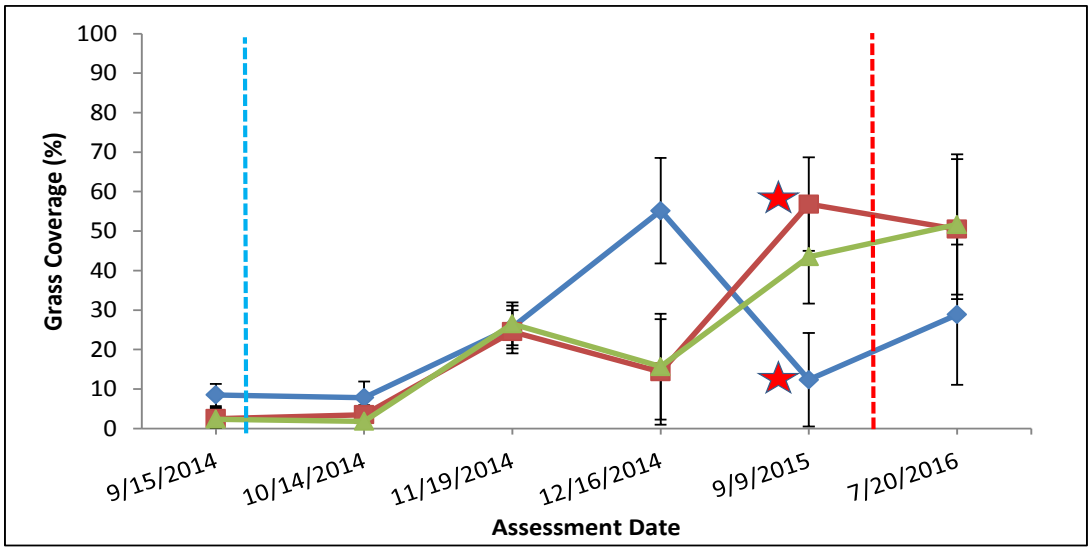


Figure 26. Grass Coverage Comparison



Key to Figures 25-26.

- Statistically Significant Event
- Mow Only
- Milestone®
- Streamline®
- Mechanical Control (mow all)
- Herbicide Control (both broadleaf herbicides)
- Error Bars

Photograph 52. Kudzu before herbicide treatment (Meigs County).

Photograph 53. Kudzu one year after herbicide treatment (Meigs County).

Treatment Cost Comparison: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing labor costs, there are several factors that influence these costs, such as variations in methods, equipment efficiency, number of staff, and occurrences per year. Table 49 describes the labor cost to mow one acre of kudzu compared to spraying one acre of kudzu with a skid sprayer and directed spray gun application. Table 50 describes the labor cost to treat one acre of kudzu for one year with each method used in this test. The materials costs are located in Table 51, which shows the per-acre and per-mile costs of each herbicide used in this test. The cost of materials can be added to the labor cost for each method to see the total cost per method.

Table 49. Zone Three, Test 4, RIVM Method Labor Comparison

RIVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre
Batwing Mower (15-foot width)	1	$19.10	1.29	0.78	$14.90
Skid Sprayer Directed Application	1	$19.10	0.59	1.78	$34.00

Table 50. Zone Three: Test 4, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Total Cost per Acre per Year
Method 1 Treatment 1: Mow Only (SOP)	1	0	0.78	$14.90
Method 2 Treatment 1: Streamline® + Mowing	1	1	2.56	$48.90
Method 2 Treatment 2: Milestone® + Mowing	1	1	2.56	$48.90

Table 51. Zone Three: Test 4, Herbicide Mixture Cost Comparison

Herbicide Mix	Rate (oz./acre)	Cost per Acre	Cost per Mile
Method 2 Treatment 1: Streamline®	9.5	$48.93	$118.61
Method 2 Treatment 2: Milestone®	7	$6.56	$15.89

Recommendation

Mowing is not necessary to control kudzu if herbicide applications are made. Mowing without herbicide application allows kudzu to increase in density per acre and does not provide control, but may be necessary to maintain sight distance in certain cases leading up to herbicide applications. The results of this test showed that a single herbicide application in late summer provided at least two years of control over kudzu.

Make directed spray gun applications to kudzu in late summer while Kudzu is still actively growing. As a perennial vine, kudzu is most susceptible to herbicide applications in the fall as nutrients are being transported to the root system. If mowing is necessary to achieve sight distance, plan and coordinate around applications (as specified on the label). If mowing before an application, allow sufficient time to pass before applying herbicide to allow foliage regrowth for sufficient surface area to receive the herbicide in late summer. If applying herbicide before mowing, allow sufficient time for herbicide to travel through foliage and into the stems for effective treatment before mowing. If mowing can wait, the best option is to make a late summer or early fall application, and wait until the following spring before mechanically removing the kudzu. Both herbicides successfully controlled kudzu. Either Streamline® at 9.5 oz./acre or Milestone® 7 oz./acre are acceptable choices for controlling kudzu.

Foliar applied Streamline® at the 9.5 oz./acre rate is effective at controlling kudzu for over two growing seasons after treatment. The Streamline® label suggests that in some woody plant species, complete plant death may take up to several months. Making applications around the root zones of adjacent trees may cause those trees to be injured or killed. Also keep in mind that Streamline® at this rate can injure established turfgrass; however, at lower rates, Streamline® can be used as a broadleaf selective herbicide without injuring desirable grass.

Foliar applied Milestone® at the 7 oz./acre rate is effective at controlling kudzu for over two growing seasons after treatment. The Milestone® label suggests allowing at least 14 days for herbicide to work before mowing, but if more time is allowed, control results may be improved. Milestone® will not injure established turf.

*Zone Three: Test 5, Autumn Olive (*Elaeagnus umbellata*) Control with Foliar Application*

Autumn olive (*Elaeagnus umbellate*) is an invasive species of shrub that is common throughout the Ohio ROW and is of particular concern in Zone Three. This shrub species grows upwards of 20 feet tall with a wide form; it can grow in large patches and is known for encroaching open spaces within the ROW. Testing was completed along the back edge of the ROW where autumn olive was encroaching from the wood line (Photographs 54 and 55). This test evaluated the effectiveness of two different herbicides compared to mowing alone in controlling this invasive shrub.

Methods

The three methods used combinations of mowing and directed spray gun application with broadleaf selective herbicide. The equipment used in this test was a spray truck with a 200-gallon skid sprayer with a hose reel and a rotary side arm mower attached to a tractor. See Table 52 for equipment information.

Table 52. Zone Three: Test 5, Equipment

Equipment	Equipment Number
Spray Truck, GMC 2500 4WD	2220786
Spray Equipment, 200-gal. spray tank, pump, spray gun, and powered hose reel	8100159
Tractor, John Deere 6415	8931514
Rotary Arm Mower, Tiger TRB50C	6420240
D.B. Smith 4-Gallon Max Backpack Sprayer	N/A

Method 1: (1 Treatment) Mow Only (SOP): Mowing took place in spring 2015. Then, as part of the annual mow back through the county, the plots were unintentionally mowed again.

Method 2: (2 Treatments) Broadleaf selective Herbicide + Mowing: A directed broadleaf selective herbicide was applied in late summer 2014 just before the shrub started to transition into dormancy. Mowing occurred in spring 2015. Then, as part of the annual mow back throughout the county, the plots were unintentionally mowed again. A spot treatment using a backpack sprayer was applied to autumn olive regrowth in the summer of 2016.

Treatment 1: Milestone® (aminopyralid), Triclopyr 4 (triclopyr)

Treatment 2: Streamline® (aminocyclopyrachlor), Triclopyr 4 (triclopyr)

Photograph 54. Autumn olive before herbicide treatment.

Photograph 55. Autumn olive eight months after herbicide treatment.

Results

Both herbicides significantly reduced autumn olive percent coverage compared to mowing only. After two foliar herbicide applications in 2014 and 2016, the mow-only plots contained significantly more autumn olive than Milestone® + Triclopyr 4 and Streamline® + Triclopyr 4 plots (26%, 0%, and 0%, respectively) (see Figure 27).

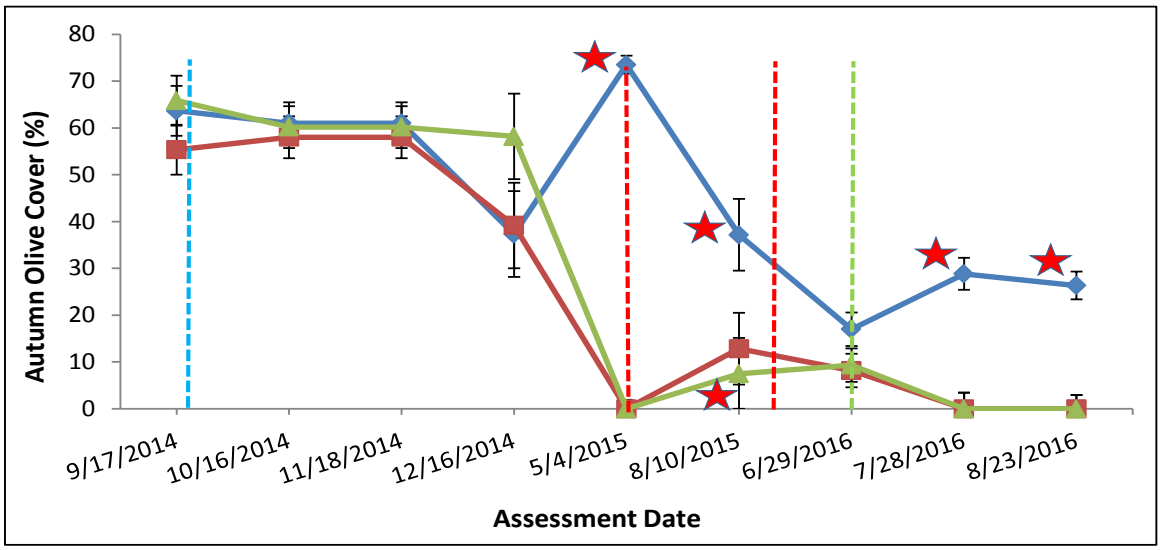
Method 1 Treatment 1: Mow Only (SOP): Mow-only plots started testing in 2014 with 64% autumn olive coverage. From late summer 2014 to spring 2015, autumn olive coverage increased by 10%, resulting in 74% autumn olive coverage. Mechanical removal in spring 2015 and fall 2015 reduced autumn olive coverage by 57%, resulting in 17% coverage in June 2016. From summer 2016 to late summer 2016, autumn olive coverage increased by 9%, resulting in 26% coverage in late summer 2016. By the end of August 2016, autumn olive coverage on mow-only plots had increased 9% during the summer and ended testing with 26% autumn olive coverage, which is significantly higher than the herbicide treated plots (Photograph 56).

Method 2: Broadleaf Selective Herbicide + Mow

Treatment 1: Milestone® + Triclopyr 4 + Mow: Milestone® + Triclopyr 4 plots started testing in 2014 with 55% autumn olive coverage. The directed foliar application of Milestone® + Triclopyr 4 in late summer 2014 reduced autumn olive coverage by 55%, resulting in 0% live autumn olive coverage in spring 2015. After the mechanical removal of dead standing autumn olive in spring 2015, there was an increase in autumn olive coverage, resulting in 8% coverage in summer 2016. The foliar spot treatment of Milestone® + Triclopyr 4 plots in June 2016 reduced autumn olive coverage by 8%, resulting in 0% coverage by late summer 2016 (Photograph 57). By the end of testing, Milestone® + Triclopyr 4 significantly reduced autumn olive coverage compared to mow only and ended testing with 0% autumn olive coverage (P=0.0008).

Treatment 1: Streamline® + Triclopyr 4 + Mow: Streamline® + Triclopyr 4 plots started testing in 2014 with 66% autumn olive coverage. The directed foliar application of Streamline® + Triclopyr 4 in late summer 2014 reduced autumn olive coverage by 66%, resulting in 0% autumn olive coverage in spring 2015. After the mechanical removal of dead standing autumn olive in spring 2015, there was an increase in autumn olive coverage, resulting in 9% coverage in summer 2016. The foliar spot treatment of Streamline® + Triclopyr 4 plots in June 2016 reduced autumn olive coverage by 9%, resulting in 0% coverage by late summer 2016 (Photograph 58). By the end of testing, Streamline® + Triclopyr 4 significantly reduced autumn olive coverage compared to mow only and ended testing with 0% autumn olive coverage (P=0.0008).

Figure 27. Autumn Olive Coverage Comparison



Key to Figure 27.

- Statistically Significant Event
- Mow Only
- Milestone® + Triclopyr 4
- Streamline® + Triclopyr 4
- Mechanical Control (mow all)
- Herbicide Control (skid spray foliar, both broadleaf herbicides)
- Herbicide Control (spot spray backpack, both broadleaf herbicides)
- Error Bars

Photograph 56. Mow-Only Plot.

Photograph 57. Milestone® + Triclopyr 4 Plot.

Photograph 58. Streamline® + Triclopyr 4 Plot.

Treatment Cost Comparison: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing these labor costs, there are several factors that influence the costs such as variations in methods, equipment efficiency, number of staff, and occurrences per year. Table 53 shows the labor cost to mow one acre of autumn olive compared to spraying one acre of autumn olive with a skid sprayer and directed spray gun application. Table 54 shows the labor cost to treat one acre of autumn olive for one year with each method used in this test. The materials costs are located in Table 55, which shows the per-acre and per-mile costs of each herbicide used in this test. The cost of materials can be added to the labor cost for each method to determine the total cost per method.

Table 53. Zone Three: Test 5, RIVM Method Labor Comparison

RIVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre
Rotary Side Arm Mower	1	$19.10	0.12	8.95	$170.95
Skid Sprayer and Backpack Directed Application	1	$19.10	0.26	4.11	$78.50

Table 54. Zone Three: Test 5, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Total Cost per Acre per Year
Method 1 Treatment 1: Mow Only (SOP)	1	0	8.95	$170.95
Method 2 Treatment 1: Streamline® + Triclopyr 4 + Mowing	1	1	13.06	$249.45
Method 2 Treatment 2: Milestone® + Triclopyr 4 + Mowing	1	1	13.06	$249.45

Table 55. Zone Three: Test 5, Herbicide Mixture Cost Comparison

Herbicide Mix	Rate (oz./acre)	Cost per Acre	Cost per Mile
Method 2 Treatment 1: Milestone® Triclopyr 4	7 256	$42.68	$103.46
Method 2 Treatment 2: Streamline® Triclopyr 4	9.5 256	$85.05	$206.17

Recommendation

Mowing is not necessary to control autumn olive if herbicide applications are made. Autumn olive colonies usually start away from the road edge along the wood line, but with a fast growth rate, autumn olive is capable of encroaching the ROW, blocking signs, and causing sight distance problems if left uncontrolled. Mowing without herbicide application allows autumn olive to increase in density per acre and does not provide control; however, this approach may be necessary to maintain sight distance in certain cases leading up to herbicide applications.

The results of this test reveal that directed herbicide applications made in late summer were effective at controlling autumn olive. Follow-up treatment of regrowth were needed to completely control autumn olive. Since autumn olive is difficult to control, herbicide tank mixes with Triclopyr 4, an oil-based herbicide (ester), are necessary for herbicide penetration into leaves and stems.

Make directed spray gun applications to autumn olive in late summer while vegetation is still actively growing. As a perennial woody shrub, autumn olive is most susceptible to herbicide applications in the late summer as nutrients are being transported to the root system. Both Streamline® at 9.5 oz./acre + Triclopyr 4 at 256 oz./acre and Milestone® 7 oz./acre + Triclopyr 4 at 256 oz./acre are acceptable choices for controlling autumn olive.

If mowing is necessary to achieve sight distance, plan and coordinate around applications (as specified on the label). If mowing before an application, allow sufficient time to pass before applying herbicide to allow foliage regrowth for sufficient surface area to receive the herbicide in late summer. If applying herbicide before mowing, allow sufficient time for herbicide to travel through foliage and into the stems for effective treatment before mowing. If mowing can wait, the best option is to make a late summer application, and wait until the following spring before mechanically removing the autumn olive. Be aware that the Streamline® label states it may take up to several months for complete plant death to occur in some woody plant species. Be mindful that making Streamline® applications around the root zones of adjacent trees may cause injury or death of those trees. Also keep in mind that Streamline® at 9.5 oz./acre can injure established turfgrass, but at lower rates can be used as a broadleaf selective herbicide without injuring desirable grass. The Milestone® label states to allow at least 14 days for herbicide to work before mowing after application is made; however, if more time is allowed, control results may be improved. Milestone® will not injure established turf.

Zone Three: Test 6, Brush Control <1" with Flail Mower and Herbicide Application

Perennial woody weeds and brush are difficult to mow and often create site distance concerns. Woody brush is usually found encroaching the roadway, growing on slopes and over guardrails. Testing was completed behind a guardrail on a foreslope that had large shrubs encroaching the ROW (Photographs 59 and 60). This test evaluates three different herbicides compared to mowing alone based on their effectiveness in controlling woody brush (primarily bush honeysuckle).

Methods

The chemical applications in this test were applied using directed spray gun applications. For these applications, a spray truck with a 425-gallon skid sprayer with a spray gun and hose reel were used. For the mechanical maintenance, a flail mower on a boom attached to a wheel loader was used. See Table 56 for equipment information.

Table 56. Zone Three: Test 6, Equipment

Equipment	Equipment Number
Spray Truck, Freightliner 114SD	2546018
Spray Equipment, 425-gal. spray tank, pump, spray gun, and powered hose reel	8100161
Wheel loader, Case 621F	5920750
Flail Arm Mower, Diamond	6590002

Method 1: (1 Treatment) *Mow Only (SOP):* Mowing was completed as a dormant season mowing just prior to spring 2016.

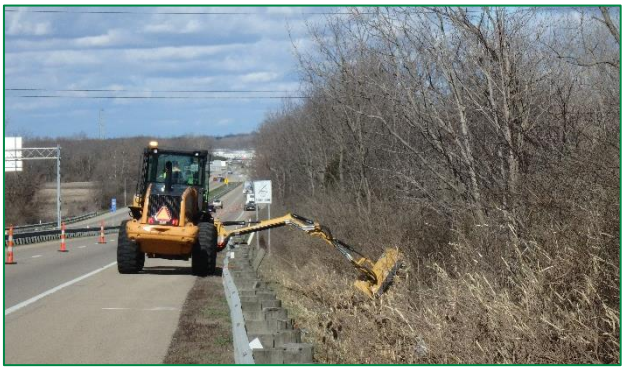
Method 2: (1 Treatment) Mowing + Skid Sprayer Directed Application: Mowing was completed as a dormant season mowing just prior to spring 2016. After the last frost had passed, a directed herbicide application was made to the ground with a skid sprayer and spray gun.

Treatment 1: Broadleaf Selective Herbicide Tordon® K (picloram)

Method 3: (2 Treatments) Skid Sprayer Directed Application: A directed herbicide application was made in spring 2016 with a skid sprayer and spray gun.

Treatment 1: Non-Selective Herbicide Rodeo® (glyphosate)

Treatment 2: Broadleaf Selective Herbicide Streamline® (aminocyclopyrachlor)



Photograph 59. Flail mowing.

Photograph 60. Tordon® K application after mowing.

Results

Both Streamline® and Tordon® K herbicides significantly reduced brush percent coverage compared to mowing only. After one herbicide application in spring 2016, the mow-only plots contained significantly more brush coverage than the Streamline® and Rodeo® plots (66%, 36%, and 0%, respectively) (Figure 28) and significantly less grass coverage than the Streamline® and Rodeo® plots (6%, 23%, and 54%, respectively) (Figure 29). Inconsistent results were obtained in control over trees (seedlings) due to large amounts of variation in tree coverage in test plots (Figure 30). The Tordon® K ground applications, however, performed significantly better than either foliar-applied herbicides, with significantly less brush coverage and significantly more grass coverage.

Method 1 Treatment 1: Mow Only (SOP): Mow-only plots started testing in March 2016 with 89% brush coverage. The mechanical mow in March reduced brush coverage by 72%, resulting in 17% brush coverage 30 days after the mow. This brush coverage quickly rebounded to a maximum of 81% by June. By the end of testing with 66% brush coverage, the mow-only plots had significantly more brush coverage than Streamline® and Tordon® K plots (Photograph 61). Also, with only 6% grass coverage, the mow-only plots had significantly less grass coverage than Streamline® and Tordon® K plots.

Method 2 Treatment 1: Mowing + Skid Sprayer Directed Application: Tordon® K plots started testing in March 2016 with 90% brush coverage. The ground application of Tordon® K was made after mechanical removal of woody brush in March. The herbicide and mechanical removal reduced brush coverage by 83%, resulting in 7% brush coverage 30 days after the application. By the end of testing with 0% brush coverage, the Tordon® K plots had significantly less brush coverage than all other herbicide treatments and mow-only plots (Photograph 62). Without having to compete with brush, grass coverage climbed to a maximum of 54% by August, which was significantly higher than all other treatments.

Method 3: Skid Sprayer Directed Application

Treatment 1: Rodeo®: Rodeo® plots started testing in March 2016 with 88% brush coverage. The foliar application of Rodeo® in May reduced brush coverage by 24%, resulting in 64% brush coverage 30 days after the application. By the end of testing with 56% brush coverage, the Rodeo® plots had brush coverage that was not significantly different than mow-only or Streamline® plots but was significantly higher than Tordon® K plots. Although grass coverage initially decreased after the May application, coverage increased to 17% by August. This grass coverage was not significantly different than mow-only or Streamline® plots but was significantly lower than the grass coverage in the Tordon® K plots (Photograph 63).

Treatment 2: Streamline®: Streamline® plots started testing in March 2016 with 81% brush coverage. The foliar application of Streamline® in May reduced brush coverage by 26%, resulting in 55% brush coverage 30 days after the application. Throughout spring and summer 2016, grass coverage climbed to a maximum of 23% by August. By the end of testing with 36% brush coverage, the Streamline® plots had significantly less brush coverage than the mow-only plots (Photograph 64).

Figure 28. Brush Coverage Comparison

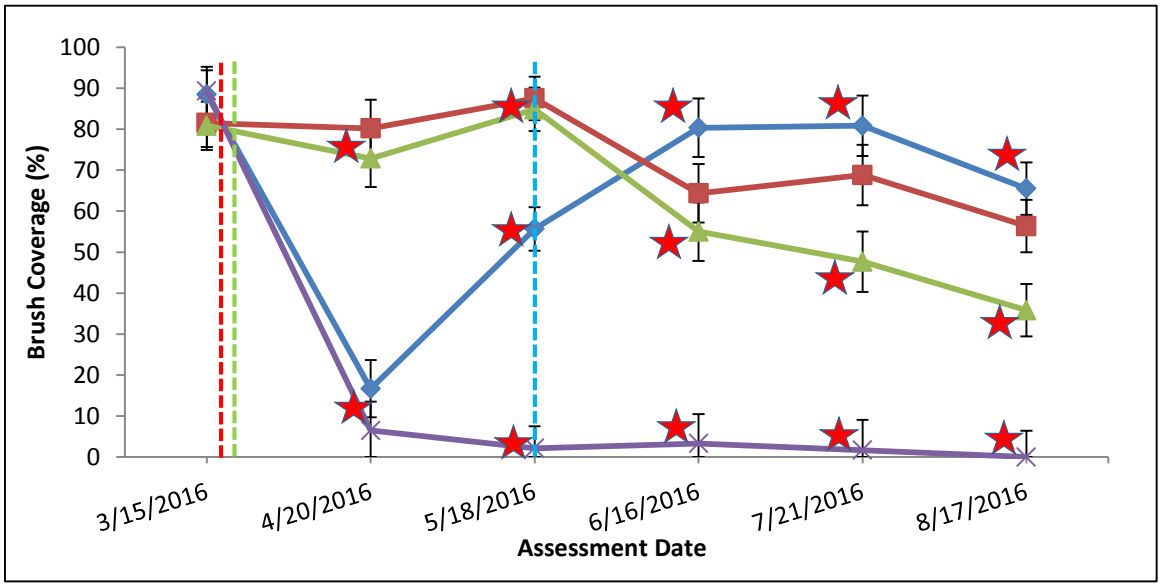


Figure 29. Grass Coverage Comparison

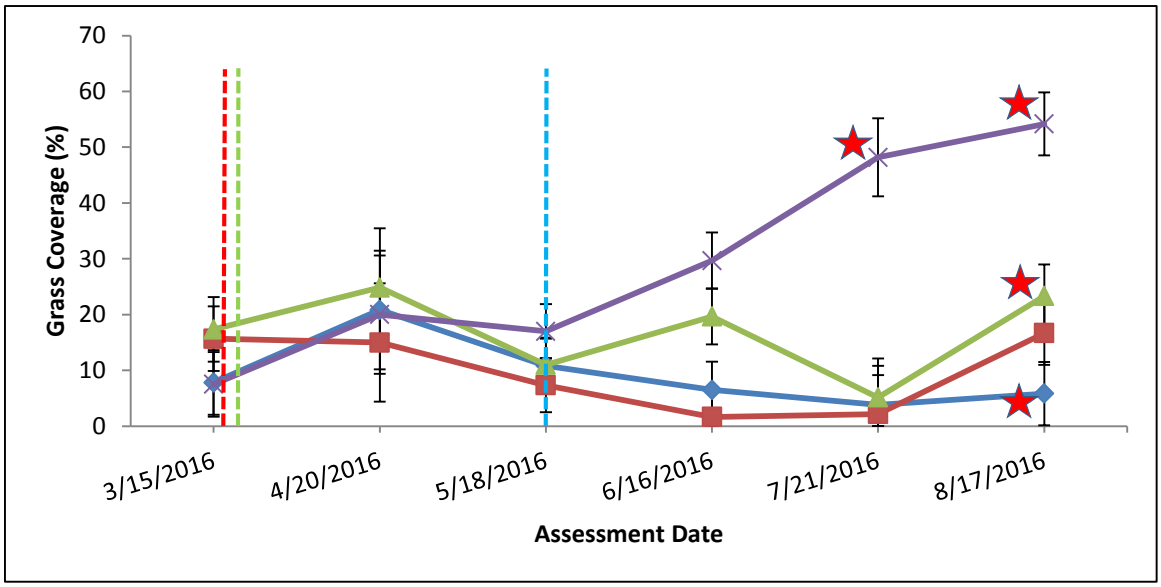
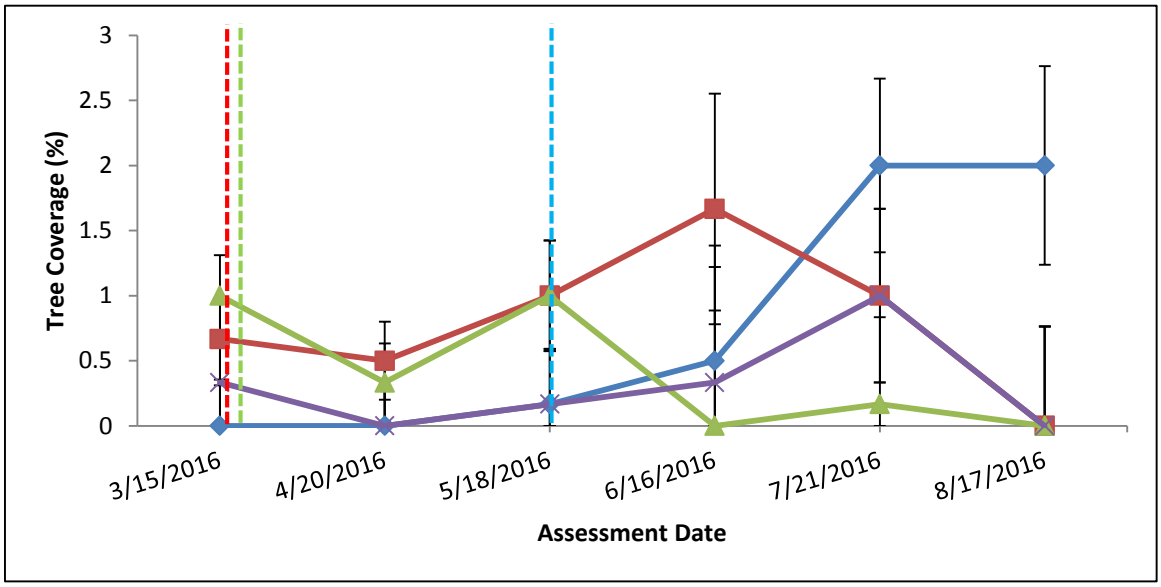


Figure 30. Tree Coverage Comparison



Key to Figures 28-30.

- Statistically Significant Event
- Mow Only
- Rodeo®
- Streamline®
- Tordon® K
- Mechanical Control (mow only, mow Tordon® K)
- Herbicide Control (Rodeo® and Streamline®)
- Herbicide Control (Tordon® K)
- Error Bars

Photograph 61. Mow-Only Plot
152 days after treatment.

Photograph 62. Tordon® K Plot
152 days after treatment.

Photograph 63. Rodeo® Plot
91 days after treatment.

Photograph 64. Streamline® Plot
91 days after treatment.

Treatment Cost Comparison: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing these labor costs, there are several factors that influence the costs, such as variations in methods, equipment efficiency, number of staff, and occurrences per year. Table 57 describes the labor cost to mow one acre of brush with a flail arm mower compared to spraying one acre of brush with a skid sprayer and directed spray gun application. Table 58 describes the labor cost to treat one acre of brush for one year with each method used in this test. In the testing of Method 3, the dead and dying brush was not removed due to time constraints. The labor cost comparison does not factor a mow into the costs of Method 3. For example, if a mow was needed due to sight distance issues or aesthetic complaints, the mow costs from Method 1 could be added to the Method 3 costs for an estimate of total cost. The materials costs are located in Table 59, which shows the per-acre and per-mile cost of each herbicide used in this test. The cost of materials can be added to the labor cost for each method in order to determine the total cost per method.

Equipment Review: The following skid sprayer equipment review is the same for Zone Three Tests 6 and 8. The skid sprayer used in these tests was part of a larger unit capable of making applications with boomless nozzles. The Road Master control panel was integral to ensuring that the herbicide was applied at the proper rate when the boomless nozzles were used. However, for Zone Three Tests 6 and 8, the boomless nozzles and control panel were not used. The hose and spray gun were used. The hose was long enough to reach long distances and the hose reel made rewinding the hose easy. The spray gun was easy to use and performed well. The only modification made to the unit was the addition of a flow meter to calibrate the applicators to avoid underapplication and overapplication. This additional piece of equipment was put in place by Davey Resource Group researchers for testing purposes. The skid sprayer and the applicators who use it could benefit from the addition of a permanent flow meter for calibration purposes.

Table 57. Zone Three: Test 6, RIVM Method Labor Comparison

RIVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre
Flail Arm Mower	1	$19.10	0.34	3.00	$57.30
Skid Sprayer Directed Ground Application	1	$19.10	1.11	0.91	$17.30
Skid Sprayer Directed Foliar Application	1	$19.10	0.94	1.08	$20.67

Table 58. Zone Three: Test 6, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Total Cost per Acre per Year
Method 1 Treatment 1: Mow Only (SOP)	1	0	3.00	$57.30
Method 2 Treatment 1: Mowing + Tordon® K	1	1	3.91	$74.60
Method 3 Treatment 1: Rodeo®	0	1	1.08	$20.67
Method 3 Treatment 2: Streamline®	0	1	1.08	$20.67

Table 59. Zone Three: Test 6, Herbicide Mixture Cost Comparison

Herbicide Mix	Rate (oz./acre)	Cost per Acre	Cost per Mile
Method 2 Treatment 1: Tordon® K	64	$22.58	$54.74
Method 2 Treatment 2: Rodeo®	256	$14.80	$35.88
Method 3 Treatment 2: Streamline®	11.5	$59.23	$143.58

Recommendation

Woody brush commonly grows behind guardrails on slopes that are not easily mowed. Woody brush in these areas can cause significant maintenance and safety concerns. Mowing without herbicide application does not provide control but may be necessary to maintain sight distance in certain cases. Mowing is not necessary to control brush if herbicide applications are made.

The results of this test reveal that high-volume directed applications should be made to control brush and reduce mowing requirements needed to keep woody brush clear of guardrails and the roadway. The results of this test, however, are partial due to time constraints related to a destroyed testing area in 2015 and reestablishment at an alternate site in 2016. For foliar applications, late summer applications are recommended, but due to time constraints of the project, a spring application was made in this test. Due to the time constraint, only the Tordon® K and mow-only plots had sufficient time to be fully evaluated. After comparing the available results from all treatments, the recommendation is to follow dormant mowing using a flail mower with a ground application of Tordon® K made in early spring when plants just start to actively grow.

When Tordon® K is applied to the ground, it is best if plants are just beginning to break dormancy and soils are not saturated. Tordon® K should be applied at 64 oz./acre. Be mindful of rain during these applications, as Tordon® K can leach through soil. Also be mindful of adjacent trees that may have root zones extending into treatment area. Those trees can be injured, especially if located downhill from the application area. Only use Tordon® K or other restricted use herbicides after consulting with the District Office of Environmental Services.

Further evaluation is needed to evaluate foliar applied Rodeo® at 256 oz./acre or Streamline® at 11.5 oz./acre. Those herbicides were applied at maximum per-acre, per-year rates in an effort to gain control while making an application that was earlier than ideal timing for perennial woody brush. This method was not mowed due to time constraints of testing but could be mowed a couple months after treatment if sight distance is an issue. If mowing is performed, the cost of mowing would need to be added to the application cost.

Once mature woody brush has been weakened and coverage has been reduced, ODOT should make broadleaf selective herbicide applications over the guardrail before woody brush reaches mature size and height to prevent the need for mechanical removal of vegetation in the future.

Zone Three: Test 7, Brush Control with Rotary WetBlade™ System

Perennial woody weeds and brush are difficult to mow and often create site distance concerns. Woody brush is usually found encroaching the roadway, growing on slopes and over guardrails. This test analyzes two different herbicides compared to mowing alone based on their effectiveness in controlling woody brush (primarily bush honeysuckle). Testing was completed behind a guardrail on a foreslope that had large shrubs encroaching the ROW. This test investigates the effectiveness of a specialized piece of equipment that cuts vegetation with a rotary blade and simultaneously applies herbicide from the cutting blades.

Methods

The equipment used in this test was a Diamond WetBlade™ 60" rotary mower on a boom attached to a wheel loader (Photograph 65). See Table 60 for equipment information.

Table 60. Zone Three: Test 7, Equipment

Equipment	Equipment Number
Wheel loader, Case 621F	5920751
Mower Engine, Diamond LBR-CA	6590003
Rotary Arm Mower, Diamond WetBlade™ WBR050-H	6420238

Method 1: (1 Treatment) Mow Only (SOP): Mowing was completed in late spring when foliage had full leaf expansion. Water was used in the WetBlade™ system, as recommended by manufacturer specifications when not using herbicide.

Method 2: (2 Treatments) WetBlade™ mowing with Broadleaf Selective Herbicides: Broadleaf selective herbicide was directly applied to bush honeysuckle while simultaneously mowing in late spring.

Treatment 1: Milestone (aminopyralid)

Treatment 2: Triclopyr 3 (triclopyr)

Photograph 65. Rotary WetBlade™ mowing in Montgomery County.

Results

Both herbicides that were applied showed inadequate results and led to brush coverages and tree coverages that were not significantly different from the mow-only plots (see Figures 31 and 32). After one mow and cut stem application of herbicides in late summer 2016, the mow-only plots contained higher amounts of brush coverage but values were statistically analyzed and found to be not significantly different.

The results of this test, however, are partial due to time constraints related to a destroyed testing area in 2014 and 2015 and reestablishment at an alternate site in 2016. Late summer applications are recommended, but due to time constraints of the project a spring application was made in 2016.

Method 1 Treatment 1: Mow Only (SOP): Mow-only plots started testing in June with 82% brush coverage and 9% tree coverage. The mow in June reduced brush coverage by 69%, resulting in 13% coverage 30 days after the mow. Although brush coverage steadily increased to a maximum of 43% coverage by the end of testing, brush coverage was not significantly different in the mow-only plots compared to the Milestone® or Triclopyr 3 plots. By the end of testing, tree coverage decreased by 2% and ended testing with 7% tree coverage, which was not significantly different than either of the herbicide treatments (Photograph 66).

Method 2: WetBlade™ mowing with Broadleaf Selective Herbicides

Treatment 1: Milestone®: Milestone® plots started testing in June with 84% brush coverage and 10% tree coverage. The cut stem application of Milestone® reduced brush coverage by 80%, resulting in 4% coverage 30 days after mowing and application. Although brush coverage steadily increased to a maximum of 15% coverage by the end of testing, brush coverage was not significantly different in the Milestone® plots from either of the other treatments. By the end of testing, tree coverage decreased by 6% and ended testing with a tree coverage of 4%, which was not significantly different than either of the other treatments (Photograph 67).

Treatment 2: Triclopyr 3: Triclopyr 3 plots started testing in June with 75% brush coverage and 14% tree coverage. The cut stem application of Triclopyr 3 reduced brush coverage by 72%, resulting in 3% coverage 30 days after the application. Although brush coverage steadily increased to a maximum of 16% coverage by the end of testing, brush coverage was not significantly different in the Triclopyr 3 plots from either of the other treatments. By the end of testing, tree coverage decreased by 12% and ended testing with a tree coverage of 2%, which was not significantly different than either of the other treatments (Photograph 68).

Figure 31. Brush Coverage Comparison

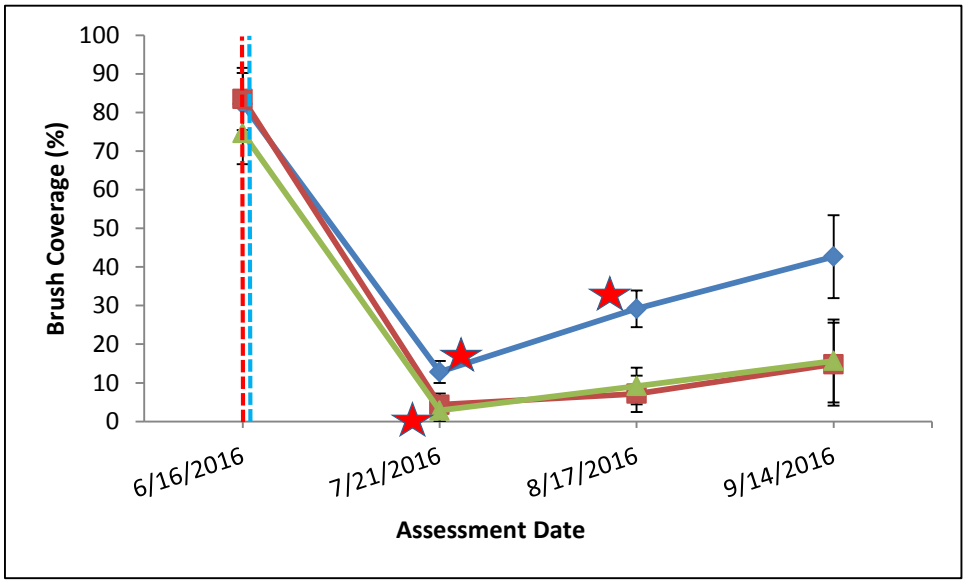
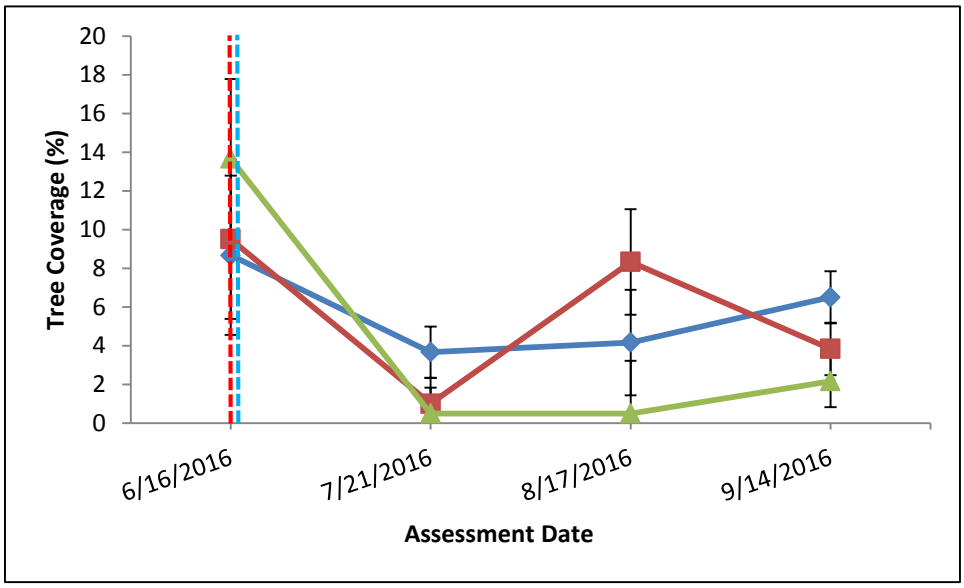


Figure 32. Tree Coverage Comparison



Key to Figures 31-32.

- Statistically Significant Event
- Mow Only
- Milestone®
- Triclopyr 3
- Mechanical Control (mow all)
- Herbicide Control (both broadleaf herbicides)
- Error Bars

Photograph 66. Mow-Only Plot.

Photograph 67. Milestone® Plot.

Photograph 68. Triclopyr 3 Plot.

Treatment Cost Comparison: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing these labor costs, there are several factors that influence the costs, such as variations in methods, equipment efficiency, number of staff, and occurrences per year. Table 61 describes the labor cost to mow one acre of brush with a rotary arm mower compared to the cost of chemical applications while simultaneously mowing one acre with the Diamond WetBlade™ rotary arm mower. Table 62 describes the labor cost to treat one acre of brush for one year with each method used in this test. The materials costs are located in Table 63, which shows the per-acre and per-mile cost of each herbicide used in this test. The cost of materials can be added to the labor cost for each method to determine the total cost per method.

Equipment Review: The Diamond WetBlade™ System is a new technology that incorporates chemical applications while simultaneously mowing. This piece of equipment is a discrete way to apply water-based herbicides (never oil-based to keep the system from clogging) in areas that can be mowed at the same time. The unit uses herbicide at a concentrated rate that comes out slowly while mowing. The Diamond WetBlade™ System has a 15-gallon tank for the herbicide mixture which may be too small to mow for a full day without being refilled. The Diamond WetBlade™ System administers the herbicide mixture at a rate set by the operator between 1 and 20 ounces per minute. Choosing the proper rate at which to apply and verify the unit is dispensing at can be challenging. The rate selected by the operators should be used when practicing calibration to determine how much total volume will be applied per acre before preparing an herbicide mixture. Creating a worksheet that provides calculations based on the most important variables is recommended. The following variables should be included: time it takes to mow an acre, ounces per minute total volume rate, labeled herbicide rate, and total acres of target vegetation that need to be controlled. Mowing can be done with the WetBlade™ mower head without herbicide in the tank, but water should be in the tank and flowing through the unit to prevent seals from drying out. Since the unit is more complicated than a traditional rotary arm mower, a dedicated operator should use the WetBlade™ system to reduce the learning curve experienced by new operators. The mowing operator should be a licensed applicator or be under the direction of a licensed applicator to ensure the herbicides are being applied at the proper rate throughout the system.

Table 61. Zone Three: Test 7, RIVM Method Labor Comparison

RIVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre
Rotary Arm Mower	1	$19.10	0.29	3.26	$62.27
Rotary WetBlade™ Arm Mower	1	$19.10	0.33	3.26	$62.27

Table 62. Zone: Three Test 7, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Total Cost per Acre per Year
Method 1 Treatment 1: Mow Only (SOP)	1	0	3.26	$62.27
Method 2 Treatment 1: Milestone® + Mowing	1	1	3.26	$62.27
Method 2 Treatment 2: Triclopyr 3 + Mowing	1	1	3.26	$62.27

Table 63. Zone Three: Test 7, Herbicide Mixture Cost Comparison

Herbicide Mix	Rate (oz./acre)	Cost per Acre	Cost per Mile
Method 2 Treatment 1: Milestone®	7	$6.56	$15.89
Method 2 Treatment 2: Triclopyr 3	342	$39.25	$95.15

Recommendation

If brush begins to encroach the road or create sight distance concerns and mowing needs to be performed, herbicides should be used. While using the Diamond WetBlade™ System, two maintenance activities can be simultaneously accomplished. Due to the site relocation in 2016, there was a small window to assess the vegetation results leading to inconclusive results. Although the window for assessments was short, the results of this test show that by applying herbicide while mowing, shrub coverage will initially be significantly reduced compared to mowing only and will retain lower coverage than mowing alone within the first 90 days after application. Although shrub coverage was lower than mowing alone, by 60 days after application the shrub coverage percentage was rising through the end of the last assessment. Due to a steady rise in shrub coverage and inconsistent tree coverage control, a second herbicide application should be made. A second application would further decrease brush and tree coverages. Further testing and assessments would need to be made to observe the vegetation response from the Diamond WetBlade™ rotary arm mower beyond 90 days after application.

When using the Diamond WetBlade™ rotary arm mower or similar simultaneous mowing and application system, herbicide applications should be made in late summer when perennial woody brush is most susceptible to herbicide treatments. By using this type of equipment, labor is saved by avoiding a separate herbicide application, but a follow-up herbicide treatment the following season may be necessary to achieve optimal control. In the future, a broadcast application for maintenance with a skid sprayer with boomless nozzles to control broadleaf weeds and woody brush behind the guardrail could replace the need for repeated mowing with the rotary arm mower which is much more costly and time-consuming than spraying herbicide. Only use water-based (amine) liquid concentrate herbicides in the Rotary WetBlade™ system to avoid clogging. If mowing without herbicides in the tank, be sure to fill the tank with water and flow at its lowest setting to avoid overheating and destruction of the spindle fluid seals.

Zone Three: Test 8, Brush Control >1" with Forestry Mulcher and Herbicide Application

While brush and small trees are difficult and time-consuming to mow, they become larger maintenance challenges if left unmaintained. This test evaluates three different herbicides used in combination with mowing (compared to mowing alone) for their effectiveness in controlling brush and small trees.

Methods

The chemical applications in this test were applied using directed spray gun applications. For these applications, a spray truck with a 425-gallon skid sprayer with a spray gun and hose reel were used (Photograph 69). For the mechanical maintenance, a skid steer with a forestry mulcher attachment was used (Photograph 70). See Table 64 for equipment information.

Table 64. Zone Three: Test 8, Equipment

Equipment	Equipment Number
Spray Truck, International 4900	2340161
Spray Equipment, 425-gal. spray tank, pump, spray gun, and powered hose reel	8100161
Skid Steer, Bobcat T770 IT4	5910115
Forestry Mulcher Attachment, Bobcat FRC50	3410004

Method 1: (1 Treatment) *Mow Only (SOP):* Mowing was completed with the forestry mulcher in early spring 2015.

Method 2: (1 Treatment) Mowing + Skid Sprayer Directed Application: Mowing was completed with the forestry mulcher in early spring 2015. Following the mowing, a ground application was made with broadleaf selective herbicide.

Treatment 1: Broadleaf Selective Herbicide Tordon® K (picloram)

Method 3: (2 Treatments) Skid Sprayer Directed Application + Mowing: A directed foliar herbicide application was made in the summer. After this herbicide treatment, the vegetation was mowed with a forestry mulcher attached to a skid steer during the dormant season.

Treatment 1: Non-Selective Herbicide Ecomazapyr 2 SL (imazapyr)

Treatment 2: Broadleaf Selective Herbicide Triclopyr 3 (triclopyr)

Photograph 69. Tordon® K application after mowing.

Photograph 70. Forestry mulcher mowing brush.

Results

Both Tordon® K and Ecomazapyr 2 SL reduced shrub coverage for sustained periods of time. The reductions in shrub coverages obtained by these two herbicides is notable when compared to mow only (see Figures 33 and 34). Tordon® K plots showed a significant reduction in shrub coverage (73%) and a significant increase in grass coverage (40%) and held these coverages through two years of assessments, putting the Tordon® K plots ahead of the other treatments in desired vegetation results.

Method 1 Treatment 1: Mow Only (SOP): Mow-only plots started testing in 2015 with 76% shrub coverage, 14% deciduous tree coverage, and 7% grass coverage. Mechanical removal of vegetation in spring 2015 temporarily reduced shrub and tree coverages, providing vegetation control through 2015. By spring 2016, a rebound in shrub and deciduous tree coverages was seen. Shrub coverage reached a maximum of 61% in spring 2016, and deciduous tree coverage exceeded the 14% coverage at the start of the test, reaching a maximum of 47% in summer 2016. Grass coverage fell to 6% by the end of testing (Photograph 71). These percentages reveal that lasting woody vegetation control was not achieved and that this undesirable vegetation will persist into the future, which will require annual maintenance.

Method 2 Treatment 1: Mowing + Skid Sprayer Directed Application: Tordon® K plots started testing in 2015 with 76% shrub coverage, 15% deciduous tree coverage, and 6% grass coverage. Mechanical removal of vegetation in spring 2015 was immediately followed by the ground application of Tordon® K. This method reduced shrub coverage by 75% and deciduous tree coverage by 15%, resulting in 1% shrub coverage and less than 1% deciduous tree coverage. Shrub coverage was well controlled through the next two growing seasons, with only 3% coverage by summer 2016. This represented the lowest levels of shrub coverage obtained by any method or herbicide. Deciduous tree coverage was not as well controlled, with 11% coverage by summer 2016. Heavy reductions in shrub coverage allowed for significant increases in grass coverage up to 46% by the end of testing (see Figure 35 and Photograph 72). Tordon® K enabled grass coverage and the desired vegetation to become significantly higher than the grass coverage obtained by mow only (6% coverage, P=0.0222) or Ecomazapyr 2 SL (11% coverage, P=0.0391). Overall Tordon® K had the best results of all the methods tested.

Method 3: Skid Sprayer Directed Application + Mowing

Treatment 1: Ecomazapyr 2 SL: Ecomazapyr 2 SL plots started testing in 2015 with 68% shrub coverage, 12% deciduous tree coverage, and 17% grass coverage. The foliar directed application of Ecomazapyr 2 SL in summer 2015 was followed by mechanical removal of vegetation the following winter. This method reduced shrub coverage by 60%, resulting in 8% coverage by summer 2016. Although initially controlled by the treatment, deciduous tree coverage increased to 20% by the end of testing. Grass coverage saw an overall reduction from 17% at the start of testing to 11% by summer 2016 (Photograph 73). With strong reductions in shrub coverage and overall increase in tree coverage from 2015 to 2016, foliar application of Ecomazapyr® 2 SL did not show as good of results as the Tordon® K plots.

Treatment 2: Triclopyr 3*:* Triclopyr 3 plots started testing in 2015 with 84% shrub coverage, 8% deciduous tree coverage, and 6% grass coverage. The foliar application of Triclopyr 3 in summer 2015 was followed by mechanical removal of vegetation the following winter. This method reduced shrub coverage by 54%, resulting in 30% coverage by summer 2016. Although initially controlled by the treatment, deciduous tree coverage returned to 6% coverage by summer 2016. Grass coverage saw a steady increase in coverage up to 38% coverage by the end of testing (Photograph 74). With poor reductions in shrub and tree coverage, yet an overall increase in grass coverage from 2015 to 2016, Triclopyr 3 did not show as good of results as Tordon® K or Ecomazapyr 2 SL.

Figure 33. Brush Coverage Comparison

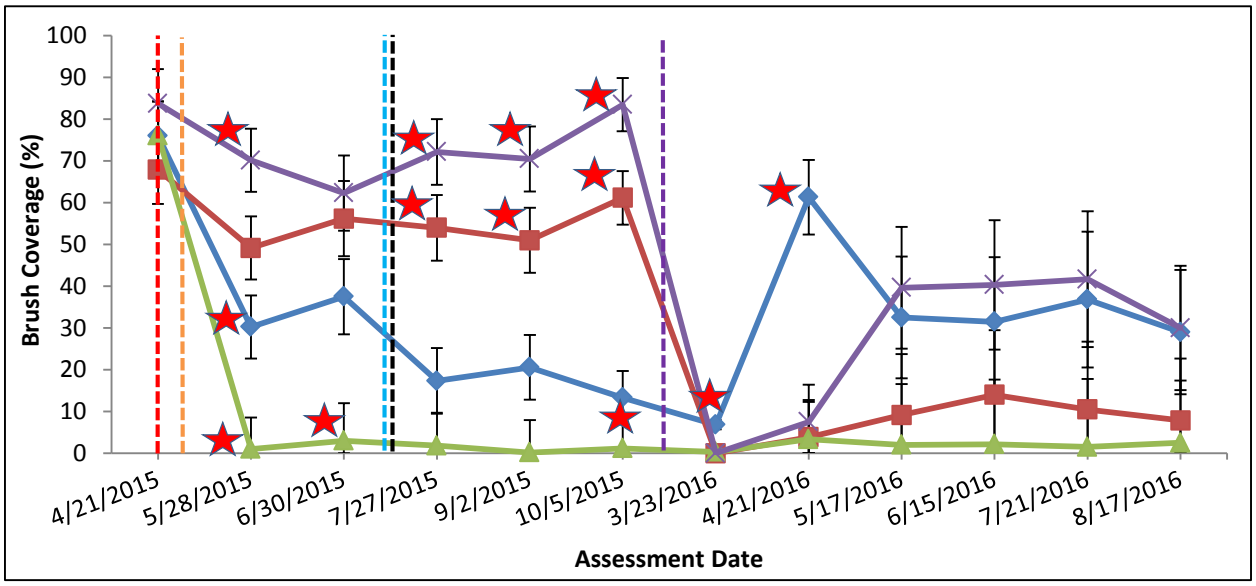


Figure 34. Deciduous Tree Coverage Comparison

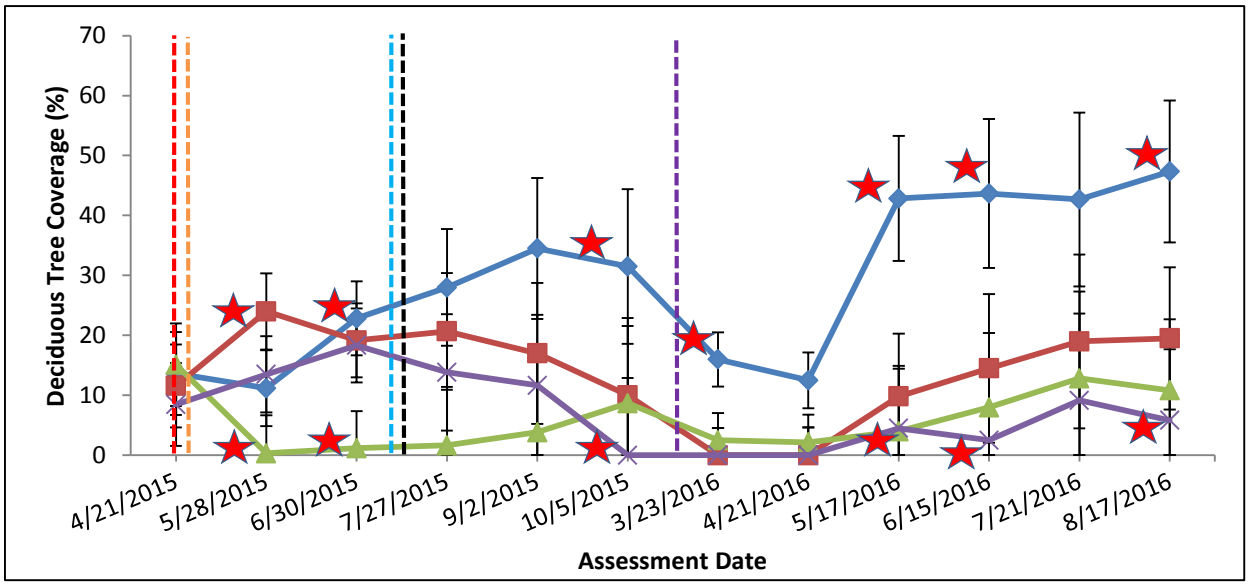
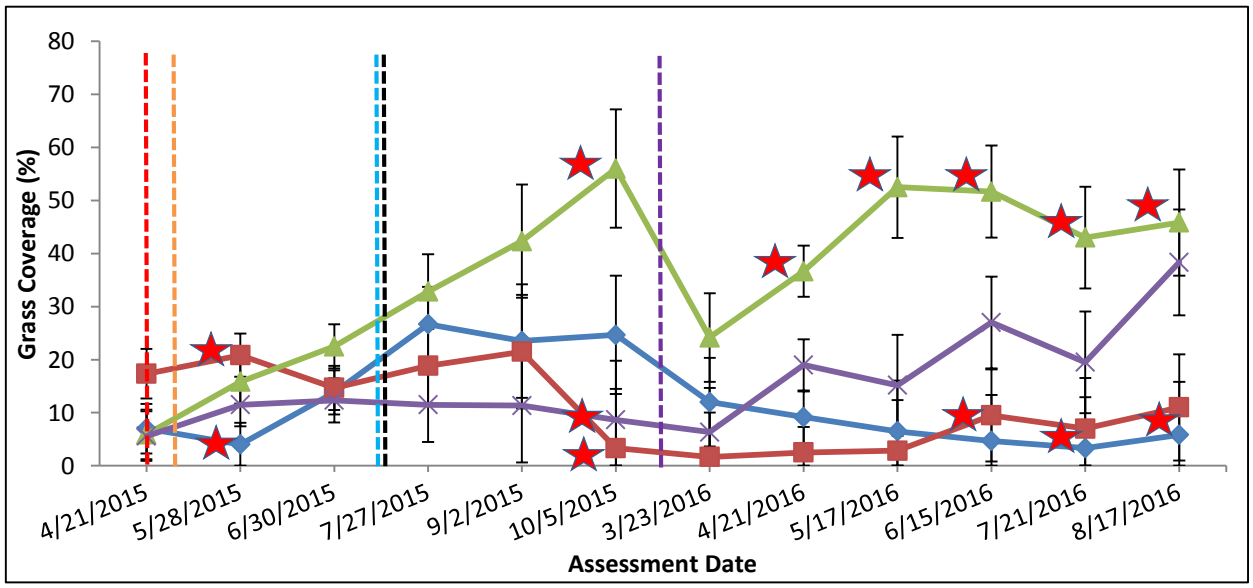


Figure 35. Grass Coverage Comparison



Key to Figures 33-35.

Statistically Significant Event
Mow Only
Ecomazapyr 2 SL
Tordon® K
Triclopyr 3
Mechanical Control (mow only, mow Tordon® K)
Mechanical Control (mow Triclopyr 3, Ecomazapyr 2 SL)
Herbicide Control (spray Tordon® K)
Herbicide Control (Spray Triclopyr 3, Ecomazapyr 2 SL)
Unauthorized spray (damage to Triclopyr 3)
Error Bars

Photograph 71. Mow-Only plot.

Photograph 72. Tordon® K plot.

Photograph 73. Ecomazapyr 2 SL plot.

Photograph 74. Triclopyr 3 plot.

Treatment Cost Comparison: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing these labor costs, there are several factors that influence the costs, such as variations in methods, equipment efficiency, number of staff, and occurrences per year. Table 65 describes the labor cost to mow one acre of brush with a skid steer and forestry mulcher compared to spraying one acre with a skid sprayer and directed spray gun application. Table 66 describes the labor cost to treat one acre of brush for one year with each method used in this test. The materials costs are located in Table 67, which shows the per-acre and per-mile cost of each herbicide used in this test. The cost of materials can be added to the labor cost for each method to determine the total cost per method.

Table 65. Zone Three: Test 8, RIVM Method Labor Comparison

RIVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre
Skid Steer Forestry Mulcher	1	$19.10	0.18	6.94	$132.55
Skid Sprayer Directed Ground Application	1	$19.10	0.41	2.44	$46.60
Skid Sprayer Directed Foliar Application	1	$19.10	0.69	1.58	$30.16

Table 66. Zone Three: Test 8, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Total Cost per Acre per Year
Method 1 Treatment 1: Mow Only (SOP)	1	0	6.94	$132.55
Method 2 Treatment 1: Mowing + Tordon® K	1	1	9.38	$179.16
Method 3 Treatment 1: Ecomazapyr 2 SL + Mowing	1	1	6.47	$123.54
Method 3 Treatment 2: Triclopyr 3 + Mowing	1	1	6.47	$123.54

Table 67. Zone Three: Test 8, Herbicide Mixture Cost Comparison

Herbicide Mix	Rate (oz./acre)	Cost per Acre	Cost per Mile
Tordon® K	64	$22.58	$54.73
Ecomazapyr 2 SL	96	$14.72	$35.67
Triclopyr 3	384	$44.10	$106.91

Recommendation

Forestry mulcher mowing can be necessary to clear mature brush to preserve sight distance or aesthetic quality of the roadsides. Clearing brush should always be paired with herbicide applications to prevent unwanted regrowth. When cleared without using herbicides, woody brush regrows significantly faster and thicker than if an herbicide application was made. Re-mowing these areas annually with the forestry mulcher is a slow maintenance operation.

Areas that are mowed with the forestry mulcher should be treated with herbicide to reduce tree and shrub regrowth. This allows for future mowing with a batwing mower, which is faster than the forestry mulcher. The results of this test reveal that Tordon® K and Ecomazapyr 2 SL test plots controlled woody brush better than mowing without herbicide. However, ground applications of Tordon® K controlled woody brush better than either foliar applied herbicide, provided adequate deciduous tree control, and showed significant increases in grass coverage compared to Ecomazapyr 2 SL and mow only.

Remove mature brush with forestry mulcher during dormant season, then make ground application of Tordon® K at 64 oz./acre in the spring when plants begin to break dormancy and soils are not saturated. Be mindful of rain during these applications, as Tordon® K can leach through soil. Also be mindful of adjacent trees that may have root zones extending into the treatment area. Those trees can be injured, especially if they are located downhill from the application area. Only use Tordon® K or other restricted use herbicides after consulting with the District Office of Environmental Services.

Foliar applications of Ecomazapyr 2 SL at 96 oz./acre or Triclopyr 3 at 384 oz./acre should be made in late summer to early fall when woody brush is most susceptible to foliar applications. Better control was achieved with both of the foliar applied herbicides than mowing without herbicide. A higher level of control was expected from the foliar applications than was observed. Control results could potentially be improved by adjusting the water hardness or pH to be more favorable to the herbicides applied and by making a more careful application with smaller droplets for better coverage. Foliar applications should be made to ensure proper coverage of the entire shrub without dripping onto the ground.

Once mature brush has been weakened and coverage has been reduced, ODOT should consider making broadleaf selective herbicide applications to those areas before woody brush reaches a mature size and height to prevent the need for mechanical removal of vegetation.

Zone Three: Test 9, Selective Brush Control with Foliar Application

Brush on slopes such as under bridges or on retaining walls can be difficult and dangerous to access for removal. Testing was completed on a rocky backslope of the ROW where brush and small diameter trees were present but unwanted. This test evaluates the effectiveness using three different foliar herbicides compared to cutting brush alone.

Methods

The chemical applications in this test were applied using directed spray gun applications. For these applications a spray truck with a 200-gallon skid sprayer with a spray gun and hose reel were used (Photograph 75). For the mechanical removal, chainsaws and brush loppers were used (Photograph 76). See Table 68 for equipment information.

Table 68. Zone Three: Test 8, Equipment

Equipment	Equipment Number
Spray Truck, GMC 2500 4WD	2220786
Spray Equipment, 200-gal. spray tank, pump, spray gun, and powered hose reel	8100159
Chain saws	-
Brush loppers	-

Method 1: (1 Treatment) Manual Removal Only (SOP): Brush was cut down with a crew scrambling up the rocky slope with chainsaws and brush loppers in spring 2015. Cut vegetation was left on the site.

Method 2: (3 Treatments) Skid Sprayer Directed Application: A directed application was made in late summer 2014 with a skid sprayer and spray gun. Although not entirely necessary, the applicator chose to scramble up some of the rocks to get closer to the target vegetation. Sprayed vegetation was not removed.

Treatment 1: Broadleaf Selective Herbicide Triclopyr 3 (triclopyr)

Treatment 2: Non-Selective Herbicide Ecomazapyr 2 SL (imazapyr)

Treatment 3: Non-Selective Herbicide Rodeo® (glyphosate)

Photograph 75. Foliar application being made to brush.

Photograph 76. Manual removal of brush.

Results

With one foliar herbicide treatment and one manual removal, all methods reduced woody vegetation percent coverage and woody vegetation height, with no significant difference between methods by summer 2016 (see Figures 36 and 37).

Method 1 Treatment 1: Mow Only (SOP): Manual removal plots started testing in 2014 with 15% woody vegetation coverage and an average height in 2014 of 16 feet. Manual removal occurred in spring 2015. By summer 2016, woody percent coverage was back up to 12%, and woody vegetation height was back up to 7 feet (Photograph 77). While no one was injured during testing, the risk of injury by climbing the rocky slope was high.

Method 2: Skid Sprayer Directed Application

Treatment 1: Triclopyr 3: Triclopyr 3 plots started testing in 2014 with 19% woody vegetation coverage and an average height of 15 feet in 2014. The directed foliar herbicide application took place in late summer 2014 and reduced woody percent coverage by 16%, resulting in 3% woody coverage by spring 201. Additionally, the live woody vegetation height was reduced to an average of 7 feet. By the end of testing in summer 2016, the woody percent coverage had increased to 17% (Photograph 78). This represents the highest woody percent coverage recorded after treatments out of all methods.

Treatment 2: Ecomazapyr 2 SL: Ecomazapyr 2 SL plots started testing in 2014 with 15% woody vegetation coverage, and an average height of 15 feet in 2014. The directed foliar herbicide application took place in late summer 2014 and reduced woody percent coverage by 12%, resulting in 3% woody percent coverage by spring 2015. The live woody vegetation height was reduced to an average of 4 feet. By the end of testing in summer 2016, the woody percent coverage had increased to 7% (Photograph 79).

Treatment 3: Rodeo®: Rodeo® plots started testing in 2014 with 11% woody vegetation coverage and an average height of 16 feet in 2014. The directed foliar herbicide application took place in late summer 2014 and reduced woody percent coverage by 9%, resulting in 2% woody coverage by spring 2015. The live woody vegetation height was reduced to an average of 4 feet. By the end of testing in summer 2016, the woody percent coverage had increased to 5% (Photograph 80).

Figure 36. Woody Coverage Comparison

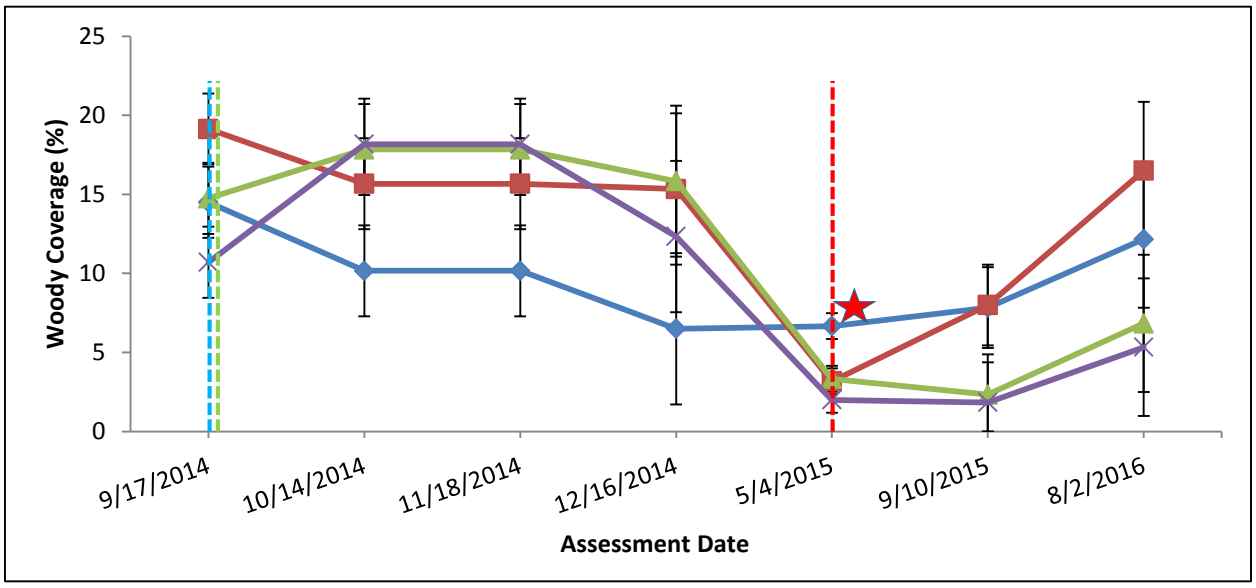
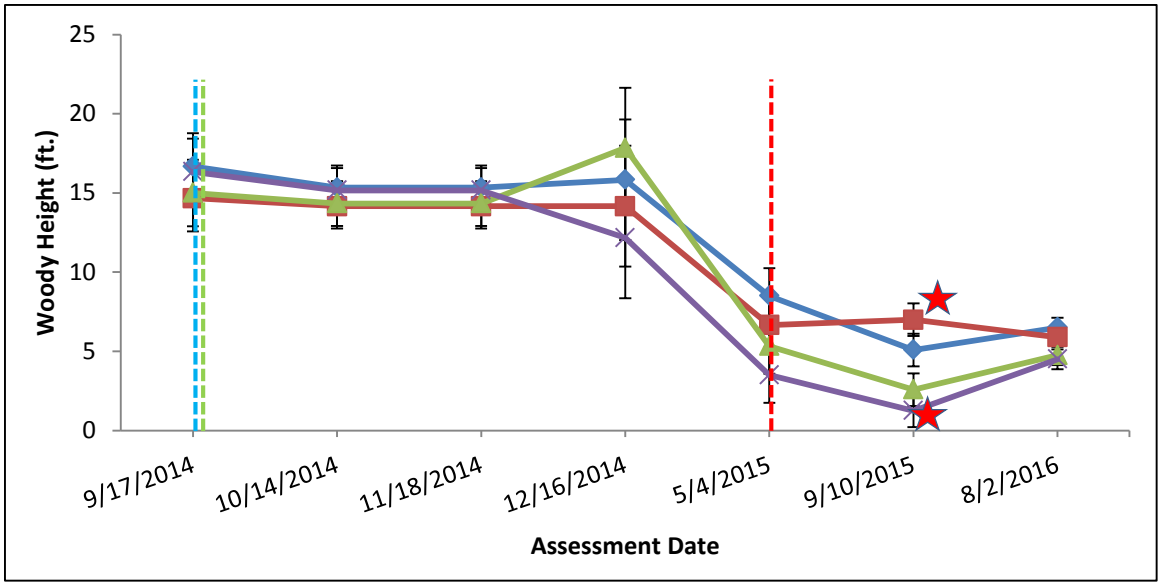


Figure 37. Woody Height Comparison



Key to Figures 36-37.

- Statistically Significant Event
- Mow Only
- Triclopyr 3
- Ecomazapyr 2 SL
- Rodeo®
- Mechanical Control (mow only)
- Herbicide Control (Ecomazapyr 2 SL and Rodeo®)
- Herbicide Control (Triclopyr 3)
- Error Bars

Photograph 77. Manual removal plot.

Photograph 78. Triclopyr 4 plot.

Photograph 79. Ecomazapyr 2 SL plot.

Photograph 80. Rodeo® plot.

Treatment Cost Comparison: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing these labor costs, there are several factors that influence the costs, such as variations in methods, equipment efficiency, number of staff, and occurrences per year. Table 69 describes the labor cost to manually remove one acre of brush compared to spraying one acre with a skid sprayer and directed spray gun application. Table 70 describes the labor cost to treat one acre of brush for one year with each method used in this test. The materials costs are located in Table 71, which shows the per-acre and per-mile cost of each herbicide used in this test. The cost of materials can be added to the labor cost for each method to determine the total cost per method.

Table 69. Zone Three: Test 9, RIVM Method Labor Comparison

RIVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre
Manual Brush Removal Crew	5	$19.10	0.06	82.22	$1,570.40
Skid Sprayer Directed Foliar Application	1	$19.10	0.22	4.71	$90.04

Table 70. Zone Three: Test 9, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Total Cost per Acre per Year
Method 1 Treatment 1: Mow Only (SOP)	1	0	82.22	$1,570.40
Method 2 Treatment 1: Triclopyr 3	0	1	4.71	$90.04
Method 2 Treatment 2: Ecomazapyr 2 SL	0	1	4.71	$90.04
Method 2 Treatment 3: Rodeo®	0	1	4.71	$90.04

Table 71. Zone Three: Test 9, Herbicide Mixture Cost Comparison

Herbicide Mix	Rate (oz./acre)	Spray Pattern Width (ft.)	Cost per Acre	Cost per Mile
Triclopyr 3	328	20	$37.67	$91.32
Ecomazapyr 2 SL	96	20	$14.72	$35.67
Rodeo®	192	20	$11.10	$26.91

Recommendation

Manual removal of vegetation is not necessary to control woody brush on rock slopes or under bridges if foliar herbicide applications are made. The terrain in these areas is often difficult and unstable, making manual removal costly and dangerous. The results of this test reveal that a single herbicide application in late summer was just as effective as manual removal providing at least two years of control. Within the second year of testing, woody vegetation coverage had shown increases in coverage (in all methods), which suggests that further maintenance will be needed in the future.

Foliar applications with a skid sprayer and spray gun are just as effective for controlling small trees and brush as manual removal. However, foliar herbicide applications are more cost-effective and safer. A spray gun is capable of spraying vegetation up to 30 feet away, resulting in less foot travel in this difficult terrain. Herbicide applications should be made to woody brush in late summer when the plants are most susceptible to systemic herbicide applications. In areas such as rock slopes or under bridges, where total vegetation control is desired, use a non-selective herbicide such as Ecomazapyr 2 SL at 96 oz./acre or Rodeo® at 192 oz./acre. Results from other brush control tests in this study indicate that Streamline® at 9.5 or 11.5 oz./acre is another good non-selective herbicide for brush control. For areas where preserving grass but eliminating trees or brush is desired, use Triclopyr 3 at 328 oz./acre or another broadleaf selective herbicide such as Milestone® at 7 oz./acre (14 oz./acre if doing spot treatments) or Perspective® at 7 oz./acre.

Zone Three: Test 10, Selective Brush Control with Basal Bark Application

Small-diameter trees on slopes such as under bridges or on retaining walls can be difficult and dangerous to access for removal. Testing was completed on a rocky backslope of the ROW where brush and small-diameter trees were present but unwanted. This test evaluates the effectiveness of using two different herbicides for basal bark application to control small-diameter trees.

Methods

The equipment used in this test was a backpack sprayer. See Table 72 for equipment information and Photographs 81 and 82 of applications.

Table 72. Zone Three: Test 10, Equipment

Equipment	Equipment Number
D.B. Smith 4-Gallon Max, Backpack Sprayer	N/A

Method 1: (1 Treatment) Untreated (SOP): The original plan for this test called for trees to be removed in the SOP, but due to the concerns over employee safety, target vegetation was left standing untreated.

Method 2: (2 Treatments) Basal Bark Herbicide: Application was made around the stem of each tree up to 18" high on the trunk using low pressure from a backpack sprayer. In this method, basal oil was mixed with the herbicide to penetrate the stems.

Treatment 1: Triclopyr 4 (triclopyr)

Treatment 2: Milestone® (aminopyralid) + Triclopyr 4 (triclopyr)

Photograph 81. Basal Bark Application.

Photograph 82. Dye in the mix helps applicators see which trees have been treated.

Results

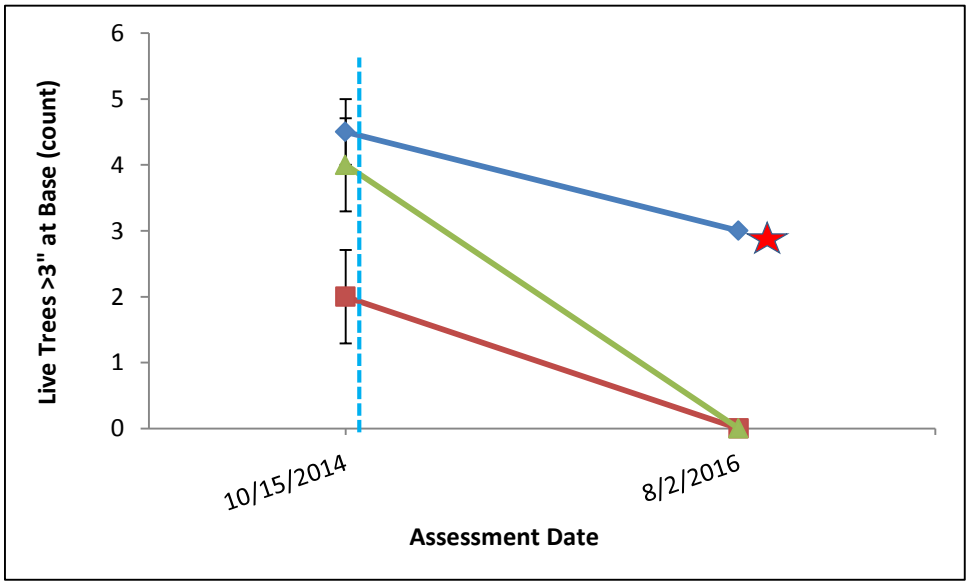
Both herbicides significantly reduced the count of living trees greater than 3 inches at their base compared to untreated plots. After one basal bark treatment in fall 2014, the untreated plots contained significantly more living trees greater than 3 inches at base than both herbicide treatments. Data obtained in 2016 were recorded in a count of living trees by size categories. Size categories were: less than 0.5 inch at base, 0.5–3 inches at base, and greater than 3 inches at base. The category less than 0.5 inch at base represents new seedlings in the plots that would not have been treated in 2014. The category 0.5–3 inches at base represents small trees that may or may not have been treated in plots depending on how big they were in 2014. The last category—greater than 3 inches at base—represents trees that would have been treated in 2014. Results are discussed below (Figure 38). Results from the middle and smallest size categories indicate that in 2016, fluctuations in live trees did not follow similar patterns as those observed in the greater than 3 inches' size class. The inconsistency with these results may speak to the small trees being accidentally missed during herbicide treatment or new seedlings having immigrated to the site. In either case, the most important size class is the greater than 3 inches' size class, as this class is comprised of the large trees that cause maintenance and sight distance concerns along the ROW.

Method 1 Treatment 1: Untreated (SOP): Untreated plots act as our baseline for this test. No manual removal was done and no herbicide was applied. In the largest size category at the end of testing in 2016, there were 3 live trees greater than 3 inches at base per plot. This was a slight reduction from the initial assessment in 2014. By the end of testing, the amount of living trees greater than 3 inches at base in the untreated plots was significantly higher than the basal bark herbicide plots (Photograph 83).

Method 2 Treatment 1: Triclopyr 4: Triclopyr 4 plots ended testing with 100% control, 0 live trees greater than 3 inches at base per plot, which was significantly less trees than the untreated plots (P=<0.0001) (Photograph 84). The amount of live trees in both the smaller size categories was not significantly different than either of the other methods at the end of testing in 2016.

Method 2 Treatment 1: Milestone® + Triclopyr 4: Milestone® + Triclopyr 4 plots ended testing with 100% control, 0 live trees greater than 3 inches at base per plot, which was significantly less trees than the untreated plots (P=<0.0001) (Photograph 85). The amount of live trees in both of the smaller size categories was not significantly different than either of the other methods at the end of testing in 2016.

Figure 38. Live Tree Count Comparison



Key to Figure 38

Statistically Significant Event
Untreated
Triclopyr 4 + Milestone®
Triclopyr 4
Basal Bark Treatment (both herbicides)
Error Bars

Photograph 83. Untreated Plot.

Photograph 84. Triclopyr 4 Plot.

Photograph 85. Milestone® + Triclopyr 4 Plot.

Treatment Cost Comparison: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing these labor costs, there are several factors that influence the costs, such as variations in methods, equipment efficiency, number of staff, and occurrences per year. Table 73 describes the labor cost to apply a basal bark herbicide application to one acre of brush and trees. Table 74 describes the labor cost to treat one acre of brush and trees for one year with each method used in this test. The materials costs are located in Table 75, which shows the mix rate and cost per gallon of each herbicide used in this test. Tree density will determine the volume of product to be used. The cost of materials can be added to the labor cost for each method to determine the total cost per method. The cost for removal of this site can be compared with Zone Three Test 9 and Test 11 manual removal costs.

Equipment Review: The following backpack sprayer review is the same for Zone Three Tests 10–11 where the backpack sprayer was used. The equipment was easy to use and generally worked well. However, there was a problem experienced with the equipment that may have been avoided with applicators more experienced with the particular backpack. The backpack pump handle is made of plastic and after sitting outside one freezing night and then driving to the test site early in the morning in the bed of the truck it had become brittle as plastic items do in freezing conditions. Just prior to its first use in the cold morning, the applicator unnecessarily pumped the handle to increase the pressure for the basal bark application causing the brittle handle to brake. The other backpack on site was not pumped and suffered no damage or difficulty in use under the weather conditions. The damaged unit was easily repaired with a replacement part.

Table 73. Zone Three: Test 10, RIVM Method Labor Comparison

RIVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre
Basal Bark Herbicide Application	1	$19.10	0.23	4.99	$95.31

Table 74. Zone Three: Test 10, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre	Total Cost per Acre per Year

			per Year	
Method 1 Treatment 1: Untreated (SOP)	0	0	0.00	$0.00
Method 2 Treatment 1: Triclopyr 4	0	1	4.99	$95.31
Method 2 Treatment 2: Milestone® + Triclopyr 4	0	1	4.99	$95.31

Table 75. Zone Three: Test 10, Herbicide Mixture Cost Comparison

Herbicide	Per Gallon Rate	Cost per 1 Gallon Mixed
Triclopyr 4	25.6 oz.	$5.44
Hy-Grade I Basal Oil	102.4 oz.	
Triclopyr 4	20.9 oz.	$6.09
Milestone®	1.28 oz.	
Alligare 90	1.28 oz.	
Hy-Grade I Basal Oil	104.5 oz.	

Recommendation – Rock Slope Basal Bark

Manual removal of vegetation is not necessary to control small-diameter trees on rock slopes or under bridges if basal bark herbicide applications are made. The terrain in these areas is often difficult and unstable, making manual removal costly and dangerous. The results of this test reveal that a single herbicide application during the dormant season provides at least two years of control over woody brush on a rock slope or under bridges.

Make basal bark applications during the dormant season with Triclopyr 4 mixed with basal oil at a 1:5 ratio per gallon. Applications are most effective on trees with stems 6 inches in diameter and less at breast height. Coverage of herbicide mix should be made around the entire stem from the base of the ground up to 18". Do not exceed 3 gallons of Triclopyr 4 per acre per year. Avoid excessive applications to the point of runoff.

The Triclopyr 4 treatment was just as effective as the Milestone® + Triclopyr 4. Since mixing Treatment 1 (Triclopyr 4 with oil) is easier than mixing Treatment 2 (Milestone® with surfactant added as a slurry to Triclopyr 4 + oil), Treatment 1 is the recommended herbicide.

*Zone Three: Test 11, Tree-of-Heaven (*Ailanthus altissima*) Control with Basal Bark Application*

Tree-of-heaven (*Ailanthus altissima*) is an invasive tree species common throughout Ohio and commonly found on the ROW. This species of medium-size tree grows rapidly and can grow upwards of 70 feet tall. It often grows in disturbed areas and forms dense stands of weak wooded trees that can outcompete native vegetation. Tree-of-heaven readily reproduces due to numerous windblown seeds and numerous stump and root sprouts after manual cutting. Testing was completed on a steep backslope of the ROW. This test evaluates the effectiveness of 2 different herbicides for basal bark application to control primarily tree-of-heaven compared to manually cutting.

Methods

The chemical applications in this test were applied using a backpack sprayer (Photograph 86). The mechanical removal was completed using chainsaws and a chipper (Photograph 87). See Table 76 for equipment information.

Table 76. Zone Three: Test 11, Equipment

Equipment	Equipment Number
D.B. Smith 4-Gallon Max, Backpack Sprayer	N/A
Chain saws	N/A
Chipper, Vermeer BC1800XL	3400156

Method 1: (1 Treatment) Manual Removal Only (SOP): Tree-of-heaven and other small trees were mechanically removed with chainsaws in spring 2015.

Method 2: (2 Treatments) Basal Bark Herbicides: Application was made around the stem of each tree up to 18" high on the trunk using low pressure from a backpack sprayer in fall 2014. In this method, basal oil was mixed with the herbicide to penetrate the stems.

Treatment 1: Triclopyr 4 (triclopyr) + Tordon® K (picloram)

Treatment 2: Triclopyr 4 (triclopyr)

Photograph 86. Foliar application being made to brush.

Photograph 87. Manual removal of brush.

Results

All methods were initially successful at reducing the treated trees, including tree-of-heaven (see Figures 39 and 40). However, as stated earlier, a main concern with tree-of-heaven is its reproductive abilities, which led to major differences in the count of tree-of-heaven and other tree saplings in 2016 between the manual removal plots and the herbicide plots (see Photographs 88 and 89). As seen in Figure 41, the manual removal of tree-of-heaven without herbicides leads to very high numbers of tree-of-heaven saplings.

Method 1: Manual Removal Only: Manual removal plots started testing in 2014 with an average of 70 trees of all species per plot, 63 of which were tree-of-heaven. All of the trees were removed in spring 2015, resulting in 0 tree-of-heaven. This level of control was short lived as saplings quickly grew back into the plots. By summer 2016, the manual removal plots had an average of 551 root sprouts and tree saplings of all species per plot, 436 of which were tree-of-heaven.

Method 2 Treatment 1: Triclopyr 4 + Tordon® K: Triclopyr 4 + Tordon® K plots started testing in 2014 with an average of 68 trees of all species per plot, 58 of which were tree-of-heaven. All of the trees were treated with basal bark herbicide application in winter 2014 and resulted in 27% of the original treated tree-of-heaven surviving by spring 2015. From spring 2015 to summer 2016, less than 1% of the original treated tree-of-heaven trees survived. By the end of testing, there was an average of three tree-of-heaven trees per plot. Triclopyr 4 + Tordon® K provided significant control over all species saplings compared to manual removal. By summer 2016, there was an average of 18 root sprouts and tree saplings of all species per plot, 5 of which were tree-of-heaven.

Method 2 Treatment 2: Triclopyr 4: Triclopyr 4 plots started testing in 2014 with an average of 66 trees of all species per plot, 53 of which were tree-of-heaven. All of the trees were treated with basal bark herbicide application in winter 2014 and resulted in 0% of the original treated tree-of-heaven trees surviving by spring 2015. By the end of testing in 2016, there was an average of 0 tree-of-heaven per plot. Triclopyr 4 provided significant control over all saplings compared to manual removal. By summer 2016, there was an average of 32 root sprouts and tree saplings of all species per plot, 10 of which were tree-of-heaven.

Figure 39. All Species Count per Method

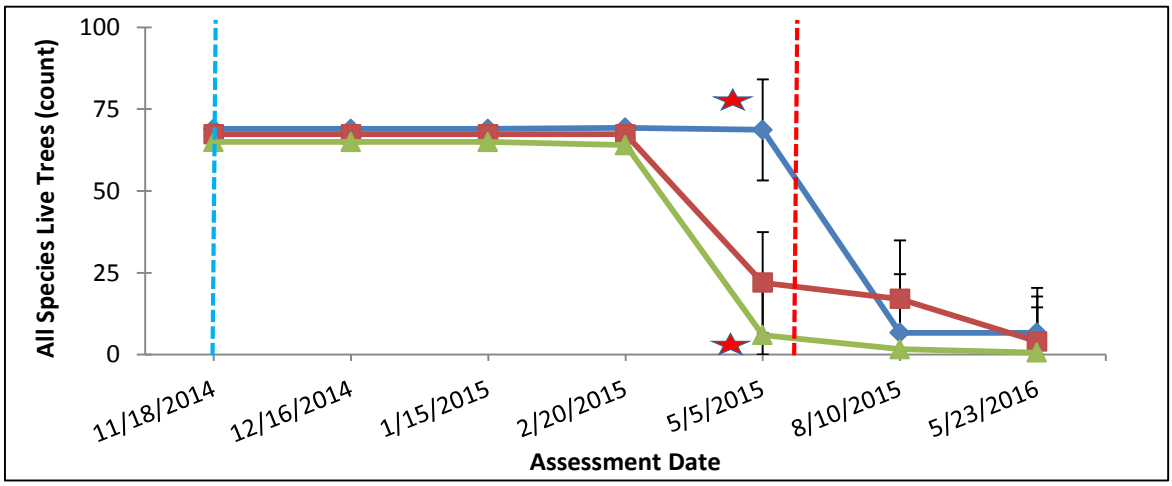


Figure 40. Tree-of-Heaven Count per Method

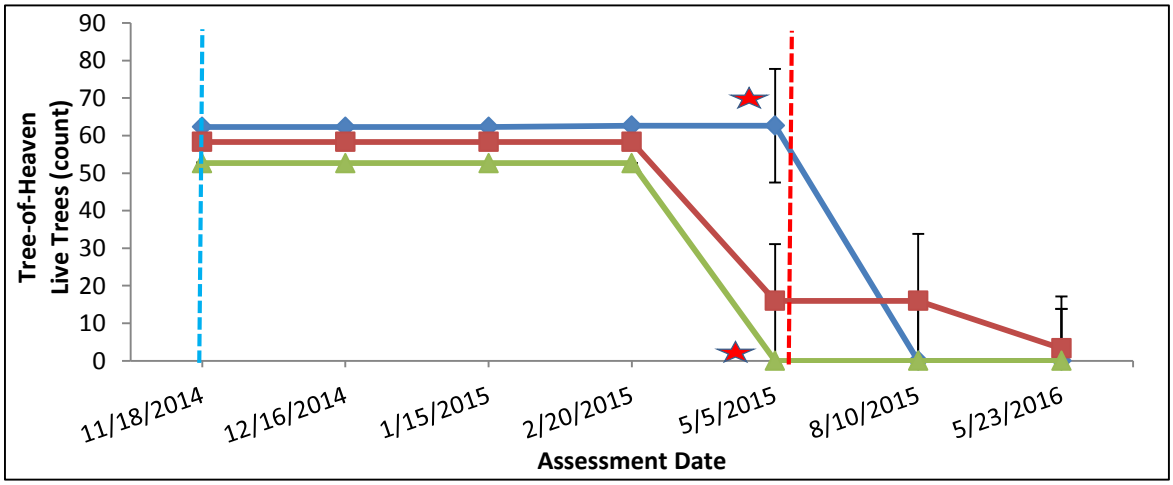


Figure 41. Initial Tree Count Compared to Final Sprout Count

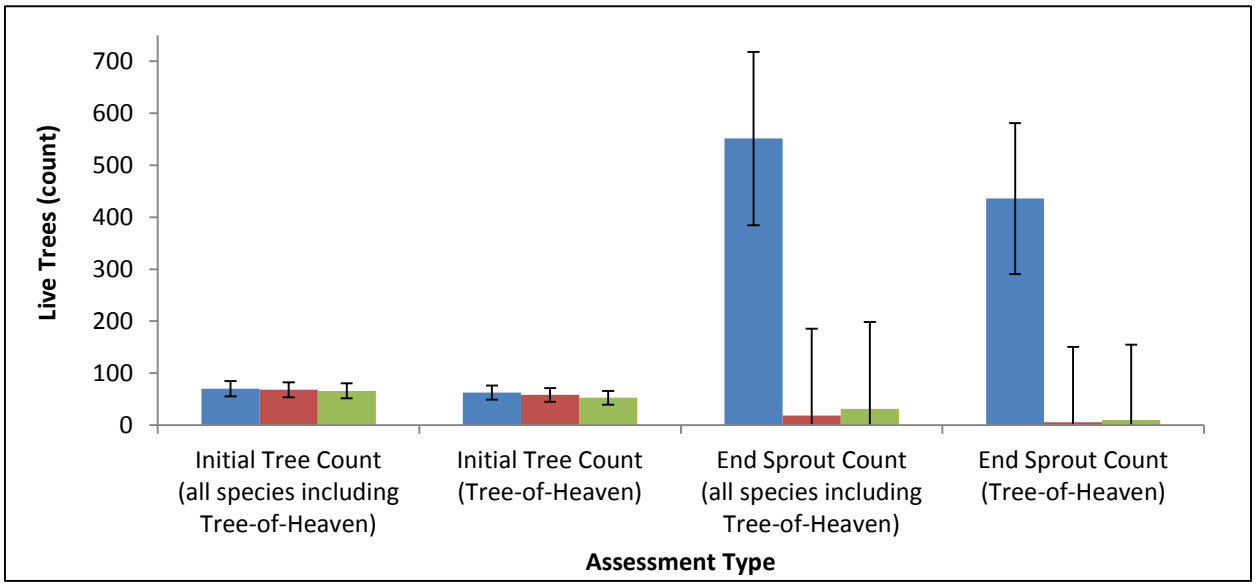
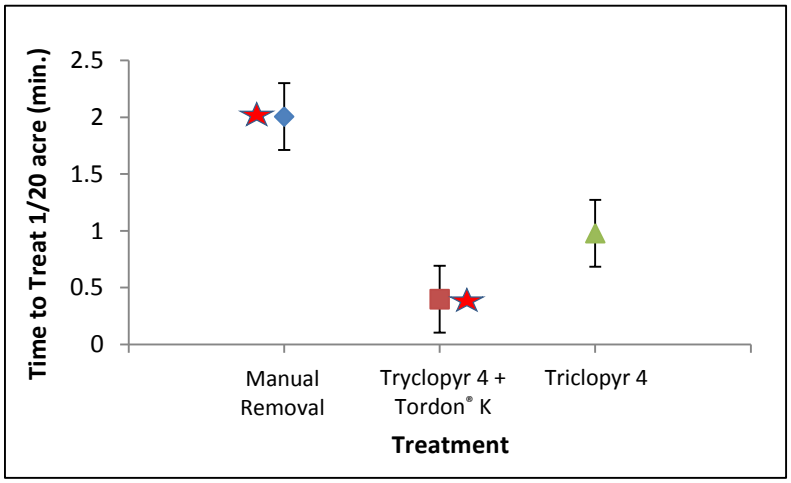


Figure 42. Job Length Comparison



Key to Figures 39-42.

- Statistically Significant Event
- Manual removal
- Triclopyr 4 + Tordon® K
- Triclopyr 4
- Mechanical Control (removal only)
- Herbicide Control (both basal herbicides)
- Error Bars

Photograph 88. Saplings growing in manual removal plot.

Photograph 89. Controlled tree-of-heaven and minimal sapling regrowth in basal bark herbicide plot.

Treatment Cost Comparison: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing these labor costs, there are several factors that influence the costs, such as variations in methods, equipment efficiency, number of staff, and occurrences per year (see Figure 42 for the job length comparison). Table 77 describes the labor cost to manually remove one acre of tree-of-heaven compared to applying a basal bark herbicide application. Table 78 describes the labor cost to treat one acre of tree-of-heaven for one year with each method used in this test. The materials costs are located in Table 79, which shows the mix rate and cost per gallon of each herbicide used in this test. Tree density will determine the volume of product to be used. The cost of materials can be added to the labor cost for each method to determine the total cost per method.

Table 77. Zone Three: Test 11, RIVM Method Labor Comparison

RIVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre
Manual Tree Removal Crew	5	$19.10	0.03	202.89	$3,875.10
Basal Bark Herbicide Application	1	$19.10	0.10	13.56	$258.94

Table 78. Zone Three: Test 11, Labor Cost Comparison

Method and Treatment	Removal Occurrences	Spray Occurrences	Total Labor Hours per Acre per Year	Total Cost per Acre per Year
Method 1 Treatment 1: Manual Removal Only (SOP)	1	0	202.89	$3,875.10
Method 2 Treatment 1: Triclopyr 4 + Tordon® K	0	1	13.56	$258.94
Method 2 Treatment 2: Triclopyr 4	0	1	13.56	$258.94

Table 79. Zone Three: Test 11, Herbicide Cost Comparison

Herbicide	Per Gallon Rate	Cost per 1 Gallon Mixed
Triclopyr 4	16 oz.	$6.27
Tordon® K	16 oz.	
Propylene Glycol	16 oz.	
Basal Oil	80 oz.	
Triclopyr 4	20.4 oz.	$3.68
Basal Oil	107.6 oz.	

Recommendation

Manual removal of vegetation is not necessary to control tree-of-heaven on slopes or under bridges if basal bark herbicide applications are made. The terrain in these areas is often difficult and unstable, making manual removal costly and dangerous. The results of this test suggest that a single herbicide application in the dormant season provides at least two years of control over tree-of-heaven.

Make basal bark applications during the dormant season with Triclopyr 4 mixed with basal oil at a 1:5 ratio per gallon. Basal bark applications are recommended for trees with stems 6 inches in diameter and less at breast height. Coverage of herbicide mix should be made around the entire stem from the base of the ground up to 18”. Do not exceed 3 gallons of Triclopyr 4 per acre per year. Avoid excessive applications to the point of runoff.

The Triclopyr 4 mixed with Tordon® K and propylene glycol did not improve control and is more difficult and costly for the applicator to prepare. Therefore, Triclopyr 4 with basal oil is the recommended herbicide mix. Also, Tordon® K or other restricted use herbicides after consulting with the District Office of Environmental Services.

Zone Three Summary

The results of tests in Zone Three confirm that when attempting to control or reduce noxious and invasive weeds, woody brush, or trees, herbicides are a necessary component. In all tests, using herbicides was more effective at reducing undesirable vegetation coverage when compared to mowing or cutting without using herbicides. In some cases, mowing can be entirely replaced by making properly timed herbicide applications. In other cases, mowing will still be necessary, but by reducing or eliminating undesirable weeds, encroachment, sight distance obstruction and aesthetic quality concerns will be alleviated.

When string trimming, mowing, and chain saw use is reduced or eliminated with the judicious use of herbicides to control noxious and invasive vegetation, employees' safety risks are reduced. Maintenance workers will not be needed on the right of way as frequently and can be there for shorter lengths of time. In many cases they can perform their work at a distance from poisonous plants thereby keeping poisonous plant toxins off of their skin.

Before making herbicide applications, it is important to follow these important steps to ensure successful applications:

- Identify target vegetation – is it a winter annual, summer annual, biennial, perennial, or woody weed?
- Plan application based on plant life cycle timing and weather requirements.
- Make broadleaf selective herbicide applications to control future infestations before they need immediate mechanical clearance.
- If mechanical removal before foliar application is necessary, allow enough time after cutting for vegetation to regrow enough before treatment to provide surface area for the herbicide to be sprayed on, or if removal is necessary after treatment, allow enough time for herbicide to work systemically through the vegetation to maximize control before cutting.
- Measure your target area to determine square footage, then convert square footage to acres.
- Decide how many gallons of total volume are to be applied per acre (spray guns are usually 100 gallons per acre).
- Choose herbicide. Mix the recommended per acre rate in the total volume applied per acre.
- Follow-up treatments to promote desirable, low-growing vegetation that is suitable for the site may be necessary.

After controlling noxious and invasive weeds, consideration should be made to selecting an appropriate seed mix and planting desirable vegetation. This will prevent undesirable plants from filling in bare patches left by large areas of controlled noxious and invasive weeds.

Trained operators should be consistently assigned to new or specialized equipment to optimize equipment performance. Training and practice improve understanding of the equipment, efficiency of use, performance, and safety.

Return On Investment: The ROI for Zone 3 is realized when the frequency of manual or mechanical vegetation control is reduced with directed herbicide treatments to problematic noxious, invasive, or woody vegetation. Directed herbicide applications to problematic vegetation will gain control over problematic vegetation over a two- to three-year period, thus avoiding the spread of the problematic vegetation and the need for future manual or mechanical control. The labor hours that would have been spent clearing vegetation year after year, or multiple times per year can be spent performing other tasks.

Noxious Weed Control Return On Investment: See Table 80 Zone Three Noxious Weed Control Return on Investment – per Acre Labor Cost Savings Analysis 3 Year Control Comparison. In this 3-year comparison, a need for mechanical removal with mowers was determined to be two times per year or a total of six times over three years. This baseline is compared to a 3-year approach using herbicides only, with one primary application and two follow-up applications. Noxious weeds, especially perennials, are tolerant of mowing and should be controlled with herbicide. In many test cases, mowing actually increased the percent coverage of noxious weeds. Once weed populations are under control and desirable vegetation cover has increased, the cost per acre for maintenance will decrease. If spraying noxious weeds rather than mowing, a ROI through labor savings can be realized in 84 acres of Zone Three noxious weed management over three years. Mowing costs $139.80 per acre over three years when mowing twice per year compared to $87.39 per acre for three herbicide applications over three years.

Table 80. Zone Three: Noxious Weed Control Return on Investment – Per Acre Labor Cost Savings Analysis 3-Year Control Comparison

Noxious Weed Control Methods	Purchase Price	3-Year Labor Cost per Acre	3-Year Labor Cost Savings per Acre	3-Year ROI Total Acres Needed	Hours Needed to Accomplish ROI Over 3 Years
Mowing Only	-	$139.80	$0.00	N/A	N/A
Skid Sprayer – Directed Spray Gun Applications	$4,425.00	$87.39	$52.41	84	292

Woody Brush Control Return On Investment: See Table 81 Zone Three Brush Control Return on Investment – per Acre Labor Cost Savings Analysis 3-Year Control Comparison. In this projected 3-year comparison, a need for manual removal with mowers was determined. Manual removal is occurring once per year for three years compared to only needing one directed herbicide application or two WetBlade™ mow with applications in that same time period. Woody brush is tolerant of mowing and should be controlled with herbicide to eliminate the need for mowing. Once woody brush populations are under control and desirable vegetation cover has increased, the cost per acre for maintenance will decrease. If spraying brush rather than mowing, a ROI through labor savings can be realized in 26 acres of Zone Three woody brush management over three years. Mowing costs $322.80 per acre over three years when mowing once per year compared to $149.58 per acre for one application over three years. Using a rotary WetBlade™ mower that simultaneously delivers herbicide while mowing would require two cut stem herbicide applications over three years at a cost of $117.28 per acre for that time period, compared to mowing only.

Table 81. Zone Three: Woody Brush Control Return on Investment Per Acre Labor Cost Savings Analysis – 3-Year Control Comparison

Noxious Weed Control Methods	Purchase Price	3-Year Labor Cost per Acre	3-Year Labor Cost Savings per Acre	3-Year ROI Total Acres Needed	Hours Needed to Accomplish ROI Over 3 Years
Mowing Only	-	$322.80	$0.00	N/A	N/A
Skid Sprayer – Directed Spray Gun Applications	$4,425.00	$149.58	$173.22	26	123
Rotary WetBlade™ Cut Stem Application	$19,708.00	$124.54	$198.26	99	1,028

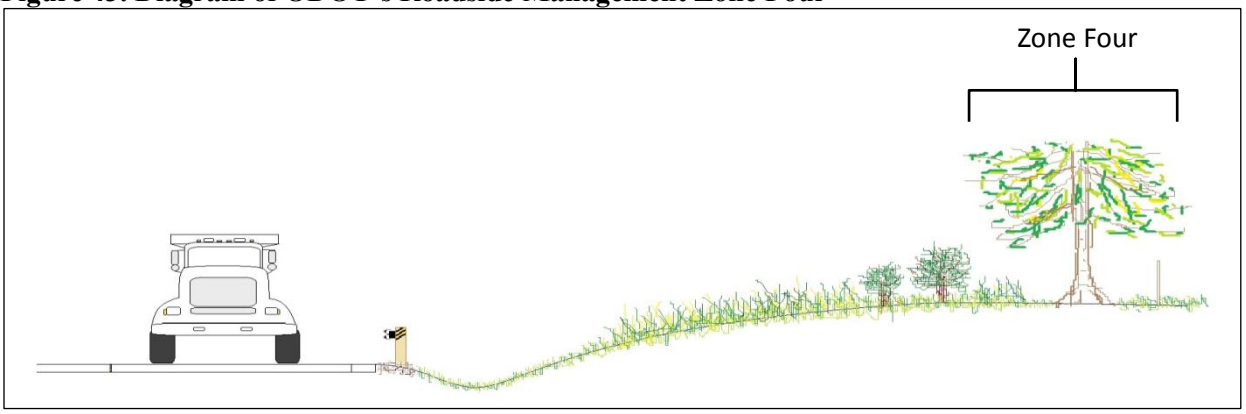
Return on Investment – Per Acre Labor Cost Savings Analysis Labor Cost Comparison. In this projected 3-year comparison, a need for mechanical removal was determined. Manual removal should occur once in three years compared to one herbicide application in that same period of time. A greater ROI may be realized if a comparison spanning more than three years was made; but only three years of results were captured in this study, hence the operative timeframe being used (see Table 82). At the end of three years, research testing plots treated with basal bark herbicide had not yet regrown to the extent requiring treatment. It could be projected that basal bark herbicides can provide several additional seasons of control. Small trees are prone to regrowth and root sprouting following mechanical removal. Those trees should be controlled with herbicide before they reach maturing size with a stem over 6 inches in diameter. If making basal bark applications rather than mechanical removal, a ROI through labor savings can be realized in less than one acre over three years. Manual removal costs $2,723 per acre over three years when removing once in that time period compared to $177.13 per acre for one basal bark application over three years. Note that foliar applications can also be made to small trees, but the results are not as favorable when compared to basal bark applications. Foliar applications to small trees growing on a slope cost $90.04 per acre over three years. A ROI for the equipment purchased for foliar applications will be realized in 2 acres sprayed over three years.

Table 82. Small-Diameter Tree Control Return on Investment – Per Care Labor Cost Savings Analysis 3-Year Control Comparison

Brush Control Methods	Purchase Price	3-Year Labor Cost per Acre	3-Year Labor Cost Savings per Acre	3-Year ROI Total Acres Needed	Hours Needed to Accomplish ROI Over 3 Years
Manual Removal (Grubbing)	-	$2,722.75	$0.00	N/A	N/A
Skid Sprayer – Directed Spray Gun Applications	$4,425.00	$90.04	$2,632.71	2	8.1
Backpack Sprayer – Basal Bark Applications	$89.33	$177.13	$2,545.62	<1	0.3

Zone Four – The Undisturbed Zone

Figure 43. Diagram of ODOT's Roadside Management Zone Four



Overview

Goal: Zone Four, which is located at the back edge of the ROW, is also known as the Undisturbed Zone (Figure 43). This zone is intended to be dictated by surrounding property and is managed to ensure that existing vegetation is not detrimental to neighboring land use (Ohio Maintenance Operations Manual, 803.4).

Overview of Maintenance Practices: The goal in Zone Four is to be undisturbed. However, in achieving that goal, clearing work may be necessary to reestablish Zone Four boundaries. Zone Four vegetation management activities include periodic tree trimming and periodic tree removal. Main concerns for this zone are large trees and brush, sight distance, visible signage, road canopy shading the roadway, and hazardous trees within the fall zone of the road. Mechanical means of vegetation management vary greatly between counties and districts depending on available equipment. In some counties, using some type of bucket truck or manual crew are the standard operating procedures, while all-terrain tree trimmers (Sky Trim or Jaraff) are the standard in other counties.

Safety: Risks associated with vegetation management in Zone Four relate to improper tree trimming and removal techniques. Whether trees are healthy or hazards, there are risks associated with tree maintenance and removal. Safety risks are largely incurred by the staff working on the trees but can also be sustained by neighboring properties or vehicles passing by when trees are felled in the wrong direction or are left to fall of their own accord. Employees who are not properly trained to perform this difficult work or who do not follow safe work practices put the whole crew at risk of injury. Crew members work around fast-moving sharp blades, projectiles, and very heavy falling objects. The terrain can be a safety risk as well; uneven slopes covered in debris can result in slips and falls.

Objective: The following tests address two tree maintenance activities; tree maintenance (trimming of branches) and tree removal. Both Zone Four activities were tested in on- and off-road scenarios. When trimming in the ROW, the objective is to remove the lateral limbs but preserve the tree. Trimming is typically needed when trees are growing outside the right-of-way but have lateral limbs growing towards the roadway or creating an obstruction. Trimming should be efficient and properly performed according to arboricultural standards. This type of trimming, called natural target pruning, requires that cuts are made just outside the branch collar and do not create bark tears, flush cuts, or stubs. If a limb has been flush cut, left as a stub, or has bark tearing, it does not meet the criteria for natural target pruning. The objective of tree removal in the ROW is to increase safety for the traveling public by decreasing shading of the roadway, improving sight distance, and mitigating hazard trees. Tree removal work needs to be performed safely and efficiently. Many tree species are capable of resprouting from the stump or roots when cut down and growing into mature trees. Therefore, all trees capable of resprouting should be treated with herbicide to prevent regrowth of the tree and lengthen the cycle of removal along the ROW.

Zone Four: Test 1, Tree Maintenance: Chemical Control of Lateral Limbs (Chemical Side Trim)

Lateral limbs can cause many issues inside the ROW, including visibility issues with sight distance, covering signs, and encroaching onto the roadway, which causes damage to passing vehicles. The mechanical method many garages rely on to maintain encroaching branches is the use of a flail mower to trim branches. This method is not a proper arboriculture practice for trees, as it compromises the trees' health and is aesthetically unappealing resulting in many public complaints. This method also causes profuse sprouting leading to areas that need to be trimmed every year to maintain the desired clearance. This test evaluated tree response to two different herbicide treatments compared to no maintenance in controlling the growth of living branches. Testing was located on the shoulder of a two-lane state route (Photographs 90 and 91) and a four-lane interstate.

Methods

Two different tests were designed to assess the effectiveness of chemical side trimming lateral limbs. The herbicide applications occurred in late summer after current season twigs and buds had hardened off and while foliage was still green. The first test analyzed the length of time for a truck with a skid sprayer, utilizing the spray gun to apply herbicide treatments to the branches extending into the ROW on a typical overgrown road. The second test, which used a backpack sprayer (Photograph 90), assessed the effectiveness of the herbicides on six species of trees. The tree species that were tested included *Acer rubrum* (red maple), *Quercus alba* (white oak), *Robinia pseudoacacia* (black locust), *Ulmus americana* (American elm), *Prunus serotina* (black cherry), and *Fraxinus americana* (white ash). See Table 83 for equipment information.

Table 83. Zone Four: Test 1, Equipment

Equipment	Equipment #
Spray Truck, GMC Sierra 4WD 2500	2220786
Spray Tank, Gregson-Clark 200 Gallon V-200 ST Skid Sprayer	8100159

Method 1 Treatment 1: Unmaintained (control): In this method, no herbicide or cutting was used. This represents a situation where the vegetation would go untreated. Individual branches were identified as control branches. The health of the control branches was routinely assessed.

Method 2: 2 Treatments Broadleaf Selective Herbicide: In this method, broadleaf selective herbicide was directly applied to the vegetation on one branch per tree.

Treatment 1: Krenite® S (fosamine)

Treatment 2: Triclopyr 3 (triclopyr)

Photograph 90. ODOT employee applying directed herbicide to trees. The herbicide application was timed for the end of summer prior to leaf coloration.

Photograph 91. Trees growing along the ROW where treated branches were growing into the ROW over the fence.

Results

Both herbicides significantly reduced the foliage on branches compared to the control. While both herbicides worked better than the control, Krenite® S significantly reduced foliage cover on branches more than Triclopyr 3 (see Figures 44–50). In the analysis of the reduction in live branch length, results have shown that in one year, Triclopyr 3 significantly reduced the average living branch length across all species (Figure 51).

Method 1 Treatment 1: Unmaintained (control): Control trees started testing in 2015 with an average of 97% foliage (average foliage between all of the tested species) on the untreated branches. The untreated branches showed an average reduction in branch foliage by 6%, resulting in 91% foliage by summer 2016. Of the five species of trees that were tested, the only species that showed reductions in branch foliage were American elm and ash. The reduction in foliage that was seen for these two species was significantly less than reductions achieved by either of the herbicides. The live branch length reduction that was seen in the control trees was significantly less than the reduction seen in Triclopyr 3 (P=<0.0001).

Method 2: Broadleaf Selective Herbicide

Treatment 1: Krenite® S: Trees treated with Krenite® S started testing in 2015 with an average of 98% foliage (average foliage between all of the tested species) on the treated branch. The foliar application of Krenite® S in summer 2015 reduced branch foliage by 91%, resulting in 7% foliage by summer 2016. Branch foliage was observed to drop from the tree after herbicide application; this left the appearance of a branch with minimal foliage 30 days after treatment (Photograph 92). Krenite® S showed very consistent results of foliage reduction across all six species that were tested. Reductions in branch foliage ranged from 79% (white oak) to 97% (American elm). These reductions resulted in branch foliage ranging from 0% (American elm) to 18% (white oak). When foliage levels were averaged across all species, Krenite® S significantly reduced foliage compared to Triclopyr 3 (P=0.0140) and the untreated plots (P=<0.0001). The average live branch length reduction across all species was 4 feet as a result of Krenite® S application. This reduction was not a significant reduction in length, and the reduction seen by Krenite® S was significantly less than what was achieved by Triclopyr 3 (P=0.0036). This result was seen after one season; it is unknown whether the living vegetation at the end of these branches will continue to extend the length of the branch in the future. Further testing or assessments would need to be done to analyze the living branch length beyond the timeframe of this project.

Treatment 2: Triclopyr 3: Trees treated with Triclopyr 3 started testing in 2015 with an average of 98% foliage (average foliage between all of the tested species) on the treated branch. The foliar application of Triclopyr 3 in summer 2015 reduced branch foliage by 61%, resulting in 37% foliage by summer 2016. Branch foliage was observed to turn brown prior to dropping from the tree after herbicide application; this left the appearance of a branch with brown foliage 30 days after treatment (Photograph 93). Triclopyr 3 showed inconsistent results from one species to the next; reductions in foliage ranged from 28% (black locust) to 96% (ash) reduction in branch foliage. These reductions resulted in branch foliage ranging from 2% (ash) to 73% (black locust). In the next growing season, the goal was for the treated branches to remain leafless. When foliage levels were averaged across all species, Triclopyr 3 significantly reduced foliage compared to untreated branches (P=0.0008) but had significantly more foliage than Krenite® S (P=0.0140). The average live branch length reduction across all species was 10 feet as a result of Triclopyr 3 application. This was the only method that showed a significant reduction in live branch length from the first assessment to the last assessment. Also, the final live branch length of 5 feet achieved by Triclopyr 3 was significantly shorter than both of the other methods. This result was seen after one season; it is unknown whether the living vegetation at the end of these branches will continue to extend the length of the branch in the future. Further testing or assessments would need to be done to analyze the living branch length beyond the timeframe of this project.

Photograph 92. White oak tree 30 days after application of Triclopyr 3. Trees treated with Triclopyr 3 show foliage with brown leaves that will hang onto the branch for some time before falling to the ground.

Photograph 93. White oak tree 30 days after application of Krenite® S. Trees treated with Krenite® S drop leaves before foliage turns brown. Trees treated with Krenite® S have less brown foliage that would lead to a better appearance than Triclopyr 3.

Figure 44. All Trees Average Foliage

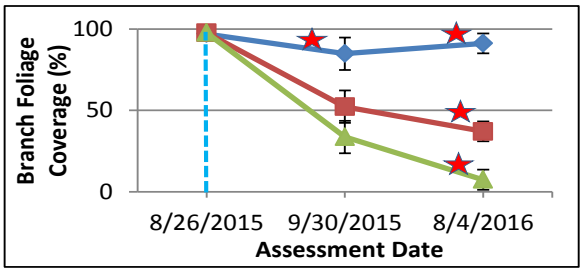


Figure 45. American Elm Foliage

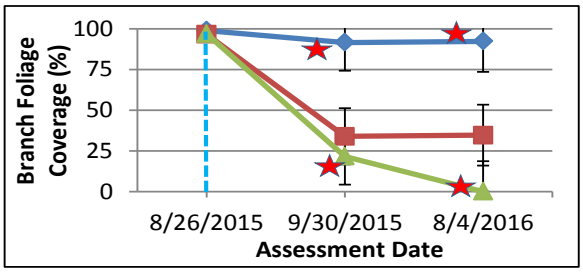


Figure 46. Black Locust Foliage

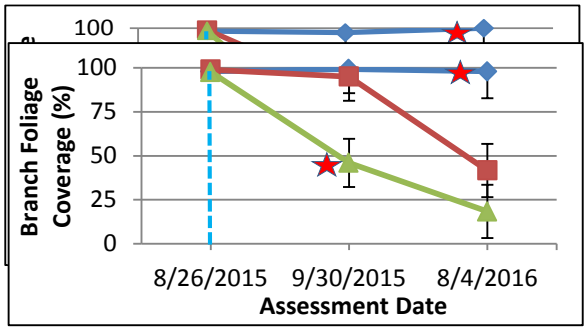


Figure 47. Black Cherry Foliage

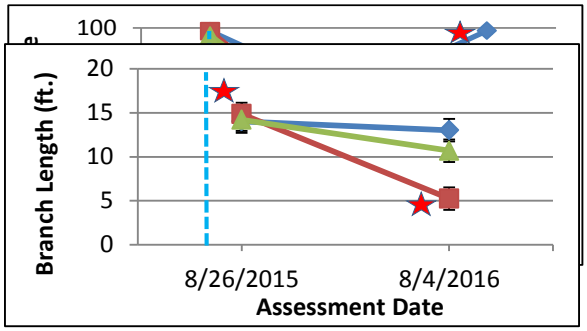


Figure 48. Red Maple Foliage
Figure 50. White Oak Foliage

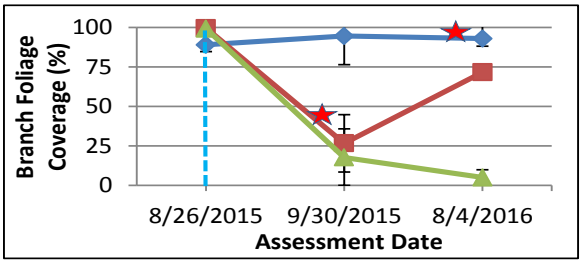
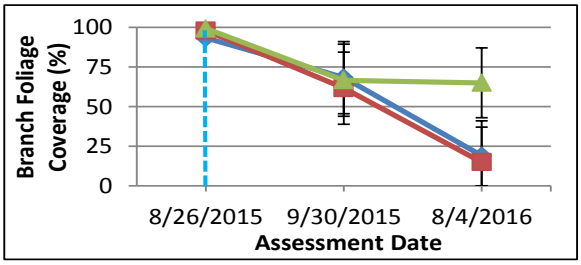


Figure 49. White Ash Foliage
Figure 51. All Trees Average Length



Key to Figures 44-51.

- Statistically Significant Event
- Untreated
- Triclopyr 3
- Krenite S®
- Herbicide Control (both broadleaf herbicides)
- Error Bars

Treatment Cost Comparisons: Labor costs for each method have been calculated based on timed maintenance activities at the first chemical side trim test that used a skid sprayer and targeted spray gun application. In analyzing the labor costs, there are several factors that influence the costs, such as variations in methods, equipment efficiency, number of staff, and occurrences per year. Table 84 describes the labor cost to spray one mile of tree branches that impede the ROW with a skid sprayer and directed spray gun application. Table 85 describes the labor cost to treat one mile of branches for one year with each method used in this test. The materials costs are located in Table 86, which shows the per-acre and per-mile cost of each herbicide used in this test. The cost of materials can be added to the labor cost for each method to determine the total cost per method. Labor costs for this test should be compared to labor costs for the other tests that involved tree maintenance (Zone Four: Tests 2 and 3).

Table 84. Zone Four: Test 1, IVM Method Labor Comparison

IVM Method	# Staff	Average Wage	Miles per Hour	Labor Hours per Mile	Cost per Mile
Skid Sprayer Directed Foliar Application	1	$19.10	0.62	1.77	$33.81

Table 85. Zone Four: Test 1, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Mile per Year	Total Cost per Mile per Year
Method 1 Treatment 1: Unmaintained	0	0	0.00	$0.00
Method 2 Treatment 1: Krenite® S	0	1	1.77	$33.81
Method 2 Treatment 2: Triclopyr 3	0	1	1.77	$33.81

Table 86. Zone Four: Test 4, Herbicide Mixture Cost Comparison

Method and Treatment	Tank Mix	Rate (oz. per Acre)	# Products	Spray Pattern Width (ft.)	Cost Per Acre
Method 1 Treatment 1: Skid Spray + Broadleaf	Krenite® S	512	1	30’	$100.67
Method 1 Treatment 1: Skid Spray + Broadleaf	Triclopyr 3	192	1	30’	$22.05

Recommendation

Tree limbs can be prevented from encroaching the ROW by controlling them with chemical methods rather than mechanical methods at a lower cost per mile and per acre. Results from this test indicate that foliage control or live branch control with herbicide can be effective but may require a follow-up application to establish complete control. The goal of using these herbicides is to prevent more costly tree limb removal with heavier equipment and a greater per-mile or per-acre labor burden. Useful applications for this method may be in selective control of branches that need clearance for sight distance without the need for removal of the branch. Such circumstances may include sight distance around signs where branches are encroaching upon the signs. Another potential use for chemical side trimming is to extend the length of time between mechanical trimming by applying the herbicide in the years following mechanical trimming when the branches are starting to grow back. Chemical side trimming could also be used when clearance is needed along a roadway but there is not enough time for mechanical maintenance crews to complete trimming a particular road. Chemical side trimming

could be completed rather quickly to extend the time by one or two years before the mechanical crew would need to perform trimming.

Applications should be made to tree limbs in late summer after buds harden off on current season growth. Due to the targeted timing of applications just prior to leaf turn, the signs (e.g., browning of leaves) of treated branches to the common passerby would not be noticeable for long, as fall color change would follow soon after application. Krenite® S at 4 gallons per acre costs $100.67 but performs significantly better than Triclopyr 3 at 1.5 gallons per acre and a cost of $22.05 per acre. Although Krenite® S performed better than Triclopyr 3 due to testing constraints, it is unknown what level of control would be achieved with a second application. Chemical side trimming should only be used in situations where the goal is to preserve a tree but remove obstructions created by limbs. Chemical side trimming can also be used to prevent tree limbs from encroaching from private property into the right-of-way by growing over the fence towards the road. Herbicides should not be used on limbs that overhang roadways due to the eventual shedding of controlled branches. The goal for chemical side trim should be to prevent the need for mechanical removal, not to provide clearance after an encroachment or site distance concern has been identified.

Zone Four: Test 2, Tree Maintenance, Equipment On-Road

Tree branches can cause many issues along the ROW, including visibility issues with sight distance, covering signs, and encroaching onto the ROW, where branches can cause damage to passing vehicles. Mechanical methods of vegetation control are the primary means to achieve desired clearance. This test analyzes three different mechanical methods for removing limbs in an on-road scenario (where the trees are reachable with equipment on the road). Testing occurred on a typical overgrown two-lane road with tree branches extending over the road. The main evaluations for this test were the efficiency and effectiveness of each treatment, and the resulting damage to trees when cutting living branches.

Methods

The equipment used in this test was an all-terrain tree trimmer, forestry bucket truck with chainsaw operator, and a typical clean-up crew consisting of an excavator, skid steer, and chainsaws (Photographs 94 and 95). See Table 87 for equipment information.

Table 87. Zone Four: Test 2, Equipment

Equipment	Equipment #
Forestry Bucket Truck, Altec® with 60-foot Boom	3300256
Chipper, Vermeer® BC 1500	3400169
All-Terrain Tree Trimmer, Kershaw SkyTrim 75 G2	3420002
Excavator, Kobelco 80 CS	4700076
Skid Steer, Case SR 250	5910098
Chainsaws	-

Method 1: Forestry Bucket Truck: In this method, a forestry bucket truck crew was used to trim lateral branches with the natural target pruning method. Equipment used by the clean-up crew consisted of an excavator, skid steer, chainsaws, and chipper.

Method 2: All-Terrain Tree Trimmer: In this method, an all-terrain tree trimmer was used to trim lateral branches. Equipment used by the clean-up crew consisted of an excavator, skid steer, chainsaws, and chipper.

Method 3: All-Terrain Tree Trimmer Followed by Forestry Bucket Truck: In this method, an all-terrain tree trimmer completed the initial pruning of target limbs by removing the heavy wood. A forestry bucket truck crew followed through to turn the branch stubs left by the all-terrain tree trimmer into natural target pruning cuts. Equipment used for the clean-up crew consisted of an excavator, skid steer, chainsaws, and chipper.

Photograph 94. ODOT employee removing branches to the branch collar while using a forestry bucket truck.

Photograph 95. All-terrain tree trimmer removing branches overhanging the road.

Results

Both Method 1: Forestry Bucket Truck and Method 2: All-terrain tree trimmer was significantly more efficient than Method 3: All-terrain tree trimmer followed by forestry bucket truck (see Figures 52 and 53). Natural target pruning was significantly reduced by using only the all-terrain tree trimmer (Figure 54). Sprouting after the trimming operation was not a result of any of the methods, and results showed that there was no significant difference between the amounts of sprouts caused by any of the methods (Figure 55). Lastly, the all-terrain tree trimmer left significantly more cuts without callus formation than the other methods (Figure 56).

Method 1: Forestry Bucket Truck: Forestry bucket truck plots were trimmed in 2014, with a job length of one hour per plot and a total job length of seven hours based on five employees performing this work. Cut limbs were evaluated using the arboricultural standard of natural target pruning. The pruning technique used in this method resulted in significantly more natural target pruned limbs compared to the all-terrain tree trimmer alone (P=<0.0001). The forestry bucket truck method resulted in an average of 87% of all cuts achieving natural target pruning (Photograph 96). With natural target pruning, a significantly larger proportion of the cuts resulted in callus and woundwood formation two years after the pruning occurred. This formation indicated that the cuts were being sealed off. The sprouting that followed on trees pruned by using the forestry bucket truck resulted in an average of 15 sprouts per tree, which was not significantly different than the other methods used for pruning.

Method 2: All-Terrain Tree Trimmer: All-terrain tree trimmer plots were trimmed in 2014 with a job length of one hour per plot and a total job length of seven hours based on six employees performing this work. Cut limbs were evaluated using the arboricultural standard of natural target pruning. The pruning technique used in this method resulted in significantly less natural target pruned limbs compared to the other two methods tested. The all-terrain tree trimmer method resulted in an average of 5% of all cuts achieving natural target pruning (Photograph 97). These improper cuts resulted in significantly more cuts without the formation of callus and woundwood two years after the pruning took place. This formation indicated that the cuts were not being sealed off, which could lead to decay throughout the tree. The sprouting that followed on trees pruned by using the all-terrain tree trimmer resulted in an average of 16 sprouts per tree, which was not significantly different than the other methods used for pruning.

Method 3: All-Terrain Tree Trimmer Followed by Forestry Bucket Truck: All-terrain tree trimmer followed by forestry bucket truck plots were trimmed in 2014 with a job length of three hours per plot and a total job length of 17 hours based on seven employees performing this work. This method was significantly slower than the other two methods in job length and was significantly slower than the all-terrain tree trimmer in total job length. Cut limbs were evaluated using the arboricultural standard of natural target pruning. The pruning technique used in this method resulted in significantly more natural target pruned limbs compared to the all-terrain tree trimmer alone (P=<0.0001). This method resulted in an average of 93% of all cuts achieving natural target pruning (Photograph 98). With natural target pruning, a significantly larger proportion of the cuts resulted in callus and woundwood formation two years after the pruning took place. This formation demonstrated that the cuts were being sealed off. The sprouting that followed this cutting method resulted in an average of 21 sprouts per tree, which was not significantly different than the other methods used for pruning.

Figure 52. Tree Maintenance Job Length

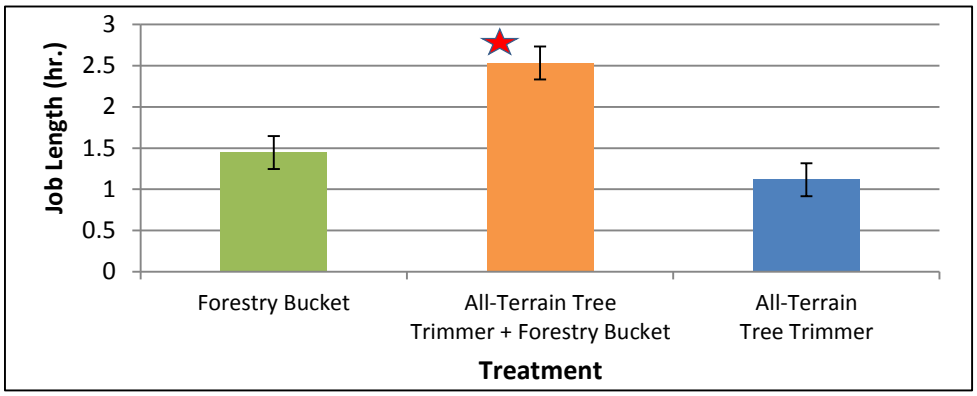


Figure 53. Tree Maintenance Total Labor Hours

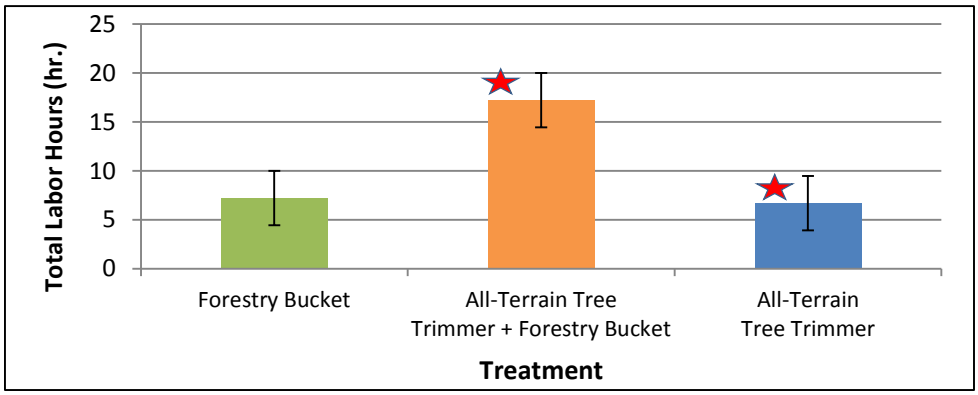


Figure 54. Tree Maintenance Percent of Cuts Achieving Natural Target Pruning

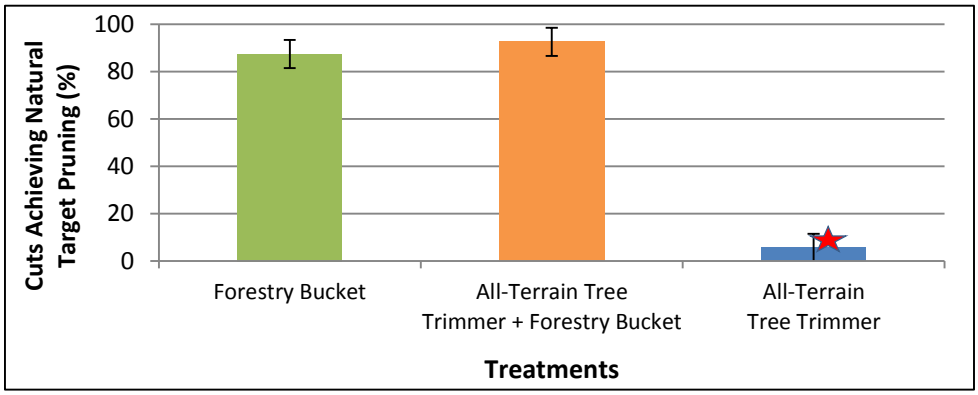
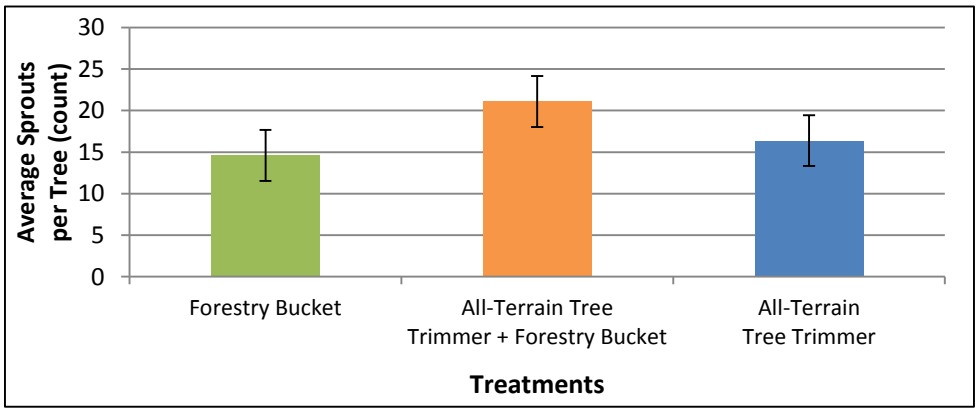


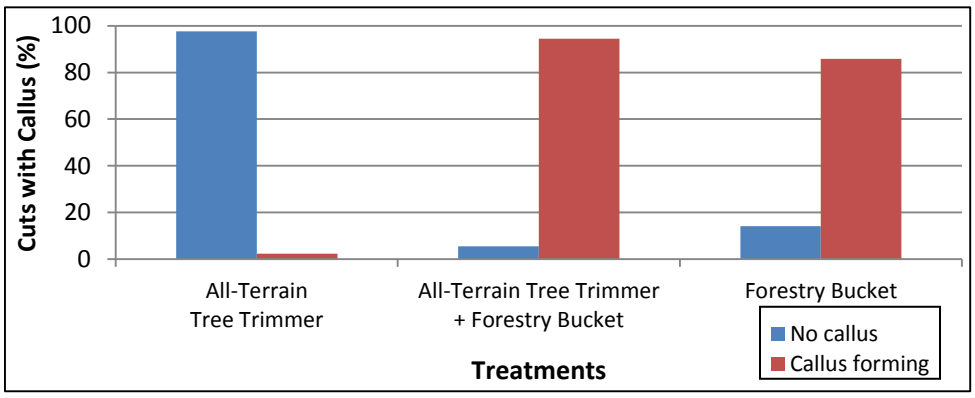
Figure 55. Tree Maintenance Average Sprouts per Tree



Key to Figures 52-55.

- Statistically Significant Event
- Forestry Bucket Truck
- All-Terrain Tree Trimmer + Forestry Bucket Truck
- All-Terrain Tree Trimmer
- Error Bars

Figure 56. Tree Maintenance Cuts Showing Signs of Callus



Photograph 96. Natural target pruning as a result of the forestry bucket truck method. Cuts can be observed to be pruned up to the branch collar.

Photograph 97. Cuts do not achieve natural target pruning as a result of the all-terrain tree trimmer method. Cuts have left long stubs.

Photograph 98. Natural target pruning as a result of the all-terrain tree trimmer followed by the forestry bucket truck method. Cuts can be observed to be pruned up to the branch collar.

Treatment Cost Comparisons: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing these labor costs, there are several factors that influence the costs, such as variations in methods, equipment efficiency, number of staff, and occurrences per year. Table 88 illustrates the labor cost to prune one mile of branches that impede the ROW with three different IVM methods. Table 89 illustrates the labor cost to prune one mile of branches for one year with each method used in this test. Labor comparisons show that two out of the three methods had labor costs that were not significantly different from each other, while the method that utilized the two pieces of pruning equipment had the largest labor cost by far. Labor costs for this test should be compared to labor costs for the other tests that involved tree maintenance (Zone Four: Tests 1 and 3).

Table 88. Zone Four: Test 2, IVM Method Labor Comparison

IVM Method	# Staff	Average Wage	Miles per Hour	Labor Hours per Mile	Cost per Mile
Forestry Bucket Truck	5	$19.10	0.02	216.65	$4,138.02
All-Terrain Tree Trimmer	6	$19.10	0.03	201.00	$3,839.10
All-Terrain Tree Trimmer + Forestry Bucket Truck	7	$19.10	0.01	532.00	$10,161.20

Table 89. Zone Four: Test 2, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Mile per Year	Total Cost per Mile per Year
Method 1: Forestry Bucket Truck	1	0	216.65	$4,138.02
Method 2: All-Terrain Tree Trimmer	1	0	201.00	$3,839.10
Method 3: All-Terrain Tree Trimmer + Forestry Bucket Truck	1	0	532.00	$10,161.20

Recommendation

Tree maintenance in an on-road scenario is a costly operation that can lead to proper or improper pruning of branches depending on the method used. To reduce the costs of pruning, establishing an efficient trimming method is advised which could be using a forestry bucket truck or all-terrain tree trimmer. To reduce the damage to trees, it is recommended to prune branches in a way that results in natural target pruning, as recommended by ISA.

Through testing, the forestry bucket truck method and all-terrain tree trimmer method both were observed to trim and chip branches significantly faster than the all-terrain tree trimmer followed by the forestry bucket truck method. In this analysis, the entire job was recorded, meaning that the trimming time was added to the chipping time. In this type of work, the chipping operation was observed to be the limiting factor in performing efficiently. The trimming methods do not necessarily compromise the efficiency of the work to the degree that the chipping method does. Due to this chipping time, the labor costs for the forestry bucket truck and the all-terrain tree trimmer methods were not significantly different. If an efficient job is a priority, either the forestry bucket truck method or all-terrain tree trimmer method would be acceptable methods for maintaining trees from the road.

It was observed that the methods that utilized the forestry bucket truck resulted in significantly more natural target pruning cuts (which is healthier for the tree) than the all-terrain tree trimmer method. These natural target pruning cuts represent the best pruning technique to support tree health. If tree health is a priority to ODOT, utilizing a forestry bucket truck to obtain natural target pruning is recommended.

Zone Four: Test 3, Tree Maintenance, Equipment Off-Road

Tree branches can cause many issues along the ROW, including visibility issues with sight distance, covering signs, and encroaching onto the ROW, where they can cause damage to passing vehicles. In this test, an all-terrain tree trimmer was used to achieve the desired clearance. Although ODOT crews have found the all-terrain tree trimmer to be a safe, efficient, and effective tool, the criticism from maintenance supervisors is that the unit cannot complete a full day's work because it must always wait for the ground clean-up crew to catch up. This test evaluated the efficiency and limitations of two different ground clean-up crew operations following the all-terrain tree trimmer in an off-road scenario (where the trees are reachable with equipment off the road). Testing took place on trees growing over a fence line at the edge of the ROW on a divided two-lane road (Photograph 99).

Methods

This test used an all-terrain tree trimmer to trim branches. Following the trimming were the chipping operations. The first method consisted of a typical ground clean-up crew consisting of an excavator, skid steer, chainsaws, and Vermeer® BC 1500 (Brush Chipper) (Photograph 100). The second method consisted of a Bandit 1850 Whole Tree Chipper on tracks with a cab and grapple arm loader (Whole Tree Chipper) (Photograph 101). Crews for both clean-up methods were instructed to put more through the chipper than they otherwise would to test the limitations and time constraints of each chipper. See Table 90 for equipment information.

Table 90. Zone Four: Test 3, Equipment

Equipment	Equipment #
Brush Chipper, Vermeer® BC 1500	3400159
All-Terrain Tree Trimmer, Kershaw SkyTrim 75 G2	3420002
Whole Tree Chipper, Bandit 1850	3420004
Excavator, CAT® 308E2CR SB	4700103
Skid Steer, Case® 1845C	5910008
Chainsaws	-

Method 1: Brush Chipper (SOP): In this method, the all-terrain tree trimmer was followed by a typical ground clean-up crew consisting of an excavator, skid steer, chainsaws, and Vermeer® BC 1500 Brush Chipper. This method used a total of five people from start to finish.

Method 2: Whole Tree Chipper: In this method, the all-terrain tree trimmer was followed by the Bandit 1850 Whole Tree Chipper ground clean-up crew. This method used a total of two people from start to finish.

Photograph 99. ODOT employee trimming trees accessed off the road edge with an all-terrain tree trimmer.

Photograph 100. ODOT ground clean-up crew using their SOP to clean up debris behind the all-terrain tree trimmer.

Photograph 101. ODOT employee performing debris clean-up using Bandit chipper following all-terrain tree trimmer.

Results

The analysis of the results from the off-road trimming test show that employee count is a large factor in the cost of a method. Neither method showed a significant difference in job length (Figure 57). The total labor hours take into account the number of employees who worked on each method. The total labor hours were statistically different between the Brush Chipper and Whole Tree Chipper methods (Figure 58). Elapsed time for chipping operations also significantly differed across methods, with the Brush Chipper method having a significantly faster chipping time (Figure 59).

Method 1: Brush Chipper (SOP): The brush chipper method had a significantly faster chipping time than the whole tree chipper (one hour and two hours, respectively). While the chipping time was faster, the total labor hours were significantly slower than the whole tree chipper method (eight hours and six hours, respectively). This significant difference in labor time was a result of different crew sizes between the two methods.

Method 2: Whole Tree Chipper: The whole tree chipper method had a significantly slower chipping time than the whole tree chipper. While the chipping time was slower, the total labor hours were significantly faster than the whole tree chipper method. This significant difference in labor time was a result of different crew sizes between the two methods.

Figure 57. Off-Road Tree Maintenance Job Length

Figure 58. Off-Road Tree Maintenance Total Labor Hours

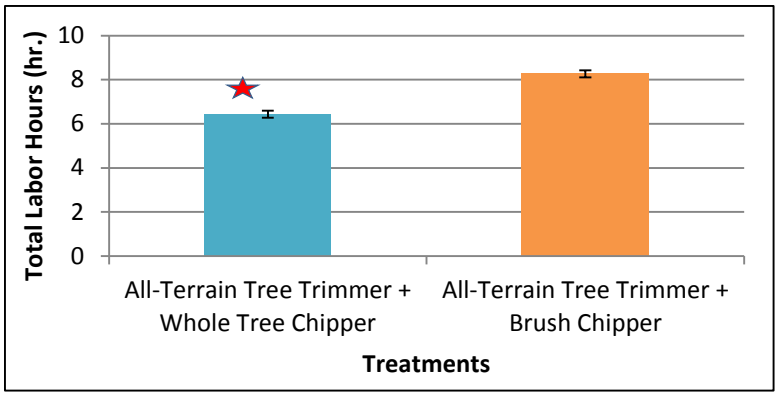
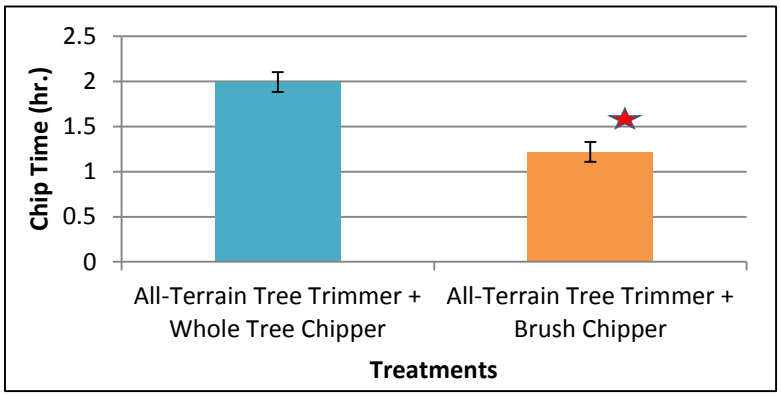
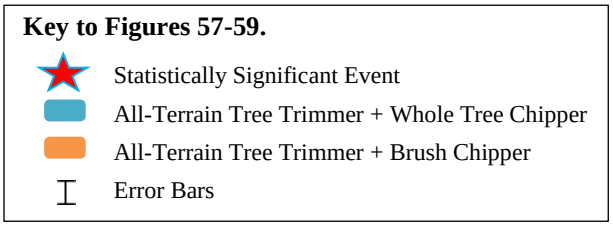


Figure 59. Off-Road Tree Maintenance Chipper Comparison





Treatment Cost Comparisons: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing these labor costs, there are several factors that influence the costs, such as variations in methods, equipment efficiency, number of staff, and occurrences per year. Table 91 describes the labor cost to prune one mile of branches in an off-road setting with two different IVM methods. Table 92 describes the labor cost to prune one mile of branches for one year with each method used in this test. Labor costs for this test should be compared to labor costs for the other tests that involved tree maintenance (Zone Four: Tests 1 and 2).

Table 91. Zone Four: Test 3, IVM Method Labor Comparison

IVM Method	# Staff	Average Wage	Miles per Hour	Labor Hours per Mile	Cost per Mile
All-Terrain Tree Trimmer + Vermeer® Chipper	5	$19.10	0.03	192.20	$3,671.02
All-Terrain Tree Trimmer + Bandit Chipper	2	$19.10	0.02	101.78	$1,944.00

Table 92. Zone Four: Test 3, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Mile per Year	Total Cost per Mile per Year
Method 1: Vermeer® Chipper (SOP)	1	0	192.20	$3,671.02
Method 2: Bandit Chipper	1	0	101.78	$1,944.00

Recommendation

Tree maintenance in an off-road scenario is a costly operation. Tree work can be dangerous. Improving safety, saving money, and recommending efficient methods that utilize the least number of employees are important metrics to measure treatment methods.

Through testing, it was observed that the Vermeer® Chipper had a significantly shorter chipping time than the Bandit Chipper. However, the Bandit Chipper had a significantly shorter total labor time than the Vermeer® Chipper. The difference between these two analyses describes a few things about this type of work.

First, the total labor time of this work is dictated by the number of employees working on a particular crew. To minimize crew size, crew members can be assigned multiple tasks instead of only one. For example, the crew member that monitors the chipper should also be in charge of bucking or cutting and reducing the size of brush. Multi-tasking will help to maximize employee efficiency and reduce crew size. Another way to minimize crew size is to utilize equipment options that allow for reductions in crew members to safely operate the equipment. For example, the Bandit Chipper only needs one crew member to operate, or if the Vermeer® Tree Commander™ is purchased, it can be operated by the excavator operator, thereby eliminating the need for employees to feed the Vermeer® BC1500.

Second, if the Bandit Chipper is used, it should always be accompanied by an excavator with a grapple to help sort and move material. The Bandit Chipper tracks and loader have been observed to be slower moving than an excavator with grapple. The slow-moving tracks and loader of this chipper to drive to and pick up debris resulted in the Bandit Chipper having significantly longer chipper time compared to the Vermeer® Chipper method.

Lastly, to improve safety around the chipping operation, crew size should be minimized. This is achieved with the Bandit Chipper, as it can perform cleanup tasks that would normally require multiple pieces of equipment. Also, staff members needed around this chipper is reduced to one operator in a cab, resulting in reduced safety risks. Safety can be improved around the Vermeer® Chipper by minimizing crew size with the Vermeer® BC 1500's optional Tree Commander™ remote control. This remote control can reduce the need for manual chipper feeding thereby improving safety and efficiency by reducing staff working around this chipper. The Tree Commander™ can be used by the operator of the excavator.

As both of these chipping methods present options for improving safety and efficiency, they both are presented as options for this type of off-road trimming work. In addition to the safety and efficiency of this equipment, it is important to look at the cost of equipment. As the Vermeer® BC, 1500 is the SOP for chipping operations within ODOT, many counties that took part in testing across the state already have one in their inventory. The Bandit Whole Tree Chipper is a new piece of equipment that comes with a very large purchase price. This purchase price should be taken into account in deciding whether to buy this piece of equipment. The ROI for all the equipment will be analyzed later in the Zone Four Summary to help with this decision process.

Zone Four: Test 4, Tree Removal, Equipment On-Road

Trees can cause many issues in the ROW from growing in unsafe locations (for errant vehicles), including being a failure hazard to the traveling public, and causing visibility issues with sight distance. Mechanical methods of vegetation control are achieved by different methods throughout the state depending on equipment availability. One of the steps often overlooked with tree removal is herbicide treatment to ensure trees do not regrow from the stumps. For that reason, a cut stump application was tested at the site and compared to no herbicide treatment. This test evaluated three different mechanical removal methods for efficiency, cost, and effectiveness, two different ground clean-up crew methods, and cost and effectiveness of stump treatments in preventing regrowth of woody vegetation. Testing took place on trees growing over and encroaching the ROW on a two-lane road.

Methods

In some districts, an all-terrain tree trimmer is shared between the counties in that district to handle tree cutting operations. While the use of the all-terrain tree trimmer is widely seen as a great tool, the prominent complaint from the maintenance managers is that the unit cannot successfully put in a full day's work because the ground clean-up crew cannot keep up. For that reason, two ground clean-up crew methods were tested to compare efficiency. Since many districts do not have access to an all-terrain tree trimmer and only have access to some form of a bucket truck or manual crew, two bucket trucks and standard ground clean-up crews were tested as alternate methods. A manual crew stepped in to make the final cuts in all plots to cut down the remaining poles and cut the stumps close to the ground. Since many species of trees removed are capable of resprouting and growing new trees from the stumps, a cut stump treatment made with a backpack sprayer was compared to a control (no herbicide). While herbicide application time was tracked, it was not factored into the removal and chipping operation times. Each removal and chipping method, therefore, would be comparable for the work completed. Efficiency and effectiveness of the herbicide treatment were analyzed after one growing season.

Table 93. Zone Four: Test 4, Equipment

Equipment	Equipment #
Lighting Bucket Truck, Telelect 40-foot Boom	3300191
Forestry Bucket Truck, Altec® 60-foot Boom	3300256
Brush Chipper, Vermeer® BC 1500	3400170
All-Terrain Tree Trimmer, Kershaw SkyTrim 75 G2	3420002
Whole Tree Chipper, Bandit 1850	3420004
Excavator, Kobelco 80 CS	4700076
Chainsaws	-
D.B. Smith 4-gallon Max Backpack Sprayer	-

The equipment used in this test included an all-terrain tree trimmer (Photograph 102), a forestry bucket truck with 60-foot boom (Photograph 103), and a lighting bucket truck with 40-foot boom (Photograph 104) for the cutting operation. For the clean-up, a ground crew was used in combination with a brush chipper (Photograph 105) or a whole tree chipper (Photograph 106). The ground crew typically consisted of 2-3 chipper operators/sawyers, 1 excavator operator, and 1 herbicide applicator for the cut stump treatment (Photograph 107). See Table 93 for equipment information.

Method 1: Lighting Bucket Truck + Brush Chipper, Cut Stump Treatment: In this method, a utility bucket truck with a 40' reach (often referred to by ODOT maintenance crews as a lighting bucket, since many of these old trucks were previously utilized by ODOT's lighting and sign crews and have moved into the maintenance garages to assist with minor tree work) was attempted to be used with a chainsaw operator to remove the crowns of trees, leaving totem poles for a manual crew to drop to the ground. Since the boom did not have a good reach, the removal work for this treatment was completed almost entirely by dropping trees whole by ground crews. The excavator entered the fall zone after a tree was felled to pull logs, while the felling of the next tree was being set up. Chainsaw operators cut up logs as necessary for the excavator to move. The excavator sorted the logs for going through the chipper or for leaving the logs on site as prearranged for the landowner. The excavator moved the smaller debris close to the brush chipper. The chipper operators loaded the debris in the brush chipper bucking up larger pieces as needed to place in the chipper. The stumps in these plots received the cut stump treatment of Triclopyr 4 mixed in basal oil. Basal oil was used instead of water as a longer period of time can pass between the final cut and the application when using basal oil.

Method 2: All-Terrain Tree Trimmer + Brush Chipper, No Stump Treatment: In this method, the all-terrain tree trimmer took down the crowns of trees leaving totem poles for a manual crew to drop to the ground. Once the all-terrain tree trimmer was a safe working distance away, the ground crew entered the work zone to clean up. Cleaning up consisted of the excavator moving the tree crowns to a pile for the workers assigned to the brush chipper to buck up and load into the chipper. Once the bank was clear enough to walk on, a chainsaw operator cut down the remaining portions of the trees and the excavator sorted the logs to go through the brush chipper or leave on site as prearranged for the landowner. The stumps were not treated with herbicide to prevent regrowth.

Method 3: All-Terrain Tree Trimmer + Whole Tree Chipper, Cut Stump Treatment: In this method, the all-terrain tree trimmer took down the crowns of trees leaving totem poles for a manual crew to drop to the ground. Once the all-terrain tree trimmer was a safe working distance away, the ground crew entered the work zone to clean up. Cleaning up consisted of the excavator moving the tree crowns to a pile in front of the whole tree chipper. The loader arm of the whole tree chipper then loaded the logs and chipped the debris. Once the bank was clear enough to walk on, a chainsaw operator cut down the remaining portions of the trees and the excavator sorted the logs to go through the chipper or leave on site as prearranged for the landowner. Although many logs were left for the landowner that were of a size the chipper could handle, it was determined prior to resting that logs of a certain size would be left in every method, no matter which chipper was to follow. The stumps in these plots received the cut stump treatment of Triclopyr 4 mixed in basal oil. Basal oil was used instead of water, since basal oil allows a longer period of time to pass between the final cut to the stump and the application.

Method 4: Forestry Bucket Truck + Brush Chipper, No Stump Treatment: In this method, a forestry bucket truck rated for tree work with a 60' reach was used with a chainsaw operator to remove the crowns of trees, leaving totem poles for a manual crew to drop to the ground. Between cuts, the groundmen entered the fall zone to drag branches to the brush chipper or, after some practice, had the excavator move branches to the brush chipper. When the forestry bucket truck was a safe working distance away, a chainsaw operator cut down the remaining portions of the trees, and the excavator sorted the logs to go through the brush chipper or leave on site as prearranged for the landowner. The chipper operators loaded the debris in the brush chipper, bucking up larger pieces as needed to place in the chipper. The stumps were not treated with herbicide to prevent regrowth.

Photograph 102. All-terrain tree trimmer followed by excavator, brush chipper, and ground crew.

Photograph 103. Forestry bucket truck followed by excavator, brush chipper, and ground crew.

Photograph 104. Lighting bucket truck, manual and ground crew members, excavator, and brush chipper.

Photograph 105. Ground crew and excavator loading the Vermeer BC 1500 brush chipper.

Photograph 106. Bandit 1850 chipper and excavator following all-terrain tree trimmer.

Photograph 107. Triclopyr 4 and dye in basal oil being used to treat stumps.

Results

In the removal of trees from an on-road setting, all of the methods had a significantly shorter job length compared to the forestry bucket truck followed by the brush chipper (see Figure 60). When comparing the total labor hours, there were no significant differences observed in total job length between any methods (see Figure 61). This finding was a result of inconsistencies in crew sizes and overall large crew sizes. At the start of testing, crew sizes for all methods were large, and the removal and clean-up crews did not work efficiently with each other. As testing wore on, the crews became more efficient at working together and less individuals took part in the testing, which in turn made each of the methods more efficient. By summer 2016, the methods that received cut stump herbicide treatments showed significantly less woody coverage than plots that did not receive any herbicide (see Figure 62).

Method 1: Lighting Bucket Truck + Brush Chipper, Cut Stump Treatment: The lighting bucket truck with 40’ boom proved to be incapable of performing tree removal under this test setting. The reach was insufficient and, therefore, barely any tree removal work was accomplished with this piece of equipment. The manual ground crew performed the felling and other cutting work. The lighting bucket truck with the brush chipper method had a significantly shorter job length then the forestry bucket truck. In contrast, the job length for the lighting bucket truck method was not significantly different than either of the all-terrain tree trimming methods. Also, when looking at crew size, the total labor hours for the lighting bucket truck method was significantly shorter than the all-terrain tree trimmer and whole tree chipper and shorter than the forestry bucket truck.

Method 2: All-Terrain Tree Trimmer + Brush Chipper, No Stump Treatment: The all-terrain tree trimmer combined with the brush chipper is the second most cost-effective method for removing trees on road. The all-terrain tree trimmer with the brush chipper did not show a significant difference in job length or total labor hours compared to any of the other methods. During testing, the all-terrain tree trimmer was observed to be a fast piece of cutting equipment that topped trees and reduced trees to totem poles in a very efficient manner. The all-terrain tree trimmer was also observed to be capable of cutting more material than the ground crew could clean up in one shift. While the all-terrain tree trimmer was fast, the clean-up method was slow in comparison. Clean-up required dragging and sorting a tangled mass of limbs and tree crowns to the chipper. This tangled material was time consuming to sort and organize for the chipper. Clean-up using the brush chipper was more efficient with the excavator moving and loading material into the chipper. Overall, this chipping method was a smooth operation, and crews worked well together in a cohesive and safe manner.

Method 3: All-Terrain Tree Trimmer + Whole Tree Chipper, Cut Stump Treatment: The all-terrain tree trimmer with the whole tree chipper did not show a significant difference in job length compared to any of the other methods. The all-terrain tree trimmer and whole tree chipper did, however, have significantly longer total labor hours than the lighting bucket truck. During testing, it was observed that the all-terrain tree trimmer was a fast piece of cutting equipment that topped trees and reduced trees to totem poles in a very efficient manner. It was observed that the all-terrain tree trimmer was capable of cutting more material than the ground crew could clean up in one shift. While the all-terrain tree trimmer was fast, the clean-up method was slow in comparison. The whole tree chipper is operated by an employee in the cab of the chipper who uses a grapple arm to load the chipper and move the chipper on its tracks. It was observed during testing that this chipper is slow in moving across the ground and slow in manipulating material to load with the grapple arm into the chipper feed. The excavator made clean-up more efficient by sorting, moving, and piling cut material for the whole tree chipper. While there was still a ground crew in this operation to cut wood, there were less people working on the ground near the chipper than in other methods.

Method 4: Forestry Bucket Truck + Brush Chipper, No Stump Treatment: The forestry bucket truck with the brush chipper had a significantly longer job length and significantly longer total labor hours than the lighting bucket truck. The long job length was mostly due to inefficient field operations and the long labor hours were due to large crew size. The inefficient field operation was notable by observing the manner in which the bucket truck removed trees. The bucket moved along the road, set up, removed one tree, then lowered the bucket and moved to the next tree instead of reaching everything possible before lowering the bucket. In this inefficient process, oftentimes there were crew members standing around waiting for work or just waiting for a safe work environment. This operation could be improved with practice by a skilled crew and foreman that function in an efficient and safe manner.

Cut Stump Treatment: The cut stump herbicide treatments significantly controlled the return of woody coverage in plots that received herbicide compared to the test plots that did not receive herbicide treatment. The use of cut stump herbicide has reduced the amount of trees that have grown back into these plots, which indicates a longer tree removal cycle in the future.

Figure 60. On-Road Removal Job Length

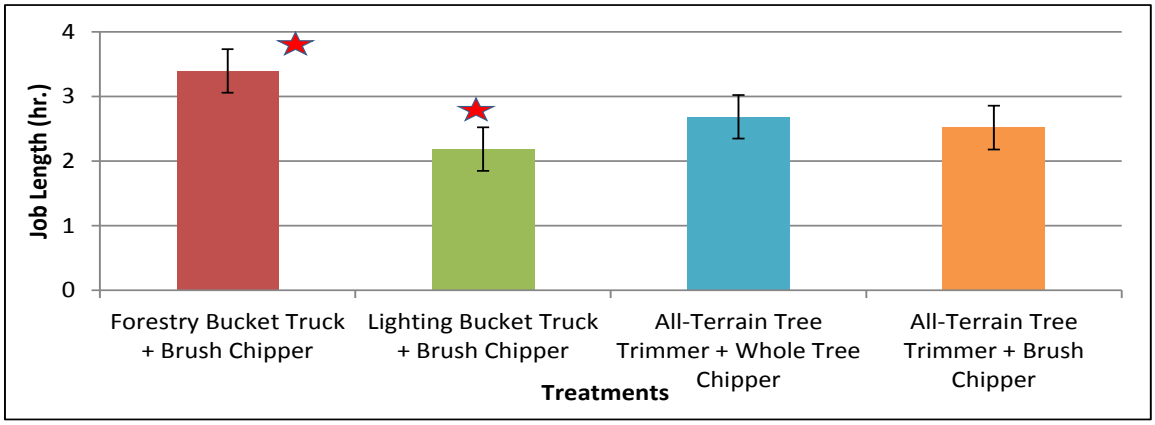


Figure 61. On-Road Removal Total Labor Hours

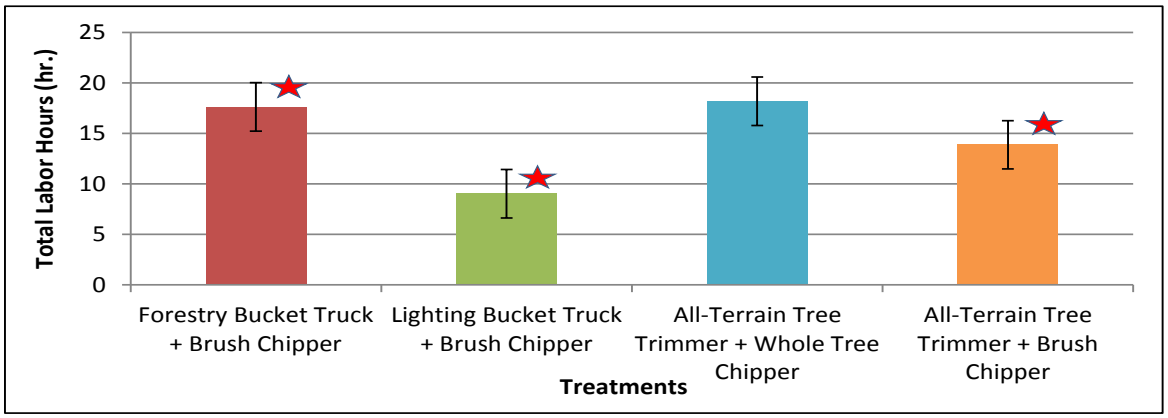
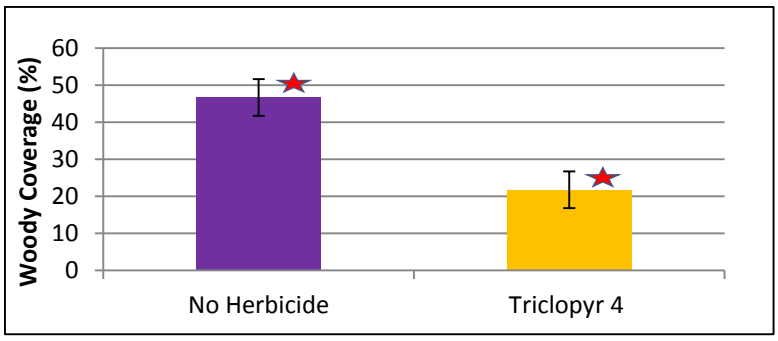


Figure 62. On-Road Removal Herbicide Results



Key to Figures 60-62.

- Statistically Significant Event
- Altec® 60' Bucket + Brush Chipper
- Lighting 40' Bucket + Brush Chipper
- Sky Trim + Whole Tree Chipper
- Sky Trim + Brush Chipper
- No Herbicide
- Triclopyr 4
- Error Bars

Treatment Cost Comparisons: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing these labor costs, there are several factors that influence the costs, such as variations in methods, equipment efficiency, and number of staff. Table 94 describes the labor cost to remove one acre of large trees with five different IVM methods. Table 95 describes the labor cost to remove one acre of large trees with each method used in this test. Labor costs for this test should be compared to labor costs for the other tests that involved tree removal (Zone Four: Tests 5 and 6). The materials costs are located in Table 96, which shows the cost to mix one gallon of herbicide used in this test. The cost of materials can be added to the labor cost for each method to determine the total cost per method.

Table 94. Zone Four: Test 4, IVM Method Labor Comparison

IVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre
Lighting Bucket Truck + Brush Chipper	6	$19.10	0.05	131.18	$2,505.50
All-Terrain Tree Trimmer + Brush Chipper	6	$19.10	0.04	151.21	$2,888.03
All-Terrain Tree Trimmer + Whole Tree Chipper	7	$19.10	0.04	188.09	$3,592.52
Forestry Bucket Truck + Brush Chipper	7	$19.10	0.03	237.93	$4,544.46
Backpack Sprayer Cut Stump Application	1	$19.10	0.32	3.87	$73.84

Table 95. Zone Four: Test 4, Labor Cost Comparison

Method and Treatment	Removal Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Total Cost per Acre per Year
Method 1: Lighting Bucket Truck + Brush Chipper + Cut Stump Treatment	1	1	135.04	$2,579.34
Method 2: All-Terrain Tree Trimmer + Brush Chipper	1	0	151.21	$2,888.03
Method 3: All-Terrain Tree Trimmer + Whole Tree Chipper + Cut Stump Treatment	1	1	191.96	$3,666.36
Method 4: Forestry Bucket Truck + Brush Chipper	1	0	237.93	$4,544.46

Table 96. Zone Four: Test 4, Herbicide Mixture Cost Comparison

Herbicide Mix	Ounces Needed to Mix 1 Gallon	Cost Per 1 Mixed Gallon
Triclopyr 4 + Hy-Grade I Basal Oil	25.6 102.4	$5.44

Recommendation

Tree removal work is time-consuming and dangerous. In an effort to increase safety and reduce costs, crews should contain the least number of employees to accomplish the work without disrupting safety and efficiency. Crew size and experience proved to be limiting factors in safety and total labor hours. With extra crew members on a job site comes a greater chance of people being in the wrong place and getting hurt. Small, efficient, and knowledgeable crews should be utilized for this type of work.

The lighting bucket truck method, which ultimately ended up being the work of a manual crew, represented the lowest total cost per acre of any method. When using a manual crew for removal, it is paramount that the crew, and mainly the sawyers, be experienced and have been properly trained in this type of work. Felling trees with improper techniques is very dangerous to life and limb of the ground crew. Improper techniques were observed during testing and should be avoided with proper training and practice of this type of work.

While the use of the all-terrain tree trimmer is widely seen as a great cutting tool, the prominent criticism from maintenance supervisors is that the unit cannot complete a full day's work because the ground clean-up crew cannot keep up. The use of a ground crew for cutting totem poles and an excavator for sorting and loading the chipper acted as a very efficient method for chipping. While this method worked efficiently, it was slow in comparison to the speed of the all-terrain tree trimmer. In testing, it was observed that the slowest part of this removal method is the chipping operation. Regardless of which chipper was utilized, the chipping operation was slow. That may be partly due to the tangled mass of tree crowns that needed to be dragged and sorted for both chippers after the all-terrain tree trimmer completed its work. Based on observations from this test, the recommended way to speed up the chipping operation is to reduce the amount of material put through the chipper. The Bandit 1850 whole tree chipper has the benefits of being self-propelled, having the option for a cab to keep employees warm in the cold weather, and features the optional grapple loader. However, the loader arm does not have the reach or flexibility of a separate excavator but is a nice feature to keep employees from feeding the chipper by hand. Feeding the chipper is a very dangerous part of any tree maintenance or removal operation. The safety risk associated with feeding the Vermeer® BC1500 chipper as well as exposure to cold can be reduced by purchasing a Tree Commander™ remote control. The Tree Commander™ can be operated from the safety and comfort of the excavator at a fraction of the cost of the Bandit 1850 whole tree chipper. As normal ODOT chipping operations do not chip more than the Vermeer® BC 1500 can handle in terms of wood diameter, a whole tree chipper such as the Bandit 1850 is not necessary.

Through this test and observations made during testing, an ideal tree crew can be recommended. Under these test parameters, the most effective method for tree removal features an all-terrain tree trimmer to cut and top trees leaving totem pole for sawyers to fell. The all-terrain tree trimmer should focus on topping trees and reducing trees to a size that is easiest for a sawyer to fell from the ground. The all-terrain tree trimer is fast at cutting, so the all-terrain tree trimmer operator should function as a ground crew member when done with this piece of equipment for the day. The ground crew is centered on the track hoe excavator feeding a brush chipper with minimal ground assistance. To reduce ground assistance, the Vermeer® BC 1500's optional Tree Commander™ remote control should be purchased and operated from the cab of the excavator to control brush chipper functions remotely. This crew would consist of one all-terrain tree trimmer operator, one excavator operator, and two to three ground crew/sawyers. In total, crews should not exceed five people.

Zone Four: Test 5, Tree Removal, Equipment Off-Road

In order to establish Zone Four as an undisturbed zone, trees need to be cleared back away from the road far enough so that they may mature without ever causing an obstruction. Trees can cause many issues in the ROW from growing in unsafe locations (for errant vehicles), being a failure hazard with a target of the traveling public, to causing visibility issues with sight distance. This test evaluated three different mechanical removal and ground clean-up crew methods for efficiency, cost, and effectiveness. Testing took place on trees growing behind a guardrail where trees needed to be accessed by equipment driven off road (Photographs 108 and 109).

Methods

In some districts, an all-terrain tree trimmer is available to go off road to remove tree crowns with a manual crew to follow and cut the remaining poles and stumps close to the ground. Since many districts do not have access to an all-terrain tree trimmer, a manual crew and standard ground clean-up crews were tested as an alternate method. While the use of the all-terrain tree trimmer is seen as a great tool by many, the prominent complaint from the maintenance managers is that the unit cannot put in a full day's work because the ground clean-up crew cannot keep up. For that reason, two ground clean-up crew methods were tested with the all-terrain tree trimmer to compare efficiency. Each ground clean-up crew was instructed to put as much tree material through the chippers as they could to test the capacity and limitations of the chippers. Since many species of trees removed were capable of resprouting and growing new trees from the stumps, a cut stump treatment made with a backpack sprayer was applied to all plots. Although herbicide application time was tracked, it was not factored into the removal and chipping operation times. Each removal and chipping method would, therefore, be comparable for the work completed. See Table 97 for equipment information.

Table 97. Zone Four: Test 5, Equipment

Equipment	Equipment Number
All-Terrain Tree Trimmer, SkyTrim 75 G2	3420002
Chainsaws	-
Brush Chipper, Vermeer® BC1500	3400159
Whole Tree Chipper, Bandit Chipper	3420004
Excavator, CAT® 308 E2CR	4700103
Skid Steer, Case® 1845C	5910008
Backpack Sprayer	-

Method 1: Manual Crew + Brush Chipper: In this method, a manual crew using chainsaws cut and felled trees. A track hoe excavator with a grapple thumb was used to move debris and feed a brush chipper hitched on the front of a skid steer. A ground crew assisted in brush clean-up and chipper feeding working in coordination with the track hoe excavator. Stumps were treated with Triclopyr 4 mixed in basal oil.

Method 2: All-Terrain Tree Trimmer + Brush Chipper: In this method, an all-terrain tree trimmer cut trees down to totem poles. After the all-terrain trimmer cleared the area, a ground crew using chainsaws cut and felled standing logs. A track hoe excavator with a grapple thumb was used to move debris and feed a brush chipper hitched on the front of a skid steer. A ground crew assisted in brush clean-up and chipper feeding working in coordination with the track hoe excavator. Stumps were treated with Triclopyr 4 mixed in basal oil.

Method 3: All-Terrain Tree Trimmer + Whole Tree Chipper: In this method, an all-terrain tree trimmer cut trees down to totem poles. After the all-terrain trimmer cleared the area, a ground crew using chainsaws cut and felled standing logs. A track hoe excavator with a grapple thumb was used to move debris and feed a self-driven whole tree chipper with a grapple arm. Stumps were treated with Triclopyr 4 mixed in basal oil.

Photograph 108. Ground crew and excavator loading brush chipper with material. The material was cut by a ground crew of sawyers.

Photograph 109. The whole tree chipper is driven on tracks, has a cab, and a grapple arm to load chipper feed. This equipment can do the job of several pieces of equipment.

Results

All methods performed the removal work with large amounts of variation between plots; the results revealed no significant difference between any of the methods in their efficiency in testing. All methods performed the job in times ranging from about 1.5 hours to nearly 2.5 hours to remove $1/10^{th}$ of an acre of large trees (see Figures 63 and 64).

Method 1: Manual Crew, Brush Chipper: The manual crew and brush chipper performed this work with a job length of about 1.5 hours and about 7 total labor hours. Both of the time measurements for this method were not significantly different than either of the other methods. The crew size for this method was 4 employees.

Method 2: All-Terrain Tree Trimmer, Brush Chipper: The all-terrain tree trimmer and brush chipper performed this work with a job length of about 2.5 hours and about 12 total labor hours. Both of the time measurements for this method were not significantly different than either of the other methods. The average crew size for this method was 5 employees.

Method 3: All-Terrain Tree Trimmer, Whole Tree Chipper: The all-terrain tree trimmer and whole tree chipper performed this work with a job length of about 2 hours and about 10 total labor hours. Both of the time measurements for this method were not significantly different than either of the other methods. The average crew size for this method was 5 employees.

Variation within the plots resulted in a standard error of over 2 hours. With such a large standard error and similar times for each method, the results showed that methods were not significantly different in the time it took for completion. Prior to testing, it was hypothesized that the use of either the all-terrain tree trimmer or whole tree chipper would reduce the amount of employees needed to perform this work. This did not prove to be the case. Between all methods, there were not significant differences in crew size. The use of the all-terrain tree trimmer was limited by its lack of ability to cut trees flush to the ground. The all-terrain tree trimmer consistently left stumps that were too large to drive over, and a sawyer cut the stumps before the all-terrain tree trimmer resumed cutting into the plot. The inefficient cutting techniques and crew sizes played large roles in inhibiting the efficiency of this test. Lastly, differences in chippers (between the whole tree chipper and brush chipper) did not lead to any significant differences in job times. The addition of the whole tree chipper did not significantly reduce the amount of time it took to remove the brush compared to either of the methods utilizing the brush chipper.

Figure 63. Removal Off-Road Job Length

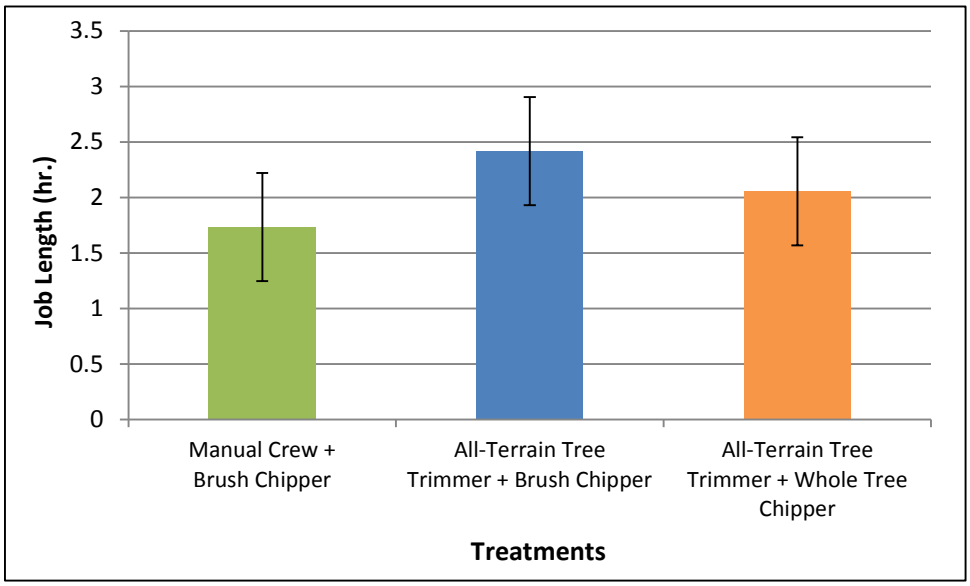
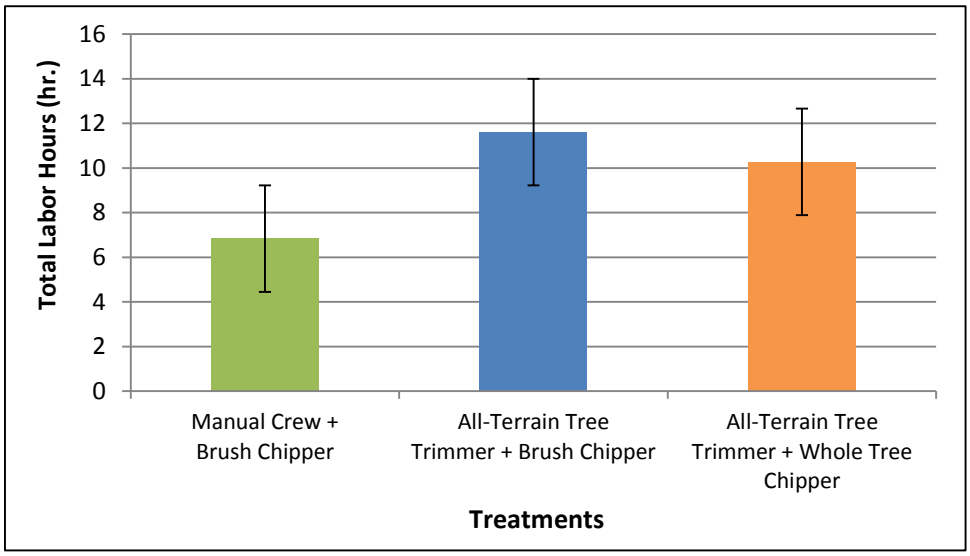


Figure 64. Removal Off-Road Total Labor Hours



Key to Figures 63 and 64.

- Statistically Significant Event
- Manual Crew + Brush Chipper
- All-Terrain Tree Trimmer + Brush Chipper
- All-Terrain Tree Trimmer + Whole Tree Chipper
- Error Bars

Treatment Cost Comparisons: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing these labor costs, there are several factors that influence the costs, such as variations in methods, equipment efficiency, and number of staff. Table 98 describes the labor cost to remove one acre of large trees with three different IVM methods. Table 99 describes the labor cost to remove one acre of large trees with each method used in this test. Labor costs for this test should be compared to labor costs for the other tests that involved tree removal (Zone Four: Tests 4 and 6). The materials costs are located in Table 100, which shows the cost to mix one gallon of herbicide used in this test. The cost of materials can be added to the labor cost for each method to determine the total cost per method.

Table 98. Zone Four: Test 5, IVM Method Labor Comparisons

IVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre
Manual Crew + Brush Chipper	4	$19.10	0.06	69.32	$1,324.01
All-Terrain Tree Trimmer + Brush Chipper	5	$19.10	0.06	120.85	$2,308.24
All-Terrain Tree Trimmer + Whole Tree Chipper	5	$19.10	0.05	102.80	$1,963.48

Table 99. Zone Four: Test 5, Labor Cost Comparisons

Method and Treatment	Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Total Cost per Acre per Year
Method 1: Manual Crew + Brush Chipper	1	0	69.32	$1,324.01
Method 2: All-Terrain Tree Trimmer + Brush Chipper	1	0	120.85	$2,308.24
Method 3: All-Terrain Tree Trimmer + Whole Tree Chipper	1	0	102.80	$1,963.48

Table 100. Zone Four: Test 4, Herbicide Mixture Cost Comparison

Herbicide Mix	Ounces Needed to Mix 1 Gallon	Cost Per 1 Mixed Gallon
Triclopyr 4 + Hy-Grade I Basal Oil	25.6 102.4	$5.44

Recommendation

Tree removal work is time-consuming and dangerous. In an effort to increase safety and reduce costs, crews should contain the least number of employees to get the work accomplished without disrupting safety and efficiency. After analyzing results and finding no significant differences in job length or total labor hours, ultimately safety must be considered when choosing equipment and crew mixes.

Crew size and experience proved to be limiting factors in safety and total labor hours. With extra crew members on a job site comes a greater chance of people being in the wrong place and getting hurt. Small, efficient, and knowledgeable crews should be utilized for this type of work.

The manual crew spent 69 hours per acre compared to both other methods requiring more than 100 hours per acre. Clearly, the manual crew using four staff members is the safest and most productive method when removing trees off-road. The results from this test also suggest that the all-terrain tree trimmer was working beyond its intended capabilities in this type of removal work. The versatility of a sawyer working on a slope and the ability to directionally drop and arrange felled trees contribute to the overall efficiency and lower labor cost when compared to all other methods. When using a manual crew for removal, it is paramount that the crew and mainly the sawyers be experienced and have been properly trained in this type of work. Felling trees with improper techniques is very dangerous to life and limb of the ground crew.

Through this test and observations made during testing, an ideal tree crew can be recommended. Under these test parameters, the most effective method for tree removal features a manual cutting crew to fell, buck, and limb trees. The ground clean-up should be centered around the track hoe excavator feeding a brush chipper with minimal ground assistance. To reduce ground assistance, the Vermeer® BC 1500's optional Tree Commander™ remote control should be purchased and operated from the cab of the excavator to remotely control brush chipper functions. This crew would consist of 2 sawyers, 1 excavator operator, and 2 ground crew (to assist excavator or sawyers). In total, crews should not exceed 5 people.

Zone Four: Test 6, Tree Removal with Tree Mulcher

In order to establish Zone Four as an undisturbed zone, trees need to be cleared back away from the road far enough so that they may mature without ever causing an obstruction. Trees can cause many issues in the ROW, including growing in unsafe locations (for errant vehicles), being a failure hazard with a target of the traveling public, and causing visibility issues with sight distance. This test evaluated two different mechanical removal methods for efficiency, cost, and effectiveness, as well as cost and effectiveness of herbicide treatments in preventing regrowth of woody vegetation. Testing took place on trees growing on the slopes along an interstate highway where some trees were reachable with the tree removal equipment parked on the edge of the road, while other trees had to be accessed off road.

Methods

The Tree Removal with Tree Mulcher test was designed to measure the efficiency and effectiveness of a tree mulcher head on an excavator (Photograph 110) compared to a forestry bucket truck with manual crew and brush chipper (Photograph 111) in removing trees reachable from on- and off-road. Additionally, two different herbicide and application methods were applied to each removal method to evaluate the effectiveness at reducing woody regrowth. Herbicide was either applied with a foliar application by a spray truck with spray nozzles on a boom (Photograph 112) or a cut stump treatment with a backpack sprayer. See Table 101 for equipment information.

Table 101. Zone Four: Test 6, Equipment

Equipment	Equipment Number
Tree Mulcher, Brown Brontosaurus 3.0 EM	3410011
Excavator, CAT® 320EL	4710093
Chainsaws	-
Brush Chipper, Vermeer® BC1500	3400166
Forestry Bucket Truck, Terex® 70’	3300251
Skid Steer, Bobcat® S750	5910105
Backpack Sprayer	-
Spray Truck	2544304
Spray Tank and Equipment	8230266

Method 1: Tree Mulcher: In this method, a whole tree mulcher head mounted to a tracked excavator was used to remove trees on a fore slope. Regrowth was treated the following summer with a foliar herbicide treatment from a spray truck with nozzles on a boom.

Method 2: Forestry Bucket Truck + Brush Chipper + Skid Steer: In this method, a manual crew with a bucket truck and clean-up equipment was used to remove trees on a fore slope. Stumps were treated with herbicide using a backpack sprayer following removal.

Photograph 110. The Brown Brontosaurus tree mulcher head on an excavator does the work of an entire tree crew with only one operator.

Photograph 111. Forestry bucket and manual crew with an average of 7 employees to remove trees.

Photograph 112. A foliar herbicide application was made in the summer after the winter removal.

Results

Both methods did not show a significant difference in job length (Figure 65). However, when the number of employees is factored into the job length, the results from the whole tree mulcher had significantly shorter total labor hours (Figure 66). Additionally, the herbicide results showed that both herbicide application methods significantly reduced the woody percent coverage compared to the control (Figure 67).

Method 1: Tree Mulcher: The tree mulcher crew performed the removal of trees in an average of 5 hours (job length) per plot. This equals a total labor time of seven hours per plot when considering the crew members (operator plus some spotter time). This method had significantly lower total labor hours than the bucket truck method (P=0.0186), which equates to a significantly lower cost to perform this type of tree removal. While this method performed the job quickly, there were weather constraints that affected how this equipment could work. Due to the site conditions, the slopes could neither be too wet nor icy for the excavator to safely maneuver on the slopes. With these constraints, the work took longer to perform, as the operator had to wait for proper conditions to complete work. This method took an extra month to finish compared to the bucket truck and manual crew.

Method 2: Forestry Bucket Truck + Brush Chipper + Skid Steer: The bucket truck and manual crew performed the removal of trees in an average of eight hours per plot. This equals to total labor hours of 56 when considering the seven crew members. This method took significantly longer labor hours to complete compared to the tree mulcher. The bucket truck was limited in what it could reach in the plots and mainly assisted the manual crew with taking the crowns out of the front row of trees. The manual crew was unhampered by wet, cold, or icy conditions. It did not make the work take any longer than if there were mild weather. However, there was the safety concern of potential slips, trips, and falls with employees working on the slope.

Herbicide: Initially, the intent was to treat the entire plots of each cutting method with herbicide. However, when the equipment that performed the herbicide application was only able to reach the front 20’ of the plots, the backside of those plots was used as a control. The herbicide test showed no significant difference between the foliar spray and cut stump treatment in its ability to reduce woody vegetation coverage; the test did, however, show that the use of either herbicide reduced the woody vegetation coverage compared to the control with no herbicide. Although it is apparent herbicide treatments reduced woody coverage compared to cutting only (without herbicide), further testing could be done to distinguish the optimal technique and herbicide for treating woody shrubs.

Within all of the analysis performed for this test, there was a large amount of variation within plots. This suggests that the work performed here was variable in its difficulty throughout plots. This could be due to the size, species, and placement of trees, or the efficiency of work performed. The herbicide results also showed variability in plots, which suggests that either the herbicide applications were not consistent or the response from the vegetation was not consistent between plots. In either case, this test did show that the whole tree mulcher was the most cost-saving method of tree removal, and that the use of herbicide will reduce the amount of woody regrowth compared to not using herbicide.

Figure 65. Tree Mulcher Job Length

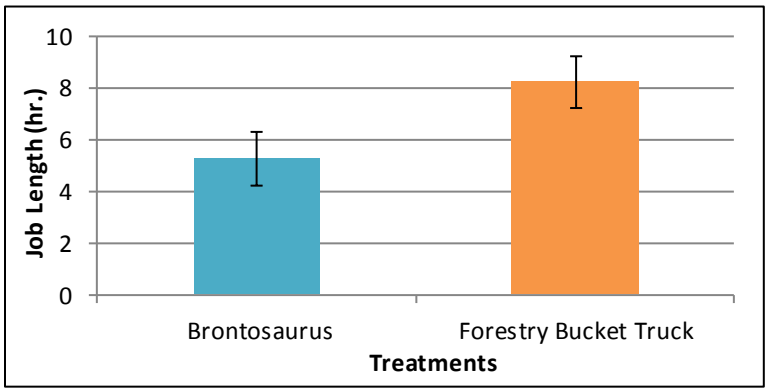
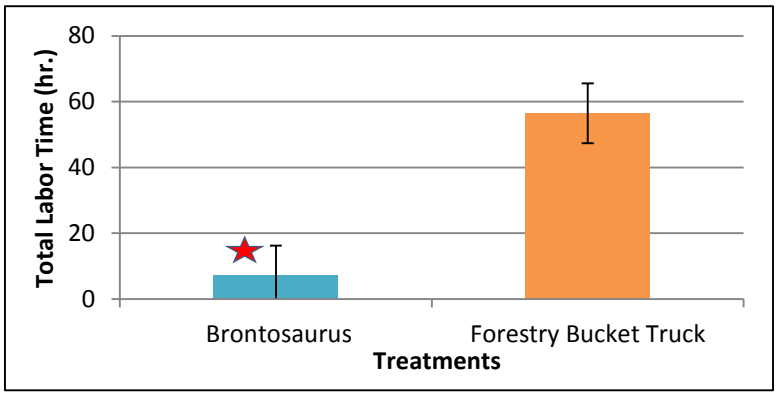


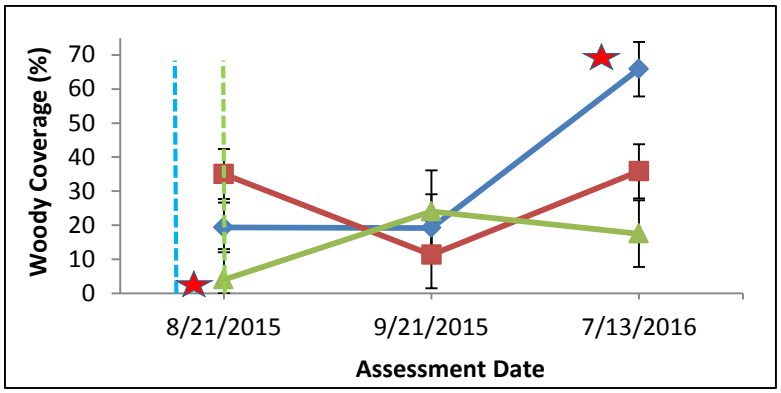
Figure 66. Tree Mulcher Total Labor Time



Key to Figures 65-66.

- Statistically Significant Event
- Brontosaurus Tree Mulcher
- Forestry Bucket Truck
- Error Bars

Figure 67. Tree Mulcher Herbicide Results



Key to Figure 67.

- Statistically Significant Event
- Mow Only
- Overdrive® + Triclopyr 3, Platoon®
- Pathway®
- Mechanical Control (mow all)
- Herbicide Control (cut stump, Pathway®)
- Herbicide Control (broadcast, Overdrive® + Triclopyr 3 + Platoon®)
- Error Bars

Treatment Cost Comparisons: Labor costs for each method have been calculated based on timed maintenance activities at the test site throughout the testing period. In analyzing these labor costs, there are several factors that influence the costs, such as variations in methods, equipment efficiency, and number of staff. Table 102 describes the labor cost to remove one acre of large trees with four different IVM methods. Table 103 describes the labor cost to remove one acre of large trees with each method used in this test. Labor costs for this test should be compared to labor costs for the other tests that involved tree removal (Zone Four: Tests 4 and 5). The materials costs are located in Table 104, which shows the cost to mix one gallon of herbicide used in this test. The cost of materials can be added to the labor cost for each method to determine the total cost per method.

Table 102. Zone Four: Test 6, IVM Method Labor Comparison

IVM Method	# Staff	Average Wage	Acres per Hour	Labor Hours per Acre	Cost per Acre
Forestry Bucket Truck + Brush Chipper	7	$19.10	0.03	229.11	$4,376.00
Tree Mulcher + Spray Truck Boom Nozzle	2	$19.10	0.06	35.50	$678.05
Spray Truck Boom Nozzle	2	$19.10	7.08	0.28	$5.35
Backpack Sprayer Cut Stump Application	1	$19.10	0.33	3.66	$69.91

Table 103. Zone Four: Test 6, Labor Cost Comparison

Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Total Cost per Acre per Year
Method 1: Forestry Bucket Truck + Brush Chipper + Cut Stump Herbicide Treatment	1	1	232.77	$4,445.91
Method 2: Tree Mulcher + Spray Truck Boom Nozzle	1	1	35.78	$683.40

Table 104. Zone Four: Test 4, Herbicide Mixture Cost Comparison

Method and Treatment	Tank Mix	Rate (oz. per Acre)	# Products	Spray Pattern Width (ft.)	Cost per Acre	Cost per gallon
Method 3 Treatment 1: Spray Truck + Broadleaf	Triclopyr 3 + Platoon® + Overdrive®	128 128 4	3	20	$34.20	-
Method 3 Treatment 2: Backpack Sprayer + Cut Stump Herbicide	Pathway® RTU	Ready to Use	1	Stump Treatment	-	$27.68

Recommendation

Results from this test indicate that a tree mulcher on an excavator is much more cost-effective than using the forestry bucket truck with a manual crew for tree removal. The goal of using the tree mulcher equipment is to improve safety and reduce labor hours when performing tree removals. The tree mulcher crew only requires one to two staff members to run the operation (an operator and a spotter), compared to a manual tree crew that requires a crew of up to seven staff (but ideally five staff). Reducing crew size not only saves on labor hours, but also reduces safety risks involved with this work. The excavator can be limited on slopes during icy or wet ground conditions, while manual crews are still able to work. Conversely, if working along the road, the operator in the excavator will not be as adversely affected by the cold as ground crews. The production rate of the tree mulcher makes up for lost time when production resumes and ground conditions improve off-road.

Differences in the effectiveness of herbicide treatments were observed between treating stumps immediately after removal and making foliar applications a season after regrowth. The stump treatments worked better than the foliar treatment at reducing woody regrowth, but neither method performed as well as expected. Results from other tests indicate that when using a tree mulcher, ground applications with Tordon® K at 64 oz. per acre could be more effective than either method used in this test at controlling regrowth of woody vegetation. As Tordon® K is a restricted herbicide, it should only be used after consulting with the District Office of Environmental Services.

Zone Four Summary

Vegetation challenges in Zone Four include safely, efficiently, and cost-effectively maintaining and removing trees that may be reachable with equipment parked on the road edge or away from the road. The previous six tests addressed many scenarios in which these challenges were met. Whether trees are healthy or hazards, there are risks associated with tree work that can be greatly reduced with safe work practices, such as practices recommended by ANSI A300 and Z133-2012 standards. It is recommended that trained operators be consistently assigned to new or specialized equipment to optimize equipment performance. Also, crews need to be focused on safety, efficiency, and proper arboricultural techniques. Herbicide applications can also be utilized in Zone Four to reduce the coverage of woody vegetation and lengthen the control period between mechanical maintenance cycles.

Tree removal was found to be most efficiently performed with the Brown Brontosaurus whole tree mulcher. The whole tree mulcher has a much lower purchase price ($23,500.00) than other pieces of forestry equipment and has a much lower per-acre labor cost ($678.05), which make it a viable option for ODOT uses. This equipment only requires one operator and mulches trees from the top down to the stump. This is a safe option that eliminates many of the hazards associated with tree removal projects.

Tree trimming was found to be most efficient with the chemical side trim if it is permissible to leave dead standing branches (that will eventually fall from self-pruning of the tree). Chemical side trim proved to be the fastest and cheapest option for trimming trees. If dead branches left on trees are not permissible, the all-terrain trimmer or the forestry bucket truck are both good options for trimming. The chipping and clean-up from trimming and removals is the slowest part of the process. For both the all-terrain trimmer and the forestry bucket truck, the job lengths and total labor hours were similar. This shows that both pieces of equipment quickly moved along the ROW, allowing for the chipping crew to move in behind the trimming crew. It was observed that the all-terrain trimmer quickly trims and tops trees but has some drawbacks compared to the forestry bucket truck. The all-terrain trimmer leads to improper arboricultural pruning of trees. Operators of the forestry bucket truck made more proper cuts with proper arboricultural pruning techniques.

In the comparison of chipping methods, the Bandit 1850 whole tree chipper was compared to Vermeer® BC1500 brush chipper in an on-road and off-road access setting. The Bandit 1850 whole tree chipper did not produce consistent results to prove that it was more efficient than the Vermeer® BC1500. The Bandit 1850 whole tree chipper did, however, show that it required less ground crew to work around the chipper compared to the Vermeer® BC1500. This did not mean that the total crew size was smaller, but only that the crew was not working on the ground next to the chipper. Through testing and observations, the Bandit 1850 whole tree chipper was clearly aided by the addition of an excavator with thumb. This excavator was able to quickly sort and pile material for the Bandit operator to then load into the chipper. The excavator also proved to be very useful in safely and efficiently loading the Vermeer® BC1500 brush chipper with minimal assistance from ground crews. Since Vermeer® offers a remote control for the Vermeer® BC1500, the excavator operator could control the chipper without the need for a ground crew member to work in close proximity to the chipper. These simple additions to safety and efficiency around the Vermeer® BC1500 make it a viable option as a tool for ODOT to use in all chipping operations.

To lengthen the time between tree removal cycles, an herbicide application should always follow a tree removal operation to treat stumps of resprouting species; otherwise, foliar herbicide should be applied the following growing season to reduce woody coverage.

Equipment Review: The Altec® Forestry Bucket Truck performed well during testing. In speaking with the operators, the up-then-over movements of the bucket was the only notable item that those who had operated other bucket trucks had to get used to, versus the more familiar option of being able to move in both directions at once with other bucket truck models. The movement of the Altec® bucket is not as fluid due to this constraint. The truck was purchased with the chipper box so that chips could be hauled away rather than left on the site. Under testing conditions, chips were always left on site. If ODOT decides they don't need to haul chips from work sites for dumping elsewhere, a flatbed bucket truck could be purchased instead if preferred.

The all-terrain tree trimmer was not purchased for testing, but a quick review will be provided. The all-terrain tree trimmer is designed for off-road use in the utility ROW for tree maintenance. Since the saw on the end of the straight boom cannot turn, performing natural target pruning is often difficult. Therefore, ISA recommends in its Best Management Practices Integrated Vegetation Management guide for electric utility ROWs that the all-terrain tree trimmer be used in rural or remote areas. There was some concern by operators for their safety if tree limbs fell through the glass into the cab. A cage around the cab, such as the cage on top of the forestry bucket truck, would make this unit safer. The tilt of the cab to get the saw to angle was considered uncomfortable by the operators as well.

The Bandit 1850 chipper is an expensive chipper with options for tracks, a cab, and grapple. The chipper can chip trees up to 18" in diameter. The chipper worked well in testing conditions and was highly praised outside of testing conditions. The purpose of testing the chipper was to determine whether the unit would enable the sky trim to get more work done each day by keeping up with the unit better than the current brush chipper set-up does. While the tracks transport the chipper on site to the piles of debris (which is helpful in terms of another piece of equipment not needing to move the chipper around), the tracks move slowly. The grapple helps the chipper pick up logs and branches for self-feeding. This is beneficial in that it eliminates the dangers associated with employees feeding chippers. However, the grapple has a short reach and is slowly maneuvered. The grapple and tracks do not replace the need to have a separate excavator with grapple attachment on site gathering logs and debris for transporting them to the chipper.

The Brown Brontosaurus tree mulcher mounted on a Caterpillar 320EL excavator is capable of mulching standing trees into chips with one employee and one piece of equipment in a few minutes. Lane closures are normally not needed when the unit is working off the road in the soft shoulder of the interstate highways. Removals are faster than with a manual crew with less manpower and less equipment used. The unit tested was run off the excavator's hydraulics. While the unit performed well, it could be stronger and faster if the optional power pack is purchased. As it is now, when the operator encounters very hard wood the operator must stop, back off the tree, and rev up the RPMs for a few moments and then approach the tree again. The operator would feel safer with a cage around the cab to keep trees from breaking through the glass into the cab. The excavator is less flexible getting into areas than a manual crew as ice, snow, and clay soils make it difficult for the tracks to keep traction when off road on slopes. When working on-road or in the soft shoulder, the excavator is very productive and unhampered by weather conditions that would normally slow down a manual crew. When trees are larger than the tree mulcher head is capable of handling, the operator reaches the head up to its highest point to knock out the top of the tree. The operator uses the tree mulcher to mow down the trunk as far as the mulcher will efficiently go, and then has a spotter notch the base of the tree and the operator knocks the tree down with either the mulcher head or the bucket head.

Return On Investment: The ROI for Zone Four is realized when safety and efficiency for tree removal and maintenance activities are maximized. Herbicide treatments after tree maintenance and removal can lengthen the control cycle. Labor savings are improved as crews work more efficiently and reduce the number of employees on a job site.

Tree Maintenance Equipment on Road Return On Investment: The ROI analysis for tree maintenance on road compares the tree maintenance methods cost of equipment, labor cost per mile, and cost savings per mile compared to a baseline method (Table 105). This baseline is generally the method that requires the most labor and largest cost per mile. In this comparison, the all-terrain tree trimmer, followed by the forestry bucket truck and a brush chipper, was used as the baseline method. This evaluation determines ROI through labor savings of each method and the number of miles it would take to realize that cost savings. The all-terrain tree trimmer and brush chipper can achieve ROI in 37 miles of trimming. The forestry bucket truck and brush chipper can achieve ROI in 31 miles of trimming. The biggest cost savings, however, comes from using chemical control methods (Chemical Side Trim) with a skid sprayer and spray gun. Chemical Side Trim can achieve ROI in only 1 mile of trimming or 1 total labor hour.

Table 105. Zone Four: Tree Maintenance On-Road Return On Investment - Per Acre Labor Cost Savings

Brush Control Methods	Cutting Equipment Purchase Price	Chipper Price	Labor Cost per Mile	Labor Cost Savings per Mile	Miles Needed for ROI	Hours Needed to Accomplish ROI
All-Terrain Tree Trimmer, Forestry Bucket Truck & Brush Chipper	$339,273.00	$42,383.00	$10,161.20	$ -	N/A	N/A
All-Terrain Tree Trimmer & Brush Chipper	$192,000.00	$42,383.00	$3,839.10	$6,322.10	37	1236
Forestry Bucket Truck & Brush Chipper	$147,273.00	$ 42,383.00	$ 4,138.02	$6,023.18	31	1574
Chemical Side Trim - Skid Sprayer	$8,073.00	N/A	$33.81	$10,127.39	1	1

Tree Maintenance Equipment Off-Road Return On Investment: The ROI analysis for tree maintenance off-road compares chippers and clean-up crews after the all-terrain tree trimmer pruning operation (Table 106). In this comparison, cost of equipment, labor cost per mile, and cost savings per mile were compared to a baseline method. In this comparison, the brush chipper was used as the baseline method. This evaluation determines ROI through labor savings of each method and the number of miles it would take to realize that cost savings. The whole tree chipper can achieve ROI in 165 miles of off-road trimming or 8,239 total labor hours.

Table 106. Zone Four: Tree Maintenance Equipment Off-Road Return on Investment - Per Acre Labor Cost Savings

Brush Control Methods	Chipper Price	Labor Cost per Mile	Labor Cost Savings per Mile	Miles Needed for ROI	Hours Needed to Accomplish ROI
Vermeer® BC1500 Chipper	42,383.00	$3,671.02	$0.00	N/A	N/A
Bandit 1850 Tree Chipper	284,567.00	$1,944.00	$1,727.02	165	8239

Tree Removal Return on Investment: The ROI analysis for tree removal compares tree removal methods on- and off-road for the cost of equipment, labor cost per acre, and cost savings per acre compared to a baseline method (Table 107). This baseline is generally the method that requires the most labor and largest cost per acre. In this comparison, the forestry bucket truck and a brush chipper was used as the baseline method. This evaluation determines ROI through labor savings of each method, and the number of acres it would take to realize that cost savings. The all-terrain tree trimmer and brush chipper can achieve ROI in 126 acres of tree removal. The all-terrain tree trimmer and whole tree chipper can achieve ROI in 283 acres of tree removal. The manual crew and brush chipper can achieve ROI in 14 acres of tree removal. The lighting bucket/manual crew and brush chipper can achieve ROI in 22 acres of tree removal. The biggest cost savings, however, comes from the tree mulcher head (Brontosaurus) mounted on an excavator. This method only requires one piece of equipment to remove and chip trees. The Brown Brontosaurus mulcher head can achieve ROI in only 6 acres of removal and 104 total labor hours. If an excavator needs to be purchased to run the Brontosaurus tree mulcher, then ROI will be realized in 108 acres or 1800 total labor hours.

Table 107. Zone Four: Tree Removal Return On Investment - Per Acre Labor Cost Savings

Tree Removal Methods	Cutting Equipment Purchase Price	Purchase Price Chippers	Labor Cost per Acre	Labor Cost Savings per Acre	Acres Needed for ROI	Hours Needed to Accomplish ROI
Forestry Bucket Truck On- and Off-Road & Brush Chipper	$147,273.00	$42,383.00	$4,460.32	$0.00	N/A	N/A
All-Terrain Tree Trimmer & Brush Chipper On- and Off-Road	$192,000.00	$42,383.00	$2,598.14	$1,862.18	126	2,517
All-Terrain Tree Trimmer & Whole Tree Chipper On- and Off-Road	$192,000.00	$284,567.00	$2,778.00	$1,682.32	283	5,666
Manual Crew Off-Road & Brush Chipper	$0.00	$42,383.00	$1,324.01	$3,136.31	14	270
Lighting Bucket Truck On-Road & Brush Chipper	$0.00	$42,383.00	$2,505.50	$1,954.82	22	361
Brown Brontosaurus Head Only On- and Off-Road	$23,500.00	$0.00	$678.05	$3,782.27	6	104
Brown Brontosaurus with Excavator Purchase On- and Off-Road	$207,416.00	$0.00	$678.05	$1,920.09	108	1,800

Appendix E
Labor Summary Tables

Zone One Labor Cost Summary Table – Method and Treatment

Zone	Test	Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Average Wage	Total Cost per Acre per Year	Total Labor Hours per Mile per Year	Total Cost per Mile per Year
One	1	Method 1 Treatment 1: Rodeo®	0	3	0.48	19.10	$9.17	0.33	$6.30
		Method 2 Treatment 1: Rodeo® + EsplAndade® 200 SC + Perspective®	0	1	0.16	19.10	$3.06	0.11	$2.10
		Method 2 Treatment 2: Rodeo® + EsplAnade® 200 SC + Oust®	0	1	0.16	19.10	$3.06	0.11	$2.10
	2	Method 1: String Trimmer (SOP)	4	0	-	19.10	-	33.28	$635.65
		Method 2: Mechanical Guardrail Mower	4	0	-	19.10	-	3.96	$75.64
		Method 3: Mechanical Guardrail Mower Followed by String Trimmer	4	0	-	19.10	-	5.40	$103.14

Zone One Labor Cost Summary Table – Method and Treatment

Zone	Test	Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Average Wage	Total Cost per Acre per Year	Total Labor Hours per Mile per Year	Total Cost per Mile per Year
Two	1	Method 1 Treatment 1: Mow Only (SOP)	4	0	1.08	19.10	$20.63	-	-
		Method 2 Treatment 1: Perspective® + Mowing	2	1	0.58	19.10	$11.08	-	-
		Method 2 Treatment 2: Triclopyr 3 + Mowing	3	1	0.85	19.10	$16.24	-	-
		Method 3 Treatment 1: Embark® 2S IVM + Perspective® + Mowing	1	2	0.35	19.10	$6.69	-	-
		Method 3 Treatment 2: Plateau® + Triclopyr 3 + Mowing	1	2	0.35	19.10	$6.69	-	-
	2	Method 1 Treatment 1: Mow Only (SOP)	4	0	25.10 - 88.74	19.10	$481.48 - 1,697.00	-	-
		Method 2 Treatment 1: Embark® 2S IVM + Perspective® + Mow Only	3	2	18.99 - 66.72	19.10	$364.15 - 1,275.82	-	-
		Method 2 Treatment 2: Plateau® + Triclopyr 3 + Mowing	3	2	18.99 - 66.72	19.10	$364.15 - 1,275.82	-	-
	3	Method 1 Treatment 1: Mow Only (SOP)	3	0	1.23	19.10	$23.49	-	-
		Method 2 Treatment 1: Plateau® + Triclopyr 3 + Mowing	2	2	1.00	19.10	$19.10	-	-
		Method 2 Treatment 2: Embark® 2S IVM + Perspective® + Mowing	3	2	1.00	19.10	$19.10	-	-
	4	Method 1 Treatment 1: Mow Only (SOP)	3	0	0.90	19.10	$17.13	-	-
		Method 2 Treatment 1: Triclopyr 3 + Mowing	3	2	0.90	19.10	$17.13	-	-
		Method 2 Treatment 2: Milestone® + Mowing	3	1	0.90	19.10	$17.13	-	-
		Method 2 Treatment 1: Plateau® + Triclopyr 3 + Mowing	2	1	0.60	19.10	$11.42	-	-
		Method 2 Treatment 2: Plateau® + Milestone® + Mowing	2	1	0.60	19.10	$11.42	-	-
	5	Method 1 Treatment 1: Unmaintained	0	0	0.00	0.00	$0.00	-	-
		Method 2 Treatment 1: Milestone®	0	1	0.03	19.10	$0.55	-	-
		Method 2 Treatment 2: Perspective®	0	1	0.03	19.10	$0.55	-	-
	6	Method 1 Treatment 1: Slope mower, Kut Kwick	2	0	2.10	19.10	$40.11	-	-
		Method 1 Treatment 2: Slope mower, Alamo Traxx™ RF	2	0	3.16	19.10	$60.36	-	-

Zone One Labor Cost Summary Table – Method and Treatment

Zone	Test	Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Average Wage	Total Cost per Acre per Year	Total Labor Hours per Mile per Year	Total Cost per Mile per Year
Three	1	Method 1 Treatment 1: Mow Only (SOP)	5	0	1.05	19.10	$20.06	-	-
		Method 2 Treatment 1: Outrider® + Mowing	5	1	2.44	19.10	$46.60	-	-
		Method 2 Treatment 2: Rodeo® + Mowing	5	1	2.44	19.10	$46.60	-	-
	2	Method 1 Treatment 1: Mow Only (SOP)	1	0	3.56	19.10	$68.00	-	-
		Method 2 Treatment 1: Milestone® + Mowing	1	1	4.31	19.10	$82.32	-	-
		Method 2 Treatment 2: Ecomazapyr® 2 SL + Mowing	1	1	4.31	19.10	$82.32	-	-
	3	Method 1 Treatment 1: Mow Only (SOP)	1	0	0.33	19.10	$6.30	-	-
		Method 2 Treatment 1: Perspective® + Mowing	1	1	1.76	19.10	$33.62	-	-
		Method 2 Treatment 2: Milestone® + Mowing	1	1	1.76	19.10	$33.62	-	-
	4	Method 1 Treatment 1: Mow Only (SOP)	1	0	0.78	19.10	$14.90	-	-
		Method 2 Treatment 1: Streamline® + Mowing	1	1	2.56	19.10	$48.90	-	-
		Method 2 Treatment 2: Milestone® + Mowing	1	1	2.56	19.10	$48.90	-	-
	5	Method 1 Treatment 1: Mow Only (SOP)	1	0	8.95	19.10	$170.95	-	-
		Method 2 Treatment 1: Streamline® + Triclopyr 4 + Mowing	1	1	13.06	19.10	$249.45	-	-
		Method 2 Treatment 2: Milestone® + Triclopyr 4 + Mowing	1	1	13.06	19.10	$249.45	-	-
	6	Method 1 Treatment 1: Mow Only (SOP)	1	0	3.00	19.10	$57.30	-	-
		Method 2 Treatment 1: Mowing + Tordon® K	1	1	3.91	19.10	$74.60	-	-
		Method 3 Treatment 1: Rodeo®	0	1	1.08	19.10	$20.67	-	-
		Method 3 Treatment 2: Streamline®	0	1	1.08	19.10	$20.67	-	-

Zone One Labor Cost Summary Table – Method and Treatment

Zone	Test	Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Average Wage	Total Cost per Acre per Year	Total Labor Hours per Mile per Year	Total Cost per Mile per Year
Three	7	Method 1 Treatment 1: Mow Only (SOP)	1	0	3.26	19.10	$62.27	-	-
		Method 2 Treatment 1: Milestone® + Mowing	1	1	3.26	19.10	$62.27	-	-
		Method 2 Treatment 2: Triclopyr 3 + Mowing	1	1	3.26	19.10	$62.27	-	-
	8	Method 1 Treatment 1: Mow Only (SOP)	1	0	6.94	19.10	$132.55	-	-
		Method 2 Treatment 1: Mowing + Tordon® K	1	1	9.38	19.10	$179.16	-	-
		Method 3 Treatment 1: Ecomazapyr 2 SL + Mowing	1	1	6.47	19.10	$123.54	-	-
		Method 3 Treatment 2: Triclopyr 3 + Mowing	1	1	6.47	19.10	$123.54	-	-
	9	Method 1 Treatment 1: Mow Only (SOP)	1	0	82.22	19.10	$1,570.40	-	-
		Method 2 Treatment 1: Triclopyr 3	0	1	4.71	19.10	$90.04	-	-
		Method 2 Treatment 2: Ecomazapyr® 2 SL	0	1	4.71	19.10	$90.04	-	-
		Method 2 Treatment 3: Rodeo®	0	1	4.71	19.10	$90.04	-	-
	10	Method 1 Treatment 1: Untreated (SOP)	0	0	0.00	19.10	$0.00	-	-
		Method 2 Treatment 1: Triclopyr 4	0	1	4.99	19.10	$95.31	-	-
		Method 2 Treatment 2: Milestone® + Triclopyr 4	0	1	4.99	19.10	$95.31	-	-
	11	Method 1 Treatment 1: Manual Removal Only (SOP)	1	0	202.89	19.10	$3,875.10	-	-
		Method 2 Treatment 1: Triclopyr 4 + Tordon® K	0	1	13.56	19.10	$258.94	-	-
		Method 2 Treatment 2: Triclopyr 4	0	1	13.56	19.10	$258.94	-	-

Zone One Labor Cost Summary Table – Method and Treatment

Zone	Test	Method and Treatment	Mow Occurrences per Year	Spray Occurrences per Year	Total Labor Hours per Acre per Year	Average Wage	Total Cost per Acre per Year	Total Labor Hours per Mile per Year	Total Cost per Mile per Year
Four	1	Method 1 Treatment 1: Unmaintained	0	0	-	19.10	-	0.00	$0.00
		Method 2 Treatment 1: Krenite® S	0	1	-	19.10	-	1.77	$33.81
		Method 2 Treatment 2: Triclopyr 3	0	1	-	19.10	-	1.77	$33.81
	2	Method 1: Forestry Bucket Truck	1	0	-	19.10	-	216.65	$4,138.02
		Method 2: All-Terrain Tree Trimmer	1	0	-	19.10	-	201.00	$3,839.10
		Method 2: All-Terrain Tree Trimmer + Forestry Bucket Truck	1	0	-	19.10	-	532.00	$10,161.20
	3	Method 1: Vermeer® Chipper (SOP)	1	0	-	19.10	-	192.20	$3,671.02
		Method 2: Bandit Chipper	1	0	-	19.10	-	101.78	$1,944.00
	4	Method 1: Lighting Bucket Truck + Brush Chipper + Cut Stump Treatment	1	1	135.04	19.10	$2,579.34	-	-
		Method 2: All-Terrain Tree Trimmer + Brush Chipper	1	0	151.21	19.10	$2,888.03	-	-
		Method 3: All-Terrain Tree Trimmer + Whole Tree Chipper + Cut Stump Treatment	1	1	191.96	19.10	$3,666.36	-	-
		Method 4: Forestry Bucket Truck + Brush Chipper	1	0	237.93	19.10	$4,544.46	-	-
	5	Method 1: Manual Crew + Brush Chipper	1	0	69.32	19.10	$1,324.01	-	-
		Method 2: All-Terrain Tree Trimmer + Brush Chipper	1	0	120.85	19.10	$2,308.24	-	-
		Method 3: All-Terrain Tree Trimmer + Whole Tree Chipper	1	0	102.80	19.10	$1,963.48	-	-
	6	Method 1: Forestry Bucket Truck + Brush Chipper + Cut Stump Herbicide Treatment	1	1	232.77	19.10	$4,445.91	-	-
		Method 2: Tree Mulcher + Spray Truck Boomless Nozzle	1	1	35.78	19.10	$683.40	-	-

Zone One Labor Cost Summary Table – RIVM Method

Zone	Test	RIVM Method	# Staff	Average Wage	Acre per Hour	Labor Hours per Acre	Cost per Acre	Mile per Hour	Labor Hours per Mile	Cost per Mile
One	1	Spray Truck (6-foot spray nozzle)	1	$19.10	6.57	0.16	$3.06	9.04	0.11	$2.10
	2	String Trimmer (SOP)	2	$19.10	-	-	-	0.32	8.32	$158.91
		Mechanical Guardrail Mower	1	$19.10	-	-	-	1.03	0.99	$18.91
		Mechanical Guardrail Mower Followed by String Trimmer String Trimmer	1	$19.10	-	-	-	3.87	1.35	$25.79

Zone One Labor Cost Summary Table – RIVM Method

Zone	Test	RIVM Method	# Staff	Average Wage	Acre per Hour	Labor Hours per Acre	Cost per Acre	Mile per Hour	Labor Hours per Mile	Cost per Mile
Two	1	Batwing Mower (15-foot width)	1	$19.10	3.86	0.27	$5.16	-	-	-
		Spray Truck (22-foot spray nozzle)	1	$19.10	24.47	0.04	$0.76	-	-	-
	2	Batwing Mower (15-foot width)	1	$19.10	1.36	0.73	$14.55	-	-	-
		String Trimming	2 - 3	$19.10	.17 - .37	5.54 - 21.45	$105.81 - 409.70	-	-	-
		Spray Truck (10-foot spray nozzle)	1	$19.10	12	0.08	$1.59	-	-	-
	3	Flail Mower	1	$19.10	2.75	0.41	$7.83	-	-	-
		Spray Truck (10-foot spray nozzle)	1	$19.10	11.25	0.09	$1.72	-	-	-
	4	Batwing Mower (15-foot mower)	1	$19.10	3.61	0.30	$5.71	-	-	-
		Batwing WetBlade™ Mower (15-foot mower + herbicide)	1	$19.10	3.61	0.30	$5.71	-	-	-
	5	Unmaintained	0	$0.00	0.00	0.00	$0.00	-	-	-
		Spray Truck (22-foot spray nozzle)	1	$19.10	26.24	0.03	$0.55	-	-	-
	6	Slope mower, Kut Kwick	1	$19.10	1.02	1.05	$20.06	-	-	-
		Slope mower, Alamo Traxx™ RF	1	$19.10	0.64	1.58	$30.18	-	-	-

Zone One Labor Cost Summary Table – RIVM Method

Zone	Test	RIVM Method	# Staff	Average Wage	Acre per Hour	Labor Hours per Acre	Cost per Acre	Mile per Hour	Labor Hours per Mile	Cost per Mile
Three	1	Batwing Mower (15-foot width)	1	$19.10	4.79	0.21	$4.01	-	-	-
		Skid Sprayer Directed Application	1	$19.10	1.41	1.39	$26.55	-	-	-
	2	Rotary Arm Mower	1	$19.10	0.30	3.56	$68.00	-	-	-
		Skid Sprayer Directed Application	1	$19.10	0.75	1.50	$28.65	-	-	-
	3	Batwing Mower (15-foot width)	1	$19.10	3.00	0.33	$6.30	-	-	-
		Skid Sprayer Directed Application	1	$19.10	0.72	1.43	$27.31	-	-	-
	4	Batwing Mower (15-foot width)	1	$19.10	1.29	0.78	$14.90	-	-	-
		Skid Sprayer Directed Application	1	$19.10	0.59	1.78	$34.00	-	-	-
	5	Rotary Side Arm Mower	1	$19.10	0.12	8.95	$170.95	-	-	-
		Skid Sprayer and Backpack Directed Application	1	$19.10	0.26	4.11	$78.50	-	-	-
	6	Flail Arm Mower	1	$19.10	0.34	3.00	$57.30	-	-	-
		Skid Sprayer Directed Ground Application	1	$19.10	1.11	0.91	$17.30	-	-	-
		Skid Sprayer Directed Foliar Application	1	$19.10	0.94	1.08	$20.67	-	-	-
	7	Rotary Arm Mower	1	$19.10	0.29	3.26	$62.27	-	-	-
		Rotary WetBlade™ Arm Mower	1	$19.10	0.33	3.26	$62.27	-	-	-
	8	Skid Steer Forestry Mulcher	1	$19.10	0.18	6.94	$132.55	-	-	-
		Skid Sprayer Directed Ground Application	1	$19.10	0.41	2.44	$46.60	-	-	-
		Skid Sprayer Directed Foliar Application	1	$19.10	0.69	1.58	$30.16	-	-	-
	9	Manual Brush Removal Crew	5	$19.10	0.06	82.22	$1,570.40	-	-	-
		Skid Sprayer Directed Foliar Application	1	$19.10	0.22	4.71	$90.04	-	-	-
	10	Basal Bark Herbicide Application	1	$19.10	0.23	4.99	$95.31	-	-	-
	11	Manual Tree Removal Crew	5	$19.10	0.03	202.89	$3,875.10	-	-	-
		Basal Bark Herbicide Application	1	$19.10	0.10	13.56	$258.94	-	-	-

Zone One Labor Cost Summary Table – RIVM Method

Zone	Test	RIVM Method	# Staff	Average Wage	Acre per Hour	Labor Hours per Acre	Cost per Acre	Mile per Hour	Labor Hours per Mile	Cost per Mile
Four	1	Skid Sprayer Directed Foliar Application	1	$19.10	-	-	-	0.62	1.77	$33.81
	2	Forestry Bucket Truck	5	$19.10	-	-	-	0.02	216.65	$4,138.02
		All-Terrain Tree Trimmer	6	$19.10	-	-	-	0.03	201.00	$3,839.10
		All-Terrain Tree Trimmer + Forestry Bucket Truck	7	$19.10	-	-	-	0.01	532.00	$10,161.20
	3	SkyTrim + Vermeer® Chipper	5	$19.10	-	-	-	0.03	192.20	$3,671.02
		SkyTrim + Bandit Chipper	2	$19.10	-	-	-	0.02	101.78	$1,944.00
	4	Lighting Bucket Truck with Brush Chipper	6	$19.10	0.05	131.18	$2,505.50	-	-	-
		All-Terrain Tree Trimmer + Brush Chipper	6	$19.10	0.04	151.21	$2,888.03	-	-	-
		All-Terrain Tree Trimmer + Whole Tree Chipper	7	$19.10	0.04	188.09	$3,592.52	-	-	-
		Forestry Bucket Truck + Brush Chipper	7	$19.10	0.03	237.93	$4,544.46	-	-	-
		Backpack Sprayer Cut Stump Application	1	$19.10	0.32	3.87	$73.84	-	-	-
	5	Manual Crew + Brush Chipper	4	$19.10	0.06	69.32	$1,324.01	-	-	-
		All-Terrain Tree Trimmer + Brush Chipper	5	$19.10	0.06	120.85	$2,308.24	-	-	-
		All-Terrain Tree Trimmer + Whole Tree Chipper	5	$19.10	0.05	102.80	$1,963.48	-	-	-
	6	Forestry Bucket Truck + Brush Chipper	7	$19.10	0.03	229.11	$4,376.00	-	-	-
		Tree Mulcher + Spray Truck Boomless Nozzle	2	$19.10	0.06	35.50	$678.05	-	-	-
		Spray Truck Boomless Nozzle	2	$19.10	7.08	0.28	$5.35	-	-	-
		Backpack Sprayer Cut Stump Application	1	$19.10	0.33	3.66	$69.91	-	-	-